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The paleoecologic significance of Paleocene palynomorph assemblages from the Ludow, Slope, and Cannonball formations, southwestern North Dakota

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University of North Dakota

THE PALEOECOLOGIC SIGNIFICANCE OF PALEOCENE PALYNOMORPH ASSEMBLAGES FROM THE LUDLOW, SLOPE, AND CANNONBALL FORMATIONS, SOUTHWESTERN NORTH DAKOTA

by

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This dissertation, submitted by Timothy J. Kroeger in partial fulfillment of the requirements for the Degree of Doctor of Philosophy from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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Dean of the Graduate School

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ABSTRACT

Paleoenvironment exerted control on the distribution of 133 palynomorph taxa from the Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation (Fort Union Group, Paleocene) of southwestern North Dakota. The strata represent fluvial-deltaic systems that prograded eastward into the Cannonball Sea. Depositional environments include distributary channels, crevasse splays, crevasse-splay feeder channels, lignite-producing swamps and/or marshes, lakes, brackish to slightly brackish bays, lake and bay fills, and marshes.

Paleoenvironmentally sensitive palynomorph taxa were identified by subjective examination of pollen diagrams and objective analysis using detrended correspondence analysis. Two paleoenvironmentally restricted palynomorph associations were recognized. The Acritarch association, composed of *Ovoidites* cf. *O. ligneolus*, *Micrhystridium* Type-2, *Psiloschizosporis* cf. *S. spriggii*, *Cymatiosphaera* sp., and three unidentified acritarch taxa, is restricted to slightly brackish to lacustrine paleoenvironments. The *Pediastrum* association is dominated by *Pediastrum*, but contains additional algal taxa including *Psilainaperturites* sp. 2, *Ovoidites* cf. *O. ligneolus*, *Botryococcus* sp., *Micrhystridium* Type-1, and several species of dinoflagellates. The *Pediastrum* association occurs in lacustrine strata and in the basal portions of brackish-water strata, indicating that brackish-water conditions were preceded by less saline environments.

Palynomorph assemblages within lignite beds are characterized by sphagnaceous spores (*Stereisporites* spp.), *Gleicheniidites* spp., *Toroisporis* sp., *Reticuloidosporites pseudomurii*, *Fraxinoipollenites variabilis*, *Rousea* cf. *R. parvicolpata*, *Rousea* sp. 1, *Rousea* sp. 2,

Retitrescolpites anguluminosus, *Cyrillaceaepollenites* cf. *C. exactus*, and *Myrtipites*? sp. 2. A possible early successional association also occurs in lignites, characterized by *Nyssapollenites* sp., *Quercoidites* cf. *Q. spissus*, *Wilsonipites* sp., *Foveotricolporites pachyexinous*, *Cranwellia subtilis*, *Triatriopollenites subtriangulus*, *Dicotetradites rallus*, *Cricotriporites plektosus*, *Sparganiaceaepollenites*? sp., and *Biretisporites furcosus*.

Kurtzipites spp., *Syncolporites* cf. *S. minimus*, and *Wilsonipites* sp. are typical of the progradational marsh deposits. *Rossipollis scabratus*, *Corollina* sp., *Sparganiaceaepollenites* cf. *S. globipites*, *Jarzenipollenites trinus*, *Triporopollenites granilabratus*, *Rousea* sp. 4, and *Striatopollis* cf. *S. trochuensis* may represent members of salt marsh floral communities. Dinoflagellate cysts, especially *Deflandrea* cf. *D. flounderensis* are typical of brackish-water strata, although some taxa have wider paleoenvironmental tolerance.

INTRODUCTION

Studies of palynomorph distribution in modern environments show that specific depositional environments can be characterized by recurring palynomorph assemblages (Muller, 1959; Rich and Spackman, 1979; Chmura, 1994; see studies cited in Traverse, 1988, chapter 17). Within ancient deposits, fossil palynomorph assemblages similarly have been demonstrated to bear relationships to certain depositional environments (Nichols and Traverse, 1971; Farley and Dilcher, 1986; Gennett *et al.*, 1986).

If the botanical affinities of the palynomorphs are confidently known, paleoecological interpretations can be made from palynomorph assemblages by comparison to the ecological requirements of modern descendants. However, botanical affinities become less certain in older rocks, and in strata as old as Late Cretaceous and early Tertiary, many palynomorphs cannot be compared confidently to modern forms. Even if botanical affinities are relatively certain, the ecological requirements of the modern descendants might not be the same as the paleoecological requirements of the plant that produced the ancient palynomorph (Cousminer, 1961; Frederiksen, 1985).

Palynomorph assemblages are composed of locally produced or autochthonous palynomorphs in combination with allochthonous elements that are transported to the depositional site by wind or water. Fossil palynomorph assemblages can range from being nearly completely autochthonous, representing the local flora, to predominantly allochthonous, consisting of an admixture of palynomorphs produced by local and distant floral communities. Unfortunately, in ancient palynomorph assemblages, autochthonous palynomorphs cannot be confidently discerned from allochthonous forms.

However, recurrent palynomorph assemblages from ancient deposits can be related to the depositional environments of the rocks from which they were recovered. Palynomorph distribution in modern depositional environments can be used as analogues to help interpret the distribution of palynomorphs in ancient rocks. In this manner, the relative contribution of autochthonous and allochthonous palynomorphs in ancient assemblages can be estimated.

The primary objective of this study is to determine if distinctive and recurring palynomorph assemblages can be recognized from subenvironments within a Paleocene fluvial-deltaic depositional system within the Ludlow, Slope and Cannonball Formations of southwestern North Dakota. If distinctive assemblages are related to their original depositional environment, the autochthonous component of the assemblages may be distinguishable from the allochthonous components. Autochthonous palynomorph assemblages may permit a limited reconstruction of the paleofloral communities that produced palynomorph assemblages.

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I would like to thank the many individuals and organizations that have contributed to the completion of this project. The dissertation advisory committee members are thanked for their patience and their answers to my many questions. Special thanks to those committee members, Drs. Nichols, Holland, Hartman, and Shubert, who served in addition to their regular duties. Drs. John Hoganson and Alan Cvancara are also thanked for their term of committee service. Special thanks to Dr. Lucy Edwards for her assistance with identification of the dinoflagellates and Dr. Robert Ravn for supplying information on published reports of the occurrence of palynomorph taxa.

Primary funding in support of this project was provided by Dr. Joseph H. Hartman of the Energy and Environmental Research Center of the University of North Dakota through grants and contracts from the National Science Foundation, U.S. Bureau of Mines, and the U.S.

Department of Energy. Additional financial support was provided by the Graduate School of the University of North Dakota, the Geological Society of America, Sigma Xi, the Beta Zeta Chapter of Sigma Gamma Epsilon, and the American Association of Stratigraphic Palynologists. Logistical support was received from the North Dakota Geological Survey, Dr. David Krause of the State University of New York-Stony Brook, the Department of Geology and Geological Engineering of the University of North Dakota, the Energy and Environmental Research Center of the University of North Dakota, and the Department of Biology and Geology at Bemidji State University.

Mr. John Brown of Brown Ranch, Mr. George Weinreis of VVV Ranch, and Mr. Al Skoggesburg of Horse Creek Land and Cattle Company provided hospitality and permitted access to private properties. Mr. Wesley Peck provided field assistance and helped construct the graphics presented here. Ms. Barbara Sahl assisted in the compilation of the data and in construction of the graphics.

Location of Study Area

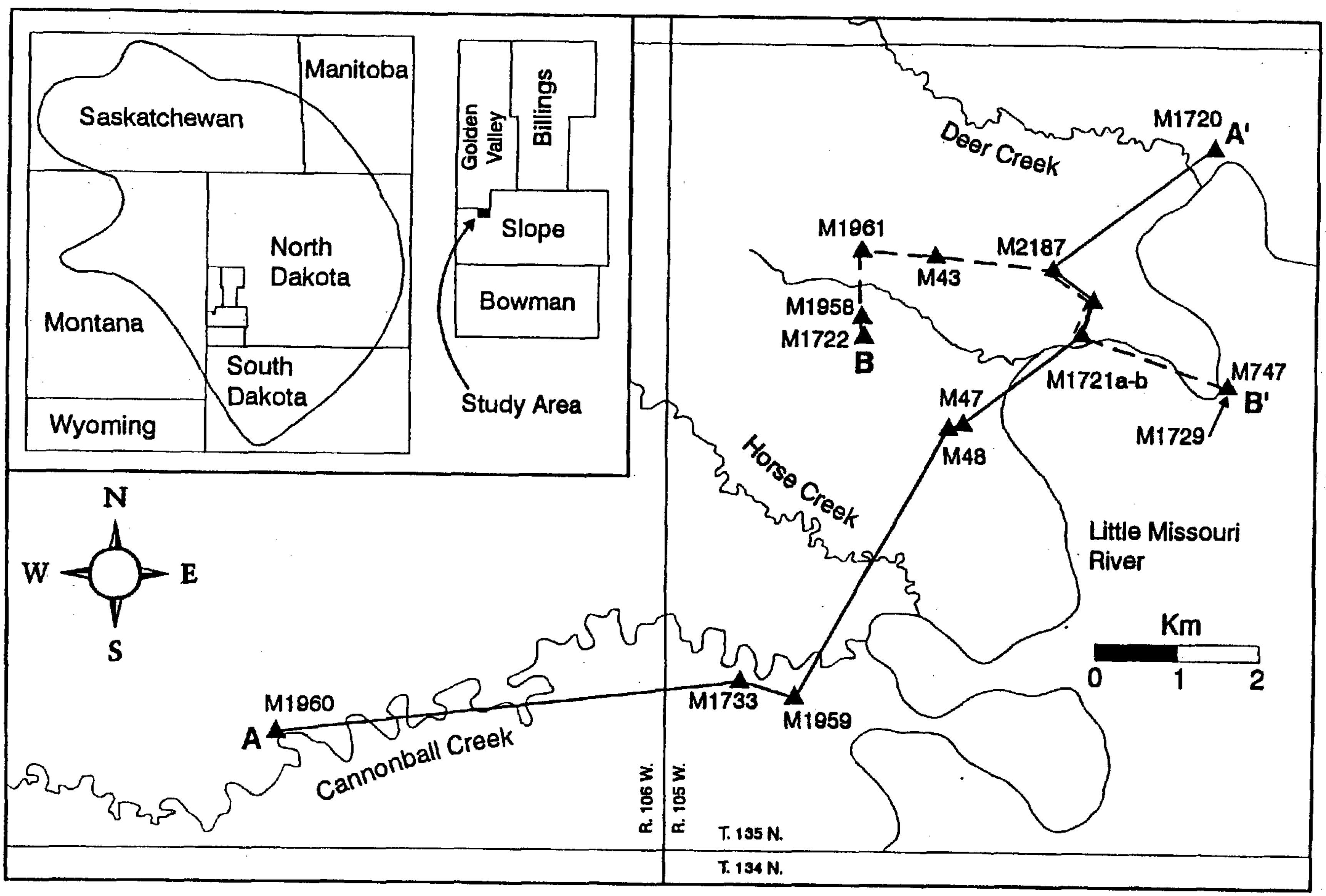
The focus of this study is the region of southwestern North Dakota where fluvial-lacustrine deposits of the Ludlow and Slope Formations interfinger with the brackish-water tongues of the Cannonball Formation. Exposures of these beds are present in northwestern Slope County, within highly dissected badlands bordering the Little Missouri River and its tributary streams. All stratigraphic data and palynologic samples were collected within T. 135 N., R. 105 W. and T. 135 N., R. 106 W., 20-25 air km north-northeast of Marmarth, North Dakota (Figure 1).

The stratigraphic portion of this study included measurement of seven stratigraphic sections. These sections, designated as M1960, M1733, M1959, M1722, M1958, M1961, M1721, and M1720, include strata assigned to the Hell Creek, Ludlow, Cannonball, and Slope Formations. Stratigraphic sections M43, M47, and M48, measured by E.S. Belt, and M747 (Van Alstine, 1974) were also used to aid correlations. Additional stratigraphic data were obtained from mud samples and the wireline log of stratigraphic test well M2187. The locations of all stratigraphic sections are illustrated in Figure 1. Information pertaining to all of the stratigraphic sections was entered into the geologic section cataloging system (M-number system) that is maintained by Dr. Joseph H. Hartman of the Energy and Environmental Research Center of the University of North Dakota. A brief description of the location of each stratigraphic section is contained in Appendix 1.

Samples for palynological analyses were collected during measurement of each section. However, due to limitations in time, only samples from section M1721 were studied in detail. Some palynomorph samples collected from sections M1720, M2187, M1729, and M1960 were used to augment stratigraphic and paleoenvironmental interpretations.

Figure 1. Location map of the study area.

Triangles represent the location of the measured stratigraphic sections. The stratigraphic section of primary interest in this study is M1721a-b. Sections included in the stratigraphic cross sections A to A' and B to B' are indicated by connecting lines. The general outline of the Williston Basin is indicated on the index map.


Manitoba
Saskatchewan
North Dakota
Montana
South Dakota
Wyoming
Golden Valley
Billings
Slope
Bowman
Study Area
N
W
E
S
Deer Creek
M1720
A'
M1961
M43
M2187
M1958
M1722
B
M1721a-b
M747
B'
M1729
M47
M48
Horse Creek
Little Missouri River
Km
0
1
2
M1960
A
M1733
M1959
Cannonball Creek
R. 106 W.
R. 105 W.
T. 135 N.
T. 134 N.

PREVIOUS PALYNOLOGIC STUDIES

Several palynologic studies within the North American Western Interior are pertinent to this study. Stanley (1965) published the earliest detailed systematic palynologic study for this region. Stanley's study resulted in a palynostratigraphic zonation of the Hell Creek and Fort Union Formations in northwestern South Dakota. In addition, he provided the first palynological record from the marginal marine strata assigned to the Cannonball Member of the Fort Union Formation.

In northeastern Montana, in the stratotype region of the Hell Creek Formation, Norton and Hall (1969) and Oltz (1969) studied the palynofloras of the Upper Cretaceous and lower Tertiary rocks. Norton and Hall's study was primarily palynostratigraphic, whereas Oltz focused on the recognition of assemblages having possible paleoecologic significance. Within this same area, Hotton (1988) demonstrated that the pattern of palynomorph extinctions across the Cretaceous-Tertiary boundary is compatible with a catastrophic extinction event such as that associated with a bolide impact.

Numerous systematic studies have been completed on the Upper Cretaceous and lower Tertiary strata of North Dakota. Robertson (1975) devised, but did not publish, a palynostratigraphic zonation that included Upper Cretaceous, Paleocene, and Eocene strata. Bergad (1974) reported on the palynology of the Hell Creek Formation, and Bebout (1977) on the palynoflora of the Golden Valley Formation. Several studies have focused on the palynology of Fort Union coals in North and South Dakota, including the works of Gerhard (1958), Trotter (1963), L.V. Moore (1974), and Steadman (1985). Numerous additional palynologic reports are applicable to the present study. The areas of study included by these previous works and their stratigraphic focus are presented in chart form in Figure 2.

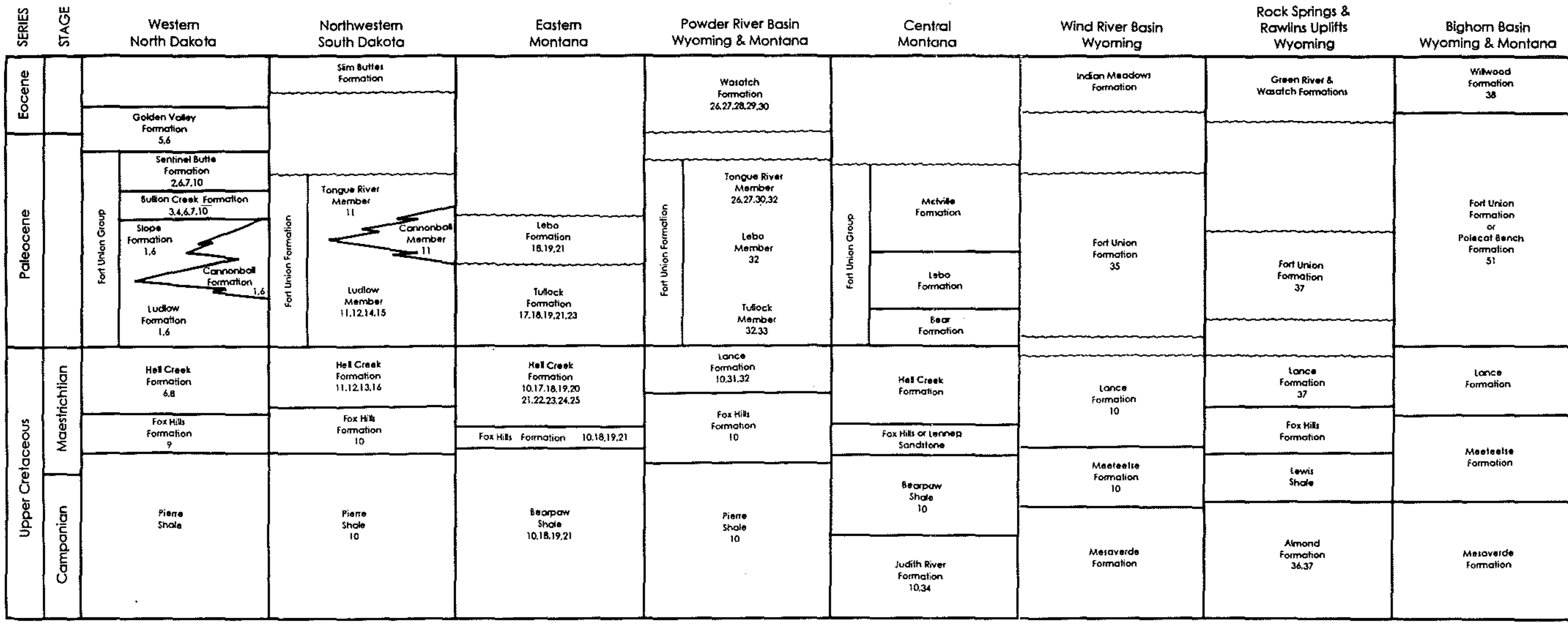
Several studies in recent years have used objective statistical methods, such as cluster analysis and ordination, to recognize similarities in palynomorph assemblages that have paleoecologic significance (Oltz, 1969 & 1971; Boulter and Hubbard, 1982; Kovach, 1988a). These statistical methods have been used in association with sedimentologic and detailed stratigraphic data to address the relationship between palynomorph assemblages and depositional environments (Farley and Dilcher, 1986; Gennett *et al.*, 1986; Farley, 1989; Fleming, 1990).

Palynomorph assemblages representing brackish-water or estuarine strata have been recognized by several workers. Paleocene and Eocene lignites of Texas that include marine-influenced assemblages were reported by Nichols and Traverse (1971) and Gennett *et al.* (1986). Other strata bearing brackish-water palynomorphs include the Dakota Formation (Upper Cretaceous) of Kansas and Nebraska (Farley and Dilcher, 1986), the Wealden strata (Lower Cretaceous) in England (Batten and Lister, 1988a and b), the Paleocene and Eocene of South Carolina (Lucas-Clark, 1989), and the Peace River Formation (Lower Cretaceous) in Alberta, Canada (Leckie and Singh, 1991).

Figure 2. Interregional stratigraphic correlation diagram.

Numbers accompanying lithostratigraphic units are keyed to the systematic palynologic works listed in Table 1.

Compiled from McGookey, 1972; McDonald, 1972; Robinson, 1972; Anderson, 1960; Snead, 1969; Sweet and Braman, 1992; Frederiksen, 1991; and Frazier and Schwimmer, 1987.


SERIES
STAGE
Western North Dakota
Northwestern South Dakota
Eastern Montana
Powder River Basin Wyoming & Montana
Central Montana
Wind River Basin Wyoming
Rock Springs & Rawlins Uplifts Wyoming
Bighorn Basin Wyoming & Montana
Eocene
Paleocene
Upper Cretaceous
Maestrichtian
Campanian
Golden Valley Formation 5,6
Fort Union Group
Sentinel Butte Formation 2,6,7,10
Bullion Creek Formation 3,4,6,7,10
Slope Formation 1,6
Cannonball Formation 1,6
Ludlow Formation 1,6
Hell Creek Formation 6,8
Fox Hills Formation 9
Pierre Shale
Slim Buttes Formation
Fort Union Formation
Tongue River Member 11
Cannonball Member 11
Ludlow Member 11,12,14,15
Hell Creek Formation 11,12,13,16
Fox Hills Formation 10
Pierre Shale 10
Lebo Formation 18,19,21
Tullock Formation 17,18,19,21,23
Hell Creek Formation 10,17,18,19,20 21,22,23,24,25
Fox Hills Formation 10,18,19,21
Bearpaw Shale 10,18,19,21
Wasatch Formation 26,27,28,29,30
Fort Union Formation
Tongue River Member 26,27,30,32
Lebo Member 32
Tullock Member 32,33
Lance Formation 10,31,32
Fox Hills Formation 10
Pierre Shale 10
Fort Union Group
Melville Formation
Lebo Formation
Bear Formation
Hell Creek Formation
Fox Hills or Lennep Sandstone
Bearpaw Shale 10
Judith River Formation 10,34
Indian Meadows Formation
Fort Union Formation 35
Lance Formation 10
Meeteetse Formation 10
Mesaverde Formation
Green River & Wasatch Formations
Fort Union Formation 37
Lance Formation 37
Fox Hills Formation
Lewis Shale
Almond Formation 36,37
Willwood Formation 38
Fort Union Formation or Polecat Bench Formation 51
Lance Formation
Meeteetse Formation
Mesaverde Formation

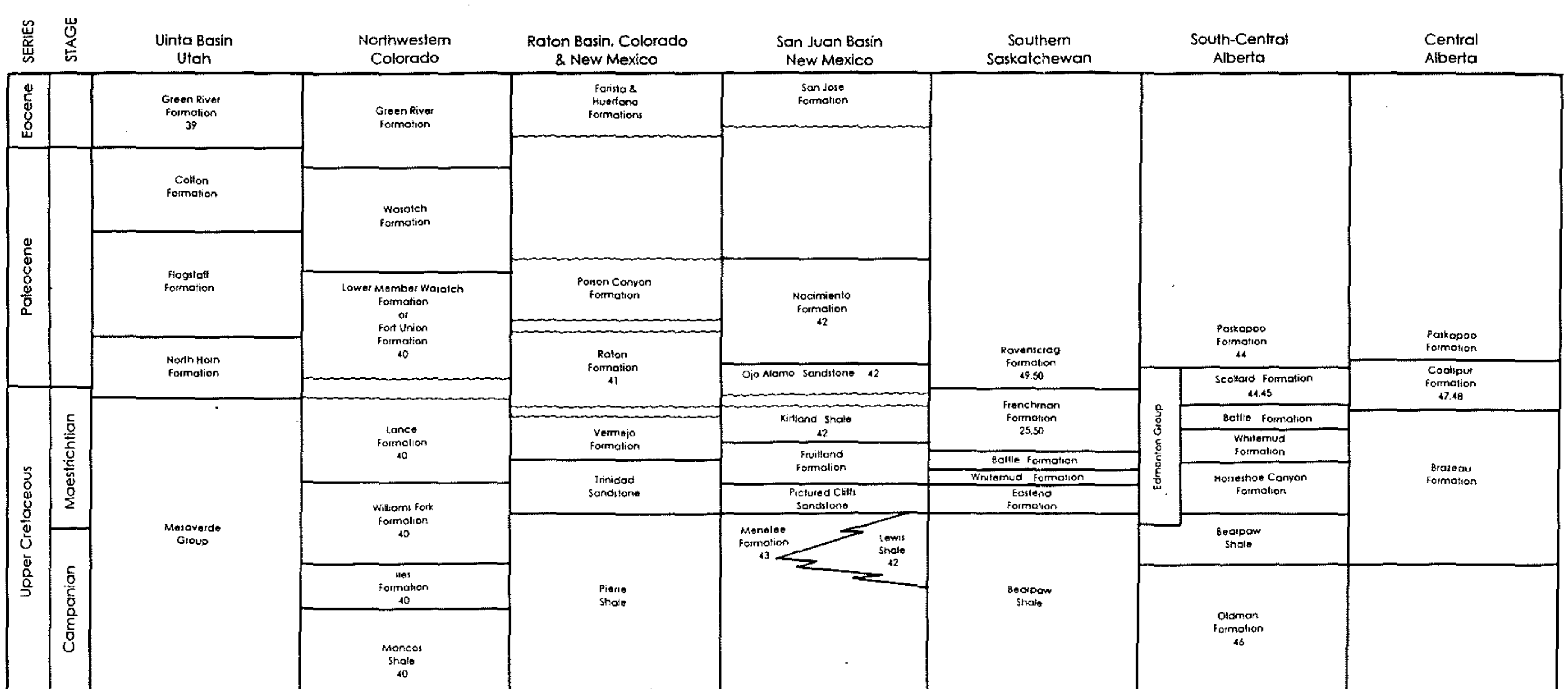

SERIES
STAGE
Uinta Basin Utah
Northwestern Colorado
Raton Basin, Colorado & New Mexico
San Juan Basin New Mexico
Southern Saskatchewan
South-Central Alberta
Central Alberta
Eocene
Paleocene
Upper Cretaceous
Maestrichtian
Campanian
Green River Formation 39
Colton Formation
Flagstaff Formation
North Horn Formation
Mesaverde Group
Green River Formation
Wasatch Formation
Lower Member Wasatch Formation or Fort Union Formation 40
Lance Formation 40
Williams Fork Formation 40
Iles Formation 40
Mancos Shale 40
Farisita & Huerfano Formations
Poison Canyon Formation
Raton Formation 41
Vermejo Formation
Trinidad Sandstone
Pierre Shale
San Jose Formation
Nacimiento Formation 42
Ojo Alamo Sandstone 42
Kirtland Shale 42
Fruitland Formation
Pictured Cliffs Sandstone
Menefee Formation 43
Lewis Shale 42
Ravenscrag Formation 49,50
Frenchman Formation 25,50
Battle Formation
Whitemud Formation
Eastend Formation
Bearpaw Shale
Paskapoo Formation 44
Edmonton Group
Scollard Formation 44,45
Battle Formation
Whitemud Formation
Horseshoe Canyon Formation
Bearpaw Shale
Oldman Formation 46
Paskapoo Formation
Coalspur Formation 47,48
Brazeau Formation

Table 1

Index of systematic palynologic studies of Upper Cretaceous and lower Tertiary rocks in the Western Interior region.

To determine the location and stratigraphic units included in each study, the index numbers are keyed to localities and rock units in the interregional stratigraphic correlation diagram (Figure 2).

Index number	Author and year
1	This study
2	Steadman, 1985
3	Melchoir, 1977
4	Melchoir and Hall, 1983
5	Bebout, 1977
6	Robertson, 1975
7	L.V. Moore, 1974
8	Bergad, 1974
9	Artzner, 1974
10	B.D. Tschudy and Leopold, 1971
11	Stanley, 1960; 1965
12	Stanley, 1961a
13	Stanley, 1961b
14	Trotter, 1963
15	Gerhard, 1958
16	Kroeger, 1985
17	Norton and Hall, 1967
18	Norton and Hall, 1969
19	Hall and Norton, 1967
20	Norton, 1965
21	Oltz, 1968; 1969
22	R.H. Tschudy, 1971
23	Hotton, 1988
24	Robertson, 1973
25	Robertson and Elsik, 1975
26	Spindel, 1970; 1975
27	Pocknall, 1987a
28	Pocknall, 1987b
29	Durkin, 1986
30	R.H. Tschudy, 1976
31	Farabee and Canright, 1986
32	Leffingwell, 1971
33	Nichols and Brown, 1992
34	B.D. Tschudy, 1973
35	Nichols and Ott, 1978
36	Stone, 1973
37	Funkhouser, 1961
38	Farley, 1987; 1989
39	Wodehouse, 1933
40	Newman, 1965
41	Fleming, 1990
42	Anderson, 1960
43	Jameossanie, 1987
44	Snead, 1969
45	Srivastava, 1966; 1968a; 1968b; 1968c; 1968d; 1968e; 1969a; 1969b; 1969c; 1969d;1969e; 1970a; 1970b; 1971; 1972a; 1978a; 1978b; 1984

Table 1 (continued)

Index number	Author and year
46	Rouse, 1957
47	Sweet, 1986
48	Jerzykiewicz and Sweet, 1986
49	Jarzen, 1982
50	Sweet, 1978
51	Wilson and Webster, 1946

MATERIALS AND METHODS

Stratigraphic Methods. Detailed stratigraphic sections were measured at all localities from which palynologic samples were collected. Locations of the sections were plotted using 1:24,000 scale U.S. Geological Survey topographic maps. The thickness of the rock units was measured using a jacob staff and an eye level or, for thin units, a tape measure. In most cases, trenches were excavated in order to expose, describe, and sample unweathered rock.

The grain size of sandstones was estimated by use of a hand lens and grain-size chart. The sandstones were not further classified on the basis of their mineral composition. Mudrocks were classified according to the classification scheme of Raymond (1993), with the addition of appropriate modifiers. The silt and clay content of the mudrocks was estimated by the general appearance of the samples and by crushing a small fragment between the teeth. Inorganic and biogenic sedimentary structures were noted and the fresh and weathered rock colors were estimated using a rock-color chart (Goddard *et al.*, 1984). However, as I suffer from slight red-green color blindness, other geologists generally perceive rock colors somewhat differently than I do. All rock samples that were processed to extract palynomorphs were also examined and described under a binocular microscope.

The stratigraphy of the stratigraphic test well M2187 was interpreted by a combination of methods. Lithologic samples were collected from the mud stream at five foot intervals, described, and stored for future study. Wireline logs of the well bore included spontaneous potential, resistivity, and gamma ray. In addition, the driller's comments were incorporated into the final interpretation. The well was drilled by Boyd Heinbaum Drilling of Bowman, North Dakota. Joseph H. Hartman, Wes Peck, David Lechner (Energy and Environmental Research Center, University of North Dakota) and I collected, compiled, and interpreted the data from M2187.

Palynological Sampling Methods. In order to determine if paleoenvironmental trends are evident in the palynomorph assemblages, many duplicate samples were collected from every paleoenvironment that could be recognized in the field. Two strategies were employed to accomplish this. Paleoenvironments that were thought to be represented by only a few lithosomes in the stratigraphic section were collected at close stratigraphic intervals and/or by collecting duplicate sections located laterally along the strike of the lithosome. Those paleoenvironments that were thought to be represented by numerous lithologic units were sampled by collecting a few palynologic samples from each lithologic unit that represented that paleoenvironment within the stratigraphic sequence.

Unweathered rock samples were collected for palynological analysis during measurement of the stratigraphic sections. In general, at least one sample was collected from each lithologic unit. However, some of the rock units consisting of winnowed sandstone were not sampled due to their tendency to be barren of palynomorphs (Traverse, 1988, p. 458). In dominantly sandy lithologic units, finer-grained and clayey horizons were preferentially sampled in order to increase the number of palynologically productive samples. Lignite horizons that lacked abundant coalified wood were also preferentially sampled.

Where more than one sample was collected from a lithologic unit, a stratified sampling technique was used in which grab samples were collected at regular, typically 20 cm, stratigraphic intervals. In some cases, the transitions between lithologies were sampled at higher resolution. For example, the transition from claystone to lignite was sampled at more closely spaced stratigraphic intervals in several cases in hopes of being able to recognize floral succession within the coal-producing swamp.

Palynological Maceration Methods. Palynomorphs were extracted from the rock matrix using the acid maceration techniques outlined in Doher (1980) and Traverse (1988, p. 462, 463). The rock samples were trimmed with a sharp knife to remove potential surface contaminants. About 1 cubic centimeter of rock was crushed with a mortar and pestle and the crushed rock was placed in polypropylene centrifuge tubes for acid maceration.

Mineral matter was removed by treating with an excess of 52 percent hydrofluoric acid followed by repeated water washes. Where necessary, a brief treatment (10 minutes) in Schulze's solution was used. Humic debris was removed by boiling for 5 to 10 minutes in 5 percent potassium hydroxide or Calgon followed by repeated washes of hot water. Any remaining mineral matter was removed by density separation using zinc chloride with a specific gravity of 2.0 centrifuged at 2000 RPM for 90 minutes.

Finely divided organic material and remaining clays were removed from the samples by short centrifuging or gravity settling methods. Filtration through nylon screens was not used on samples intended for quantitative analysis. Large organic fragments were removed from coal and carbonaceous shale samples by screening with a 125 μm brass screen. The coarse residues were scanned with a binocular microscope and megaspores and other microfossils were picked and mounted for possible future study.

Palynomorph-bearing residues were stained with safranin-O. If there was enough residue, two stained and two unstained strew mounts were prepared from each sample. Glycerine jelly was used as a mounting medium and coverslips were ringed with glyptal to prevent drying of prepared slides. Most of the slides were prepared by mixing the residue and a small drop of glycerine jelly on the coverslips and drying for a short time. The residue-bearing coverslips were then mounted to the microslides with a drop of glycerine jelly and inverted on a slide- warming tray to cure. This method allows good control of the density of palynomorphs on the slides and helps prevent the palynomorphs from concentrating along the edges of the coverslips during the curing process.

To help prevent cross contamination between palynologic samples, all glassware and plasticware was thoroughly washed after each use and immersed for at least eight hours in laundry bleach (5 percent sodium hypochlorite). Where feasible, single-use implements were used. Brass screens were thoroughly washed and cleaned in an ultrasonic cleaner after each use.

Analytical Methods. Quantitative abundances of the palynomorph assemblages in each sample were estimated by counting all identifiable palynomorphs encountered along randomly selected traverses of the microslides. For samples bearing sparse palynomorph assemblages, all palynomorphs on one or more slides were counted.

All specimens occurring completely within a specified portion of the field of view were counted. Palynomorphs intersecting the upper boundary of the field of view were counted whereas specimens intersecting the lower boundary were not counted. This counting technique should help eliminate a counting bias toward large specimens (Traverse, 1988, p. 489). Torn or partial specimens were counted only if more than one half of the palynomorph was present.

The samples were not scanned at low magnification to determine if all taxa present on the microslide had been encountered. I feel that scanning slides in this manner is strongly biased toward large and easily recognizable taxa. Any additional taxa encountered during scans would be rare, and would have minimal or no impact on the ultimate objectives of this study, the paleoenvironmental analyses. Thus little additional useful data would be obtained through a significant expenditure of time.

Early in the study, I recognized the difficulty, if not impossibility, of reliably identifying certain palynomorph types on a specimen-by-specimen basis. Systematic identification is especially problematic for bisaccate pollen and pollen of the Taxodiaceae-Cupressaceae-Taxaceae (TCT) complex. The bisaccates are commonly torn or folded and the TCT pollen is also commonly highly folded. For this reason, the bisaccates and TCT pollen were recorded as large summary groups.

Nearly every productive sample is dominated by pollen that is assignable to the TCT complex. This dominance has the potential to mask the significance of other palynomorph taxa that might have paleoenvironmental significance. For this reason I counted an adequate number of palynomorphs from each slide to give reliable estimates of the population of the non-TCT palynomorphs. Initially, at least 500 non-TCT palynomorphs were counted from each sample. However, limitations in time forced reducing that number to 250 non-TCT specimens for many of the samples. For a few sparsely palyniferous samples, fewer than 250 palynomorphs were counted. These samples are noted in Plate 3 with an asterisk (*). Census counts of several samples indicated that this sampling strategy was adequate to encounter nearly all taxa on an individual sample.

The quantitative work was completed using a Leitz Laborlux microscope equipped with bright field and phase contrast illumination systems. In most cases, the 100X oil immersion objective, yielding a total magnification of 1250X, was used to identify the palynomorphs. This level of magnification was necessary to resolve the palynomorph sculptural and structural details that are useful taxonomic features.

Photomicrographs were taken under brightfield, phase contrast or Normarski interference contrast illumination systems. Very fine-grained negatives were produced by using Kodak Technical Pan 2415 film exposed at an ISO between 50 and 200, depending on the density of the individual specimen. The film was developed for six minutes in a 1:5 dilution of HC110 developer and processed and printed using normal darkroom techniques (see Shaw, 1982, for additional information on this photographic technique). The photomicrographs were not retouched during the printing process.

Statistical Methods

Multivariate statistical techniques, including ordination (detrended correspondence analysis) and R- and Q-mode cluster analyses, were applied to the palynologic data. The ordination results were more readily related to the paleoenvironments than were the cluster analyses. For this reason, only the ordination results are presented in the paleoenvironmental interpretations. The results of the cluster analyses will not be discussed further.

In order to refer more conveniently to specific samples in the analysis of the ordination results and pollen diagrams, the samples were numbered sequentially from 1 to 112. A table relating the sample numbers to their equivalent University of

North Dakota Paleontology Collections (UND PC) accession numbers and field sample numbers is presented in Appendix 2.

The personal computer version of the pRErogram DECORANA (DEtrended CORrespondence ANAlysis), written by M.O. Hill (Hill and Gauch, 1980), was used for the detrended correspondence analyses (DCA). Detrended correspondence analysis was developed for use in modern ecological studies, but appears to be adaptable for paleoecologic data. This version of DECORANA has a limitation of 3,000 non-zero data points. Several steps were taken to reduce the data set to meet this limit. Taxa that occur in only a few samples at low relative abundance (rare species) and most of the "summary" groups of taxa were eliminated from the data set. Some species were combined if I felt that I could not differentiate them reliably on a specimen-by-specimen basis. An example of this type of lumping is the combining of *Fraxinoipollenites variabilis* and the microreticulate species of *Tricolpites* into a large group identified as the "small, microreticulate, tricolpate pollen grains." Admittedly, there is a trade-off when such steps are taken to simplify the data set. The analyses and the results are simplified, but some paleoecologic resolution may be lost through the simplification process.

An additional problem is the reliability of palynomorph counts for taxa present in very low relative abundances. Confidence limits on palynomorph relative abundance data vary with the total number of palynomorphs counted and can readily be estimated by use of nomograms such as that presented in Traverse (1988, p. 490). These nomograms indicate that palynomorphs that are present in very low relative abundances have an unspecified likelihood of not being encountered by the sampling technique used here. Thus, for every taxon that is counted in very low relative abundance, it is likely that uncounted additional taxa are present at the same relative abundance. For this reason, records that represent the occurrence of a single specimen of a palynomorph taxon in a sample are considered unreliable and therefore were removed from the DECORANA data set.

Pollen of the Taxodiaceae-Cupressaceae-Taxaceae (TCT) complex dominate the palynomorph assemblages in about 60 percent of the samples (see Plate 4), comprising over 70 percent of the assemblage in many samples. Although the relative abundance of TCT pollen is highly variable, ranging from less than 5 percent to about 95 percent of the total palynomorphs counted, their distribution does not appear to be well correlated to the paleoenvironments that have been recognized.

The high abundance of TCT pollen serves to numerically mask the contribution of other palynomorph groups (Frederiksen, 1985). In order to emphasize the less abundant palynomorph groups, the TCT complex was eliminated from the data set used in the statistical analyses and in the construction of the pollen diagrams. Thus, the relative abundance of palynomorphs was calculated by comparing the abundance of each palynomorph taxon to the total number of non-TCT palynomorphs.

Although elimination of TCT pollen from the analysis does enhance the contribution of other palynomorphs, it does distort the composition of resultant palynomorph assemblages. In samples bearing abundant TCT pollen, taxa that are, in actuality, relatively rare may appear to be common or even dominant. However, if the TCT pollen had been included in the paleoenvironmental analyses, many less abundant taxa would have been eliminated from the analyses due to very low relative abundances. Some of these less common taxa are included among those that appear to have paleoenvironmental significance.

STRATIGRAPHY

Regional Stratigraphy and Structure

General

Upper Cretaceous and Tertiary rocks are exposed within the general area of this study, which includes Slope, Golden Valley, Billings, and Bowman Counties. The Upper Cretaceous units are a regressive sequence, including rocks deposited in marine, marginal marine, and nonmarine environments during the final retreat of the Cretaceous Interior Seaway. The Tertiary rocks are predominantly nonmarine, with the exception of the thin, marginal marine deposits that are the focus of this study. Some of the interregional correlations between these strata and other Upper Cretaceous and lower Tertiary strata within the Western Interior of North America are illustrated in Figure 2.

In general, the strata dip gently, typically one to two degrees, northeastward toward the axis of the Williston Basin. However, detailed stratigraphic cross sections indicate that the dips are not consistent and some gentle anticlinal structures are present (Plate 1).

Upper Cretaceous Series

Pierre Formation. The oldest exposed rocks in this region are the dark gray shales of the Pierre Formation. The Pierre crops out in western Bowman County, where it is exposed along the northwest-southeast trending axis of the Cedar Creek Anticline (Carlson, 1979). The Pierre represents the youngest fully marine paleoenvironments in the region and bears a baculite fauna indicating a Campanian to early Maastrichtian age (Brinster, 1970).

Fox Hills Formation. The Pierre Shale is conformably overlain by the Fox Hills Formation, a dominantly sandy sequence that represents the transition from marine to nonmarine paleoenvironments. The Fox Hills Formation crops out in western Bowman and southwestern Slope counties (Carlson, 1979, 1983). Waage (1968) identified the Trail City, Timber Lake, and Iron Lightning Members in the type area of the formation in north-central South Dakota. Feldmann (1972) recognized the Timber Lake and Colgate lithofaces of the Iron Lightning Member (listed as Colgate Member by Feldmann) in Bowman County, and Carlson (1979) suggested that the Trail City Member is also present. On the basis of ammonites, Waage (1968) determined a Maastrichtian age for the Fox Hills in its type area.

Hell Creek Formation. The Fox Hills Formation is overlain by the interbedded sandstones, siltstones and claystones of the Hell Creek Formation. The Hell Creek Formation was named by B. Brown (1907) for exposures along Hell Creek, a tributary of the Missouri River in Garfield County, Montana. The name was first applied in North Dakota by Hares (1928) as the Hell Creek Member of the Lance Formation. Dorf (1940) subsequently raised the Hell Creek in North Dakota from member to formational rank. A thorough discussion of the nomenclatural history of the Hell Creek Formation in North Dakota was presented by Frye (1969).

Within southwestern North Dakota, the Hell Creek represents nonmarine, fluvial depositional paleoenvironments. The lower contact of the Hell Creek varies from conformable to disconformable to paraconformable, in general attributable to the incising of Hell Creek fluvial channels into the upper Fox Hills

Formation (Frye, 1969). Exposures of the Hell Creek are present in much of western Bowman and southwestern Slope County (Carlson, 1979, 1983).

Frye (1969) recognized five members within the Hell Creek Formation in the Little Missouri River region: the Little Beaver Creek, Marmarth, Bacon Creek, Huff, and Pretty Butte Members. The Marmarth and Huff Members consist of thick sequences of channel sandstones, whereas the Bacon Creek and Pretty Butte Members are dominated by fine-grained sediments. The Little Beaver Creek Member is dominated by lignitic sediments that are interspersed among fluvial channel sandstones. Carlson (1979) concluded that the lateral variability of these members is so great that they may not be recognizable as mappable lithologic units.

The Hell Creek Formation is well known for its dinosaurian fauna, characterized by ceratopsians. The Hell Creek palynoflora belongs to the *Wodehousia spinata* Assemblage Zone of Nichols *et al.* (1982), indicating a Maastrichtian age for the bulk of the formation. Detailed palynological studies of the uppermost Hell Creek Formation in eastern Montana indicate that the Cretaceous-Tertiary boundary may occur within the upper few decimeters of the Hell Creek Formation (Hotton, 1988; Kroeger *et al.*, 1993; Johnson *et al.*, 1989).

Paleocene Series, Fort Union Group

Ludlow Formation. The Hell Creek Formation is conformably overlain by the lignite-bearing strata of the Ludlow Formation. The Ludlow Lignitic Member of the Lance Formation was named by Lloyd and Hares (1915) for exposures of interbedded sandstone, shale and lignite near Ludlow, in Harding County, South Dakota. Although the lithologies are not greatly different from those in the Hell Creek Formation (lower Lance of Lloyd and Hares), Lloyd and Hares (1915) considered the presence of abundant lignite beds to be a primary distinguishing characteristic. Dorf (1940) raised the Ludlow to formational rank and included it as the basal formation of the Fort Union Group. He recognized that the Ludlow was Paleocene in age and bears a fossil flora distinct from that of the Lance Formation. A thorough review of the earlier literature pertaining to the Ludlow Formation was presented by W.L. Moore (1976).

In southwestern North Dakota, the Ludlow crops out in southern and western Bowman County and southwestern Slope County (Carlson, 1979, 1983). In recent years, detailed stratigraphic and sedimentologic studies of the Ludlow Formation have been published (W.L. Moore, 1976; Belt *et al.* 1984). These studies focused on the area of northwestern Slope County, including the area of this study, where the Ludlow is well exposed in badland topography in the drainage of the Little Missouri River. Although many coal beds had previously been named, these reports introduced informal names for many additional lithosomes. Although the regional correlation of some of the named lignite beds (especially the "T Cross" lignite) has been questioned (Hartman, 1989), the informal nomenclature is useful for local stratigraphic correlation and is utilized in the stratigraphic cross sections presented in Plates 1 and 2.

The lower contact of the Ludlow Formation is generally considered to be conformable and is placed at the base of the lowest persistent lignite bed (W.L. Moore, 1976). This lithostratigraphic contact approximates the Cretaceous-Tertiary boundary, although high resolution palynologic and paleobotanical studies have demonstrated that, at some localities, the basal coal can be Cretaceous in age (Johnson *et al.*, 1989).

The stratigraphic nomenclature used for the lower Paleocene rocks of eastern and central Montana was introduced into the Little Missouri River area by Frye (1969), when he assigned portions of the Ludlow Formation to the Tullock Formation and Lebo Shale. Extension of this nomenclature into western North Dakota is inconsistent with the lithologies exposed at the stratotypes of both of these units and their usage has not gained acceptance among North Dakota geologists.

Slope Formation. The Slope Formation was named for strata, formerly assigned to the upper portion of the Ludlow Formation, that are exposed adjacent to the Little Missouri River in northwestern Slope County (Clayton *et al.*, 1977). As originally defined, the Slope conformably overlies the Ludlow Formation in the Little Missouri River valley and the Cannonball Formation in central North Dakota.

The Slope Formation was erected to resolve some discrepancies regarding the extent of the Ludlow as it is mapped in South Dakota. In South Dakota, usage of the Ludlow is restricted to strata between the Hell Creek Formation and the Cannonball Formation, whereas in North Dakota, the top of the Ludlow was defined at a stratigraphically higher level. Use of the Slope Formation restricted the Ludlow Formation to strata that are more or less coeval with the stratotype of the Ludlow Formation in South Dakota.

The lower contact of the Slope Formation in the area of its stratotype (the area of this study) is arbitrarily defined as the top of the Boyce Tongue of the Cannonball Formation (equivalent to the "T Cross clay" of W.L. Moore [1976]), although Carlson (1983) proposed placing the contact slightly lower, at the base of the "T Cross" lignite. The upper contact is placed at the top of a widespread white, bleached zone that is commonly associated with a siliceous bed (silcrete). This bleached zone is interpreted to represent a deep weathering horizon or paleosol, indicating an unconformable relationship between the Slope and overlying Bullion Creek Formation (W.L. Moore, 1976).

Cannonball Formation. The strata of the Cannonball Formation in central and south-central North Dakota represent the youngest marine deposits in the interior of North America. The Cannonball was named for exposures along the Cannonball River in Grant County, North Dakota, as the Cannonball Marine Member of the Lance Formation (Lloyd, 1914). Dorf (1940) raised the Cannonball to formational rank and included it within the Fort Union Group.

The Cannonball Formation is best exposed in south-central North Dakota, where it is dominated by mudstones, although relatively thin sandstone beds are also common. This formation has also been identified in north-central and southwestern North Dakota, and nearshore facies of the Cannonball were recognized in northwestern South Dakota (Rich and Goodrum, 1982). The presence of marine strata equivalent to the Cannonball Formation has been suggested in the southern portions of Manitoba and Saskatchewan (Cvancara, 1976) and in southeastern Montana (E.S. Belt, oral comm.). The Cannonball conformably overlies the Ludlow in south-central North Dakota, and intertongues with the Ludlow further west.

Within the area of the present study, the Cannonball is currently recognized as consisting of two thin beds, intercalated within the Ludlow and Slope Formations, that contain invertebrate fossils indicating brackish-water paleoenvironments. The upper bed containing brackish-water fossils was first reported by Leonard (1908), and it was associated with the Cannonball Formation by Lloyd and Hares (1915). The lower bed was first reported by R.W. Brown (1948), who depicted the Cannonball Formation extending into the Little Missouri River valley as two thin tongues that probably represent estuarine deposits. Over the years, several informal names have been applied to the brackish-water tongues and, recently, formal names have been proposed, the Boyce (lower bed) and Three V (upper bed) Tongues of the Cannonball Formation (Hartman, 1993; Hartman *et al.*, in prep.).

Lloyd (1914) tentatively assigned the Cannonball Formation to the Tertiary, although the fossils that he collected were considered to comprise a modified Fox Hills fauna by T.W. Stanton. Numerous subsequent studies have demonstrated the Paleocene age of the Cannonball, based on fossil floral and faunal evidence (Dorf, 1940; Fox and Ross, 1942; Stanley, 1965; Cvancara, 1966; Silfer, 1990), although these age estimates have ranged from early to late Paleocene.

Bullion Creek Formation. The Slope Formation is disconformably overlain by the Bullion Creek Formation. The Bullion Creek was named for exposures of relatively light-colored strata in southeastern Golden Valley County by Clayton *et al.* (1977). The Bullion Creek consists of alternating beds of sandstone, claystone, siltstone, and lignite that have been interpreted to represent alluvial plain deposits (Jacob, 1976). The strata of the Bullion Creek are dominantly light colored, in contrast to the more somber-colored Slope and Sentinel Butte Formations.

Strata assigned to the Bullion Creek Formation have been recognized as a distinct lithologic unit since Leonard (1908) described them as the "middle member of the Fort Union." Thom and Dobbin (1924), extending the stratigraphic nomenclature of southeastern Montana into North Dakota, assigned this interval to the Tongue River Member of the Fort Union Formation. Clayton *et al.* (1977), citing different usage of the Tongue River in both South Dakota and Montana, proposed renaming this interval the Bullion Creek Formation. This nomenclatural change has been generally, but not uniformly, accepted by geologists working in North Dakota.

Sentinel Butte Formation. The Sentinel Butte Formation consists of dark gray claystone and sandstone and includes significant lignite resources. Except where incised by lower Sentinel Butte fluvial channels, the lower contact is conformable and is typically placed at the top of H T Butte lignite bed. The Sentinel Butte Formation is exposed throughout much of Billings and eastern Slope Counties (Carlson, 1983).

The name Sentinel Butte was first applied as a stratigraphic term by Leonard (1908), who referred to the Sentinel Butte group of coal beds. Thom and Dobban (1924, p. 495) applied the name Sentinel Butte shale member of the Fort Union (?) Formation to strata "typically developed at Sentinel Butte." They felt that the Sentinel Butte correlated with the Wasatch Formation, and therefore, was of Eocene age.

On the basis of fossil plant assemblages, R.W. Brown (1948) determined that Sentinel Butte shale is Paleocene in age. Subsequently, the Sentinel Butte was regarded as a member or facies of the Tongue River Formation (Fisher, 1953; Meldahl, 1956). Royse (1967) evaluated the relationship between the Tongue River and Sentinel Butte Formations, and concluded that the Sentinel Butte was distinctive and widespread, and should be raised to the rank of formation. A more complete summary of the nomenclatural history of the Sentinel Butte interval is presented by Royse (1967).

Paleocene and Eocene Series

Golden Valley Formation. The Golden Valley Formation was applied to strata, exposed in Mercer County, that previously had been referred to an unnamed member of the Wasatch Formation (Benson and

Laird, 1947). Hickey (1977) subsequently named two members, the Bear Den and Camels Butte Members. On the basis of the presence of the fern *Salvinia preauriculata*, he determined that the Camels Butte Member is Eocene in age, whereas the Bear Den Member is Paleocene. The Bear Den Member consists of white or gray, kaolinitic claystone, siltstone, and sandstone, whereas the Camels Butte Member contains similar lithologies that are yellow to tan, smectitic, and micaceous. This formation is exposed in a few localities in eastern Slope and northeastern Billings Counties, where it rests conformably on the Sentinel Butte Formation.

Eocene and Oligocene Series

White River Group. Within this region, rocks assigned to the White River Group are exposed as the caprock on the high buttes and drainage divides (Carlson, 1983). In general, these rocks are light-colored claystones, siltstones, and sandstones that unconformably overlie the Sentinel Butte or Golden Valley Formations. Within the White River Group, the Chadron and Brule Formations have been recognized in this area. Fossil mammals indicate Eocene to Oligocene age for the White River Group (Murphy *et al.*, 1993).

Oligocene and Miocene Series

Arikaree Formation. Some of the high buttes in the region are capped by a carbonate to coarse- to fine-grained clastic sequence that unconformably overlies the White River Group. These rocks are assigned to the Arikaree Formation and, based on fossil mammals, an Oligocene-Miocene age is indicated (Murphy *et al.*, 1993).

LOCAL STRATIGRAPHY AND SEDIMENTOLOGY

General Lithologic Characteristics

The strata in the area of this study generally are composed of interbedded claystone, siltstone, sandstone, and lignite. The dominant lithotypes have grain sizes in the range of silty claystones to mudstones. Pure claystones are less common, and clean siltstones are relatively uncommon. The claystones to mudstones tend to be smectitic unless their organic content is high. When dry, the surfaces of the smectitic units tend to have a rough texture, commonly referred to as popcorn texture.

The sandstones tend to be fine-grained to very fine-grained, although medium-grained sandstones are present. The results of this study indicate that, in general, the sandstone deposits can be divided into three types, based on lithic characteristics and morphology of the sandstone body.

"Type-1" sandstone bodies contain hard, gray, smectitic sandstones that have erosive, channelform bases.

"Type-2" sandstones are friable, yellowish, relatively clean sandstones that are elongate in lateral extent, but tend not to have erosive bases.

"Type-3" sandstones are friable, yellowish, relatively clean, very fine-grained sandstone to siltstone that have sheet-like lateral extent and lack erosive bases. The upper portion of these sandstones bear root traces at some localities. Two of the Type-3 sandstones were traced laterally and observed to merge with Type-2 channelform sandstone bodies.

The lignite beds exposed in this area range in thickness from a few centimeters to about 2.5 meters. Large pieces of coalified wood are common within the thicker lignites of the Ludlow and Slope Formations. On the other hand, the thinner lignite beds commonly lack the large woody fragments. The lignite beds tend to be overlain by one of two lithologies: massive silty claystone to claystone beds or Type-3 sandstones. Locally, where coal beds have been burned, the overlying claystones are baked to a hard, red porcelanite that is commonly referred to as clinker.

Areal Distribution of Lithologic Units

The Hell Creek, Ludlow, and Slope Formations, and the Boyce and Three V Tongues of the Cannonball Formation are exposed in the area of this study. Cross sections illustrating the stratigraphic relationships of these rock units and some of the informally named lithologic units are presented in Plates 1 and 2. The location of the stratigraphic sections and the lines of the cross sections is given in Figure 1.

The Hell Creek Formation crops out at low elevations along the banks of Cannonball Creek in the southwest portion of the study area (Carlson, 1983). Both Upper Cretaceous and Paleocene rocks are exposed in section M1960 and were encountered in stratigraphic test well M2187. The position of the palynologically determined Cretaceous-Tertiary boundary at these sites is approximately coincident with the Hell Creek-Ludlow formational contact at the base of the lowest, persistent lignite bed (Kroeger, unpublished data) (Plate 1).

The Ludlow and Slope Formations are exposed throughout much of the study area. The contact between the Ludlow and Slope Formations, as mapped by Carlson (1983, pl. 1) in T. 135 N., R. 105 W., appears to be positioned at least 30.5 m higher than the level of contact based on the original definition of the Slope Formation (Clayton *et al.*, 1977).

The areal distribution of the Boyce and Three V Tongues of the Cannonball Formation is not depicted on any published map. Most exposures of the Boyce Tongue are on the east side of the Little Missouri River in T. 135 N., R. 105 W. (Belt *et al.*, 1984, fig. 9). On the basis of the results of this study, exposures in sections 15, 29, and 30 (Figure 1, stratigraphic sections M1721, M1733, and M1959) are also considered here to represent the Boyce Tongue (Van Alstine, 1974; Hartman, 1993, and this study). The Three V Tongue is exposed in much of T. 135 N., R. 105 W. and adjacent areas to the north and east (Belt *et al.*, 1984, fig. 14) on the east and west sides of the Little Missouri River.

Detailed Local Stratigraphy

The palynologic samples analyzed in this study were collected from the upper portion of the Ludlow Formation, the Slope Formation, and the Boyce and Three V Tongues of the Cannonball Formation. That portion of the Slope Formation lying between the Boyce and Three V Tongues of the Cannonball Formation will be referred to as the lower Slope Formation whereas the portion of the Slope Formation lying above the Three V Tongue is referred to as the upper Slope Formation (Figure 3). This division of the Slope Formation is convenient when used in discussions pertaining to the immediate area covered by this study but is not intended for inclusion in the regional lithostratigraphic nomenclature.

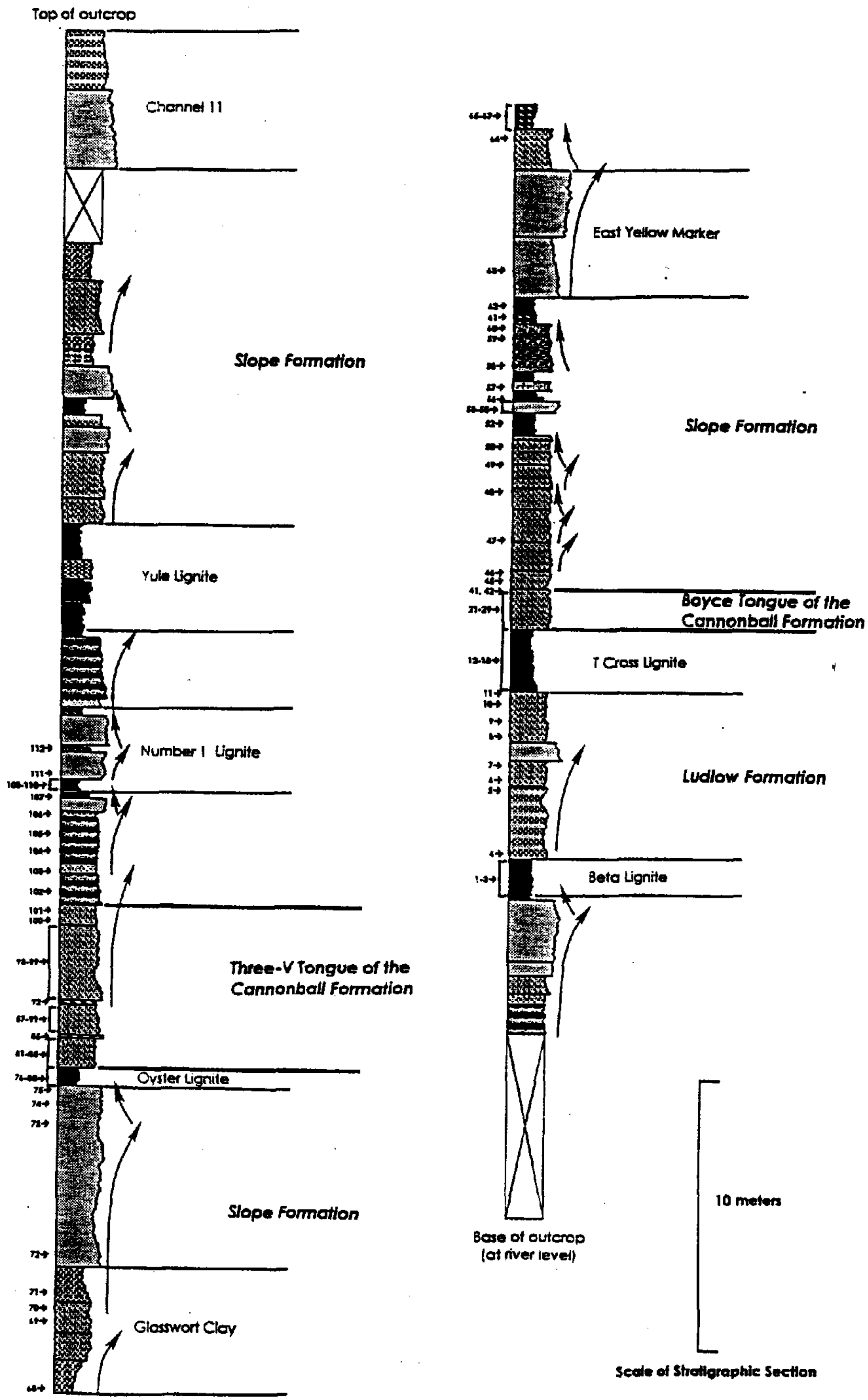
Most of the palynologic samples were collected during measurement of stratigraphic section M1721a-b (Figure 1), and the local stratigraphy discussed here pertains primarily to section M1721 and immediately adjacent areas. A stratigraphic column, representative of section M1721a-b, indicating the stratigraphic position of the samples collected for palynological analysis is included in Figure 3. Detailed lithologic descriptions of the rock units in section M1721a-b are included in Appendix 3.

Figure 3. Stratigraphic column representing stratigraphic section M1721a-b.

The stratigraphic position of the palynological samples is indicated by the small numbers to the left of the column. Refer to Plate 1 for the explanation of the stratigraphic and lithologic symbols.

The formal lithostratigraphic units are identified in bold type and have their boundaries indicated by a bold line. The informal lithostratigraphic units are identified in unbolded type and have their boundaries indicated by a narrow line.

An arrow flaring to the right indicates a lithologic sequence that coarsens upward in grain size. An arrow flaring to the left indicates a lithologic sequence that fines upward in grain size.


Top of outcrop
Channel 11
Slope Formation
Yule Lignite
Number 1 Lignite
Three-V Tongue of the Cannonball Formation
Oyster Lignite
Slope Formation
Glasswort Clay
East Yellow Marker
Slope Formation
Boyce Tongue of the Cannonball Formation
T Cross Lignite
Ludlow Formation
Beta Lignite
Base of outcrop (at river level)
10 meters
Scale of Stratigraphic Section

Ludlow Formation. Only the upper portion of the Ludlow Formation is exposed in M1721. Interbedded silty claystone and clayey, very fine-grained sandstone are the dominant lithologies, although relatively thin lignite beds and claystone beds are also present. Two named lignite beds are present, the "Beta" and "T Cross" (*sensu* Moore, 1976). The contact between the Ludlow Formation and the overlying Boyce Tongue of the Cannonball Formation is placed at the top of the "T Cross" lignite (Hartman, 1993).

When exposed by trenching, the primary, inorganic, sedimentary structures are typically well preserved. Root traces are not common except directly beneath lignite beds where relatively large, coalified, horizontal roots are commonly preserved. Finely divided plant remains are typically abundant, whereas well-preserved leaf fossils were not noted.

The sandy units typically contain thin claystone interbeds, small-ripple laminae, and horizontal, parallel laminae. The sandy units may either fine or coarsen upward in grain size. The Ludlow sandstones in M1721 are thin and sheet-like in lateral extent; erosional bases and channel-form boundaries are not present.

Boyce Tongue of the Cannonball Formation. The Boyce Tongue of the Cannonball Formation was first reported by R.W. Brown (1948), who noted the occurrence of the bivalve *Corbula* at a lower horizon than the oysters previously reported by Leonard (1908). Brown interpreted the *Corbula*-bearing bed to represent a westward extension of the Cannonball Formation.

Van Alstine (1974) reported additional fossils from the Boyce Tongue, including the foraminiferids *Trochammina* sp. and ?*Haplophragmoides* sp. and the molluscan bivalves *Corbicula berthoudi*?, *Corbula* (*Bicorbula*) *subtrigonalis*, and ?*Ostrea* sp. In more recent studies, the oyster is referred to as ?*Ostrea* form V (Hartman *et al.*, in prep.).

Samples for palynological analysis from the Boyce Tongue were collected in section M1729, and from 3 sites, separated laterally by 15-20 m, in section M1721. Detailed stratigraphic sections of each locality and the stratigraphic position of the palynomorph samples are presented in Figure 4.

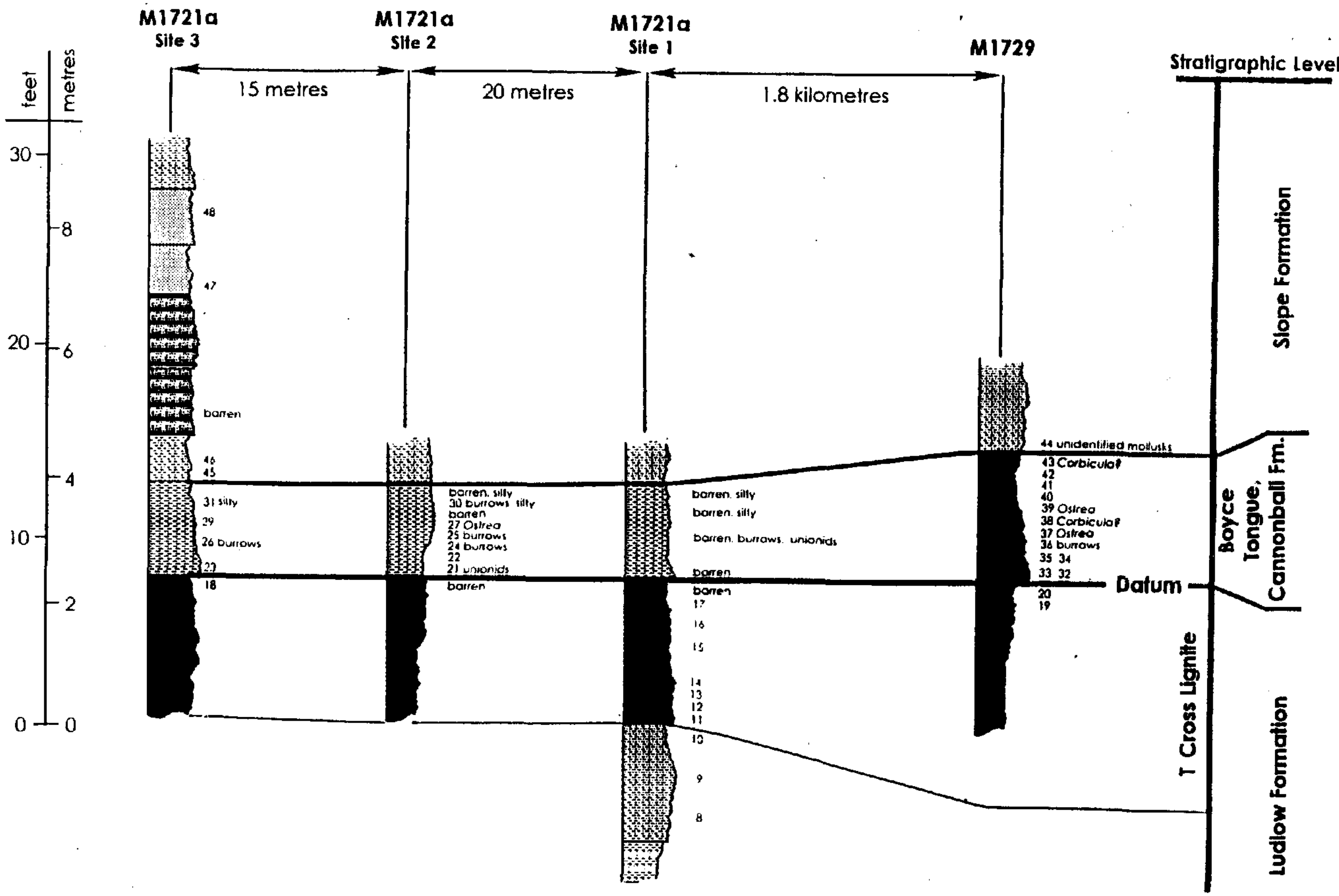
In general, the Boyce Tongue consists of dark (5GY3/2 to 5G4/1), nonswelling, carbonaceous mudstone and claystone that is commonly jarositic along bedding planes and vertical fractures. Bioturbation is intense in some horizons and horizontal-burrow ichnofossils are common, commonly completely obliterating all primary, inorganic, sedimentary structures. The Boyce Tongue overlies the "T Cross" lignite (*sensu* Moore, 1976) in relatively sharp contact.

In section M1721, the Boyce Tongue is 1.5 m thick and contains a bivalve and gastropod fauna that is preserved as carbonized impressions. The bivalves consist of *Corbula* (*Bicorbula*) *subtrigonalis*, *Ostrea*? sp., and unidentified unionid bivalves. Gastropod taxa include *Campeloma nebrascense*?, *Lioplacodes tenuicarinata*, and additional unidentified gastropods (Hartman *et al.*, in prep.). The gastropods, unionids, and *Corbula* (*Bicorbula*) *subtrigonalis* are common in the lower 0.75 m of the bed, whereas impressions of *Ostrea*? sp. (probably the same species as ?*Ostrea* form V) are restricted to a relatively thin zone above the freshwater fossils. Invertebrate fossils are absent in the uppermost portion, but fragmented plant remains become abundant in the zone of transition to the mudstone of the overlying lithologic unit.

The Boyce Tongue is about 2.0 m thick in section M1729. The invertebrate fauna consists of the species reported by Van Alstine (1974) (see above). These fossils most commonly occur as carbonized impressions, but fossils containing shell material and gypsum-replaced shell material are also present. Compared to section M1721, the lithology of the Boyce Tongue in section M1729 tends to be siltier and the primary sedimentary structures are more consistently destroyed by intense bioturbation. The transition to the overlying siltstone is

Figure 4. Detail of stratigraphy and sampling localities in the Boyce Tongue of the Cannonball Formation and associated strata.

See Plate 1 for explanation of the lithologic symbols.


M1721a
Site 3
M1721a
Site 2
M1721a
Site 1
M1729
Stratigraphic Level
15 metres
20 metres
1.8 kilometres
feet
metres
30
20
10
0
8
6
4
2
0
48
47
barren
46
45
31 silty
29
26 burrows
23
18
barren, silty
30 burrows silty
barren
27 Ostrea
25 burrows
24 burrows
22
21 unionids
barren
barren, silty
barren, silty
barren, burrows, unionids
barren
barren
17
16
15
14
13
12
11
10
9
8
44 unidentified mollusks
43 Corbicula?
42
41
40
39 Ostrea
38 Corbicula?
37 Ostrea
36 burrows
35 34
33 32
20
19
Datum
Slope Formation
Boyce Tongue, Cannonball Fm.
T Cross Lignite
Ludlow Formation

marked by increase in silt content, lack of bioturbation, and the common occurrence of unidentifiable, crushed bivalves that have preserved shell material.

Slope Formation, lower portion. Section M1721 was measured in the stratotype area of the Slope Formation (Clayton *et al.*, 1977); therefore this stratigraphic section is a detailed study of the formation's stratotype. The lithology of the lower Slope Formation is comparable to that of the upper part of the Ludlow Formation; it consists of interbedded claystone, siltstone, sandstone, and lignite. In general, inorganic sedimentary structures are well preserved and root traces are uncommon, except directly below lignite beds. Root traces present in horizons unassociated with lignite beds are typically small (less than 2.0 mm in diameter) and vertical and are not concentrated beneath a particular source horizon that could be interpreted as a well-developed paleosol.

The East Yellow Marker of Moore (1976) is a 2.5 m thick, cliff-forming, yellowish, fine-grained, Type-3 sandstone that caps the lower cutbanks of the Little Missouri River in the northeast corner of section 15, T. 135 N., R. 105 W. The uppermost 0.5 m of the sandstone is cemented with calcite and displays climbing-ripple laminae (Reineck and Singh, 1980, p. 110). In this area, this sandstone is sheet-like in lateral extent, but about 800 m to the northeast the East Yellow Marker appears to merge with the Straight sandstone (Moore, 1976), a 10-15 m thick, yellowish Type-2 sandstone. The upper portion of the Straight sandstone is also calcite cemented and displays abundant climbing-ripple laminae and water escape structures, both indicators of rapid deposition. The Straight sandstone is the only channel-form sandstone body within the lower Slope Formation in this immediate area.

Moore (1976) also recognized a distinctive claystone bed directly overlying the upper bed of the Upper Coal Pair. He referred to this bed as the Glasswort clay for the salt-tolerant plants (*Salicornia*) that thrive on outcrops of this bed. In section M1721, the Glasswort clay is poorly exposed and was not examined or sampled in detail during this study.

Three V Tongue of the Cannonball Formation. The Three V Tongue of the Cannonball Formation was first recognized by Leonard (1908), who reported the presence of fossil oysters in the general area of this study. This oyster-bearing rock unit was subsequently regarded as a westward extension of the Cannonball Formation by Lloyd and Hares (1915).

Within the area of M1721, the Three V Tongue is easily recognized due to the relative abundance of small lenses and pods of fossil oysters. The primary components of the fauna are the bivalves *Crassostrea subtrigonalis*?, *Ostrea* sp. form V, *Corbicula berthoudi*?, *Corbula* (*Bicorbula*) *subtrigonalis*, and a possible occurrence of *Ostrea* cf. *O. crenulimarginata*?. A few vertebrate fossils are also known, including a shark tooth of *Carcharias taurus*, a ray tooth of ?*Myliobatis* sp., and vertebrae of the freshwater reptile *Champsosaurus* sp. (Van Alstine, 1974; Hartman *et al.*, in prep.).

A distinctive, laterally persistent, 0.2 m thick, black, carbonaceous mudstone located about 2.3 m above the base of the Three V Tongue serves as a useful marker bed. The pods of *Crassostrea subtrigonalis*? are restricted to that portion of the Three V Tongue lying below the marker, whereas the remainder of the bivalves appear to occur above it. Most of the invertebrates are preserved as shell material or gypsum-replaced shell material, although carbonized impressions were also discovered above the black marker bed.

Lithologically, the Three V Tongue is similar to the Boyce Tongue in that it consists of dark, carbonaceous, nonswelling, silty claystones. Jarosite is common on bedding planes and along vertical fractures and large selenite crystals are common on the surface of outcrops. Extensive bioturbation appears to have destroyed the primary sedimentary structures, causing claystone to have a blocky fracture pattern. Horizontal burrows are common on horizontal fracture planes.

The top of the Three V Tongue is difficult to define. The silty claystone lithology continues for about 6.1 m above the base of the unit. All invertebrate fossils discovered during this study were found within this lithology. The silty claystone is overlain by a sequence of interbedded siltstone, very fine-grained sandstone and claystone that is extensively bioturbated in only a few thin beds. Hartman (1993, fig. 3) placed the upper contact at the transition from silty claystone to clayey sandstone, whereas Van Alstine (1974) placed the top of the U-tongue of the Cannonball Formation (= Three V Tongue) at the base of the lowest overlying lignite bed. Moore (1976) considered the upper contact of the oyster clay (= Three V Tongue) to be an unconformable surface with relief of several feet. Such a distinctive unconformity was not noted in section M1721. The upper contact, as defined by Hartman (1993), will be followed here.

Slope Formation, upper portion. The portion of the Slope Formation lying above the Three V Tongue is lithologically similar to the lower portion of the Slope Formation and the upper part of the Ludlow Formation. However, a greater number of beds bearing root traces was noted within the upper Slope Formation. Most of the beds in the silty claystone to siltstone range of grain sizes contain root traces, whereas in the lower Slope Formation, root traces are common only directly beneath lignite beds.

Within the upper Slope Formation, two series of named lignites are exposed in section M1721, the Number 1 and Yule lignites. The section is capped by a 3.0 m thick, fine-grained, cross-bedded sandstone that has been referred to as "channel #11" (Belt *et al.*, 1984, fig. 5). No invertebrate fossils were noted from the upper Slope Formation during the course of this study.

The white siliceous beds and the bleached zone that delimit the top of the Slope Formation (Clayton *et al.*, 1977) are not exposed in section M1721, presumably having been removed by erosion. They are exposed several kilometers to the northwest capping isolated small plateaus on the upland terrain and several kilometers to the northeast within the Little Missouri River valley (Belt *et al.*, 1984).

Regional Depositional Framework

The area of this study lies within the southwestern portion of the Williston Basin, a large intracratonic basin with its depocenter in northwestern North Dakota (Figure 1). The Paleocene strata in the Williston Basin tend to have thickness trends that are parallel to the basin axis, suggesting that basin subsidence influenced depositional patterns (Cherven and Jacob, 1985).

The return of marine conditions in North Dakota during the early Paleocene can probably be related to a rise in eustatic sea level (Haq *et al.*, 1987). Because the Cannonball Formation lacks physical connections to coeval marine strata of the continental margin, the direction of the marine connections between the Cannonball Sea and the ocean basins is uncertain. On the basis of faunal similarities, connections with the Arctic and North Atlantic Oceans to the north and northeast (Erickson, 1978), Gulf of Mexico to the south (Fox and Ross, 1942), or both northerly and southerly connections (Brown, 1962) have been proposed.

The predominantly non-marine depositional setting for the strata included in the Ludlow and Slope Formations has long been recognized (Leonard, 1908; Lloyd and Hares, 1915). Belt *et al.* (1984) interpreted the Ludlow Formation (Ludlow and Slope Formations of this report) to represent the deposits of a highly constructive delta that was prograding northeasterly into the Cannonball Sea. On the basis of the percentage of sandstone in the Cannonball Formation, Cherven and Jacob (1985) recognized a large eastwardly prograding delta that they named the Marmarth Delta System for exposures near Marmarth, North Dakota. Within the vicinity of the present study, they interpreted the Ludlow and Slope Formations to represent a lobe of this delta.

Depositional Environments

Sandstones. Within the deltaic depositional framework, numerous sub-environments have been interpreted to be represented. There is general agreement among previous workers that the Type-1 sandstones were deposited by fluvial channels, most likely by delta distributary channels (Belt *et al.*, 1984).

The Type-3 sandstones have been interpreted as crevasse-splay deposits (Belt *et al.*, 1984). Several features of the Type-3 sandstones support this interpretation, including: 1) sheetlike morphology of the sandstone bodies, 2) sedimentary structures indicating rapid deposition, 3) root traces in the upper portion some of the sandstones, indicating subaerial exposure, and 4) their stratigraphic position overlying coals or flood-basin deposits.

Several depositional settings have been proposed for the Type-2 sandstones, including tidal channels (Moore, 1976), crevasse-splay feeder channels (Belt *et al.*, 1984), and deltaic, bar-finger sands (Cherven and Jacob, 1985). Several features of these sandstones support an interpretation for their origin as crevasse-splay feeder channels, including: 1) sedimentary structures that indicate unidirectional flow, 2) the sandstone bodies connect laterally to deposits that are interpreted to represent crevasse-splays, 3) there is not an intimate association with marine deposits as would be expected in bar-finger sands (Fisk, 1961), and 4) the sedimentary structures are of larger scale than is found in bar-finger sands. (Fisk, 1961).

Massive Claystones and Silty Claystones. The massive claystone, mudstone, or silty claystone beds within the study area can be divided into two general groups based on the presence or absence of brackish-water invertebrate fossil assemblages. The Boyce and Three V Tongues of the Cannonball Formation are included within this lithotype. The fine-grained nature of these beds and their fauna suggest deposition within lakes and bays ranging in salinity from fresh to brackish.

The massive claystones commonly directly overlie lignite beds, suggesting that the lakes or bays in which they were deposited developed due to flooding of persistent, flood-basin swamp environments. This flooding could be the result of basinal subsidence, compaction of underlying sediments, or marine transgression due to eustatic changes.

On the basis of the species composition and low diversity of the faunal assemblages in the Three V and Boyce Tongues, their depositional environment is interpreted to have had lowered to fluctuating salinities (Lloyd and Hares, 1915; Brown, 1948; Van Alstine, 1974; Hartman *et al.*, in prep.). Belt *et al.* (1984) interpreted the Boyce and Three V Tongues of the Cannonball Formation as interdistributary bay deposits. However, because interdistributary bay environments are defined as areas of open water within an active delta (Coleman and Gagliano, 1965), I feel that this interpretation may be somewhat too specific. Other deltaic paleoenvironments could have yielded deposits of similar nature. Of particular interest to this interpretation are the differences in the Boyce Tongue between sections M1721 and M1729, stratigraphic sections located about 1.8 km apart.

In section M1729, there is little evidence of paleoenvironmental change during the deposition of the Boyce Tongue. All invertebrate fossils that have been discovered are consistent with deposition in a brackish-water paleoenvironment, and the deposit is consistently bioturbated throughout. In section M1721a, freshwater and brackish-water invertebrate fossils are present in close vertical juxtaposition. The sequence of fossil occurrences suggests that the lower portion of the bed was deposited under freshwater conditions that gave way later to increased salinity.

With the exception of a thin zone containing brackish-water fossils, this lithologic sequence is consistent with that described for deltaic lacustrine environments in the Atachafalaya Basin of Louisiana by Coleman (1966). In the Mississippi delta region, such lakes probably form due to compaction and subsidence in flood basins and are commonly called round lakes or distributary flank depressions. Over time, these lakes are enlarged through continued subsidence and wave erosion until a stream or distributary channel is diverted into the lake, after which the lakes rapidly fill with sediment (Coleman, 1966). Modern examples include Grand and Six Mile Lakes in the Atachafalaya Basin. The lakes contain fresh to brackish water and commonly merge seaward with open bays having broad marine connections, such as Vermilion and Cote Blanche Bays on the central Louisiana coast (Coleman and Gaglianio, 1965). The Boyce Tongue within the study area may represent a similar transitional environment between a predominantly freshwater lake and brackish-water bay.

Interlobe basins within the modern Mississippi River delta also have variable salinities ranging from saline to brackish to freshwater. Interlobe basins are not located between active distributary channels, but rather are large-scale basins that are isolated by delta lobe abandonment when major distributaries switch from one delta complex to another (Kosters *et al.*, 1987). The change from lacustrine to brackish conditions that is evident within the Boyce Tongue is more consistent with lacustrine-open bay and interlobe basin depositional environments than with an interdistributary bay setting.

The Three V Tongue could represent either interdistributary bay, open bay, or interlobe basin depositional environments. In the modern northern Gulf of Mexico, *Crassostrea* is common in similar settings, typically occurring in reefs aligned perpendicular to the flow of currents (Parker, 1960). Some paleoenvironmental change during deposition of the Three V Tongue may be indicated by the restriction of the lenses of *Crassostrea subtrigonalis*? to below the level of the thin "black marker bed." Above the marker bed, the invertebrate fauna is sparser and more closely resembles that of the Boyce Tongue in section M1729. Van Alstine (1974) and Hartman *et al.* (in prep.) interpreted the Boyce Tongue to represent higher salinities than the Three V Tongue. If true, the "black marker bed" may denote the approximate level of a slight increase in salinity during deposition of the Three V Tongue.

Lignite underclays. Most of the lignite beds are underlain by dark-brown claystones or carbonaceous shales, although some lignites are underlain by sandier strata. The claystones typically contain very abundant plant leaf fossils that, in some cases, are well preserved. Their fine-grained nature and the presence of abundant plant material suggests a quiet, floodbasin depositional environment in relatively close proximity to swamps or marshes. Nearly all of the underclay horizons contain root traces, but it generally was not possible to verify whether the traces originate from within the claystones themselves or from the overlying coal bed.

Both marsh and shallow lacustrine depositional environments are probably represented by the underclays. Under lacustrine conditions, the transition to lignite could represent the infilling of the lake by shoreline encroachment or by the accumulation of peat in floating "peat islands" that anchor and enlarge over time to fill in lakes (Rich and Spackman, 1979). In the modern Mississippi delta region, such floating peat blankets are common within the freshwater portion of Barataria Bay, an interlobe basin located between the modern Balize delta complex and the abandoned Lafourche complex (Kosters *et al.*, 1987).

Where the under-coal beds are sandy, they are generally rooted throughout and probably represent marsh depositional environments.

Lignites. The thicker lignite beds are underlain by rooted claystones suggesting that the plants that produced the lignite were growing at the site of deposition. The large pieces of coalified wood that are commonly present suggest that the lignites originated in wooded, swamp settings. The depositional conditions of the thinner lignites are uncertain. Many are underlain by clayey, rooted horizons, but were not noted to contain large pieces of coalified wood. These lignites could represent marsh environments, but without additional study, including coal petrography, this conclusion is speculative.

Most active deltas have rates of clastic deposition too high to allow the development of thick, low ash peat deposits (McCabe, 1984). However, where clastic influx is lower, such as abandoned portions of deltaic complexes and inland swamps, thicker peats do accumulate. Thus, the Ludlow and Slope Formation lignites probably do not represent active deltaic paleoenvironments.

For the purpose of palynological analysis, the lignites are classified into three general types:

Type-1 lignites are the most common type of lignite. They are overlain by massive claystone beds, suggesting that peat deposition was halted by rising of the water table, causing the peat swamps to drown. Drowning of a coal swamp is indicative of rapid subsidence, sudden rise in the water table, or changes in the rate of peat accumulation. In coastal paleoenvironments, such as are proposed for this stratigraphic interval, changes in salinity might affect the rate of peat accumulation by altering the floral communities and exposing existing peat to more alkaline conditions, causing it to degrade (McCabe, 1984). Type-1 lignites are not associated with sandy deposits, and are interpreted to have been deposited in flood basin or delta swamps some distance from active fluvial channels.

Type-2 lignites are present in the Lower and Upper Coal Pairs (LCP and UCP) and Number 1 lignites. These lignite beds are typically terminated by Type-3 sandstones, suggesting that the coal swamp environment was suffocated by coarser clastic sediment when streams crevassed into swampy floodbasins. The contacts between the coal and sandstone beds do not appear to be erosive. The underclays beneath these beds are typically sandy and are interpreted as marsh deposits. Thus, the Type-2 lignite sequences may represent flood basin environments that are more proximal to sources of coarse clastic sediment and may represent the edaphically drier environments of the distal levee settings.

Type-3 lignites are very thin, laterally discontinuous, lignite stringers. These lignites are less than 10 cm thick, and generally are not associated with well-developed, rooted underclays. These lignites may represent allochthonous deposits that formed by the concentration of organic debris by gentle currents, or by the preservation of thin mats of floating peat.

Silty Claystone and Mudstone. The most common rock type present in the study area is nonmassive, silty claystone to mudstone. Commonly thin interbeds (about 5-10 cm thick) of claystone are present and finely divided plant material is abundant. Inorganic sedimentary structures are nearly always well preserved and typically consist of small-ripple laminae and parallel, horizontal laminae. Throughout most of section M1721, biogenic sedimentary structures are uncommon within this lithology except for the upper portion of the Slope Formation, where root traces become abundant. Trace fossils of invertebrates are rare, occurring only in a few thin horizons.

The silty claystone and mudstones typically occur within a sequence of many beds that, on the whole, tend to coarsen upward in grain size. In some cases, however, individual beds may fine upwards. The sequences are commonly overlain by a lignite underclay and lignite bed. Such sequences are exemplified by the silty claystones and mudstones that overlie the Glasswort clay and Three V Tongue of the Cannonball Formation.

The fine-grained nature of this rock type suggests deposition as overbank deposits relatively far removed from main fluvial channel systems. Moore (1976) proposed a similar depositional environment, but he puzzled over the lack of root traces. Belt *et al.* (1984) placed units of this lithology in one of two facies associations, the lower portion of the crevasse association or the levee association.

I feel that the paucity of root traces in the upper part of the Ludlow and lower portion of the Slope Formation is best explained by subaqueous deposition into standing water bodies as lacustrine delta fill sequences and interdistributary bay and delta interlobe fill sequences. Lake or bay fill sequences are initiated when a stream is diverted into a lake or bay, greatly increasing the rate of clastic deposition. The fill sequences overlie fine-grained lacustrine or brackish deposits and are commonly overlain by marsh or swamp deposits, indicating that filling progressed to near the water surface (Coleman, 1966; Coleman and Prior, 1982; Chmura, 1994).

The sedimentary structures and coarsening-upward lithologic sequences that are common in the silty claystone and clayey siltstone lithologies is consistent with the description of lacustrine delta fills in the Atachafalaya basin of southern Louisiana (Coleman, 1966). Kosters *et al.* (1987) also described alternating beds of sandy silt and clay in a fill sequence within Barataria Bay on the modern Mississippi River delta. They noted a gradual increase in organic content through the sequence, culminating in a peat.

The transition from intensely bioturbated brackish-water deposits to bay fill sequences lacking trace fossils is consistent with observations in bays along the northern Gulf of Mexico. Shepard (1964) noted that benthic faunas intensely bioturbated these bays except in the areas near stream mouths where the salinity was lower and the sedimentation rate was much higher.

Drier edaphic conditions are suggested by the abundant root traces within Lower Coal Pair to Upper Coal Pair interval and in the upper portion of the Slope Formation. The drier conditions allowed the establishment of vegetation on mineral soils (silty claystones and mudstones) between episodes of clastic sedimentation. The drier soil conditions may have been the result of two factors, the establishment of subaerial levee environments within this area, or continued eastward deltaic progradation, placing this area in a better drained, alluvial plain, depositional setting.

Paleoenvironments Used in Analysis of Palynomorph Distribution

In order to determine if paleoenvironmental trends are present within the distribution of palynomorph assemblages, the paleoenvironments represented by each sample must be determined as accurately as possible. Macroscopic inorganic and biogenic sedimentologic features and the types of molluscan assemblages were utilized to determine these paleoenvironments.

Brackish-water Environments. Strata were considered to be of brackish-water origin if they contained brackish-water mollusk assemblages, or were part of a lithologic unit that bears only brackish-water fossils. Although beds containing horizontal-burrow ichnofossils are typical of the brackish-water strata, these ichnofossils were not considered to be diagnostic of brackish-water paleoenvironments. Some thin strata within the Boyce Tongue in section M1721 were considered to represent slightly brackish paleoenvironments. These strata bear sparse molluscan assemblages that are indicative of brackish water, but are interbedded with strata that bear freshwater mollusks. The paucity of brackish-water fossils and the evidence for fluctuating salinity suggests that only slightly brackish conditions were present.

Lacustrine Environments. The strata assigned to lacustrine paleoenvironments are characterized by a lithology of massive to fissile claystone. Little or no sandstone or siltstone is present within lacustrine strata. Freshwater mollusks are present in some cases, but are not a prerequisite for this paleoenvironment. Root traces are absent. Other plant fossils may be present, and are commonly well preserved.

Lake Fill and Bay Fill Environments. The lake fill and bay fill paleoenvironments are relatively thick sequences of interbedded siltstones and claystones that overlie lacustrine or brackish-water strata. The sequences tend to grow coarser in grain size from bottom to top. Molluscan fossils are absent, and root traces are rare, and are never concentrated along distinct horizons.

Lake fill and bay fill paleoenvironments are distinguished from marsh paleoenvironments by the absence of root traces and concentrated organic horizons. However, if the emergent vegetation along the fringes of progradational marshes was sparse, the root traces would also be sparsely distributed and the resulting deposits would probably be classified as lake or bay fill deposits.

Marsh Environments. Only clastic-dominated marsh environments are included in this category. If any marshes were isolated enough from clastic influx to produce coal beds, they would be classified in the lignite paleoenvironments. However, due to the difficulty of differentiating between the coal-producing paleoenvironments, the presence of lignites having a marsh origin has not been confirmed.

Within the Mississippi River delta region, marshes having high clastic influx occur in progradational settings, forming after lake or bay environments have been filled by clastic sediments. The organic-rich marshes that lead to the deposition of thick peats are present in freshwater portions of transgressive areas (Chmura, 1994).

The strata here included in the marsh paleoenvironments are characterized by abundant, small diameter (less than 5 mm) root traces.

The root-bearing horizons may be overlain by thin, carbonaceous horizons that are interpreted to also represent marshes. Although these strata cannot be confirmed to represent wetland deposits, the general interpretation of a deltaic stratigraphic succession suggests that such wetlands were probably present. The strata that are here interpreted to represent marshes tend to be associated with the sandier strata that are stratigraphically positioned within the Lower Coal Pair to Upper Coal Pair sequence. This suggests that the marshes were relatively proximal to the channel systems.

Lignite Producing Environments. The lignite producing paleoenvironments were classified as either the Type-1, Type-2, or Type-3 environments, based on the criteria listed above. Only one sample of the Type-3 lignites (number 5) was included in the palynological analysis. Therefore, this sample was combined with the Type-2 lignites during paleoenvironmental analysis of the palynomorph assemblages. On a megascopic scale, the type of lignite cannot be correlated to differences in the producing vegetation.

Lignite Underclays. The clay beds that typically underlie lignite beds were not further divided into different depositional environments.

PALYNOLOGICAL RESULTS

Introduction

Detailed study of palynomorph assemblages was limited to samples collected between the base of the Beta lignite and the lower portion of the Number 1 coal group (Figure 3). Of the 121 samples from sections M1721a-b and M1729 that were studied in detail, 112 yielded palynomorphs in sufficient abundance for quantitative study. To determine the possible presence of additional brackish-water deposits, samples from M1720, M2187, and the upper portion of M1721 were scanned to determine if dinoflagellate cysts were present.

One hundred and thirty-three taxa or taxonomic groups are described. Of these taxa, 30 are thought to be spores or resistant cysts of algae, whereas the remainder are pollen and spores of higher plants. At least eleven of the algal taxa are cysts of dinoflagellates and the remainder are attributed to other algal groups or are regarded as probable algal spores of uncertain affinities. Spores of unquestioned fungal origin are relatively uncommon and are not included in this study. Megaspores attributable to *Azolla* and *Isoetes* are present, but were not sampled systematically and therefore are not included in this study. In general, palynomorph preservation is excellent to fair.

In addition to the palynomorph taxa described in this report, many more palynomorph taxa were documented. However, many of these taxa occur in only one or few samples or in very low relative abundances and therefore are not readily incorporated into the paleoecological analysis. These rare taxa are combined into several summary groups (e.g. "others") for the stratigraphic analysis. In general, palynomorph taxa are included in the paleoenvironmental analyses only if their relative abundance exceeds one percent in three or more samples.

Within this report, the term "palynomorph assemblage" is used to refer to the palynomorphs present within an individual sample. "Palynomorph association" is used to refer to a distinctive suite of palynomorph assemblages that appears to have some paleoenvironmental or paleofloral significance.

Stratigraphic Distribution of Palynomorphs

A restricted stratigraphic interval was chosen for this study in hopes of limiting changes in palynomorph assemblages due to organic evolution or regional floral changes due to climatic change and floral migration. By limiting the factors of evolution and regional flora change, changes in palynomorph assemblages might more readily be attributed to localized paleoenvironmental effects.

The relative abundances of the 133 palynomorph taxa plus the summary taxa are displayed in a pollen diagram (Plate 3). The samples in this diagram are arranged in ascending stratigraphic order, with the exception that samples from the two localities of the Boyce Tongue are maintained as separate groups. The relative positions of key stratigraphic levels are also indicated on the pollen diagram.

Several taxa are restricted to the stratigraphic interval of the Boyce Tongue in section M1721. Examples include Acritarch Type-1, Acritarch Type-2, and Acritarch Type-3. All records of *Pterospermella australensis* are from strata below the level of the Lower Coal Pair. Acritarch Type-4 is stratigraphically restricted to the Three V Tongue of the Cannonball Formation. The only other taxa that are stratigraphically restricted occur only in one or two samples, and thus are inadequately represented.

All of the palynomorph taxa listed above are thought to have been produced by algae and thus might be expected to be quite paleoenvironmentally sensitive. The particular paleoenvironmental setting encountered in the Boyce Tongue in section M1721 appears to be unique within this section, as brackish-water mollusks are closely interbedded with freshwater mollusks. The uniqueness of this paleoenvironmental setting is a likely reason for the stratigraphic restriction of the three acritarch taxa.

Relationship of Palynomorph Assemblages to Depositional Environment

Two methods were employed to identify the relationship between the composition of the palynomorph assemblages and depositional environment. The first method is more subjective and involves construction of a pollen diagram in which the samples are arranged according to the depositional environment of the stratum from which they were collected (Plate 4). The second method involves objective analysis using multivariate statistical methods.

Results of Subjective Paleoenvironmental Analysis. A pollen diagram was constructed in which the samples were arranged according to their interpreted paleoenvironments (Plate 4). All taxa except those that occur in only one or two samples are included in this pollen diagram. When analyzing the pollen diagram, four types of occurrence trends were considered:

1) taxon exhibits no clear paleoenvironmental trends in its occurrence,
2) taxon has a strong tendency to occur almost exclusively in one or two paleoenvironments,
3) taxon has a weak tendency to be more abundant, or more typical of certain paleoenvironments, and
4) a relatively common taxon tends not to occur in one or more paleoenvironments.

The paleoenvironmental trends in palynomorph occurrence that are interpreted from the pollen diagram are summarized in Table 2. Only taxa that exhibit either positive or negative trends in their occurrence are included in the table. Those taxa not listed in the table are considered to exhibit no well-defined paleoenvironmental trends.

On the basis of the subjective paleoenvironmental analysis, two paleoenvironmentally distinctive, recurrent palynomorph associations can be identified. The associations are herein named the *Pediastrum* association and the Acritarch association, in reference to their dominant palynomorph taxa.

Samples bearing the *Pediastrum* association tend to be dominated by the green alga *Pediastrum*. Other algal or probable algal taxa are also commonly present in this association including *Psilainaperturites* sp. 2, *Ovoidites* cf. *O. ligneolus*, *Botryococcus* sp., *Micrhystridium* Type-1, and some species of dinoflagellates.

The occurrence of the *Pediastrum* association is restricted, as it was recovered only from the basal portions of the Boyce and Three V Tongues of the Cannonball Formation. The most conspicuous occurrence of this association is from the base of the Boyce and Three V Tongues in section M1721a-b. However, the *Pediastrum* association is probably also present at the base of the Boyce Tongue in section M1729, even though *Pediastrum* does not dominate the palynomorph assemblages at that locality. The high relative abundance of terrestrial palynomorphs in section M1729 suggests that the signature of the *Pediastrum* association has been swamped by terrestrial palynomorph influx.

The Acritarch association is also dominated by algal palynomorphs and has an unusual paucity of terrestrial palynomorphs. The samples bearing this association contain the most conspicuous occurrences of Type-1, Type-2, and Type-3 acritarchs, *Ovoidites* cf. *O. ligneolus*, *Micrhystridium* Type-2, *Psiloschizosporis* cf. *S. spriggii*, and *Cymatiosphaera* sp. The Acritarch association was recovered only from the Boyce Tongue of the Cannonball Formation in section M1721a. It is

Table 2

Summary diagram indicating trends in the paleoenvironmental occurrence of palynomorph taxa. Only taxa demonstrating a positive or negative occurrence trend are listed.

++ = strong positive occurrence trend
+ = weak positive occurrence trend
- = negative occurrence trend

TAXON	INTERPRETED PALEOENVIRONMENTS								
	Type 1 lignite	Type 2 lignite	Lignite underclays	Marsh	Lake fill	Bay fill	Lacus-trine	Slightly brackish	Brackish
Deflandrea cf. flounderensis									++
Spinidinium? pilatum									+
Peridinioid sp. 1									+
Dinoflagellate sp. 1	-		+	-	-	-	+	+	+
sum chorate dinoflagellates						+			+
sum proximate and cavate dinoflagellates	-	-							++
Baltisphaeridium sp.									+
Botryococcus sp.	-	-	+				+	+	
Cymatiosphaera sp.								++	
Micrhystridium type-1	-	-			-	-	+	++	++
Micrhystridium type-2							++		
Ovoidites cf. O. ligneolus	-	-	-	+	-		++	++	+
Pediastrum spp.	-	-		-			++	++	+
Polyporina sp.							++	+	+
Psiloschizosporis laevigatus	+		-		-	-	-	-	+
Psiloschizosporis cf. P. spriggii								+	
Pterospermella australis								++	
Sigmopollis hispidus			+						
Tetraporina sp.			+						
Acritarch type-1								++	
Acritarch type-2							++	++	
Acritarch type-3								++	
Acritarch type-4									++
Axolla cretacea	-	-	-	+	+		-	-	-
Azolla spp.	-	-	-						
Biretisporites furcosus	+	+	-				-	-	
Cyathidites diaphana	+	-	+	+	+	+	-	-	
Gleicheniidites spp.	+								+
Laevigatosporites spp.							-	-	
Osmundacidites cf. O. wellmanii						-		-	

Table 2 (continued)

++ = strong positive occurrence trend
+ = weak positive occurrence trend
- = negative occurrence trend

TAXON	INTERPRETED PALEOENVIRONMENTS								
	Type 1 lignite	Type 2 lignite	Lignite underclays	Marsh	Lake fill	Bay fill	Lacus- trine	Slightly brackish	Brackish
Reticuloidosporites pseudomurii	++	-		+			-	-	
Stereisporites (Distancoraesporites) spp.	+	-	-				-		+
S. (D.) radiatus	+	-	-	-	-	-	-	-	+
S. (Stereisporites) and S. (Distverrusporis) spp.	++		-				-		++
S. (Stereigranisporis) spp.									++
Toroisporis sp.	+								
Araucariacidites australis						+			+
Corollina sp.	-			-	+	+			+
Psilainaperturites sp. 1	+		+	-	-	-	+	+	+
Psilainaperturites sp. 2	-	-		-	-		+		+
Bisaccate Pollen	+	-	-	+	+	+	-	-	
Arecipites tenuiexinous	+	-	-	+		+	-	-	
Arecipites columellus	+								
Liliacidites? sp.					+	+			
Monocolpopollenites cf. M. texensis						+			+
Rossipollis scabratus									+
Pandaniidites typicus	-	-			+	+		-	
Sparganiaceaepollenites cf. C. globipites	-	-		+	-	-	-	-	+
Sparganiaceaepollenites sp.	-	-	-		+	+	-	-	-
Sparganiaceaepollenites? sp.	-	+		+			-		
Dicotetradites rallus	-	+	+		+	+		-	
Cricotriporites plektosus	-			+	+		+	-	
Jarzenipollis trinus			-	+		-	-		+
Labrapollis granulatus				+	-	-	-		+
Labrapollis sp.									+
Momipites waltmanensis	-		-	+	-	-		-	+
Momipites leffingwellii	+		-	-		+		-	+
Sum Momipites spp.			-				-	-	
Triatriopollenites subtriangulus		++		++	++	++	-		+

Table 2 (continued)

++ = strong positive occurrence trend
+ = weak positive occurrence trend
- = negative occurrence trend

TAXON	INTERPRETED PALEOENVIRONMENTS								
	Type 1 lignite	Type 2 lignite	Lignite underclays	Marsh	Lake fill	Bay fill	Lacus-trine	Slightly brackish	Brackish
Triporopollenites granilabratus	+	+	-	+	-				++
Triporopollenites infrequens	-	-	-	+		+		-	
Ulmipollenites spp.	-	-		+		+	+	-	
Cupuliferoideaepollenites microscabratus	+								
C. mutabilis		+							
Fraxinoipollenites variabilis	+		-	-		+	+		
Retitrescolpites anguluminosus	+	-	-						+
Rousea parvicolpata	++	++		+			+		+
Rousea sp. 1	+								
Rousea sp. 2		-	-	+	-	-	-	-	+
Rousea sp. 4	+		-		+	+	-	-	+
Rousea sp. 5			-		-		-		
Striatopollis cf. S. trochuensis	-			-	-	-	-		+
Syncolporites cf. S. minimus			+	+	+	-	-	-	+
Brevicolporites colpella	-			+	+	-	-	-	-
Caprifoliipites cf. C. microreticulatus				+					
Cyrillaceaepollenites cf. C. exactus	+	-			-	-		-	+
Foveotricolporites pachyexinous	-						-	-	
Foveotricolporites spp.		-	-					-	-
Kurtzipites parvus	-	-	+	++	+	+			
K. polyformis	-	-					-	-	-
K. trispissatus	-	-					-	-	
Sum Kurtzipites spp.	-	-		+	+	+			
Myrtipites? sp. 2	+	-	-	-	-	-	-	-	+
Nyssapollenites sp.				-	-	-		-	++
Polotricolporites rotundus	+								
Quercoidites cf. Q. spissus	-	+	-	+	-	-	-		
Rhoipites pisinnus						+			
Simpsonipollis sp. 2			+						
Wilsonipites sp.	-	+		+	+		-	-	

present in only three samples, but is remarkably consistent within those samples. These samples were assigned to the lacustrine and slightly brackish paleoenvironments.

Results of Detrended Correspondence Analysis. The data were analyzed using the ordination technique of detrended correspondence analysis (DCA). Ordinations represent the relationships between samples along a continuous scale, with similar samples plotting close together and dissimilar samples far apart (Gauch, 1982; Kovach, 1988b). Because each ordination axis is plotted on a continuous scale, ordinations are useful to help recognize the presence of paleoecological gradients. DCA is an objective technique in that it derives the ordination values from the data matrix only, requiring no endpoint selection or weighting.

Using eigenvalues, DCA condenses the variability expressed in a data set from many dimensions to the few axes that express most of the variability. The first DCA axis expresses the maximum amount of variability, whereas subsequent axes (DECORANA calculates 4 axes in all) represent sequentially less of the variability. The underlying causes of the variability represented in each of the ordination axes can be independent, causing the second ordination axis to vary independently from the first. Since paleoenvironment may be a primary cause of the variability, each axis should be examined for expression of a paleoenvironmental gradient. Thus, similar first axis values between samples or species indicates a degree of similarity regardless of the second axis values.

DECORANA calculates the sample ordination scores by taking a weighted mean of the scores of all the species in each sample. Thus the samples will tend to plot in the same region of the scatter diagram as do the dominant species within that sample.

Four DECORANA analyses, using different portions of the data set, were performed. The first analysis utilized the complete data set. After plotting the results of the first analysis, those samples that plotted far from the main sample group (the outlier samples) were deleted from the data set, and DECORANA analysis was rerun. In this manner, a better distinction is possible within the main sample grouping. The third DECORANA analysis included only palynomorph assemblages from the lignite beds in an attempt to discriminate between assemblages from the Type-1 and Type-2 lignites. The fourth analysis included the lignite data after removal of an outlier sample.

In order to accommodate the limitations of the DECORANA program, the data set was reduced as previously described in the methods section. The results of the DECORANA analyses are presented in a scatter diagram on which the first two ordination axes are plotted. The units used for the ordination axes are the average standard deviation of species turnover (sd) (Gauch, 1982).

DECORANA Analysis of All Samples. Scatter diagrams of the first two ordination axes are plotted in Figures 5 and 6. The sample ordination clearly isolates the samples bearing the Acritarch and *Pediastrum* associations from the main grouping of the samples. Samples 51 and 56, both collected from underclays beneath lignite beds, plot away from the main body of samples and have first-axis values in the range of the *Pediastrum* association. Both of these samples have significant components of algal microfossils, including *Pediastrum,* indicating similarity to the *Pediastrum* association.

Most of the other samples that plot outside of the main grouping of samples were collected from lignites. These samples tend to have low first-axis values, but do not plot in a group, indicating high variability in the composition of their palynomorph assemblages. In the species ordination (Figure 6), most of the algal species tend to have medial to high first-axis values. The distinctive Acritarch association forms a tight group possessing very high first-axis values, whereas the *Pediastrum* association forms a group with medial first-axis values. Taxa that tend to be present in brackish-water strata, but not

Figure 5. Detrended correspondence analysis of the samples. The scatter diagram includes the first two ordination axes derived by DECORANA analysis of all samples. Symbols on the diagram are keyed to depositional environment represented by the sample. Sample numbers can be determined by reference to the ordination values that are presented in Table 3.

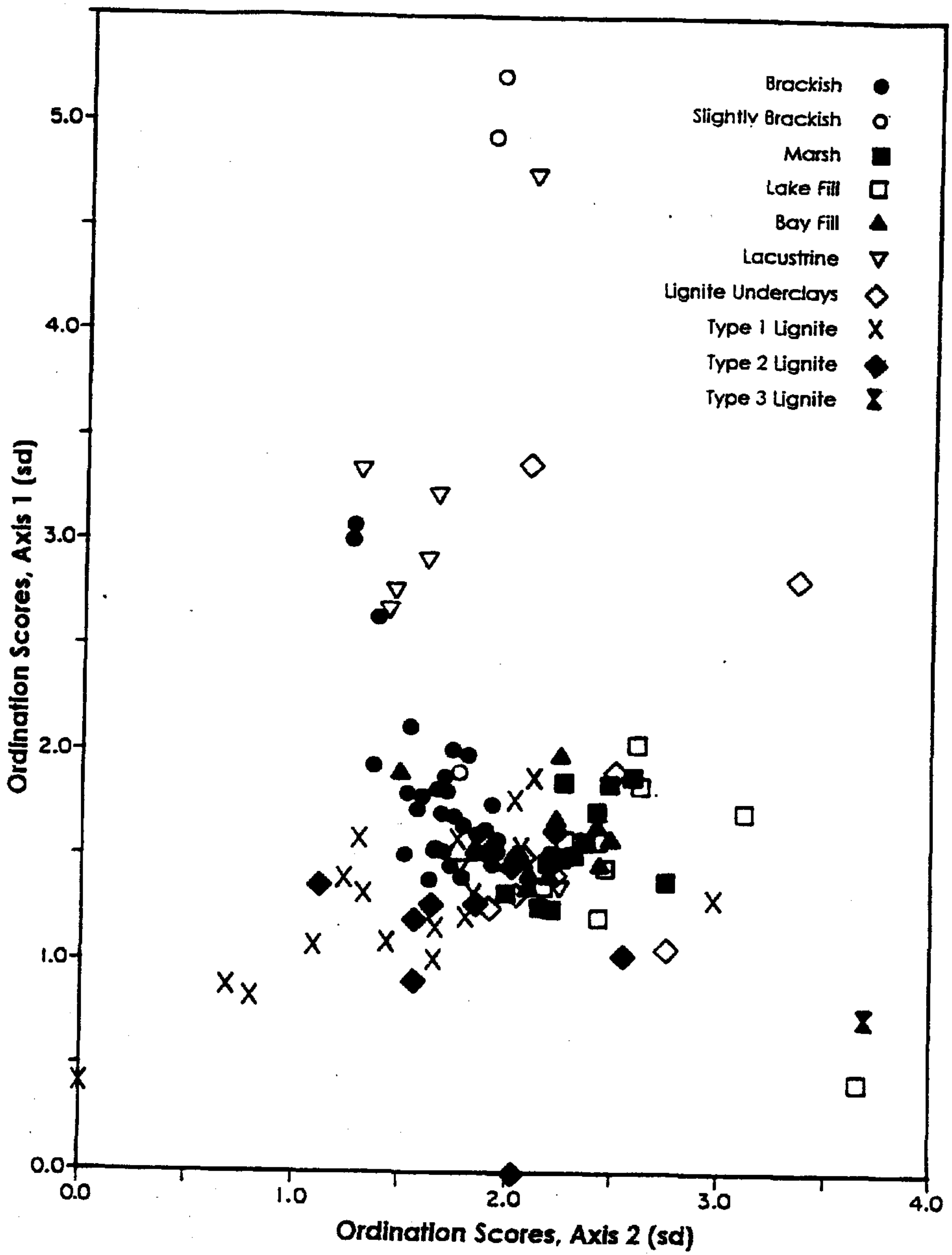

Brackish
Slightly Brackish
Marsh
Lake Fill
Bay Fill
Lacustrine
Lignite Underclays
Type 1 Lignite
Type 2 Lignite
Type 3 Lignite
Ordination Scores, Axis 1 (sd)
Ordination Scores, Axis 2 (sd)
0.0
1.0
2.0
3.0
4.0
5.0

Table 3
First and second ordination axes scores for DCA sample ordination of all samples.

See Figure 4 for scatter plot of ordination results. Symbols on the diagram are keyed to the depositional environments used on Figure 4.

Sample number	UND PC number	Ordination axis 1 (sd)	Ordination axis 2 (sd)	Symbol
1	A2939	1.08	1.10	X
2	A2940	1.60	1.30	X
3	A2942.1	1.77	2.03	X
4	A2951	1.85	2.62	□
5	A2952	0.74	3.68	**X**
6	A2953	1.59	2.26	□
7	A2954	1.46	2.46	□
8	A2955	1.58	2.38	■
9	A2956	1.51	2.31	■
10	A2957	1.44	2.21	◊
11	A2958	1.44	2.09	◊
12	A2817	1.55	2.07	X
13	A2818	1.30	2.95	X
14	A2819	0.83	0.79	X
15	A2820.1	1.59	1.75	X
16	A2821.0	1.40	1.24	X
17	A2822.2	1.10	1.43	X
18	A2838.0	1.88	2.10	X
19	A2834	1.33	1.84	X
20	A2873	1.22	1.80	X
21	A2829	2.78	1.46	▽
22	A2830	3.23	1.65	▽
23	A2839	2.68	1.42	▽
24	A2831	3.34	1.28	▽
25	A2832	2.92	1.60	▽
26	A2840	4.76	2.08	▽
27	A2833	5.22	1.92	○
28	A2816	4.94	1.89	○
29	A2841	1.91	1.76	○
30	A2836.0	2.64	1.37	●
31	A2842	1.88	1.70	●
32	A2874	1.54	1.68	●
33	A2875.0	1.79	1.59	●
34	A2876	1.93	1.36	●
35	A2877.0	1.81	1.69	●
36	A2878	1.71	1.68	●
37	A2919	1.73	1.57	●
38	A2879	1.80	1.52	●
39	A2880	2.00	1.73	●
40	A2881	1.53	1.88	●
41	A2882	1.98	2.24	▲
42	A2883	1.68	2.21	▲
43	A2884	1.48	2.07	▲
44	A2885	1.35	2.09	▲
45	A2959	1.58	2.47	▲
46	A2960	1.46	2.43	▲
47	A2962	1.66	2.41	▲
48	A2963	1.22	2.42	□
49	A2964	1.59	2.41	□
50	A2965	0.43	3.65	□
51	A2966	3.37	2.08	◊

Table 3 (continued)

Sample number	UND PC number	Ordination axis 1 (sd)	Ordination axis 2 (sd)	Symbol
52	A2967	1.36	1.12	◆
53	A2968	1.72	2.41	■
54	A2969	1.86	2.47	■
55	A2970	1.86	2.25	■
56	A2971	2.83	3.35	◇
57	A2972	2.04	2.60	□
58	A2974	1.62	2.21	◆
59	A2976	1.72	3.11	□
60	A2977	1.91	2.50	◇
61	A2978	1.46	2.02	◆
62	A2979	1.51	1.92	◆
63	A2980	1.89	2.58	■
64	A2981	1.39	2.74	■
65	A2982	0.00	2.03	◆
66	A2983	1.03	2.54	◆
67	A2984	1.29	1.84	◆
68	A2985	1.45	1.72	▽
69	A2987	1.49	2.24	■
70	A2988	1.47	2.19	■
71	A2989	1.36	2.24	▽
72	A2991	1.38	2.18	□
73	A2992	1.26	2.14	■
74	A2993	1.25	2.18	■
75	A2994.1	1.32	2.02	◇
76	A2995	1.17	1.65	X
77	A2843.1	1.01	1.65	X
78	A2844	0.88	0.68	X
79	A2845	0.42	0.00	X
80	A2846.1	1.33	1.31	X
81	A2847	1.75	1.92	●
82	A2848.1	1.65	1.78	●
83	A2849	3.01	1.25	●
84	A2850	3.08	1.26	●
85	A2851	2.12	1.53	●
86	A2852	1.98	1.80	●
87	A2853	1.61	1.87	●
88	A2854	1.52	1.84	●
89	A2855	1.39	1.62	●
90	A2856	1.52	2.19	●
91	A2857	1.63	1.89	●
92	A2858.0	1.53	1.69	●
93	A2859	1.82	1.66	●
94	A2860	1.51	1.51	●
95	A2861	1.46	1.73	●
96	A2862	1.40	1.78	●
97	A2863	1.46	1.92	●
98	A2864	1.69	1.74	●
99	A2865	1.57	1.94	●
100	A2866	1.52	1.93	●
101	A2867	1.59	1.95	●
102	A2868	1.51	2.02	▲
103	A2869	1.90	1.48	▲
104	A2870	1.40	2.19	▲
105	A2871	1.41	2.09	▲
106	A2872	1.49	1.82	▲
107	A2996	1.06	2.75	◇
108	A2997	0.91	1.56	◆

Table 3 (continued)

Sample number	UND PC number	Ordination axis 1 (sd)	Ordination axis 2 (sd)	Symbol
109	A2998	1.27	1.64	♦
110	A2999	1.20	1.56	♦
111	A3000	1.34	1.99	■
112	A3001	1.26	1.90	◇

in the Acritarch or *Pediastrum* associations, plot at the upper part of the main grouping of species. Those species that appear to be typical of marsh paleoenvironments and Type-3 lignites tend to plot with relatively low first-axis values, and high second-axis values. Taxa that tend to be present in Type-1 lignites plot with very low first- and second-axis values.

DECORANA Analysis Without Outlier Samples. The data were re-ordinated after deleting the outlier samples. A scatter diagram of the sample ordination is plotted in Figure 7. With respect to paleoenvironment, three nonunique fields can be recognized; the brackish-water samples plot in a relatively small region that has medial first-axis values and low to medial second-axis values. Most of the terrestrial and freshwater nonlignite samples plot in a somewhat larger field having low first-axis values and low to medial second-axis values. The upper part of this field overlaps with the brackish-water field. The lignite samples tend to plot as widely scattered points outside of these two fields, again indicating the high variability present in the palynomorph assemblages of the lignite samples.

Two of the non brackish-water samples (numbers 68 and 103) that plot within the brackish-water field were collected from mudstones that are extensively bioturbated with horizontal burrows. Both of these samples were collected from the Slope Formation; Sample 68 is the lowest sample collected from the Glasswort clay, whereas sample 103 was collected within the bayfill sequence that overlies the Three V Tongue of the Cannonball Formation. Extensive bioturbation is rare in the Ludlow and

Figure 6. Detrended correspondence analysis of the species.

The scatter diagram includes the first two ordination axes derived by DECORANA analysis in which all samples were included. See Table 4 for index to taxa abbreviations.

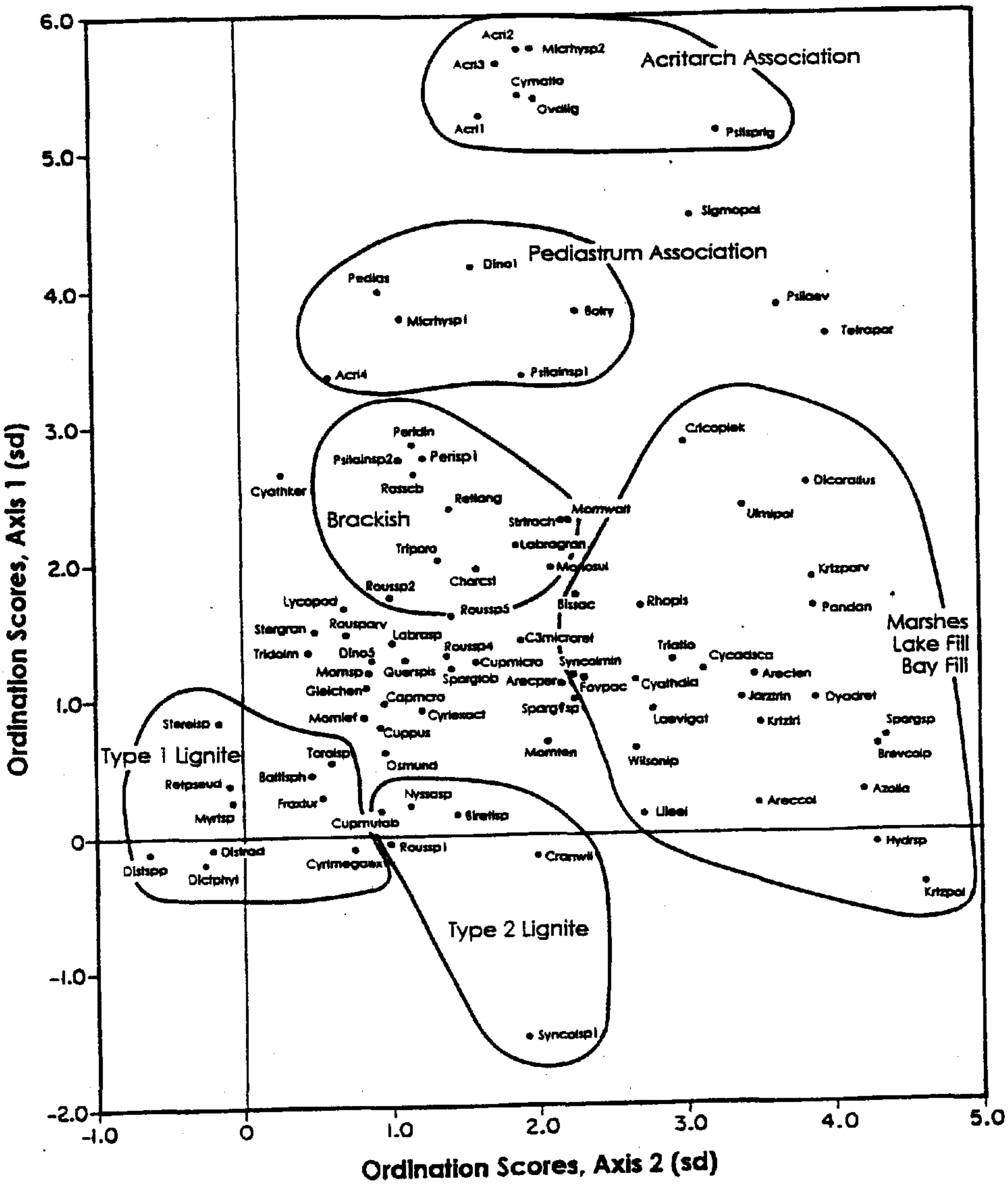

Acritarch Association
Pediastrum Association
Brackish
Marshes
Lake Fill
Bay Fill
Type 1 Lignite
Type 2 Lignite
Ordination Scores, Axis 1 (sd)
Ordination Scores, Axis 2 (sd)
6.0
5.0
4.0
3.0
2.0
1.0
0
-1.0
-2.0
-1.0
0
1.0
2.0
3.0
4.0
5.0
Acri2
Micrhysp2
Acri3
Cymatio
Ovalig
Acri1
Psilsprig
Sigmopol
Dino1
Pedias
Micrhysp1
Botry
Psilaev
Tetrapor
Acri4
Psilainsp1
Peridin
Psilainsp2
Perisp1
Cyathker
Rassch
Retlong
Cricopiek
Dicoralus
Ulmipol
Striroch
Momwalt
Labrogran
Tripora
Charcsl
Kritzparv
Roussp2
Lycopod
Roussp5
Rhopis
Bissac
Pandan
Stergran
Rousparv
Labrasp
Roussp4
C3microrel
Triatio
Cycadsca
Tridolm
Dino5
Cupmicro
Syncolmin
Arecten
Momsp
Querspis
Sparglob
Arecpere
Fovpac
Cyathdia
Gleichen
Capmcro
Jarzrin
Dyadret
Momlef
Cyrilexact
Spargfsp
Laevigat
Kritzri
Sparglsp
Cuppus
Steroisp
Toraisp
Momten
Wilsonip
Brevcolp
Osmund
Battisph
Nyssasp
Azolla
Retpseud
Fraxtur
Areccol
Myrtsp
Cupmutab
Biretisp
Lilsel
Roussp1
Hydrsp
Distrad
Cramwil
Distspp
Cyrlmegaex
Dictphyl
Kritzpol
Syncolsp1

Table 4
Index of taxon name abbreviations for DCA species ordinations (Figures 5 and 9). Abbreviations are arranged alphabetically.

ABBREVIATION	TAXON
Acri1	Acritarch Type-1
Acri2	Acritarch Type-2
Acri3	Acritarch Type-3
Acri4	Acritarch Type-4
Areccol	*Arecipites columellus*
Arecper	*Arecipites pertusus*
Arecten	*Arecipites tenuiexinous*
Azolla	*Azolla cretacea*
Baltisp	*Baltisphaeridium* spp.
Biretisp	*Biretisporites furcosus* & *Toroisporis major*
Bissac	Sum of bisaccate pollen
Botry	*Botryococcus* sp.
Brevcolp	*Brevicolporites colpella*
C3microret	Sum of small, microreticulate tricolpates
Capmcro	*Caprifoliipites* cf. *C. microreticulatus*
Chorcst	Sum of chorate dinoflagellate cysts
Cranwl1	*Cranwellia subtilis*
Cricoplek	*Cricotriporites plektosus*
Cupmicro	*Cupuliferoideaepollenites* cf. *C. microscabratus*
Cupmutab	*C. mutabilis*
Cuppus	*Cupuliferoipollenites pusillus*
Cyathdia	*Cyathidites diaphana*
Cyathker	*Cyathidites kerguelensis*
Cycadsca	*Cycadopites scabratus*
Cymatio	*Cymatiosphaera* spp.
Cyrlexact	*Cyrillaceaepollenites* cf. *C. exactus*
Cyrlmegaex	*Cyrillaceaepollenites* cf. *C. megaexactus*
Dicorallus	*Dicotetradites rallus*
Dictphyl	*Dictyophyllidites* sp.
Dino1	Dinoflagellate? sp. 1
Dino5	Dinoflagellate sp. 5
Distrad	*Stereisporites (Distancoraesporis) radiatus*
Distspp	*S. (Distancoraesporis)* spp.
Dyadret	*Dyadonypites reticulatus*
Fovpach	*Foveotricolporites pachyexinous*
Fraxtur	*Fraxinoipollenites turonicus*
Gleichen	*Gleicheniidites* spp.
Hydrsp	*Hydrosporis* spp.
Jarztrin	*Jarzenipollenites trinus*
Krtzparv	*Kurtzipites parvus*
Krtzpol	*Kurtzipites polyformis*
Krtztri	*Kurtzipites trispissatus*
Labragran	*Labrapollis granulatus*
Labrasp	*Labrapollis* sp.
Laevigat	*Laevigatosporites* spp.
Lileei	*Liliacidites* cf. *L. leei*
Lycopod	Sum lycopod and *Selaginella* type spores
Micrhysp1	*Micrhystridium* Type-1
Micrhysp2	*Micrhystridium* Type-2
Momlef	*Momipites leffingwellii*
Momten	*Momipites tenuipolus* & *M. anellus*
Momwalt	*Momipites waltmanensis*
Momsp	*Momipites* sp. indeterminate
Monosul	*Monosulcites* sp.
Myrtsp?	*Myrtipites* sp. 2
Nyssasp	*Nyssapollenites* sp.
Osmund	*Osmundacidites* cf. *O. wellmanii*

Table 4 (continued)

ABBREVIATION	TAXON
Ovdlig	*Ovoidites* cf. *O. ligneolus*
Pandan	*Pandaniidites typicus*
Pedias	*Pediastrum* spp.
Peridin	Other Peridinioid dinoflagellates (except Peridinioid sp. 1)
Psilaev	*Psiloschizosporis laevigatus*
Psilainsp1	*Psilainaperturites* sp. 1
Psilainsp2	*Psilainaperturites* sp. 2
Psilsprig	*Psiloschizosporis* cf. *P. spriggii*
Querspis	*Quercoidites* cf. *Q. spissus*
Retiang	*Retitrescolpites anguluminosus*
Retpseud	*Reticuloidosporites pseudomurii*
Rhopis	*Rhopites pisinnus*
Rosscb	*Rossipollis scabratus*
Rousparv	*Rousea* cf. *R. parvicolpata*
Roussp1	*Rousea* sp. 1
Roussp2	*Rousea* sp. 2
Roussp4	*Rousea* sp. 4
Roussp5	*Rousea* sp. 5
Sparglob	*Sparganiaceaepollenites* cf. *S. globipites*
Spargsp	*Sparganiaceaepollenites* sp.
Sparg?sp	*Sparganiaceaepollenites*? sp.
Stereisp	*Stereisporites* (*Stereisporites*) and *S.* (*Distverrusporis*) spp.
Stergran	*Stereisporites* (*Stereigranisporis*) spp
Strtroch	*Striatopollis trochuensis*
Sigmopol	*Sigmopollis hispidus*
SPPeri	Peridinioid sp. 1
Syncolmin	*Syncolporites minimus*
Syncolsp1	*Syncolporites* sp. 1
Tetrapor	*Tetraporina* sp.
Toroisp	*Toroisporis* sp.
Triatrio	*Triatriopollinites subtriangulus*
Tripor	*Triporopollenites granilabratus*
Tridolm	*Tricolporopollenites* cf. *T. dolium*
Ulmipol	*Ulmipollenites rallus*
Wilsonip	*Wilsonipites* sp.

Slope Formations, whereas it is nearly ubiquitous within the brackish-water tongues of the Cannonball Formation. A thorough scan of the palynomorph assemblages from these two samples reveals that dinoflagellate cysts are present (mostly peridinioid sp. 1 and dinoflagellate sp. 1), although not in relative abundances typical of the brackish-water beds. Thus, several lines of evidence suggest that some brackish influence was present during the deposition of these two particular horizons: 1) The presence of dinoflagellate cysts; 2) the general similarity of the palynomorph assemblages from samples 68 and 103 to those from the brackish-water samples, as evidenced by the DECORANA analysis; and 3) the presence of horizontal burrows.

Figure 7. Detrended correspondence analysis of the samples with outlier samples removed.

Samples plotting away from the main sample grouping in Figure 4 have been deleted from the data set. The scatter diagram includes the first two ordination axes derived by DECORANA analysis. Symbols on the diagram are keyed to depositional environment represented by the sample. Sample numbers can be determined by reference to the ordination values that are presented in Table 5.

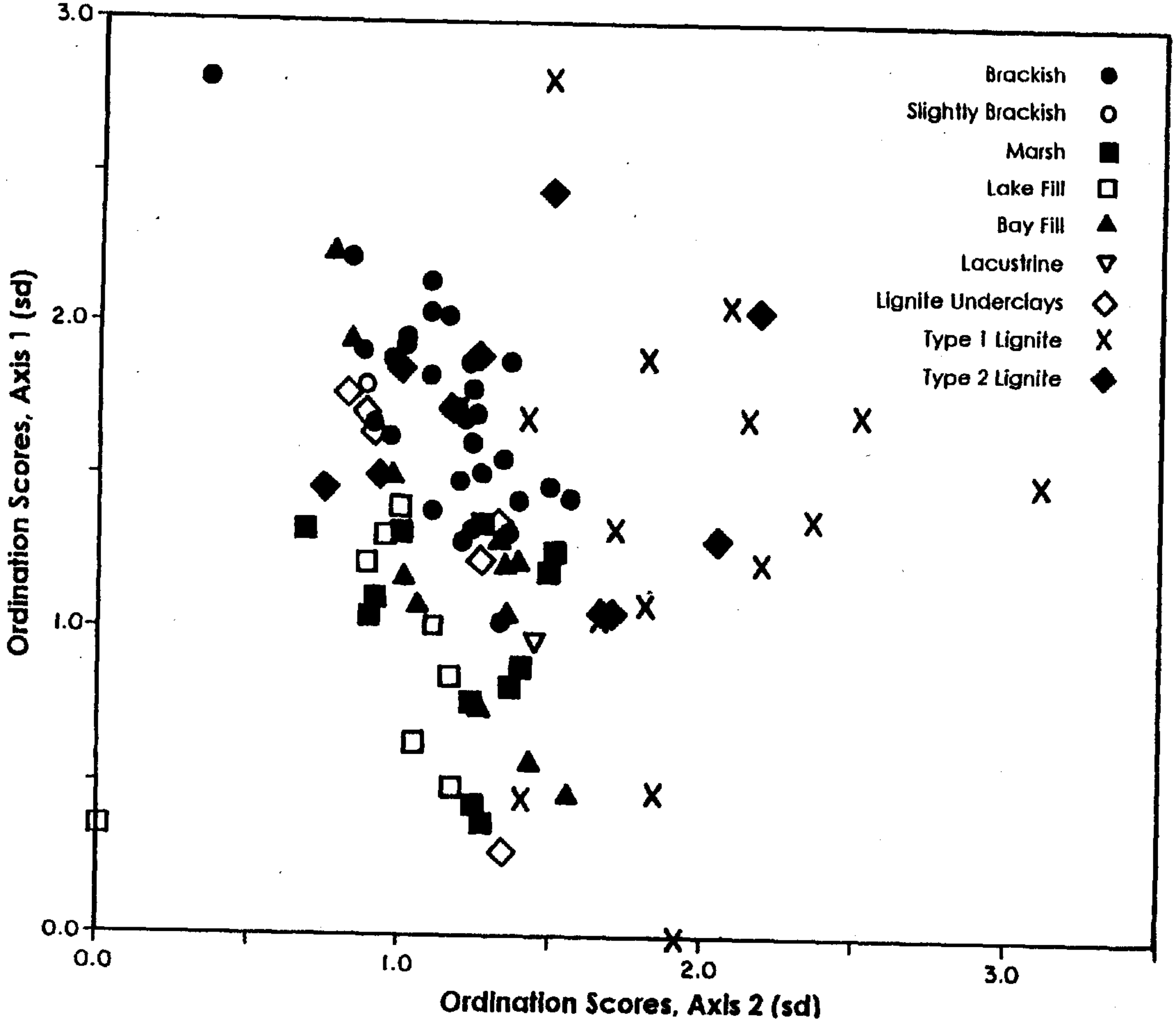

Brackish
Slightly Brackish
Marsh
Lake Fill
Bay Fill
Lacustrine
Lignite Underclays
Type 1 Lignite
Type 2 Lignite
3.0
2.0
1.0
0.0
0.0
1.0
2.0
3.0
Ordination Scores, Axis 1 (sd)
Ordination Scores, Axis 2 (sd)

Table 5
First and second ordination axes scores and associated sample and accession numbers for DCA sample ordination with the outlying samples deleted. See Figure 6 for scatter plot of ordination results.

Sample number	UND PC number	Ordination scores axis 1 (sd)	Ordination scores axis 2 (sd)	Symbol
1	A2939	1.70	2.50	X
2	A2940	2.06	2.07	X
3	A2942.1	0.48	1.84	X
4	A2951	0.49	1.17	□
6	A2953	1.22	0.88	□
7	A2954	1.01	1.10	□
8	A2955	0.74	1.25	■
9	A2956	0.89	1.39	■
10	A2957	1.35	1.31	◇
11	A2958	1.64	0.90	◇
12	A2817	1.69	1.40	X
13	A2818	0.46	1.40	X
14	A2819	1.49	3.09	X
15	A2820.1	1.05	1.69	X
16	A2821.0	1.89	1.80	X
17	A2822.2	1.37	2.35	X
18	A2838.0	0.00	1.91	X
19	A2834	1.33	1.69	X
20	A2873	1.09	1.80	X
29	A2841	1.80	0.87	O
30	A2836.0	2.81	0.34	●
31	A2842.	1.83	1.09	●
33	A2875.0	1.96	1.01	●
34	A2876	2.14	1.08	●
35	A2877.0	1.87	1.22	●
36	A2878	2.03	1.14	●
37	A2919	2.04	1.09	●
38	A2879	2.22	0.82	●
39	A2880	1.93	1.00	●
40	A2881	1.69	1.20	●
41	A2882	0.74	1.26	▲
42	A2883	1.17	1.00	▲
43	A2884	1.29	1.32	▲
44	A2885	1.22	1.38	▲
45	A2959	0.57	1.43	▲
46	A2960	1.08	1.05	▲
47	A2962	0.47	1.55	▲
48	A2963	1.31	0.94	□
49	A2964	0.85	1.16	□
52	A2967	2.05	2.17	◆
53	A2968	0.81	1.36	■
54	A2969	0.44	1.24	■
55	A2970	1.10	0.91	■
57	A2972	0.64	1.04	□
58	A2974	1.46	0.74	◆
59	A2976	0.36	0.00	□
60	A2977	1.23	1.26	◇
61	A2978	1.50	0.95	◆
62	A2979	1.85	0.99	◆
63	A2980	0.38	1.27	■
64	A2981	1.05	0.89	■
66	A2983	1.06	1.66	◆
67	A2984	1.69	1.22	◆
68	A2985	1.73	1.18	▽
69	A2987	1.33	0.67	■

Table 5 (continued)

Sample number	UND PC number	Ordination scores axis 1 (sd)	Ordination scores axis 2 (sd)	Symbol
70	A2988	1.32	0.98	■
71	A2989	0.97	1.44	▽
72	A2991	1.40	0.99	□
73	A2992	1.35	1.27	■
74	A2993	1.26	1.50	■
75	A2994.1	1.77	0.81	◇
76	A2995	2.81	1.47	X
77	A2843.1	1.69	2.14	X
78	A2844	1.97	2.62	X
80	A846.1	1.23	2.17	X
81	A2847	1.29	1.21	●
82	A2848.1	1.42	1.38	●
85	A2851	1.88	0.96	●
86	A2852	1.67	0.90	●
87	A2853	1.49	1.19	●
88	A2854	1.61	1.23	●
89	A2855	1.78	1.23	●
90	A2856	1.03	1.33	●
91	A2857	1.32	1.35	●
92	A2858.0	1.43	1.55	●
93	A2859	1.70	1.24	●
94	A2860	1.87	1.35	●
95	A2861	1.56	1.33	●
96	A2862	1.47	1.48	●
97	A2863	1.51	1.26	●
98	A2864	1.91	0.86	●
99	A2865	1.33	1.23	●
100	A2866	1.63	0.95	●
101	A2867	1.39	1.10	●
102	A2868	1.21	1.34	▲
103	A2869	2.23	0.76	▲
104	A2870	1.05	1.34	▲
105	A2871	1.50	0.96	▲
106	A2872	1.94	0.82	▲
107	A2996	0.28	1.34	◇
108	A2997	2.44	1.48	◆
109	A2998	1.89	1.25	◆
110	A2999	1.30	2.04	◆
111	A3000	1.19	1.49	■
112	A3001	1.71	0.87	◇

DECORANA Analysis of Lignite Samples. Two DECORANA analyses of the lignites were performed. The first analysis (Figure 8) includes all lignite samples and displays a general trend in which the samples collected from the Type-2 lignites have relatively high to medial first-axis values, whereas the other coals tend to have medial to low values on the first axis.

In the second analysis, sample number 5 was removed from the data set as an outlying sample. Since sample 5 was the only sample collected from the Type-3 lignites, it does not aid in differentiating the Type-1 from the Type-2 lignites and its removal from the data set is justified. A plot of the results (Figure 9) again shows the samples from Type-2 lignites plotting with medial to high first-axis values and the other coals plotting with low to medial values. Some of the Type-1 coals that plot with higher first-axis values (numbers 76 and 12) were collected from the basal portions of their respective coal beds, suggesting that those samples may represent a relatively early stage in the ecologic succession of coal swamps. If this is true, the similarity of these palynomorph assemblages of these samples to the Type-2 lignite assemblages suggests that the Type-2 lignites may represent coal swamps or marshes that did not proceed as far through coal floral succession as compared to the Type-1 lignites.

The species ordination of the coal samples (Figure 10) can be interpreted to contain three fields. Field number 1 has low first-axis values and high second-axis values and is characterized by *Arecipites columellus*, *A. pertusus*, *Retitrescolpites anguluminosus*, and *Ulmipollenites* spp. Within the lignites, these species appear to be most prominent in three samples from the T Cross lignite (samples 18, 19, and 20), a Type-1 lignite deposit.

The second field has medial to high first-axis values and medial second-axis values. It is characterized by species such as *Nyssapollenites* sp., *Dicotetradites rallus*, *Brevicolporites colpella*, *Triatriopollenites subtriangulus*, and *Cricotriporites plektosus* among others. These species tend to be abundant in the assemblages from the Type-2 lignites.

The third field has medial to low first-axis values and low second-axis values. This field is characterized by *Reticuloidosporites pseudomurii* and most other fern spores, sphagnaceous spores, and numerous angiosperm taxa. These species tend to occur in the samples from the Type-1 lignites.

Figure 8. Detrended *correspondence* analysis *of* lignite samples.

The scatter diagram includes the first two ordination axes derived by DECORANA analysis. Symbols are keyed to the lignite beds from which the samples were collected.

Type-1 lignites include the Beta, T Cross, and Oyster lignites. Type-2 lignites include the Lower Coal Pair through the Upper Coal Pair and the Number 1 lignite.

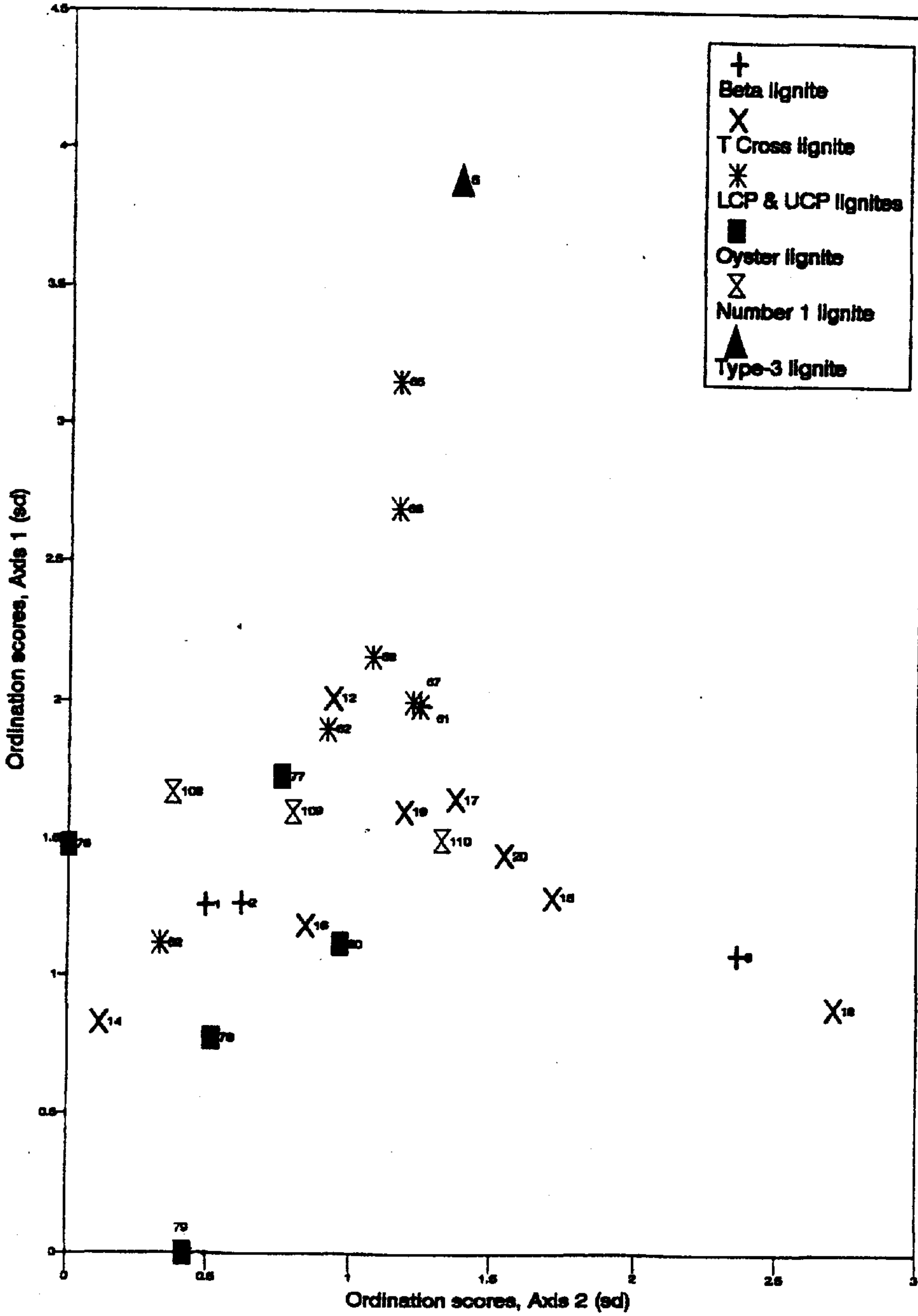

Beta lignite
T Cross lignite
LCP & UCP lignites
Oyster lignite
Number 1 lignite
Type-3 lignite
Ordination scores, Axis 1 (sd)
Ordination scores, Axis 2 (sd)

Figure 9. Detrended correspondence analysis of lignite samples after removal of outlier sample from data set.

The scatter diagram includes the first two ordination axes derived by DECORANA analysis. Symbols are keyed to the lignite beds from which each sample was collected.

Type-1 lignites include the Beta, T Cross, and Oyster lignites. Type-2 lignites include the Lower Coal Pair through the Upper Coal Pair and the Number 1 lignite.

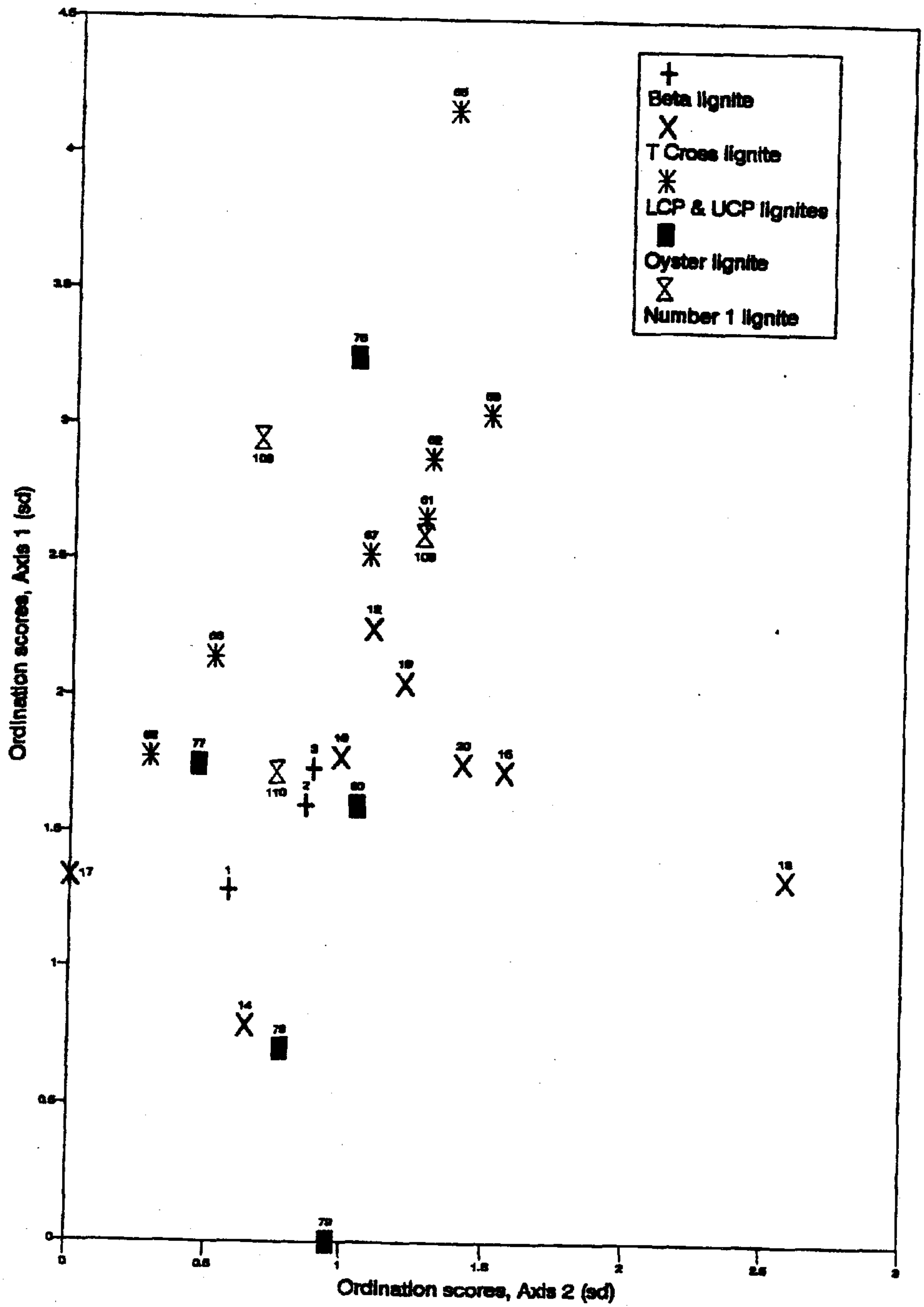
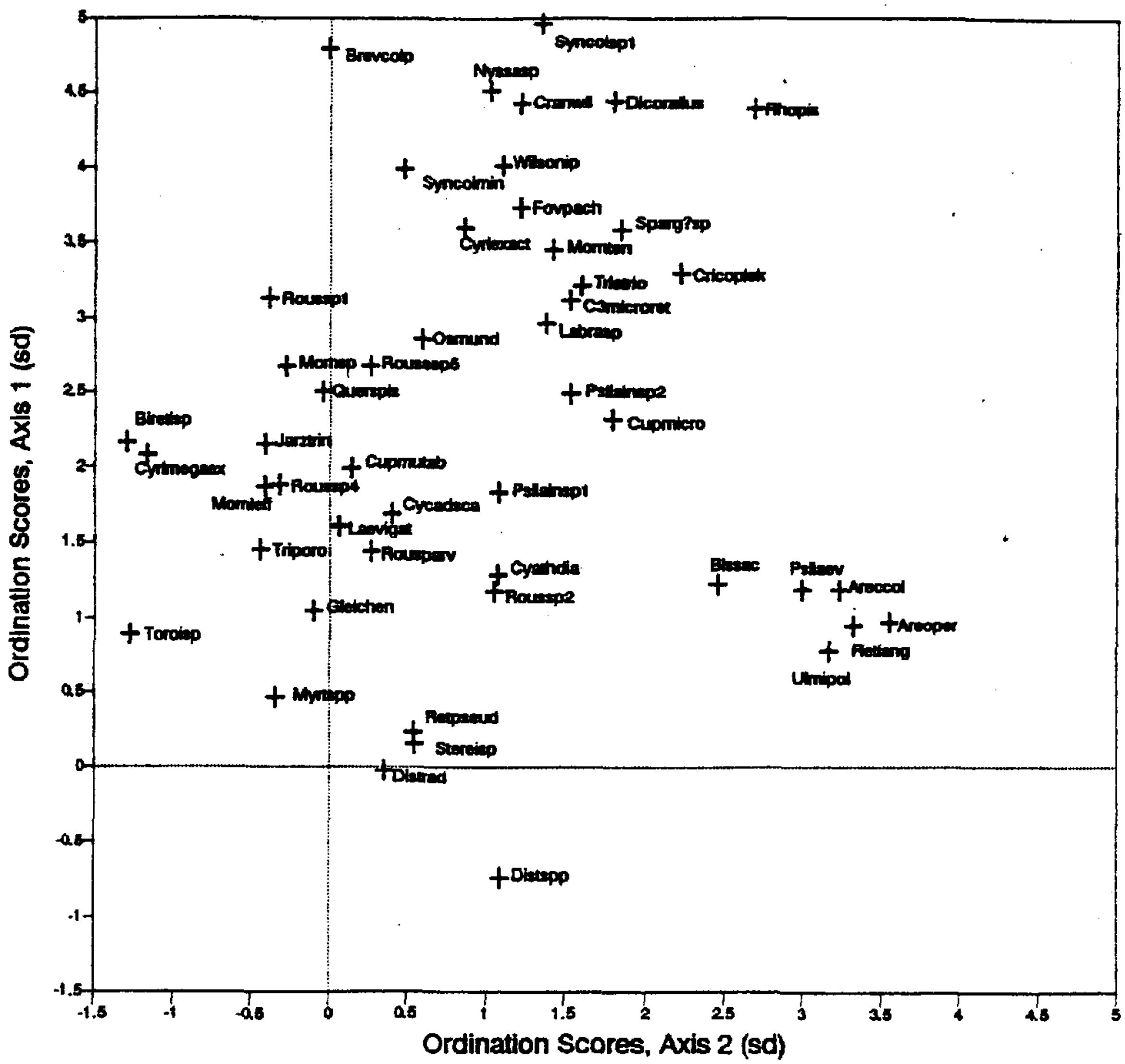

Beta lignite
T Cross lignite
LCP & UCP lignites
Oyster lignite
Number 1 lignite
Ordination scores, Axis 1 (sd)
Ordination scores, Axis 2 (sd)

Figure 10. Detrended correspondence analysis of the species present in lignite samples after removal of outlier sample from data set.

The scatter diagram includes the first two ordination axes derived by DECORANA analysis. See Table 4 for index to abbreviations of the species names.


Ordination Scores, Axis 1 (sd)
Ordination Scores, Axis 2 (sd)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Brevcolp
Nyssasp
Wilsonip
Syncolmin
Fovpach
Cyrlexact
C3microret
Labrasp
Osmund
Mornsp
Psilainsp2
Cupmicro
Cupmutab
Roussp4
Psilainsp1
Cycadsca
Laevigat
Triporoi
Rousparv
Cyathdia
Roussp2
Psilaev
Areccol
Gleichen
Toroisp
Areoper
Ulmipol
Stereisp
Distrad
Distspp

INTERPRETATION AND DISCUSSION

Introduction

Many factors must be considered when attempting to interpret the significance of the paleoenvironmentally sensitive palynomorph distribution patterns that have been identified. The palynomorph assemblage present in a given sample may largely represent pollen or spore production by the local floral community, or it may also include a significant proportion of palynomorphs that have been transported to the site of deposition by the wind or water. Even if an assemblage is locally produced, and therefore represents the local flora, the relative abundance of palynomorphs does not indicate the relative abundances of the producing plants within that community. The palynomorph assemblages present at any given locality are dependent upon a number of factors, including (Rich, 1978):

1) Number of palynomorphs produced,
2) Distribution potential of the palynomorphs,
3) Potential for the palynomorphs to be preserved.

Palynomorph Production: For pollen and spores, the number of palynomorphs present is dependent primarily upon the number of pollen or spores produced by each plant and the number of plants of a given species that are growing within a given area. Since palynological identifications are usually not possible at the plant species level, a given palynomorph species may represent the pollen or spore production by members of plant genus or even family within a given region.

In general, those plants that utilize the wind as a pollination vector (aenomophilous plants) produce vastly larger quantities of pollen than do those that use animals to ensure pollination (zoophilousplants)

(Faegri and Iverson, 1964). The aenomophilous plants are expected to be overrepresented in the palynological record.

Many of the algal palynomorphs represent the encysted or vegetative remains of unicellular or colonial algae. In these cases, each cyst or fossil colony represents a single alga or algal colony, and the relative abundance of the fossils will reflect the relative abundance of the particular alga. However, many algae do not produce bodies that are preservable as fossils, and thus many algal taxa are not represented in the fossil record.

Distribution Potential. Several factors determine the distribution potential of each type of palynomorph. Aenomophilous plants tend to produce smaller and less ornamented pollen, better suited to aerodynamic transport (Faegri and Iverson, 1964). In a forest, the taller trees have a much greater pollen distribution potential than do the plants living in the shrubby or herbaceous understory (Jansenn, 1973).

In the present study, paleoenvironmental trends in small, finely sculptured pollen such as *Tricolpites hians*, *Tricolpites* cf. *T. minutus*, and *Cupuliferoideaepollenites microscabratus* are difficult to recognize. Most likely, these pollen were produced by aenomophilous plants, and were readily widely dispersed.

Large quantities of palynomorphs are also transported by water. The composition of stream-transported palynomorph assemblages will reflect the vegetation in the stream's drainage basin (Peck, 1973; Crowder and Cuddy, 1973). In addition, palynomorphs are introduced into the stream by erosion of river banks during channel migration (Campbell and Chmura, 1994). In a coastal setting, currents and storm action can act to redistribute palynomorphs (Chmura, 1994).

Jansenn's (1973) four palynomorph distribution zones can be applied to ancient assemblages. Local distribution represents the immediate plant community, and even relatively minor vegetation types may be recognizable. Extralocal distribution represents greater transport and mixing, suppressing the local palynomorph signal. Regional distribution includes palynomorphs from outside the depositional area. Extraregional distribution includes palynomorphs that are transported very long distances to the site of deposition and may represent different elevation or climate zones.

Preservation Potential. The potential for a palynomorph to be preserved is largely determined by the amount of sporopollenin present within the exine. Although sporopollenin is very persistent in most geological environments, it is subject to degradation in oxidizing and basic environments (Traverse, 1988). Wetting and drying cycles have also been demonstrated to cause mechanical degradation (Campbell, 1991). Thus the preservability of any palynomorph will depend on the composition of its exine and upon how long the palynomorph is exposed to the degradational environment. Both oxidation and mechanical degradation are more common in certain depositional environments, and may have influenced the composition of palynomorph assemblages in paleoenvironments where they were more severe.

There are also differences in the ability of different palynomorphs to survive the chemical treatments used during the maceration process (Frederiksen, 1985). Since different maceration processes are used to extract palynomorphs from different rock types, differential survival of palynomorph assemblages could be misinterpreted to represent paleoenvironmentally caused changes. In processing the palynomorph samples used in this study, a minimum of chemical maceration treatments were used, in efforts to reduce the effects of differential preservation.

Relationship of Palynomorph Assemblages to Local Floral Communities

Numerous studies have shown that the palynomorphs present in the sediment commonly represent the local flora. In southern Louisiana marshes, Chmura (1994) discovered that pollen assemblages present in the sediment are representative of the floral community for each salinity-controlled floral zone. Rich (1978) and Rich and Spackman (1979) showed that freshwater marsh and swamp floral communities could be recognized by their pollen and spore signatures within peat deposits. In these settings, palynomorphs originating from more distant areas are present, but they are numerically dominated by the locally produced species.

Other studies have demonstrated that significant quantities of palynomorphs are transported by rivers and streams (Muller, 1959; Crowder and Cuddy, 1973; Campbell and Chmura, 1994). A significant portion of these palynomorphs are interpreted to represent reworked pollen, probably eroded from the banks and levees of the river. These palynomorphs are ultimately deposited when the rivers drop their sediment load as they enter lakes and seas. Even after deposition, the palynomorphs are subject to additional transport due to wave and tidal action (Chmura, 1994).

The degree to which the palynomorph assemblages represent the local floral communities is dependent upon the depositional environment. Coal-producing swamps and marshes typically have high local pollen production and relatively low exposure to fluvial flood waters. Thus, they are expected to be dominated by locally produced palynomorphs. Calm lacustrine settings are also expected to be relatively isolated from fluvial input, but because their local pollen production is low, the atmospheric influx is important, as might be the local production of algal palynomorphs. Depositional environments exposed to high fluvial clastic influx are expected to reflect the quantity of palynomorphs transported in the rivers, and may not be very representative of the local flora. Wave-washed shoreline environments may have high local production from shoreline swamps and marshes, but considerable reworking may occur due to wave action and currents, masking the local pollen signature.

In transgressive-regressive sequences, the transgressive portion of the sequence tends to bear palynomorph assemblages that are more representative of the local paleoenvironments, including the shoreline, brackish zones, and freshwater zones. The regressive portion of the sequence bears mainly transported palynomorphs that originate from behind the shoreline (Frederiksen, 1985). In the modern Mississippi River delta, Chmura (1994) noted a similar relationship. Marshes in transgressive areas reflected extralocal pollen deposition whereas the progradational marshes, dominated by fluvial input, contained a high proportion of allochthonous palynomorphs of regional origin.

Within the lithologic sequences present in the upper part of the Ludlow, and the Cannonball and Slope Formations, the transgressive sequences are represented by the brackish-water and lacustrine strata, and probably most of the coal beds and their underclays. The regressive sequences include the lake and bay fill sediments and the marsh deposits.

Lignite-producing Floral Communities. Lignites are produced by the accumulation and preservation of plant material in swamps and marshes. The distribution of floral communities within swamps and marshes is primarily controlled by salinity, groundwater levels and the amount of mineral nutrients available (Penfound and Hathaway, 1938; McCabe, 1984). Groundwater levels are controlled by the complex interaction of basinal subsidence or uplift, rate of peat accumulation, and sea level changes (Frederiksen, 1985). Within a given peat swamp or marsh, relatively minor changes in the water table or water chemistry can lead to the development of distinct floral communities. In addition, destructive events, such as fires, can lead to the destruction of portions of a swamp, leading to new floral communities as the vegetation is reestablished (Rich, 1978; Frederiksen, 1985).

If the palynomorph assemblages from lignites are representative of the local floral communities, a suite of palynomorph samples from lignites would probably sample several different lignite-producing floral communities. The inclusion of multiple plant communities should lead to high variability in the palynomorph assemblages among the lignite samples. The DCA sample ordinations indicate that, compared to other depositional environments, the palynomorph assemblages from lignites have much greater variability.

Several palynomorph taxa tend to be more common or abundant within the lignites. The plants that produced these palynomorphs were probably members of the coal swamp plant communities. Taxa included are the sphagnaceous spores (*Stereisporites* spp.), *Gleicheniidites* spp., *Toroisporis* sp., *Reticuloidosporites pseudomurii*, *Fraxinoipollenites variabilis*, *Rousea* cf. *R. parvicolpata*, *Rousea* sp. 1, *R.* sp. 2, *Cyrillaceaepollenites* cf. *C. exactus*, and *Myrtipites*? sp. 2. In addition, the relative abundance of TCT pollen tends to high, suggesting that the TCT producers were important members of the coal swamp communities. More specific associations within the Type-1 and Type-2 lignites are discussed below. Numerous taxa also demonstrate a marked decrease in relative abundance in the coal samples, indicating that their parent plants were not coal swamp dwellers. Notable among these taxa are *Corollina*, *Psilainaperturites* sp. 2, most algal palynomorphs, *Cyathidites diaphana* (tends not to occur in Type-2 lignites), and all three species of *Kurtzipites* (see Table 2 for complete listing).

Several, more restricted, palynomorph associations appear to be present within the lignite samples, although they are not as well defined as the previously named Acritarch and *Pediastrum* associations. These associations probably represent, at least in part, palynomorph production by different floral communities.

Within the Type-1 lignites at least two associations appear to be present. The first association is characterized by sphagnaceous spores, *Reticuloidosporites pseudomurii*, and *Psilaschizosporis laevigatus*. The second association is characterized by species of *Arecipites*, bisaccate pollen, *Cupuliferoidaepollenites microscabratus*, and *Retitrescolpites anguloluminosus*.

Although only one sample (sample number 5) was studied from the Type-3 lignites, this sample contains a distinct assemblage bearing abundant *Azolla cretacea*, *Azolla* spp., and *Hydrosporis* spp. (probable microspores of *Azolla*). This is the only lignite sample in which *Azolla* was recorded in any abundance. Also present in this sample is abundant *Brevicolporites colpella*, and *Sparganiaceaepollenites* sp. The Type-3 lignites are interpreted to represent allochthonous or floating accumulations of peat. An interpretation of floating peat mats is consistent with some of the species present in this palynomorph assemblage. *Azolla* is a floating fern and *Sparganiaceaepollenites* sp. may represent a member of the Sparganiaceae, a family of emergent aquatic plants.

Specific palynomorph associations are difficult to identify within the Type-2 lignites, although several taxa tend to occur more commonly within them as compared to the Type-1 lignites. Included are *Nyssapollenites* sp., *Quercoidites* cf. *Q. spissus*, *Wilsonipites* sp., *Foveotricolporites pachyexinous*, *Cranwellia subtilis*, *Triatriopollenites subtriangulus*, *Dicotetradites rallus*, *Cricotriporites* plektosus, *Sparganiaceaepollenites*? sp., and *Biretisporites furcosus*. Most of these taxa are small and relatively smooth sculptured and were probably produced by aenomophilous plants. However, since these taxa are more common in the Type-2 lignites, they may represent pollen production by aenomophilous plants within the local or extralocal plant communities. *Dicotetradites rallus* and *Biretisporites furcosus* are larger, and probably were not transported by wind, and probably represent the local flora. *Dicotetradites rallus* is commonly associated with freshwater algal palynomorphs, suggesting that it may have been produced by an aquatic plant. The Type-2 lignites bear more uniform palynomorph assemblages than do the Type-1 lignites, suggesting that they represent only one or very few plant communities, or that they have a significant component of allochthonous palynomorphs.

The Number 1 lignite was sedimentologically classified as a Type-2 lignite. The palynomorph assemblages from the Number 1 (samples 108, 109, and 110) have characteristics of both the Type-1 and Type-2 lignites. The basal sample is palynologically similar to the other Type-2 lignites, whereas the upper two samples are more typical of the Type-1 lignites. A similar situation is present in the oyster lignite (samples 76-79) in that the basal sample is more characteristic of the Type-2 lignites and the upper samples resemble the Type-1 lignites.

Type-2 lignites are sedimentologically characterized by their occurrence within sandy sequences, suggesting that they were deposited in closer proximity to the main fluvial channels than were the Type-1 lignites. Due to the high clastic influx, this paleoenvironment was probably less stable than the Type-1 lignite swamps were, and the floral communities might be expected to have represented an earlier or arrested stage of coal floral succession. The occurrence of Type-2 palynomorph assemblages in the basal samples of sequences that bear Type-1 palynomorph assemblages is also suggestive of ecologic succession.

On the basis of palynomorphs, the flora of the Type-2 lignites appears to have been different from that of the Type-1 lignites. However, because the botanical affinities of most of the palynomorphs are uncertain, the nature of the floral differences between the two lignite types cannot be precisely determined. On the basis of the close association of the Type-2 lignites with the marsh paleoenvironments, it is tempting to speculate that they represent marsh lignites. However, coals may represent vastly different paleoenvironments from those represented by their enclosing beds (McCabe, 1984). Other techniques, such as coal petrography, could provide additional information about the type of plants present in the lignite-producing paleoenvironments, and could aid in the interpretation of the palynomorph assemblages.

Better resolution of the palynomorph associations present within the lignites could be achieved by designing a study that focused only on the lignites and the transition from lignite underclay to lignite. If numerous plant communities are represented by different palynomorph associations, the 25 lignite samples used in this study are inadequate to confidently characterize these associations.

None of the lignites show very good evidence of brackish-water influence, despite the fact that the T Cross and oyster lignites are overlain by brackish-water strata. Similar trends were noted in some Eocene lignites of east Texas by Frederiksen (1985). He speculated that the groundwater in the coal swamps may not have increased in salinity enough to affect the coal swamp flora.

Marsh Floral Communities. Research on the distribution of palynomorphs in modern fresh to brackish-water marshes in southern Louisiana indicated that local floral communities may not be faithfully represented, but the extralocal marsh communities, representing salinity-controlled floral zones, could be recognized (Chmura, 1994). Regional pollen influx, originating from outside the marsh areas, is commonly evident, especially in the proximal freshwater marshes located closer to the regional pollen sources and the more distal salt and brackish marshes where significant tidal transport occurs. Marshes in progradational areas also have high regional pollen influx due to high fluvial transport. Palynomorph distribution studies in freshwater marshes of the Okefenokee Swamp of Georgia showed that the floral zones in the marsh could be recognized from their palynomorph assemblages (Rich, 1978).

The marsh deposits encountered in the present study contain palynomorph assemblages that are characterized by *Kurtzipites* spp., *Syncolporites minimus*, *Wilsonipites* sp., and several additional taxa (see Table 2). On the basis of the modern analogues cited above, these palynomorphs were probably produced by the marsh flora.

At the present, different types of marsh deposits cannot be recognized. In a coastal depositional setting, such as is proposed for these strata, several types of marshes would be expected to be present, ranging from freshwater marshes to salt marshes (Penfound and Hathaway, 1938; Chmura, 1994). Some marshes may well be represented by lignite beds and the depositional environments of some marsh strata have been misinterpreted, and are presently identified with some other depositional setting.

Upon evaluating the palynological results of Trotter (1963) and Stanley (1965) for the lower Tertiary of northwestern South Dakota, Rich and Goodrum (1982) concluded that the swamps were dominated by freshwater palynomorphs. The brackish-water flora still remained unidentified. I believe that the palynomorph assemblages from the brackish-water strata may be able to provide some insight as to the composition of the salt or brackish-water marshes.

Modern brackish-water bays are commonly bordered by brackish-water marshes, and the palynomorph production of the marshes would be expected to be well represented in the brackish environments. At least some of the terrestrial palynomorphs that have their most conspicuous occurrences in the Boyce and Three V Tongues of the Cannonball Formation probably originated from the surrounding brackish or salt marshes. Such taxa include *Rossipollis scabratus*, *Corollina* sp., *Sparganiaceaepollenites* cf. *S. globipites*, *Jarzenipollenites trinus*, *Triporopollenites granilabratus*, *Rousea* sp. 4, and *Striatopollis* cf. *S. trochuensis*.

If the brackish or salt marshes are represented within the assemblages of the presumed brackish-water strata, pollen of the Chenopodiaceae-Amaranthaceae group is conspicuous in its absence. Modern tidal communities typically include members of the Chenopodiaceae, and Frederiksen (1985) noted that their pollen is characteristic of modern tidal marshes. Nichols and Traverse (1971) included probable chenopod pollen within their "marine influence assemblage," and noted that it was probably produced by coastal dwelling plants. Three pollen species assignable to *Chenopodopollis* were encountered during this study, but none is present in sufficient abundance to warrant inclusion in the quantitative analysis. Since the Chenopodiaceae are aenomophilous, and produce large quantities of pollen, the absence of their pollen in these strata indicates that they were probably not important members of the flora of the region.

The presence of the plants that produced *Corollina* sp. in a coastal plant community is consistent with some previous interpretations of the paleoecology of the Cheirolepidiaceae. Alvin (1982) noted that these plants apparently occurred in a wide range of warm habitats, including coastal habitats. In upper Paleocene lignites from Texas, Nichols and Traverse (1971) included *Corollina* pollen (as *Classopollis torosus*) within the marine-influenced palynomorph assemblage.

Brackish and slightly brackish communities. Palynomorph assemblages from the brackish and slightly brackish-water strata typically consist of both algal and terrestrial palynomorphs. Dinoflagellate cysts occur in abundance only in brackish-water strata, but they are not ubiquitous to all strata thought to represent brackish conditions. *Deflandrea* cf. *D. flounderensis* appears to be the most reliable dinoflagellate indicator species for the Boyce and Three-V Tongues. This species is relatively common, and appears to be restricted to the more saline paleoenvironments.

Although more commonly found in brackish-water strata, dinoflagellate sp. 1, peridinioid sp. 1, and some chorate cysts were also recorded from strata lacking distinct brackish-water indicator mollusks. Similar palynomorph assemblages containing small, pale, peridinioid dinoflagellates that are similar to peridinioid sp. 1 have been reported from Paleocene and Eocene strata in South Carolina (Lucas-Clark, 1989), and the Lower Cretaceous (Albian) of Alberta (Leckie and

Singh, 1991), where their occurrence is interpreted to represent brackish to slightly brackish paleoenvironmental conditions.

Terrestrial palynomorphs tend to be abundant in the brackish-water strata, but in comparison to other depositional environments, they tend to be much more uniform in their relative abundance. This more uniform occurrence is more indicative of assemblages that have been mixed during transport than of assemblages that represent local plant communities. The consistent, relatively high abundance of sphagnaceous spores is indicative of water transport, as these spores are not likely to be transported aerially.

Muller's (1959) study of palynomorph distribution in the modern Orinoco Delta suggests that atmospheric input in the marine portion of deltaic sequences is relatively minor. Most of the Orinoco palynomorphs appear to have been transported by water. A similar distribution pattern is also suggested by the brackish-water deposits in the present study.

There appears to be a proportional relationship between the amount of silt present in the brackish-water deposits and the relative abundance of terrestrial palynomorphs. The abundance of terrestrial palynomorphs in the silty horizons is suggestive of transport to the site of deposition as water-borne clastic particles. However, a few horizons within the slightly brackish paleoenvironments have nearly pure, laminated, claystone lithologies, indicating low clastic influx. Samples from these horizons bear palynomorphs of either the Acritarch or *Pediastrum* associations, and tend to contain a very low abundance of terrestrial palynomorphs. If atmospheric pollen influx were an important component within the brackish-water paleoenvironments, terrestrial palynomorphs would be expected to comprise a significant portion of the assemblages at the sites having low clastic influx. High algal productivity, such as is observed in algal blooms, may have produced the acritarchs and *Pediastrum* in unusually high absolute abundances, masking the input of allochthonous terrestrial palynomorphs.

The two most distinctive palynomorph associations were identified from the brackish, slightly brackish, and lacustrine paleoenvironments. The *Pediastrum* association was recorded in the basal beds of the Three V and Boyce Tongues in section M1721. This association may also be present near the base of the Boyce Tongue in section M1729, but appears to be masked by a high relative abundance of terrestrial palynomorphs.

Since *Pediastrum* is typically attributed to freshwater conditions, its abundance at the base of the brackish-water tongues suggests that the bays or lakes represented by the Cannonball tongues originated as freshwater lakes, and subsequently grew more brackish. The sequence in which the mollusks occur in the Boyce Tongue in section M1721a (see depositional environments section) is in agreement with an interpretation of increasing salinity. In the Three V Tongue, the *Pediastrum* association occurs in strata that contain the oyster *Crassostrea*. Since *Crassostrea* is considered a brackish-water indicator fossil, *Pediastrum* may also have tolerated brackish conditions. I have encountered reports of modern species *Pediastrum* occurring in "alkaline lakes," including brackish-water Devils Lake, in northeastern North Dakota (Moore and Carter, 1923).

Planktic algae, such as *Pediastrum*, could also be readily washed into a marine environment by fluvial currents (Evitt, 1963). However, the paucity of terrestrial palynomorph taxa in some samples bearing the *Pediastrum* association argues against significant transport of algal palynomorphs as clastic particles from a freshwater setting into a marine or brackish depositional environment. Another possibility is that a vertical salinity gradient existed at times. As lighter freshwater entered the bays, it may have overridden the more saline waters, resulting in saline bottom conditions and freshwater conditions in the upper water column.

The Acritarch association was recorded from slightly brackish and lacustrine beds within the Boyce Tongue in section M1721a. The three samples bearing this association have unusual abundances of algal palynomorph taxa that are generally rare in all other samples. Whatever paleoenvironmental conditions provided optimal conditions for the Acritarch association were apparently not repeated throughout this stratigraphic sequence.

The Acritarch association is present in the only lithologic unit in this stratigraphic sequence in which fluctuating salinities are suggested by the occurrence of freshwater mollusks in close association with ?*Ostrea* sp. Saline conditions are also indicated by several of the palynomorph taxa, such as *Pterospermella australiensis*, *Cymatiosphaera* spp., and *Micrhystridium* Type-2, which are commonly reported in marine palynomorph assemblages. These are also the only strata, associated with brackish deposits, that consist of nearly pure, finely laminated claystone, indicating very low clastic influx. The low rate of clastic influx suggests some distance from fluvial input sources possibly affecting nutrient levels in the bay or lake. Since nutrient levels are a common factor controlling algal populations (Round, 1971), the Acritarch association may represent nutrient conditions that were not conducive to the growth of the algal palynomorphs more typical of the Boyce and Three V Tongues.

Lacustrine Communities. Most of the samples from lacustrine strata were collected from the lower portion of the Boyce Tongue in section M1721a. The *Pediastrum* association is present in most of these samples, although one sample bears the Acritarch association. In contrast to the Three V Tongue, the *Pediastrum* association occurs here in association with freshwater mollusks, indicating a lacustrine depositional setting. The presence of the Acritarch association in strata interpreted to be lacustrine suggests that the sedimentological differences between the lacustrine and slightly brackish strata are slight, and might not be readily evident.

Other lacustrine strata are present, but were not sampled in as much detail as was the lacustrine portion of the Boyce Tongue. The three additional samples that were studied are nearly devoid of algal palynomorphs, but rather are dominated by small, microreticulate, tricolpate pollen such as *Tricolpites hians* and *Tricolpites* cf. *T. minutus*, triporate and bisaccate pollen, and *Laevigatosporites* spp. The dominance of the smaller angiosperm and bisaccate pollen is indicative of pollen deposition due to atmospheric influx. This is consistent with the claystone lithologies present in the lacustrine beds, indicating a relatively low amount of water-transported pollen due to low clastic influx. In addition, the morphology of *T. hians* and *T.* cf. *T. minutus* is relatively nonspecific. These pollen taxa may represent several species or even genera of plants that could have inhabited several different paleoenvironments.

Although most of the lacustrine deposits are finely laminated, some lacustrine strata are weakly bioturbated with horizontal burrows. Thorough examination of these samples indicates that a few specimens of the peridinioid sp. 1 and dinoflagellate sp. 1 are present, suggesting some brackish influence. Horizontal burrows are rare throughout this entire lithologic sequence except for within the Boyce and Three V Tongues. The association of bioturbation with dinoflagellate taxa typical of the brackish-water tongues suggests that the presence of bioturbation may be a good indicator of brackish or slightly brackish depositional environments.

Lacustrine Fill Assemblages. Many palynomorph taxa that are characteristic of the marshes are also typical of the strata that are interpreted to have been deposited as lake fill sequences. After a lake has been filled by a lake fill sequence, marshes typically develop on the filled surface (Coleman, 1966). Thus, Walther's law of facies succession indicates that the lake fill sediments would have been deposited laterally adjacent to the marshes. The proximity of the lake fill deposits to the marshes might be expected to yield similar palynomorph assemblages. In general, however, due to the high clastic influx in the lake fill paleoenvironments, the palynomorph assemblages are probably largely representative of regional influx through water borne transport.

A few taxa have conspicuous occurrences in lake fill strata, including *Azolla cretacea*, *Pandaniidites typicus*, *Sparganiaceaepollenites* sp., *Dicotetradites rallus*, and *Kurtzipites* spp. Their occurrence in the lacustrine fill deposits suggests that their producing plants were members of riparian marsh communities. The genus *Pandaniidites* has probable botanical affinities with *Pandanus*, a coastal inhabitant with paleotropical distribution that is typically associated with brackish or saline conditions (Jarzen, 1978). The mode of occurrence of *Pandaniidites* here is more suggestive of a freshwater marsh, rather than a salt marsh or mangrove depositional environment.

Bay fill assemblages. Palynomorph assemblages of the bay fill deposits bear general similarity to those of the brackish-water deposits, with the exception that dinoflagellate cysts are much less abundant. In addition, they are also typically similar to the assemblages of the lake fill sequences.

These similarities are not surprising, as the bay fill sequences are defined by their association above the brackish-water deposits and the depositional process and origin of the sediments is similar to that of the lake fill sequences. Water-transported palynomorphs probably comprise the bulk of the terrestrial component of the bay fill assemblages, and any local or extralocal input is likely to have been derived from the surrounding marshes. A few palynomorph taxa have conspicuous occurrences in the bay fill sequences, but are not typically abundant in the brackish-water assemblages. Included are *Pandaniidites typicus*, *Fraxinoipollenites variabilis*, *Kurtzipites* spp. As mentioned earlier the plants that produced *Pandaniidites* and *Kurtzipites* appear to have been members of freshwater marshes. Their occurrence in the bay fill sequences may indicate seaward encroachment of freshwater marshes during progradation of a bay fill sequence.

Although the bay fill sequences are defined by their stratigraphic position immediately overlying the brackish-water deposits, they do not display much sedimentologic evidence of brackish influence, except for the occurrence of a few thin beds that are bioturbated with horizontal burrows. These bioturbated beds typically contain dinoflagellate cysts, although not in the relative abundance and diversity that is present in the brackish-water beds. The presence of these horizons suggests that relatively short term, brackish conditions were probably recurrent during bay fill sequences.

Lignite Underclay Assemblages. Most of the undercoal strata are relatively silt-free claystones that contain moderate to high amounts of plant debris. However, since the undercoal beds were not further subdivided according to depositional environment, their palynomorph assemblages may represent floral communities from several depositional settings.

The palynomorph assemblages of the lignite underclays are quite variable, potentially due to several factors. Most importantly, more than one depositional environment is probably represented, leading to high variability in palynomorph assemblages. In addition, the early stages of coal marsh or swamp succession, possibly representing several plant communities, may have contributed palynomorphs to the lignite underclays, again leading to high variability.

Little similarity is present between the palynomorph assemblages of the lignite underclays and the lignites themselves. Rather, the underclay assemblages bear a closer similarity to those from marsh and lacustrine fill depositional environments. If the early successional stages of the coal swamps were marshes, as has been proposed for some modern peat-producing settings (Rich, 1978; Rich and Spackman, 1979), marshes would be expected to have significant palynomorph contribution to the underclays.

Several samples from the underclays bear relatively abundant algal palynomorphs, including *Tetraporina* sp., *Botryococcus* sp., *Pediastrum* sp., *Sigmopollis hispidus*, and dinoflagellate sp. 1. In the DCA scatter diagrams, two of these samples (numbers 51 and 56) have similar first axis values to the samples bearing the *Pediastrum* association. This similarity and the abundance of algal palynomorphs suggests that some of the peat swamps or marshes were preceded by lacustrine to somewhat brackish conditions. Thus, the growth of coal swamps probably occurred by encroachment over shallow lakes.

SUMMARY AND CONCLUSIONS

Stratigraphy and Depositional Environments

The stratigraphic sequence present within the Ludlow, Slope and Cannonball Formations (Paleocene, Fort Union Group) in the area of this study represents deposition within a fluvial-deltaic paleoenvironmental setting. The delta was generally prograding eastward into the Cannonball Seaway, the last epicontinental seaway that existed in the interior of North America. The maximum westward transgression of the Cannonball Sea is represented by the Boyce and Three V Tongues of the Cannonball Formation.

The Boyce and Three V Tongues are two thin intervals of brackish-water strata that represent open bay, interlobe basin, or interdistributary bay depositional environments. These strata are characterized by bioturbated, carbonaceous mudstones that contain a restricted molluscan fauna that is indicative of brackish-water paleoenvironments, although lacustrine paleoenvironments are present at one locality.

The Ludlow and Slope Formations represent deposition under more terrestrial conditions. Diverse depositional environments are present, including distributary channel, crevasse-splay feeder channel, crevasse splay, lacustrine, peat-forming swamp, marsh, lacustrine delta fills, and bay fills. In general, there is little evidence for brackish-water influence, but thin, bioturbated horizons bearing dinoflagellate cysts are present, suggesting that at least slightly brackish conditions were recurrent during deposition of the Ludlow and Slope Formations. The consistent occurrence of dinoflagellate cysts within strata that are bioturbated by invertebrates suggests that the bioturbation may be a good paleoenvironmental indicator for brackish to slightly brackish conditions.

Palynological Results

Analysis of the distribution of 133 palynomorph taxa or taxonomic groups indicates that paleoenvironment exerted control upon the relative abundance of some taxa. Recognition of paleoenvironmentally controlled distributions was accomplished both subjectively, by visual analysis of pollen diagrams, and objectively, by detrended correspondence analysis (DCA) using the computer program DECORANA. Both methods yielded similar conclusions, but the objective analysis probably requires less time and effort. However, limitations in the size of the data set for the version of DECORANA that was used required some data simplification, and could ultimately result in some loss of paleoenvironmental resolution.

Palynomorph Associations and Floral Communities

Two distinctive palynomorph associations that occur within lacustrine and brackish-water strata were identified, the *Pediastrum* association and the Acritarch association. The *Pediastrum* association occurs in lacustrine strata and at the base of the brackish-water strata, suggesting salinity increased over time in the brackish paleoenvironments. The *Pediastrum* association may have tolerated brackish conditions or fresh and brackish waters may have been in vertical juxtaposition due to density differences. The Acritarch association is restricted to a narrow stratigraphic interval in strata that are interpreted to represent lacustrine and slightly brackish conditions. The Acritarch association consists nearly entirely of algal palynomorphs, including three types of acritarchs, *Micrhystridium* type-2, and *Pterospermella australiensis*. The two associations probably represent autochthonous algal growth within the lakes and bays.

Using modern peat-forming and deltaic depositional environments as analogues, palynomorph distribution mechanisms that affected palynomorph deposition in the ancient environments can be recognized. The palynomorphs present in lignites are interpreted to have been produced locally, and probably represent, although incompletely, several plant communities growing within the peat swamps. The plants that produced *Stereisporites* spp., *Gleicheniidites* spp., *Toroisporis* sp., *Reticuloidosporites pseudomurii*, *Fraxinoipollenites variabilis*, *Rousea* cf. *R. parvicolpata*, *Rousea* sp. 1, *R.* sp. 2, *Cyrillaceaepollenites* cf. *C. exactus*, *Myrtipites*? sp. 2, and the TCT pollen complex were all probably members of the coal swamp flora.

Three more restricted associations are found within the coal palynoflora, and may represent individual plant communities. Association 1 consists of *Stereisporites* spp., *Reticuloidosporites pseudomurii*, and *Psilaschizosporis laevigatus*. Association 2 contains three species of *Arecipites*, bisaccate pollen, *Cupuliferoidaepollenites microscabratus*, and *Retitrescolpites anguloluminosus*. The third association contains abundant *Nyssapollenites* sp., *Quercoidites* cf. *Q. spissus*, *Wilsonipites* sp., *Foveotricolporites pachyexinous*, *Cranwellia subtilis*, *Triatriopollenites subtriangulus*, *Dicotetradites rallus*, *Cricotriporites plektosus*, *Sparganiaceaepollenites*? sp., and *Biretisporites furcosus*.

The marsh deposits that were recognized were deposited as progradational marshes, and tend to be dominated by water-transported palynomorphs. However, several taxa occur more abundantly in the marsh deposits, and probably were produced by the marsh flora. Included are *Kurtzipites* spp., *Syncolporites minimus*, and *Wilsonipites* sp. Although brackish marsh deposits were not identified, at least some of the terrestrial palynomorphs that occur more abundantly in brackish-water strata were probably produced by the brackish marshes. Possible brackish-marsh taxa include *Rossipollis scabratus*, *Corollina* sp., *Sparganiaceaepollenites* cf. *S. globipites*, *Jarzenipollenites trinus*, *Triporopollenites granilabratus, Rousea* sp. 4, and *Striatopollis* cf. *S. trochuensis*.

The palynomorph assemblages present in the brackish-water strata typically contain a large proportion of terrestrial palynomorphs, indicating that they are largely transported by water. Although dinoflagellate cysts occur in other paleoenvironments, they are most abundant, but not ubiquitous, in brackish strata. The species *Deflandrea* cf. *D. flounderensis* appears to be the best indicator species for the more saline of the brackish paleoenvironments.

Lacustrine strata tend to be dominated by algal palynomorphs, either the *Pediastrum* association or the Acritarch association, or they tend to be dominated by pollen grains that probably represent atmospheric influx. Several of the palynomorph assemblages of the lignite underclays bear a similarity to the *Pediastrum* association, and probably represent deposition in shallow lakes.

The lacustrine delta fill and bay fill paleoenvironments are both progradational environments and are dominated by fluvially transported terrestrial palynomorphs. However, proximity to the marshes during deposition is reflected by a general similarity of the lake fill and bay fill assemblages to the assemblages from the marshes. Bay fill sequences include thin horizons that were probably influenced by brackish conditions.

Application of the Results

Some of the paleoenvironmentally sensitive palynomorph assemblages identified in this study have been used to help recognize the presence of brackish-water strata at additional localities (Kroeger, unpublished data). In the stratigraphic test well M2187, palynological analysis of the drill cuttings allowed confirmation of the presence of both brackish-water tongues of the Cannonball Formation. The stratigraphic interval of the Three V Tongue yielded palynomorph assemblages that contained dinoflagellate taxa, including *Deflandrea* cf. *D.*

flounderensis. Palynomorph assemblages bearing Peridinioid sp. 1 were extracted from the stratigraphic interval of the Boyce Tongue.

Palynomorphs were also extracted from cuttings collected from a second stratigraphic test well, M2188, located about 13.5 km northwest of M2187. Palynomorph assemblages containing Peridinioid sp. 1 are present in a stratigraphic interval that is approximately equivalent to the Three V Tongue. The stratigraphic interval that is approximately equivalent to the Boyce Tongue bears only a few dinoflagellates, mostly assignable to Dinoflagellate sp. 1. These observations indicate that the Three V Tongue of the Cannonball Formation extends further west than has previously been documented. In addition, less saline conditions are indicated for the Three V Tongue interval in M2188 by the presence of Peridinioid sp. 1 and the absence of most of the dinoflagellate taxa typical of the Three V Tongue in M2187.

Recognition of paleoenvironmentally diagnostic palynomorph taxa might be used to aid in the interpretation of depositional environments, especially in areas of poor outcrop, or from well cores or cuttings. For example, an abundance of *Kurtzipites* could be used as an indicator of marsh paleoenvironments or paleoenvironments that were relatively close to marshes.

Directions for Additional Study

Many possiblities exist for continued studies within the region of this study. The strata included in this study did not include rocks that were deposited in paleoenvironments associated with fluvial meander belts. Thus, this study provides little or no information on the palynomorphs that were produced by the flora living on the edaphically drier environments of the levees. Study of palynomorph distribution in the Hell Creek Formation (Kroeger, 1985) indicated that meander belt paleoenvironments yielded palynomorph assemblages distinct from the flood basin paleoenvironments. Similar palynofloral differences might be expected in the Ludlow and Slope Formations also.

Sampling additional paleoenvironments in detail may allow the refinement of the palynomorph associations noted in this study. For example, detailed sampling of the coal beds might permit sharper differentiation between the Type-1 and Type-2 lignite deposits. Detailed sampling of lacustrine paleoenvironments might permit confirmation of the variations in salinity that are proposed in this study.

The widespread application of the results of studies such as this also requires data from strata of different ages and from different geographic regions. Changes in the floral structure due to evolution and regional floral changes naturally result in differing associations between palynomorphs and the depositional environment. Since Tertiary-aged palynomorph assemblages have been compared with paleoenvironmental data in relatively few studies, the data set is still incomplete.

SYSTEMATIC PALYNOLOGY

Introduction

Taxonomy. With a few exceptions, the palynomorphs described in this study are classified into form-genera and form-species. Palynomorph form-genera and form-species are diagnosed on the basis on morphologic features alone. Thus, a single form-taxon may encompass palynomorphs produced by more than one biologic taxon if the morphology of the palynomorphs falls within the circumscription of the form-taxon.

A few palynomorph taxa are placed into modern genera, including *Pediastrum*, *Botryococcus*, and *Azolla*. In these three instances, use of the modern genera is consistent with the prior usage of palynologists working within the Western Interior of North America. There is general agreement among palynologists that the taxa encountered represent the modern genera. In all cases, I have followed International Code of Botanical Nomenclature (Greuter *et al.*, 1988). Except where noted, the nomenclatural opinions expressed in the Genera File of Fossil Spores (Jansonius and Hills, 1976 and updates) have been followed.

Numerous species of dinoflagellate cysts were documented during the course of this study. They were described, photographed, and placed into morphologic groups that, in most cases, appear to be consistent enough in morphology to constitute species. The descriptions, photomicrographs, and some specimens were sent to Dr. Lucy Edwards (U.S. Geological Survey-Reston) who, where possible, provided identifications.

Format of Systematics. The following format is followed in the systematic descriptions.

Identification of the genus.

Abbreviated synonymy of the genus. With the exception of the dinoflagellate genera, an abbreviated synonymy of the genus is presented.

Type species of the genus.

Diagnosis of the genus. The diagnosis of the genus is presented verbatim from the original source or as cited in Jansonius and Hills (1976). Diagnoses are not provided for the dinoflagellate taxa.

Discussion of the genus.

Identification of the species.

Plate and figure numbers of the illustrated specimen(s). The illustrations are presented in Plates 5-19 (pages 380-409). In the numbering of the figures, each specimen is assigned a figure number; different focal levels of the same specimen are designated by the same figure number with the addition of lower case letter subscripts.

Abbreviated synonymy of the species. The nomenclatural synonymy presented here is not exhaustive, and is intended to indicate the original assignment of the species, the presently accepted nomenclature, and any emendations that are here followed. Additional names that have been applied to the species by palynologists working in the northern Great Plains are also listed in synonymy.

Where a palynomorph taxon is compared to (cf.) a previously described taxon, a synonymy list of the previously described taxon is included. In these cases, the synonymy list does not imply taxonomic identity with the specimens described here, but is intended to provide the reader with reference to the previously described species.

Description of the North Dakota specimens of the taxon.

Descriptions are provided for all palynomorph taxa, using the descriptive terminology of Kremp (1965), Traverse (1988), and

Evitt (1985). Descriptions are not based upon single specimens, but document the morphologic variability among the specimens observed during the present study. An emended description, based on the study specimens, is provided if confidently identified specimens differ significantly from the original or emended description of a taxon.

Dimensional data for the palynomorphs consists of the maximum dimension(s) of the specimens. Measurements were made using an ocular micrometer and were estimated to 0.5 micrometer (μm). Dimensions listed in the descriptions include the range of the measurements, with the average of those measurements listed in parentheses. For example, the dimensions 19-(21.9)-23 μm indicate that the specimens measured had a range from 19-23 μm and the average of all specimens measured was 21.9 μm. The number of specimens measured is also indicated. For prolate specimens, the length of the polar axis is listed first, followed by the equatorial diameter.

Discussion.

Comments. This section includes comments on the morphology, botanical affinities, comparisons to similar taxa, paleoecology, and the present taxonomic assignment.

Occurrences. The stratigraphic occurrences of each taxon is listed. For the less common species, all the samples bearing that species are listed, in ascending stratigraphic order, by their University of North Dakota Paleontology Collections accession numbers (example: UND-PC A2878). The occurrences of taxa that were recorded in more than 25 samples are illustrated in Plate 3. The stratigraphic position of the sample sites is indicated in Figures 3 and 4.

The following terms are used to indicate the relative abundance of palynomorph taxa:

Rare: Occurs at greater than one percent of the non-TCT palynomorph sum in fewer than five samples.

Uncommon: Occurs at greater than five percent of the non-TCT palynomorph sum in only a few samples or is present between one and five percent in numerous samples.

Common: Occurs at greater than five percent of the non-TCT palynomorph sum in numerous samples or is present between one and five percent in nearly all samples.

Abundant: Occurs at greater than five percent of the non-TCT palynomorph sum in many samples or dominates the palynomorph assemblage in numerous samples.

Previous Records. This section lists many of the previous records of the occurrences of palynomorph species. The search for earlier records was focused on studies from the Great Plains and Rocky Mountain regions and was otherwise not exhaustive. For previous reports from Upper Cretaceous and lower Tertiary strata of the Western Interior of North America, the geologic age(s) of the stratigraphic units are indicated in Figure 2. For studies outside of the Western Interior region, the geologic age(s) of the stratigraphic units are listed in parentheses.

Illustrated Specimens. All microslides bearing illustrated palynomorphs and at least one microslide containing a residue from every productive sample are stored in the Paleontology Collections of the University of North Dakota. The original photographic materials were retained by the author.

The microslides are labeled with both the UND-PC accession numbers and their original field numbers. Accession numbers are listed as four digits preceded by a capital "A". If splits of a sample were processed, the accession number is followed by a period (.) followed by the number of that sample split. The accession number is followed by a dash (-) and a number indicating the number of the microslide prepared from that particular sample. For example, "A2878.2-4" means the fourth slide prepared from the second split of sample UND-PC A2878.

The position on the microslides of the illustrated palynomorphs is given in millimeters (mm) from an inscribed reference mark (an "X" encircled in black ink). The palynomorphs can readily be located by moving the microscope stage the requisite distance "across" (long direction of the microslide), and then the requisite orthogonal distance, given as "up" or "down" in the specimen coordinates.

SYSTEMATIC DESCRIPTIONS

Algal Palynomorphs

Dinoflagellates

Numerous species of dinoflagellate cysts were found in the samples examined during the course of this study. In general, the occurrence of the cysts is characteristic of the brackish-water tongues of the Cannonball Formation, although they are not ubiquitous within those units. The dinoflagellates are present in abundance in only a few samples, and numerous morphotypes remain poorly documented. Because the microslides were not scanned after counting the palynomorphs, only a few specimens of the less common dinoflagellates were located. Additional study, better documenting the rarer dinoflagellate forms, is required.

Genus *Deflandrea* Eisenack 1938

Deflandrea cf. *D. flounderensis* Stover 1974

Plate 5, Figures 1, 2

Deflandrea flounderensis Stover, 1974, p. 174, 175, pl. 3, figs. 1a-c, 2.

Description of North Dakota Specimens

Cavate cysts, outline in dorso-ventral aspect more or less pentagonal. Apical-antapical dimensions 75-90 μm, cingular dimension 66-75 μm (n = 3). Development of antapical horns variable, left horn typically larger and acuminate, right horn rounded. Apical horn relatively blunt, with apical pore. Endophragm of most specimens spherical, leaving large pericoel in apical and antapical ends; rare specimens with endophragm nearly parallel to outer cyst. Periphragm with blunt, short processes 1-1.5 μm high by about 1 μm wide at the base; processes typically 1.5-3 μm apart. In well-preserved specimens, processes support a very thin, incomplete ectophragm. Paratabulation outlined by areas lacking spines and ectophragm. Paracingulum ascending, bounded by closely spaced processes. Archeopyle intercalary, adnate, pentagonal with attachment along base of pentagon.

Discussion

Comments. *Deflandrea* cf. *D. flounderensis* is typical of both of the brackish-water tongues of the Cannonball Formation, especially in those horizons bearing brackish-water invertebrate fossils.

Occurrences. Slope Formation and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2841, A2874, A2880, A2881, A2836, A2847, A2849, A2850, A2851, A2852, A2853, A2854, A2855, A2856, A2857, A2859, and A2861. Maximum relative abundance in any sample is 26.0 percent.

Previous Records. *Deflandrea flounderensis* has previously been reported only from the lower Eocene of southeastern Australia (Stover, 1974).

Illustrated Specimens. Plate 2, Figure 1: UND-PC A2874-2, 17.0 mm across X 2.5 mm up. Plate 5, Figure 2: UND-PC A2880-2, 24.2 mm across X 14.2 mm up.

Genus *Diphyes* Cookson 1965

Diphyes colligerum (Deflandre & Cookson) Cookson

emend. Davey & Williams 1966

Plate 5, Figure 4

Hystrichosphaeridium colligerum Deflandre & Cookson, 1955, p. 278, pl. 7, fig. 3.

Diphyes colligerum (Deflandre & Cookson) Cookson, 1965, p. 86, 87, pl. 9, figs. 1-12.

Diphyes colligerum (Deflandre & Cookson) Cookson emend. Davey & Williams, 1966, p. 96, 97, pl. 4, figs. 2, 3.

Description of North Dakota Specimens

Chorate cysts, more or less spherical, endophragm diameter 25-30 um. Processes numerous, hollow, about 10 um long, about 5 um wide at base, 1-3 um wide at distal ends; distal ends flat topped. A single large, blunt process present at antapical end. Apical end of cyst lacks processes. Archeopyle not observed in any specimens.

Discussion

Occurrences. Boyce Tongue of the Cannonball Formation; single specimens of *Diphyes colligerum* were recorded from samples UND-PC A2847 and A2853.

Previous Records. Stanley's (1965) report from the Cannonball Member of the Fort Union Formation in northwestern South Dakota provides the only record of *Diphyes colligerum* from the Western Interior of North America. Drugg and Stover (1975) reported an early Paleocene to late Eocene range for this species.

Illustrated Specimen. Plate 5, Figure 4: UND-PC A2874-4, 17.8 mm across X 6.8 mm up.

Genus *Phelodinium* Stover & Evitt 1978

Phelodinium magnificum (Stanley) Stover & Evitt 1978

Plate 5, Figure 3

Deflandrea magnifica Stanley, 1965, p. 218, pl. 20, figs. 1-6.

Senegalinium magnificum (Stanley) Harland, 1977, p. 188, pl. 25, fig. 2.

Phelodinium magnificum (Stanley) Stover & Evitt, 1978, p. 118.

Description of North Dakota Specimens

Cavate dinoflagellate cysts, outline more or less rhomboid; apical-antapical diameter about 95 μm. Apical horn short, with pore; antapical horns well developed, nearly equal in size. Paracingulum distinct. Periphragm thin, unornamented, readily folded; endophragm indistinct, visible in phase contrast only, almost completely fills periphragm except extreme apical and antapical areas.

Discussion

Comments. The North Dakota specimens of *Phelodinium magnificum* are somewhat smaller than those described from the Cannonball Member of the Fort Union Formation in northwestern South Dakota by Stanley (1965).

Previous Records. Cannonball Member of the Fort Union Formation, northwestern South Dakota (Stanley, 1965); Bearpaw Shale, northeastern Montana (Harland, 1977); Vincentown Formation (Paleocene and Eocene), Atlantic Coastal Plain, New Jersey (Aurisano, 1989); Severn (Maastrichtian) and Brightseat (Paleocene) Formations, Maryland (Whitney, 1984); Brightseat(?) and Aquia Formations (Paleocene), Maryland and Virginia (as the *P. magnificum* complex) (Edwards *et al.*, 1984); Aquia Formation (Paleocene) northeastern Virginia (as *P. magnificum* complex, not illustrated) (Edwards, 1989); Ripley and Providence Formations (Maastrichtian) and Clayton Formation (Paleocene) Georgia (not illustrated) (Firth, 1987); Moreno Formation (Maastrichtian and Paleocene), central California (Drugg, 1967); Navarro Group (Maastrichtian), Texas (Zaitzeff and Cross, 1971); Almond Formation, south-central Wyoming (Stone, 1973); and Monmouth Group (Campanian and Maastrichtian), New Jersey (May, 1980)

Occurrences. Boyce and Three V Tongues of the Cannonball Formation; single specimens were recorded in samples UND-PC A2849, A2850, and A2879.

Illustrated Specimen. Plate 5, Figure 3: UND-PC A2879-2, 2.3 mm across X 5.9 mm up.

Phelodinium sp.

Plate 5, Figures 5, 6

Peridinaceae cyst sp. D in Edwards, 1980, pl. 9, fig. 3.

Phelodinium sp. in Edwards, 1989, pl. 1, fig. 9.

Description of North Dakota Specimens

Cavate dinoflagellate cysts, outline roughly pentagonal, apical-antapical dimension (including horns) about 110 μm, cingular diameter about 70 μm. Apical horn elongated, left antapical horn prominent, right horn reduced. Endophragm distinct, more or less parallels periphragm except for area of horns. Archeopyle distinct, intercalary. Wall smooth.

Discussion

Comments. Although this species has not yet been formally described, Edwards (1994, written comm.) noted that its known range is from Biozone NP 5 through the remainder of the Paleocene.

Previous Records. Aquia Formation (Paleocene), northeastern Virginia (grouped with the *P. magnificum* complex) (Edwards, 1989); and Nanafalia and Tuscahoma Formations (Paleocene), Georgia and Alabama (Edwards, 1980).

Occurrences. *Phelodinium* sp. was recorded only from the Boyce Tongue of the Cannonball Formation; sample UND-PC A2880.

Illustrated Specimens. Plate 5, Figure 5: UND-PC A2880-2, 26.5 mm across X 7.8 mm up. Plate 5, Figure 6: UND-PC A2880-2, 5.9 mm across X 4.9 mm up.

Genus *Senegalinium* Jain & Millepied 1973

Senegalinium microgranulatum (Stanley) Stover & Evitt 1978

Plate 5, Figure 8

Deflandrea microgranulata Stanley, 1965, p. 219, pl. 19, figs. 4-6.

Senegalinium microgranulatum (Stanley) Stover & Evitt, 1978, p. 123.

Description of North Dakota Specimens

Cavate dinoflagellate cysts, maximum dimension about 70 μm. Cingulum distinct, bordered on top and bottom by a single row of coalesced grana. Archeopyle adnate, pentagonal, other evidence of paratabulation lacking. Apical horn short, with apical pore; antapical horns not well developed. Periphragm with coarsely scabrate ornamentation. Endophragm more or less parallels periphragm except for horn areas.

Discussion

Occurrences. Slope Formation and Three V Tongue of Cannonball Formation; single specimens of this species were recorded in samples UND-PC A2960 and A2857.

Previous Records. Cannonball Member of the Fort Union Formation, northwestern South Dakota (Stanley, 1965); Almond Formation, south-central Wyoming (Stone, 1973); and Navarro Group (Maastrichtian), Texas (Zaitzeff and Cross, 1971).

Illustrated Specimen. Plate 5, Figure 8: UND-PC A2960-4, 8.6 mm across X 14.3 mm up.

Genus *Spinidinium* Cookson & Eisenack 1962

Spinidinium? pilatum (Stanley) Costa & Downie 1979

Plate 5, Figure 7

Wetzeliella pilata Stanley, 1965, p. 222, pl. 21, figs. 12-16.

Spinidinium? pilatum (Stanley) Costa & Downie, 1979, p. 43.

Description of North Dakota Specimens

Cavate dinoflagellate cysts, outline pentagonal; apical-antapical diameter about 50 μm, cingular diameter 42 μm. Antapical horns distinct, left horn more prominent, both acuminate; apical horn relatively blunt, with apical pore. Periphragm thin, about 0.5 μm; paratabulation outlined by processes about 2 μm long by 0.7-1.0 μm wide, expanded at distal ends, wall flexes outward to form processes. Endophragm circular, commonly indistinct. Paracingulum approximately level, bordered by short, narrow spines that are more closely spaced than other processes. Archeopyle intercalary, adnate.

Discussion

Comments. *Spinidinium? pilatum* is similar in many respects to Peridinioid sp. 1 (see below), but differs in having distinct, regularly spaced, flat-topped processes. This species occurs in a number of samples, but is never very abundant. Due to the thin wall, specimens are commonly highly folded.

Occurrences. Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2874, A2881, A2847, A2848, A2849, A2850, A2851, A2853, A2855, A2857, and A3000. Maximum relative abundance in any sample is 1.6 percent.

Previous Records. Cannonball Member of the Fort Union Formation, northwestern South Dakota (Stanley, 1965); and Antarctica (Paleocene) (Askin, 1988; Palamarczuk, 1982).

Illustrated Specimen. Plate 5, Figure 7: UND-PC A3161-3, 13.3 mm across X 2.6 mm up.

Peridinioid sp. 1

Plate 5, Figures 9, 10; Plate 6, Figure 1

Description

Cavate dinoflagellate cysts, outline peridinioid, cysts relatively small, typically less than 50 μm in apical-antapical diameter; antapical horns variable, in some specimens left horn prominent and acuminate, in other specimens, antapical horns approximately equal; apical horn short, with pore 2-3 μm in diameter. Cingulum distinct, level to slightly descending. Archeopyle intercalary, usually adnate, angular, otherwise paratabulation indistinct. Periphragm thin, about 0.5 μm thick; ornamentation variable, including psilate, spinulate, and sparsely distributed, narrow processes about 3 μm long. Endophragm usually not very distinct, typically nearly parallel to periphragm except for area of apical and antapical horns.

Discussion

Comments. This group of cysts is the most common type of dinoflagellate recorded in this study. These cysts have thin, easily folded walls and notable morphologic variability, and thus are difficult to adequately characterize. The endophragm is indistinct in many specimens, although its presence can generally be confirmed under phase contrast.

The Peridinioid sp. 1 is similar to, but apparently not conspecific with, several previously described species. Similar taxa include *Senegalinium? dilwyense* (Cookson & Eisenack) Stover & Evitt 1978, *S. obscurum* (Drugg) Stover and Evitt 1978, *Alterbidinium circulum* (Heilmann-Clausen) Lentin & Williams 1989, and *Isabelidinium? viborgense* Heilmann-Clausen 1985.

Occurrences. Slope Formation and Boyce and Three V Tongues of the Cannonball Formation. Peridinioid sp. 1 was recorded in about 25 percent of the productive samples (see Plate 3). Maximum relative abundance in any sample is 4.4 percent.

Illustrated Specimens. Plate 5, Figure 9: UND-PC A2840-4, 14.3 mm across X 13.3 mm up. Plate 5, Figure 10: UND-PC A2840-4, 12.8 mm across X 18.1 mm up. Plate 6, Figure 1: UND-PC A3159-2, 21.4 mm across X 9.5 mm up.

Dinoflagellate? sp. 1

Plate 6, Figures 2-4

Description

Proximate dinocysts?, outline more or less rectangular with somewhat convex sides; apical-antapical dimension 47-70 μm, cingular dimension 30-42 μm. A few specimens have weakly developed antapical horns. Wall about 0.3 μm thick, unornamented, typically highly folded. Most specimens with well-defined fold extending down long axis, possibly a reflection of sulcus; a constriction typically evident in midsection of cysts, suggesting a cingulum. Tears in wall of some specimens oriented at nearly right angles to one another, suggesting paratabulation, although definite paratabulation was not observed. Distinct archeopyle lacking although an apical opening with angular margins is present in some specimens.

Discussion

Comments. Dinoflagellate? sp. 1 is quite consistent in size and shape. Specimens are consistently observed in the same orientation, possibly indicating dorso-ventral flattening. The rectangular outline and lack of a line of dehiscence differentiates this species from those assigned to *Psiloschizosporis*.

Dinoflagellate? sp. 1 is relatively common and frequently co-occurs with the Peridinioid sp. 1. Both taxa appear to have relatively broad paleoenvironmental tolerance, although they are more common in strata of brackish-water origin.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation. Dinoflagellate? sp. 1 was recorded in about 25 percent of the productive samples (see Plate 3). Maximum relative abundance in any sample is 5.1 percent.
Illustrated Specimens. Plate 6, Figure 2: UND-PC A2919-4, 15.7 mm across X 10.8 mm up. Plate 6, Figure 3: UND-PC A3152-3, 17.0 mm across X 5.9 mm up. Plate 6, Figure 4: UND-PC A2878-4, 21.8 mm across X 12.4 mm up.

Dinoflagellate sp. 2

Plate 6, Figure 5

Description

Chorate dinoflagellate cysts, outline more or less circular, cingular diameter 36-76 μm. Wall thin, readily folded; covered with processes up to 10 μm long, 1-2 u wide except at their base where they broaden, distal ends of processes typically flat topped and flared. Paratabulation indistinct except around archeopyle. Archeopyle apical, several notches in archeopyle margin reflect paratabulation.

Discussion

Comments. Dinoflagellate sp. 2 is similar to *Cyclonephelium lemniscatum* Stanley 1965. However, the processes in the North Dakota specimens are smaller than is indicated by the original description.
Occurrences. Slope Formation and the Three V Tongue of the Cannonball Formation; samples UND-PC A2884, A2885, A2992, A2855, and A2866. Maximum relative abundance in any sample is 1.8 percent.
Illustrated Specimens. Plate 6, Figure 5: UND-PC A3098.1-1, 7.5 mm across X 5.6 mm up.

Dinoflagellate sp. 3

Plate 6, Figure 6

Description

Chorate dinoflagellate cysts, outline more or less circular; diameter exclusive of processes 46-56 μm. Processes dense, narrow, 10-15 um long, distal ends trifid or tetrafid. Archeopyle commonly evident, apical.

Discussion

Occurrences. Slope Formation; a single specimen of this species was recorded in samples UND-PC A2968 and A2996.

Illustrated Specimen. Plate 6, Figure 6: UND-PC A2923-2, 15.3 mm across X 2.7 mm up.

Dinoflagellate sp. 4

Plate 6, Figure 7

Description

Chorate dinoflagellate cysts; outline more or less circular; diameter 70-80 μm. Wall covered with elongate processes 15-20 μm long, flared distally. Archeopyle typically distinct, apical.

Discussion

Occurrences. Slope Formation and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2884, A2865, A2868, and A3000. Maximum relative abundance in any sample is 0.7 percent.

Illustrated Specimen. Plate 6, Figure 7: UND-PC A2883-3, 19.6 mm across X 10.6 mm up.

Dinoflagellate sp. 5

Plate 6, Figures 8-10

Description

Dinoflagellate cysts, outline circular to ovoid, apical and antapical horns lacking, maximum dimension between 35 and 40 μm. Epitheca larger than hypotheca. Wall appears single layered in most specimens, although one specimen appears cavate. Wall thin, ornamented with evenly spaced, filiform processes 8-10 μm long and 0.7 μm wide at base; hairs spaced 4-5 μm apart. A few specimens with short spinules instead of long processes. Paracingulum distinct, lined on both margins by single row of processes. Archeopyle typically not evident.

Discussion

Comments. The sculpture of "Dinoflagellate sp. 5" is similar to that of *Paleohystrichophora infusorioides* Deflandre 1934, but that species has an elongate theca and well developed apical and antapical horns.

Occurrences. Slope Formation and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2881, A2964, A2847, and A2866, A2867. Maximum relative abundance in any sample is 1.1 percent.

Illustrated Specimens. Plate 6, Figure 8: UND-PC A2842-4, 10.9 mm across X 16.7 mm up. Plate 6, Figure 9: UND-PC A2842-2, 20.1 mm across X 8.7 mm up. Plate 6, Figure 10: UND-PC A2842-4, 18.7 mm across X 2.8 mm up.

Acritarchs and Other Algal Palynomorphs

The taxa described in this section include palynomorphs of probable algal origin that do not appear to be affiliated with the dinoflagellates. If specific biological affinities have been proposed for a taxon, those affinities are indicated in the discussion section. Algal taxa whose biological affinities are unknown are considered to be acritarchs.

Most palynomorphs classified as acritarchs were formerly grouped within the hystrichosphaerids. When many hystrichosphaerids were discovered to be dinoflagellate cysts, Evitt (1963) introduced the term "acritarch" to accommodate palynomorphs, formerly classed as hystrichosphaerids, that could not be demonstrated to have dinoflagellate affinities. In present usage, acritarchs include a large range of presumed algal bodies that have uncertain affinities.

Genus *Baltisphaeridium* Eisenack 1958 emend. Downie & Sarjeant 1963

Baltisphaeridium Eisenack, 1958, p. 398.

Baltisphaeridium Eisenack 1958 emend. Downie & Sarjeant, 1963, p. 89.

Type Species: *Baltisphaeridium longispinosum* (Eisenack) Eisenack 1959

Generic Diagnosis

"Hystrichospheres with spherical to oval shells not divided into fields or plates, bearing ± numerous processes, simple, branching or ramifying, hollow to solid, always with closed tips. The processes are not connected together distally and no outer shell, complete or incomplete, is present; the processes are most often of a single basic type, but processes of two or more types may be present. Mean and modal diameter of shell greater than 20 μ" (Downie and Sarjeant, 1963, p. 89).

Discussion

Baltisphaeridium is differentiated from *Micrhystridium* solely on the basis of size. In arguing for retention of both genera, Downie and Sarjeant (1963) felt that they represented natural size modes.

Baltisphaeridium spp.

Plate 7, Figures 7, 8

Description

Inaperturate to fissurate acritarchs, outline ovoid to circular; dimensions excluding processes generally 25-35 μm. Wall about 0.5 μm thick; covered with spine-like processes; processes solid, generally greater than 5 μm long, hair-like to rather stout, densely to moderately packed. Most specimens lacking distinct aperture, although some specimens with closed fissura.

Discussion

Comments. In general, the acritarchs are thought to represent phytoplankton algae of uncertain affinities. Tappan (1980) mentioned a resemblance between *Baltisphaeridium* and the prasinophyte algae.

Occurrences. Slope Formation and Three V Tongue of the Cannonball Formation; samples UND-PC A2874, A2959, A2966, A2848, A2854, A2855, A2866, and A2868. Uncommon; maximum relative abundance in any sample is 2.4 percent.

Illustrated Specimens. Plate 7, Figure 7: UND-PC A2959-3, 5.5 mm across X 3.8 mm up. Plate 7, Figure 8: UND-PC A2848.1-3, 10.4 mm across X 8.3 mm up.

Genus *Botryococcus* Kuetzing 1849

Botryococcus Kuetzing, 1849, p. 892.

Type Species: *Botryococcus braunii* Kuetzing 1849

Generic Diagnosis

Thallus small, irregularly botryoidal, greatly lobed, lobes joined, forming rounded mass, enclosed in a delicate gelatinous, mostly hyaline membrane, internal granules distinct attached and embedded (Kuetzing, 1849, p. 892, translated).

Discussion

Tappan (1980, p. 841) listed several form-genera that are considered to be junior synonyms of *Botryococcus*. Guy-Ohlson (1992) made a detailed comparison between fossil material and modern *Botryococcus*, (Chlorophyta or green algae) demonstrating that the fossils are referable to the modern genus.

Botryococcus lives in lakes, ponds, ditches, reservoirs, bogs, and wet mud from the tropics to the subarctic. Populations may bloom and form floating mats several centimeters in thickness. Although predominantly a freshwater alga, several studies that reported *Botryococcus* from brackish- to salt-water habitats were cited by Gray (1960). The morphology of *Botryococcus* colonies is influenced by the stage of growth and environmental conditions; similar morphologic variability has been noted in fossil specimens (Guy-Ohlson, 1992).

Botryococcus sp.

Plate 7, Figures 9, 10

Description

Solitary or multiple-joined masses of cup-like chambers; shape typically subcircular, overall dimensions 24-60 μm. Cup-like cavities 4-5 μm in diameter, commonly in multiple units of 4 cups per unit; wall around cups about 1.5 μm thick.

Discussion

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation. *Botryococcus* sp. was recorded in about 33 percent of the productive samples (see Plate 3). Common; maximum relative abundance in any sample is 5.9 percent.

Previous Records. Bearpaw, Fox Hills, Hell Creek, Tullock and Lebo Formations, northeastern Montana (Norton and Hall, 1969); Almond Formation, south-central Wyoming (Stone, 1973); Brandon Lignite

(Oligocene-Miocene), Vermont (Traverse, 1955); Elko Formation (Eocene), Nevada (Wingate, 1983); Frenchman Formation, south-central Saskatchewan (Jarzen, 1978); and Mascall Formation (Miocene), Oregon (Gray, 1960). Guy-Ohlson (1992) noted a wide geographic distribution of *Botryococcus* in rocks ranging in age from the Precambrian to the Recent.

Illustrated Specimens. Plate 7, Figure 9: UND-PC A2951-3, 10.0 mm across X 9.3 mm up. Plate 7, Figure 10: UND-PC A2816-3, 21.7 mm across X 8.5 mm up.

Genus *Cymatiosphaera* O. Wetzel 1933 emend. Deflandre 1954

Cymatiosphaera O. Wetzel, 1933, p. 27.

Cymatiosphaera O. Wetzel 1933 emend. Deflandre, 1954, p. 257, 258.

Type Species: *Cymatiosphaera radiata* O. Wetzel ex Deflandre 1954

Generic Diagnosis

"Shell globular, spherical or ellipsoidal, the external surface divided into polygonal fields by membranes perpendicular to the surface, without any equatorial differentiation of the fields or processes of any kind; the outer margins of the membranes straight or slightly concave, entire, serrated or somewhat corroded. Surface of shell smooth, punctate, or granular.

Dimensions.- Very variable, from a few microns to more than 100 μ, ridges included" (Deflandre, 1954; cited in Deflandre and Cookson, 1955, p. 288).

Cymatiosphaera spp.

Plate 7, Figure 11 ; Plate 8, Figures 1, 2

Description

Inaperturate acritarchs, shape flattened spherical, outline subcircular; diameter of endophragm 12.0-35.0 μm (n = 10). Wall two layered, endophragm about 2 μm thick; periphragm diaphanous, thrown into high narrow ridges that enclose polygonal lumina; ridges higher at their intersections, many specimens have only fragments of periphragm remaining.

Discussion

Comments. The specimens here assigned to *Cymatiosphaera* spp. appear to be divisible into two distinct morphologic groups. One type is larger, with a less distinct reticulum and more pronounced ridges of the periphragm (Plate 7, Figure 11; Plate 8, Figure 1), whereas the second form is smaller, with low periphragm ridges and more distinct reticulum (Plate 8, Figure 2). The former morphologic group resembles *C. wetzeli* Deflandre 1954, except for the notably smaller size. The latter group may be referable to *C. eupeplos* (Valensi) Deflandre 1954. Tappan (1980) noted that *Cymatiosphaera* may be attributable to the prasinophyte algae (Chlorophyta or green algae).

Occurrences. Slope Formation and the Boyce Tongue of the Cannonball Formation; samples UND-PC A2833, A2816, A2841, A2836, A2964, A2966, A2989, A2869, and A2867. Common only in the Boyce Tongue of the Cannonball Formation; maximum relative abundance in any sample is 13.6 percent.

Illustrated Specimens. Plate 7, Figure 11: UND-PC A2833-2, 7.8 mm across X 19.1 mm up. Plate 8, Figure 1: UND-PC A2833-2, 26.1 mm across X 10.0 mm up. Plate 8, Figure 2: UND-PC A2832-3, 15.8 mm across X 3.1 mm up.

Genus *Micrhystridium* Deflandre 1937 emend. Downie & Sarjeant 1963

Micrhystridium Deflandre, 1937, p. 79.

Micrhystridium Deflandre 1937 emend. Downie & Sarjeant, 1963, p. 92.

Type Species: *Micrhystridium inconspicuum* (Deflandre) Deflandre 1937

Generic Diagnosis

"Hystrichospheres with spherical or oval shells not divided into fields or plates, bearing process with closed tips, most often simple, rarely branching or ramifying, without distal connexions of any kind. The processes are generally of one type only. Mean and modal diameter of shell less than 20 μ" (Downie and Sarjeant, 1963, p. 92).

Micrhystridium Type-1

Plate 8, Figures 3-5, 7

Description

Inaperturate to fissurate acritarchs, shape more or less spherical, commonly folded; diameter excluding processes 7.0-19.0 μm. Wall less than 0.5 μm thick; ornamented with solid spiny processes up to 3.0 μm long; processes generally simple, but may have bifid, trifid, or more complex terminations; processes dense to sparse. Most specimens inaperturate, a single, straight, open or closed fissura may be present.

Discussion

Comments. Considerable variability in the concentration and length of the processes is present within this group. Some specimens have sculpture similar to that of *Sigmopollis hispidus*, but lack the sigmoidal aperture that is characteristic of species assigned to *Sigmopollis*. *Micrhystridium* Type-1 is differentiated from *M.* Type-2 by the presence of solid, narrow, spinose processes, rather than hollow, cone-like processes. Most specimens in this group are assignable to *Micrhystridium inconspicuum* (Deflandre) Deflandre 1937 or *M. densispinum* Valensi 1953. Acritarchs, such as *Micrhystridium*, were probably produced by phytoplankton of uncertain affinities (Tappan, 1980).

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation. *Micrhystridium* Type-1 was recorded in over 33 percent of the productive samples (see Plate 3) and tends to be more

common in samples collected from brackish-water paleoenvironments. Common; maximum relative abundance in any sample is 5.4 percent.
Illustrated Specimens. Plate 8, Figure 3: UND-PC A2919-1, 20.7 mm across X 4.8 mm up. Plate 8, Figure 4: UND-PC A2875.0-2, 17.4 mm across X 17.7 mm up. Plate 8, Figure 5: UND-PC A2832-2, 20.1 mm across X 1.2 mm up. Plate 8, Figure 7: UND-PC A2874-2, 12.5 mm across X 5.8 mm up.

Micrhystridium Type-2

Plate 8, Figures 6, 8

Description

Inaperturate acritarchs, shape spherical; diameter 12.0-16.0 μm. Wall two layered, total thickness about 1.0 μm, outer layer diaphanous. Outer layer forms hollow processes of variable length that are typically cone-like; processes generally relatively sparsely distributed.

Discussion

Comments. *Micrhystridium* Type-2 distinguished from *Micrhystridium* Type-1 by the presence of hollow, cone-like processes that are formed from the outer layer of the wall. The processes in *Micrhystridium* Type-1 are narrow, solid, and spinose.
Occurrences. Slope Formation and Boyce Tongue of the Cannonball Formation; samples UND-PC A2832, A2833, A2816, A2874, and A2885. Relatively abundant in some samples collected from the Boyce Tongue in section M1721, elsewhere rare. Maximum relative abundance in any sample is 17.7 percent.
Illustrated Specimens. Plate 8, Figure 6: UND-PC A2832-2, 17.4 mm across X 1.4 mm up. Plate 8, Figure 8: UND-PC A2832-2, 20.8 mm across X 2.9 mm up.

Genus *Ovoidites* Potonié ex Krutzsch 1959 emend. Potonié 1966

Ovoidites Potonié, 1951, pl. 21, fig. 185 (no diagnosis provided).

Ovoidites Potonié ex Krutzsch, 1959, p. 249.

Ovoidites Potonié ex Krutzsch emend. Potonié, 1966, p. 201.

Type Species: *Ovoidites ligneolus* Potonié ex Krutzsch 1959

Generic Diagnosis

"Outline ovoid to pointed oval, exine with a more or less tectate reticulum consisting of compact muri (not of rows of pila, pilaria, baculi, etc, as e.g. in some of the Iridaceae where simple reticula may exist also); the exine may open on one or both sides along a longitudinal line and finally can fall apart in two halves" (Potonié, 1966, p. 201, translated in Jansonius and Hills, 1976, card 1841).

Ovoidites cf. *O. ligneolus* Potonié ex Krutzsch 1959

Plate 8, Figures 9-11

Pollenites? ligneolus Potonié, 1931b, pl. 2, fig. V25a.

Ovoidites ligneolus (Potonié) Potonié, 1951, pl. 21, fig. 185.

Ovoidites ligneolus Potonié ex Krutzsch, 1959, p. 249.

Schizophacus ligneolus (Potonié) Thomson & Pflug 1953 in Sweet and Braman, 1992, figs. 14q, 14r (invalid combination, basionym not stated, incorrect citation given).

Description of North Dakota Specimens

Fissurate palynomorphs, outline elongate ovoid to somewhat rectangular, dimensions 31.0-(62.5)-88.0 X 20.0-(27.9)-36.0 μm (n = 17). Exine 0.7 to 2.5 μm thick, single layered; sculpture nearly smooth to irregularly rugulate; ridges in rugulate specimens 2-3 μm wide, vallae about 0.5-1.0 μm wide; rugulae commonly united to form subdued reticulum; lumina 1-2 μm in diameter, typically elongated in direction of long axis of grain. Complete specimens fissurate; fissura nearly encircles the long axis of grain, typically not gaping. Many specimens torn in half along the line of dehiscence.

Discussion

Comments. The specimens, here compared to *Ovoidites ligneolus*, are similar in general morphology to *O. ligneolus*, but they are smaller (140 μm for *O. ligneolus*) and lack the exolamella that was described for that species. However, a thin exolamella could easily be lost due to taphonomic processes.

More than one morphotype may be included within this species. Many larger specimens are complete, more ovoid in shape, and tend to have the weakly reticulate walls (Plate 8, Figure 9). The smaller specimens tend to be completely torn in half, more rectangular in outline, and have rugulate or nearly smooth walls (Plate 8, Figures 10 and 11). Additional study is required to determine if these morphotypes constitute separate species.

Detrended correspondence analysis by Fleming (1990) suggested deposition of *Ovoidites ligneolus* within marsh environments. The most significant occurrence of this species in the present study is within the Boyce Tongue of the Cannonball Formation. Rich *et al.* (1982), van Geel (1976, 1978) and van Geel *et al.* considered spores of this type to have been produced by the Zygnemataceae (Chlorophyta or green algae).

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *Ovoidites* cf. *O. ligneolus* was recorded in over 33 percent of the productive samples (see Plate 3). Common, maximum relative abundance is 30.9 percent.

Previous Records. Spores that appear to be conspecific with *Ovoidites* cf. *O. ligneolus* have been reported from the following strata: Tullock Member of Fort Union Formation, Powder River Basin, Montana and Wyoming (as *Schizophacus* sp.) (Nichols and Brown, 1992); Frenchman Formation, south-central Saskatchewan (as *Pontederia* sp.) (Jarzen, 1978); and Upper

Cretaceous and lower Tertiary of Wyoming and Colorado (as *Pontederia* sp.) (R.H. Tschudy, 1961).

Ovoidites ligneolus has been reported from the Cannonball Member of Fort Union Formation, northwestern South Dakota (Stanley, 1965); Tongue River and Ludlow Formations, North Dakota (Robertson, 1975); Raton Formation, Colorado and New Mexico (Fleming, 1990); Judith River Formation, north-central Montana (B.D. Tschudy, 1973); Hell Creek Formation, northeastern Montana (Oltz, 1969); Paskapoo Formation, Alberta, Canada (Snead, 1969); Hell Creek Formation, North Dakota (Bergad, 1974); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); and the upper Maastrichtian and lower Paleocene of Alberta and Saskatchewan (Sweet and Braman, 1992).

Illustrated Specimens. Plate 8, Figure 9: UND-PC A2923-2, 8.7 mm across X 5.8 mm up. Plate 8, Figure 10: UND-PC A2832-2, 25.9 mm across X 3.2 mm up. Plate 8, Figure 11: UND-PC A2832-2, 17.0 mm across X 3.2 mm up.

Genus *Pediastrum* Meyen 1829

Pediastrum Meyen, 1829, p. 772.

Generic Diagnosis

Thallus free, small, flat, cellulosic, generally circular or stellate, composed of a single layer of cells, peripheral cells bifid or bidentate, interior cells angular. Enclosed substance includes green angular granules (in fresh water) (diagnosis translated from Kuetzing, 1849, p. 191).

Discussion

These specimens can be confidently compared to the modern green alga *Pediastrum* (Chlorophyta or green algae, Family Hydrodictyaceae). Modern *Pediastrum* occupies benthic or planktic habitats in quiet freshwater pools or lakes (Bold, 1967). Large summer populations of the

Chlorococcales (including *Pediastrum*) are common in temperate eutrophic lakes (Round, 1981).

Pediastrum spp.

Plate 8, Figure 13

Description of North Dakota Specimens

Coenobium disk-like, compact, no open spaces between coenocytes; diameter of coenobia highly variable, up to 85 μm, coenocytes 10-15 μm in diameter. Outermost row of coenocytes with 2 processes per cell, processes 5-10 μm long. Wall less than 0.5 μm thick, sparsely punctate; commonly highly folded and distorted impressions of pyrite(?) crystals.

Discussion

Comments. Most specimens here assigned to *Pediastrum* appear to be comparable to *Pediastrum bifidites* Wilson & Hoffmeister 1953, which in turn, was noted to resemble the modern species *P. boryanum* (Turpin) Meneghini 1915. However, many specimens are too poorly preserved, or too folded or distorted, to be able to ascertain that they belong to a single species.

Although the modern habitat of *Pediastrum* is freshwater, several fossil occurrences from marine strata have been reported. The marine occurrences were attributed to transport by streams into a marine environment (Stanley, 1965; Evitt, 1963). Detrended correspondence analysis of palynomorph occurrences in the Raton Formation by Fleming (1990) placed *Pediastrum* in a group that was interpreted to represent freshwater lake assemblages. In the present study, *Pediastrum* commonly dominates palynomorph assemblages in the basal beds of both brackish-water tongues of the Cannonball Formation. However, *Pediastrum* spp. are uncommon in the portions of those strata believed to have been deposited under more saline conditions.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation. *Pediastrum* spp. was recorded in over 25 percent of the productive samples (see Plate 3). Abundant; maximum relative abundance in any sample is 65.8 percent.

Previous Records. Within the northern Great Plains, *Pediastrum* has been reported from the following strata: Cannonball Member of the Fort Union Formation, northwestern South Dakota (Stanley, 1965); Raton Formation, Colorado and New Mexico (Fleming, 1990); Almond Formation, south-central Wyoming (Stone, 1973); Tongue River, Cannonball, Ludlow, Sentinel Butte, and Golden Valley Formations, North Dakota (Robertson, 1975); Frenchman Formation, south-central Saskatchewan (Jarzen, 1978); Elko Formation (Eocene), Nevada (Wingate, 1983); and upper Maastrichtian and lower Paleocene of Alberta and Saskatchewan (Sweet and Braman, 1992).

Illustrated Specimen. Plate 8, Figure 13: UND-PC A2892-3, 23.0 mm across X 4.2 mm up.

Genus *Polyporina* Naumova 1939 ex Potonié 1960

Polyporina Naumova 1939 ex Potonié, 1960, p. 134.

Type Species: *Polyporina multistigmosa* (Potonié) Potonié 1960

Generic Diagnosis

"With numerous foveae, more or less closely spaced, distinctly recessed, with double contours; exine between the circular foveae more distinctly granulate than in the foveae" (Potonié, 1960, translated in Jansonius and Hills, 1976, card 2111).

Discussion

Potonié (1960) compared *Polyporina* to the pollen of the Chenopodiaceae and some authors have assigned chenopod-type pollen to the genus (Srivastava, 1969a). Krutzsch (1966) considered the type species to represent a freshwater planktonic organism. Palynomorphs of Quaternary age that are similar to, but somewhat larger than, the specimens here assigned to *Polyporina* were considered to be zygospores or aplanospores having affinities with the Zygnemataceae or Oedogoniaceae (Chlorophyta or green algae) (van Geel, 1976, 1978; van Geel *et al.*, 1989).

Polyporina sp.

Plate 8, Figure 12

Description

Inaperturate(?) palynomorphs; shape lenticular, outline subrectangular to subcircular; maximum dimension 25.0-(28.0)-35.5 μm (n = 10). Wall about 0.5 μm thick, single layered, psilate to weakly scabrate, commonly resists staining (safranin O). About 20 funnelform pits present on each surface; pits about 3 μm apart, about 2.0 μm wide at surface, decreasing inward to about 0.8 μm diameter, do not contain pores.

Discussion

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2942, A2821, A2838, A2839, A2831, A2832, A2840, A2878, A2919, A2882, A2977, A2846, A2847, A2848, A2849, A2853, A2859, and A2861. Uncommon; maximum relative abundance in any sample is 1.2 percent.

Illustrated Specimen. Plate 8, Figure 12: UND-PC A3153-2, 18.0 mm across X 15.4 mm up.

Genus *Psiloschizosporis* Jain 1968

Psiloschizosporis Jain, 1968, p. 31.

Type Species: *Psiloschizosporis cacheutensis* Jain 1968

Generic Diagnosis

"Sporomorphs circular to oval, outline smooth; splitting longitudinally into two concave halves; exine psilate, smooth to pitted" (Jain, 1968, p. 31).

Discussion

Species assigned to *Psiloschizosporis* were previously accommodated within *Schizosporis* Cookson & Dettmann 1959. The genotype of *Schizosporis*, *Schizosporis reticulatus*, has a complexly layered wall and distinctly reticulate sculpture. Jain (1968) and Pierce (1976) considered this wall structure distinctive enough to warrant the erection of new genera to accommodate species, previously assigned to *Schizosporis*, that have simpler wall structure.

The genus *Schizophacus* Pierce 1976 was intended to contain species, previously assigned to *Schizosporis*, that have a simpler wall structure and rugulate to psilate sculpture. However, *Psiloschizosporis* clearly has priority over *Schizophacus* for those species having smooth walls. At best, *Schizophacus* could be retained for forms having rugulate sculpture similar to that in the genotype, *S. rugulatus* (Cookson & Dettmann) Pierce 1976.

Ovoidites Potonié ex Krutzsch 1959 has also been applied to palynomorphs of the type here assigned to *Psiloschizosporis* (Rich *et al.*, 1982; Nakoman, 1966). However, *Ovoidites* has reticulate sculpture (Potonié, 1966) and thus appears to be distinct from *Psiloschizosporis*.

Several studies (van der Wiel, 1982; van Geel *et al.*, 1983; 1989; Rich *et al.*, 1982) have associated *Psiloschizosporis*-type spores with the zygospores or aplanospores produced by *Spirogyra* (Zygnemataceae, Chlorophyta). In Quaternary peat-forming environments, Rich *et al.* (1982) found this type of spores to be indicators of deposition in fresh-water marshes. Van Geel *et al.* (1989) considered similar Quaternary spores to indicate temporarily shallow, open water environments.

Psiloschizosporis laevigatus (Stanley) n. comb.

Plate 8, Figures 14, 15

Schizosporis laevigatus Stanley, 1965, p. 268, 269, pl. 23, figs. 6, 7, pl. 37, figs. 4, 5 (basionym).

Schizophacus laevigatus (Stanley) Nichols & Brown, 1992, p. F10, pl. 1, fig. 1.

Description of North Dakota Specimens

Fissurate palynomorphs, outline elongate oval to subcircular; dimensions 62.0-(84.3)-112.0 X 40.8-(50.0)-72.0 μm (n = 10). Wall 0.5 to 2 μm thick, single layered, psilate to faintly scabrate. Fissura extends nearly completely around the long dimension of the grain, typically not gaping.

Discussion

Comments. The North Dakota specimens of *Psiloschizosporis laevigatus* have a somewhat greater size range and more variable wall thickness than was described for this species by Stanley (1965). In all other aspects, however, they appear to be identical. Several workers have identified similar palynomorphs as *Schizophacus parvus* (Cookson & Dettmann) Pierce 1976, but that species is described as having a more complexly layered wall, and is not here considered synonymous with *P. laevigatus*.

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation. *Psiloschizosporis laevigatus* occurs in about 60 percent of the productive samples (see Plate 3). Common; maximum relative abundance in any sample is 13.0 percent.

Previous Records. Cannonball Member of Fort Union Formation, northwestern South Dakota (Stanley, 1965); and Tullock Member of Fort Union Formation, Powder River Basin, Montana and Wyoming (Nichols and Brown, 1992).

Illustrated Specimens. Plate 8, Figure 14: UND-PC A2931-3, 20.1mm across X 11.5 up. Plate 8, Figure 15: UND-PC A2931-3, 22.5 mm across X 10.5 mm up.

Psiloschizosporis cf. *P. spriggii* (Cookson & Dettmann) n. comb.

Plate 9, Figures 1, 2, 4, 5

Schizosporis spriggii Cookson & Dettmann, 1959, p. 216, pl. 1, figs. 15-20 (basionym).

Schizophacus spriggii (Cookson & Dettmann) Pierce, 1976, p. 30.

Description of North Dakota Specimens

Inaperturate to fissurate palynomorphs, outline circular, dimensions 41-(77.7)-95 μm (n = 10). Wall single layered, 0.5-1.0 μm thick, psilate to scabrate. Distinct line of dehiscence or fissura present in most specimens.

Discussion

Comments. Palynomorphs here compared to *Psiloschizosporis spriggii* are more variable in size and have thinner walls than was originally described for the species. Tappan (1980) considered this species to have affinities with the prasinophyte algae (Chlorophyta or green algae).

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2953, A2822, A2839, A2832, A2833, A2816, A2880, A2885, A2959, A2850, A2852, and A2855. Uncommon; maximum relative abundance in any sample is 6.5 percent. *Psiloschizosporis* cf. *S. spriggii* tends to occur in samples collected from brackish-water paleoenvironments.

Illustrated Specimens. Plate 9, Figure 1: UND-PC A2931-3, 13.7 mm across X 9.6 mm up. Plate 9, Figures 2 and 4: UND-PC A2879-2, 4.7 mm across X 12.0 mm up. Plate 9, Figure 5: UND-PC A2953-4, 26.0 mm across X 8.7 mm up.

Genus *Pterospermella* Eisenack 1972

Pterospermella Eisenack, 1972, p. 597.

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

Discussion

Pterospermella was erected to accommodate algal palynomorphs that previously were assigned to *Ptermospermopsis* W. Wetzel 1952. Eisenack (1972) proposed this nomenclatural change because he considered the systematic position of *Ptermospermopsis* to be uncertain due to an insufficient understanding of the genotype, *P. danica* W. Wetzel 1952. Tappan (1980) attributed similar cysts, ranging in age from Precambrian to Holocene, to the phycoma phase of the prasinophyte alga *Pterosperma*.

Pterospermella australiensis (Deflandre & Cookson 1955)
Eisenack *et al.* 1973
Plate 9, Figure 6

Pterospermopsis australiensis Deflandre & Cookson, 1955, p. 286.

Pterospermella australiensis (Deflandre & Cookson 1955) Eisenack *et al.*, 1973, p. 959.

Description of North Dakota Specimens

Lenticular-shaped cysts, outline circular to subcircular; diameter 25-41 μm (n = 5). Central body more or less spherical, encircled by wide membranous flange. Flange membrane less than 0.5 μm thick, generally numerous radially directed folds present on flange.

Discussion

Comments. The North Dakota specimens of *Pterospermella australiensis* have a slightly larger size range than was noted by Deflandre and Cookson (1955); otherwise, they appear to be identical.

Occurrences. Ludlow and Slope Formations and the Boyce Tongue of the Cannonball Formation; samples UND-PC A2818, A1832, A2833, A2816, A2841, A2959, and A2966. Rare; maximum relative abundance in any sample is 1.8 percent.

Previous Records. Lower Cretaceous, Australia (Deflandre and Cookson, 1955); Cannonball Member of Fort Union Formation, northwestern South Dakota (Stanley, 1965); and Almond Formation, south-central Wyoming (Stone, 1973).

Illustrated Specimen. Plate 9, Figure 6: UND-PC A2832-2, 8.7 mm across X 4.7 mm up.

Genus *Sigmopollis* Hedlund 1965

Sigmopollis Hedlund, 1965, p. 90.

Type Species: *Sigmopollis hispidus* Hedlund 1965

Generic Diagnosis

"Spheroidal; equatorial contour circular to subcircular. A single aperture, doubly recurved, sigmoidal, simple. When aperture is open, exinous areas adjacent to aperture appear as two laterally adjacent, but opposing opercula" (Hedlund, 1965, p. 90).

Sigmopollis hispidus Hedlund 1965

Plate 9, Figure 3

Sigmopollis hispidus Hedlund, 1965, p. 92, pl. 1, figs. 1-12.

Description of North Dakota Specimens

Fissurate palynomorphs; shape flattened spheroidal; dimensions 22.5-(24.1)-27.0 μm (n = 6). Wall about 0.5 μm thick, single layered; sculpture of thin, apiculate hairs 0.5 to 2 μm long, hairs spaced 1-2 μm apart, oriented nearly perpendicular to the wall; hairs of some specimens blunt, possibly due to degradation. Fissura distinctly sigmoidal, open to closed, extends about one-half the circumference.

Discussion

Comments. Specimens of Quaternary age, having similar apertures and spines were questionably assigned to the algae and were considered to represent eutrophic to mesotrophic, open-water environments (Pals *et al.*, 1980; van Geel *et al.*, 1983). Bergad (1974) considered similar specimens from the Hell Creek Formation of North Dakota to be fungal spores, but he did not elaborate on this association.

Sigmopollis psilatus Piel 1971, a species possessing a thicker, psilate wall, was encountered rarely in this study. This species was combined with *S. hispidus* in the quantitative analysis.

Occurrences. Slope Formation and Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2832, A2833, A2816, A2836, A2876, A2971, A1977, A2978, A2987, and A2860. Rare; maximum relative abundance in any sample is 2.0 percent.

Previous Records. Elko Formation (Eocene), Nevada (Hedlund, 1965; Wingate, 1983); Hell Creek Formation, south-central North Dakota (Bergad, 1974); Tullock Member of Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); Oligocene of central British Columbia (Piel, 1971); Edmonton Formation, Alberta (Snead, 1969); Ravenscrag Formation, southern Saskatchewan (Jarzen, 1982); Edmonton Formation, Alberta (Srivastava, 1985); and upper Maastrichtian and lower Paleocene of Alberta and Saskatchewan (Sweet and Braman, 1992).

Illustrated Specimens. Plate 9, Figure 3: UND-PC A2816-3, 19.3 mm across X 8.4 mm up.

Genus *Tetraporina* Naumova ex Bolkhovitina 1953

Tetraporina Naumova, 1939, p. 354 (nom. nud.).

Tetraporina Naumova ex Bolkhovitina, 1953, p. 102.

Type Species: *Tetraporina pellucida* Bolkhovitina 1953

Generic Diagnosis

Emended diagnosis of Lindgren (1980, p. 346): "Acid resistant, unicellular, tetrahedral or parallelepipedal microfossils with or without obvious dehiscence mechanism. Wall single-layered or double-layered."

Discussion

In recent years, there has been debate concerning the nomenclatural status of *Tetraporina*. The emended diagnosis of Lindgren (1980) does not strictly apply, as it applies to *Tetraporina* Naumova ex Potonié 1960 rather than to *Tetraporina* Naumova ex Bolkhovitina 1953. However, the diagnosis of Bolkhovitina, "Pollen with four pores, without folds" (cited in Jansonius and Hills, 1981, card 3917) is so imprecise that it is of little value. Thus Lindgren's diagnosis is cited here to provide a better framework for placing the fossils here assigned to *Tetraporina* (see also Jansonius and Hills, 1981).

The type species designated by Jansonius and Hills (1977), *Tetraporina pellucida*, does not have pore-like invaginations at the corners of the cysts. However, such specimens are typically assigned to *Tetraporina* and would be included under Lindgren's emended diagnosis. Upon further study, it may prove useful to restrict *Tetraporina* to species lacking pore-like structures (as in *T. pellucida*), and to assign species possessing the pore-like structures to a different genus, such as *Tetrapidites* Klaus ex Meyer 1956.

Tetraporina sp.

Plate 9, Figures 7, 8

Description

Inaperturate quadrate cysts, sides straight to strongly concave, corners flattened to invaginated; maximum diameter 26.0-(30.6)-39.0 μm (n = 9). Wall single layered, about 0.5 μm thick; psilate to weakly scabrate. Invaginated, pore-like dehiscence(?) areas present on each corner.

Discussion

Comments. Similar palynomorphs from Quaternary deposits were regarded as zygospores of the zygnemataceous alga *Mougeotia* (Chlorophyta) (van Geel, 1976; Pals *et al.*, 1980; van der Wiel, 1982). The retuse angles are former points of attachment to the vegetative cells, which are not preserved. Van der Wiel (1982) regarded these zygospores to indicate stagnant, shallow, mesotrophic freshwater.

Occurrences. Slope and Ludlow Formations and Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2818, A2834, A2832, A2840, A2933, A2816, A2836, A2885, A2966, A2969, A2968, A2971, A2972, A2977, and A2866. Uncommon, maximum relative abundance in any sample is 9.0 percent.

Previous Records. Tullock Member of Fort Union Formation, Powder River Basin, Montana and Wyoming (Nichols and Brown, 1992); Ravenscrag Formation, southern Saskatchewan (as Zygospore Form B) (Jarzen, 1979); and upper Maastrichtian and lower Paleocene of Alberta and Canada (Sweet and Braman, 1992).

Illustrated Specimens. Plate 9, Figure 7: UND-PC A2832-2, 9.2 mm across X 6.5 mm up. Plate 9, Figure 8: UND-PC A2818-2, 20.0 mm across X 19.4 mm up.

Acritarch Type-1

Plate 6, Figures 11, 12

Description

Inaperturate to fissurate palynomorphs, outline circular to ovoid; maximum dimension 29.0-(32.1)-40 μm (n = 6). Wall single layered, about 1.0 μm thick (including sculpture); sculpture of closely spaced baculae about 0.5 μm diameter by 0.8 μm long; in some specimens baculae heads partially fused, resulting in microreticulate sculpture. Inaperturate to fissurate; fissura open to closed, rarely sigmoidal.

Discussion

Comments. Spores possessing a sculpture pattern similar to Acritarch Type-1 were described from Quaternary sediments by van Geel (1978) and van Geel *et al.* (1981). These spores, designated as "Type 60 microfossils", were considered to be spores of *Closterium* (Desmidiaceae). However, the "Type 60 microfossils" commonly have projections on the ends of the spores, and thus do not appear to be directly comparable to Acritarch Type-1 of the present study. Van Geel (1989) illustrated microfossils of probable algal origin (Type 128B) that have finely baculate sculpture similar to that in Acritarch Type-1. However, Type 128B microfossils have sigmoid apertures and thus are not directly comparable to Acritarch Type-1.

Occurrences. Boyce Tongue of the Cannonball Formation; samples UND-PC A2840, A2833, A2816, and A2841. The occurrence of Acritarch Type-1 is restricted to the western exposures of the Boyce Tongue. Rare; maximum relative abundance in any sample is 3.4 percent.

Illustrated Specimens. Plate 6, Figure 11: UND-PC A2833-2, 27.2 mm across X 6.5 mm up. Plate 6, Figure 12: UND-PC A2832-2, 14.2 mm across X 2.4 mm up.

Acritarch Type-2

Plate 7, Figures 1, 2

Description

Inaperturate to operculate(?) palynomorphs, outline ovoid; dimensions 33.0-(35.7)-48.0 X 20.5-(26.7)-31.0 μm (n = 9). Wall two layered; inner layer about 0.5 μm thick; outer layer very thin, diaphanous, commonly lacking; wall psilate. Many specimens have operculum-like aperture near one end; other specimens inaperturate; longitudinal fold commonly present; line of dehiscence never present.

Discussion

Comments. Acritarch Type-2 is similar in shape to algal spores assigned to *Schizophacus laevigatus*. However, they differ from *S. laevigatus* by their generally smaller size and by the lack of a line of dehiscence. They probably represent resistant algal cysts.

Occurrences. Slope Formation and Boyce Tongue of the Cannonball Formation; samples UND-PC A2839, A2832, A2840, A2833, A2816, A2836, A2842, and A2971. Acritarch Type-2 has its most conspicuous occurrence in samples from the Boyce Tongue in section M1721. Uncommon; maximum relative abundance in any sample is 22.9 percent.

Illustrated Specimens. Plate 7, Figure 1: UND-PC A2832-2, 13.8 mm across X 3.2 mm up. Plate 7, Figure 2: UND-PC A2832-2, 20.0 mm across X 5.1 mm up.

Acritarch Type-3

Plate 7, Figure 3

Description

Acritarchs with ovoid to circular outline; maximum dimension 18.0-(19.8)-22.0 μm (n = 8). Wall about 1.5 μm thick, single layered, psilate to scabrate, readily accepts safranin-O stain. A circular opening about 8 μm in diameter present in some specimens, operculum-like flap rarely retained. All specimens have angular fissura, extending entire length of specimen in many cases.

Discussion

Comments. The relatively thick wall, more or less circular outline, and fissura differentiate Acritarch Type-3 from similar palynomorphs. The angular boundaries of the fissura of some specimens indicates that this species may represent a dinoflagellate.

Occurrences. Boyce Tongue of the Cannonball Formation; samples UND-PC A2839, A2832, A2833, and A2816. Type-3 acritarchs were recorded only in samples from the western exposures of the Boyce Tongue of the Cannonball Formation. Rare; maximum relative abundance in any sample is 3.2 percent.

Illustrated Specimens. Plate 7, Figure 3: UND-PC A2831-1, 12.5 mm across X 17.6 mm up.

Acritarch Type-4

Plate 7, Figures 4-6

Description.

Fissurate(?) palynomorphs, outline ovoid to subcircular, probably originally spherical or nearly so; maximum dimension 34.0-(38.6)-44.5 μm (n = 11). Wall two layered, typically highly folded; inner wall about 0.5 μm thick, sculpture of sparse, more or less evenly spaced grana, 0.5-1.5 μm in diameter, coarseness and density of grana vary among specimens, sculpture typically lacking within about 5 μm of the fissura(e); periphragm diaphanous, closely attached to surface of grana except near fissura where distinct separation of layers is evident; in some specimens, periphragm absent, presumably stripped away. One or two relatively short fissura(e) always present, but commonly indistinct due to folding of body; in elongate specimens, fissura(e) are typically at one end of body; otherwise, orientation of fissura(e) indistinct. Brown bodies commonly present.

Discussion

Comments. Acritarch Type-4 is readily recognized by its distinctly granulate wall and the presence of a very thin periphragm. The size range for this taxa and the structure of its wall is similar to that described by Drugg (1967) for *Membranosphaera maastrichtica* Samoilovitch ex Norris & Sargent 1965. However, no specimens displaying the apical archeopyle characteristic of that species were noted. An inaperturate palynomorph of similar size and possessing similar sculpture to Acritarch Type-4 was illustrated by Wingate (1983, pl. 1, fig. 5). He questionably considered its affinities to be algal.

Occurrences. Slope Formation and Three V Tongue of the Cannonball Formation; samples UND-PC A2848, A2849, A2850, A2852, A2858, A2859, A862, A2867, and A2868. Rare; maximum relative abundance in any sample is 3.3 percent.

Illustrated Specimen. Plate 7, Figure 4: UND-PC A2649-4, 19.2 mm across X 16.9 mm up. Plate 7, Figures 5, 6: UND-PC A2849-4, 18.9 mm across X 5.0 mm up.

Trilete and Monolete Spores

Genus *Azolla* Lamarck 1783

DIAGNOSIS.

"Massulae-round to oval in outline, size range 100 μm to perhaps well over 500 μm; characterized by appendages that bear anchor-shaped processes on a moderately long shaft (glochidia)" (Stanley, 1965, p. 256).

Discussion

Microspore massulae of *Azolla* are distinctive and fossil specimens can unequivocally be assigned to the extant genus. I am unaware of any form-genus that has been erected to accommodate similar microspore massulae. Isolated microspores similar to those produced by *Azolla* are assigned to the form-genus *Hydrosporis* Krutzsch 1962.

Azolla cretacea Stanley 1965

Plate 9, Figure 9

Azolla sp. in R.H. Tschudy, 1961, p. 54, pl. 1, figs. 7, 8.

Azolla cretacea Stanley, 1965, p. 256, 257, pl. 33, figs. 1-5.

Description of North Dakota Specimens

Microspore massula bearing intact microspores. Microspores trilete, more or less spherical, about 20-22 μm diameter (3 specimens); wall thickness and sculpture obscured by massula. Overall diameter of the massula 99 X 68.5 μm; glochidia bearing anchor-shaped termini, glochidia about 1.3 μm wide, swelling slightly and then again constricting before meeting flukes. Flukes with long trailing terminae with reflexed tips.

Discussion

Comments. *Azolla cretacea* Stanley is distinguished from *A. bohemica* Pacltová 1960 by having narrower glochidia that lack hollow centers (see Krutzsch, 1962, p. 70). *A. geneseana* Hills and Wiener 1965 lacks a constriction at the intersection of the glochidial stalk and the flukes (Srivastava, 1968a).

R.H. Tschudy (1961) considered *Azolla* sp. massulae to be indicative of lacustrine environments. Nichols and Brown (1992) noted a tendency for *A. cretacea* to occur in samples containing the freshwater algal palynomorphs *Psiloschizosporis* (*Schizophacus*) and *Tetraporina*, again suggesting an aquatic environment.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2952, A2954, A2956, A2829, A2942, A2884, A2885, A2959, A2860, A2962, A2963, A2964, A2976, A2981, A2987, A2992, A2993, A2853, A2860, A2862, and A2896. Uncommon; maximum relative abundance in any sample is 7.1 percent.

Previous Records. Hell Creek Formation and Ludlow Member of the Fort Union Formation, northwestern South Dakota (Stanley, 1965); Wind River and Fort Union Formations, Colorado and Wyoming (as *Azolla* sp.) (R.H. Tschudy, 1961); Tullock Member of Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); Bearpaw, Fox Hills, Hell Creek, Tullock and Lebo Formations, northeastern Montana (Norton and Hall, 1969); Lance Formation and Tullock and Tongue River

Members of Fort Union Formation, east-central Wyoming (Leffingwell, 1971); Hell Creek and Tullock Formations, northeastern Montana (Oltz, 1969); Edmonton Formation, Alberta, Canada (Srivastava, 1966, 1967, 1968; Kaiparowits Formation (Maastrichtian), Utah (Lohrengel, 1970); and upper Maastrictian and Paleocene, northeastern Montana (Nichols *et al.*, 1982).

Illustrated specimens. Plate 9, Figure 9: UND-PC A2923-1, 19.4 mm across X 5.5 mm up.

Azolla spp.

Plate 9, Figure 13

Discussion

Comments. All specimens assignable to *Azolla*, but not attributable to *A. cretacea*, are included in this group. Included are microspore massulae that lack any glochidia and specimens that may be parts of the megaspore float apparatus (figured specimen).

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; sample UND-PC A2952, A2953, A2954, A2955, A2956, A2957, A2958, A2818, A2880, A2882, A2883, A2884, A2885, A2959, A2960, A2974, A2981, A2989, A2993, A2847, A3001. Uncommon; maximum relative abundance 5.7 percent.

Illustrated Specimen. Plate 9, Figure 13: UND-PC A2923-2, 20.6 mm across X 2.0 mm up.

Genus *Biretisporites* Delcourt & Sprumont 1955

emend. Delcourt *et al.* 1963

Biretisporites Delcourt & Sprumont, 1955, p. 40.

Punctatisporites Ibrahim emend. Delcourt & Sprumont, 1955 (pars), p. 29.

Hymenophyllumsporites Rouse, 1957, p. 363.

Biretisporites Delcourt & Sprumont emend. Delcourt *et al.*, 1963, p. 283, 284.

Type Species: *Biretisporites potoniaei* Delcourt & Sprumont 1955

Generic Diagnosis

"Microspores trilete with a triangular to subtriangular amb. Laesurae enclosed within elevated lips which are upturned extensions of proximal exine. Exine smooth or almost so" (Delcourt *et al.*, 1963, p. 283, 284).

Biretisporites furcosus (Stanley) n. comb.

Plate 10, Figures 1, 3

Hymenophyllumsporites furcosus Stanley, 1965, p. 249, pl. 31, figs. 1-5 (basionym).

Intertriletes furcosus (Stanley) Oltz, 1969, p. 126, pl. 40, fig. 49.

Description of North Dakota Specimens

Trilete spores, amb subtriangular, sides convex to straight, rarely slightly concave, apices rounded. Equatorial diameter 34-(54.7)-81 μm (n = 10). Exine single layered, 1.5-2.5 μm thick, psilate. Laesurae extend about three-fourths spore radius, bordered by raised margos about 2.0 μm wide, margos typically fork at their distal ends.

Discussion

Comments. Spores assigned to *Biretisporites furcosus* (Stanley) n. comb. agree well with Stanley's original description except for a somewhat larger size range (40-60 μm for Stanley's specimens). An insufficient number of specimens were encountered to determine if more than one population is present based on spore size.

Oltz (1969) transferred the species to *Intertriletes* Anderson 1960, citing the presence of a sculptured contact in some of the illustrated specimens of *Hymenophyllumsporites furcosus* (Stanley, 1965, pl. 31, figs. 1-5). However, the holotype (figs. 1, 2) lacks a sculptured contact area, making transfer to *Intertriletes* inappropriate.

Norton and Hall (1969) described two similar species, *Hymenophyllumsporites parvus* Norton and *Hymenophyllumsporites pseudomaximus* (Pflug & Thomson) Norton, from the Hell Creek, Tullock and Lebo Formations of northeastern Montana. Although these two species are similar in size and shape, and may be conspecific with *Biretisporites furcosus*, it is not possible to ascertain that the laesurae are bordered by the raised margos that are characteristic of *B. furcosus*.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2940, A2942, A2954, A2955, A2817, A2821, A2822, A2875, A2883, A2885, A2962, A2964, A2965, A2967, A2976, A2977, A2979, A2982, A2983, A2984, A2989, A2993, A2845, A2849, A2855, A2856, A2863, A2870, A2997, A2999, and A3000. Uncommon; maximum relative abundance in any sample is 6.2 percent.

Previous Records. Hell Creek and Fort Union Formations, northwestern South Dakota (Stanley, 1965); and Hell Creek and Tullock Formations, northeastern Montana (Oltz, 1969).

Illustrated Specimens. Plate 10, Figure 1: UND-PC A2884-3, 15.6 mm across X 5.7 mm up. Plate 10, Figure 3: UND-PC A2884-3, 6.0 mm across X 4.7 mm up.

Genus *Cicatricosisporites* Potonié & Gelletich 1933 emend. Pocock 1965

Cicatricosisporites Potonié & Gelletich, 1933, p. 522, pl. 1, fig. 1.

Cicatricosisporites Potonié & Gelletich emend. Pocock, 1965, p. 156.

Type Species: *Cicatricosisporites dorogensis* Potonié & Gelletich 1933

Generic Diagnosis

"Trilete spores with two-layered exine; nexine smooth and thinner than or as thin as sexine, showing little tendency to thicken at the apices, ornamented with ribs of more or less regular width and height, caniculate to cicatricose" (Pocock, 1965, p. 156).

Cicatricosisporites spp.

Plate 10, Figure 2

Description

Trilete spores, shape in equatorial view more-less heart-shaped, pointed on distal end, amb generally triangular with concave sides; equatorial dimensions 30 to 40 μm. Spore wall about 2.5 μm thick; sculpture cicatricose to caniculate, some specimens have muri joined across vallae forming foveolate sculpture.

Discussion

Comments. Most specimens assigned to *Cicatricosisporites* spp. have a sculpture similar to that of the illustrated specimen. A gradation from cicatricose sculpture to foveolate sculpture is present within the spores assigned to this genus. A similar gradation in sculpture was noted by Elsik (1968a) in spores from the Rockdale Formation (Paleocene) of Texas. Those spores having distinctly foveolate sculpture could be assigned to *Ischyosporites* Balme 1957 or *Microreticulatisporites* Knox 1950. They are included here under *Cicatricosisporites* because of the gradational nature of the sculpture. These spores are probably attributable to the schizeaceous ferns.

Occurrences. Slope Formation and the Boyce Tongue of the Cannonball Formation; samples UND-PC A2885, A2865, A2867, and A2869. Rare; maximum relative abundance in any sample is 1.2 percent.

Illustrated Specimens. Plate 10, Figure 2: UND-PC A2278-4, 8.3 mm across x 13.2 mm up.

Genus *Cyathidites* Couper 1953

Cyathidites Couper, 1953, p. 27.

Type Species: *Cyathidites australis* Couper 1953

Generic Diagnosis

"Free anisopolar, trilete, laesurae clearly defined, long, always over two-thirds of the radius of the spore. Spores triangular, apices broadly rounded, and sides concave between apices in polar view. Both proximal and distal surfaces convex, distal markedly so. Exine psilate" (Couper, 1953, p. 27).

Cyathidites diaphana (Wilson & Webster) Nichols & Brown 1992

Plate 10, Figures 4, 5

Deltoidospora diaphana Wilson & Webster, 1946, p. 273, fig. 3.

Lygodiosporites adriennis (Potonié & Gelletich) Potonié, Thomson, & Thiergart ex Potonié *in* Anderson, 1960, p. 14, pl. 9, fig. 17.

Cardioangulina diaphana (Wilson & Webster) Stanley, 1965, p. 248, pl. 30, figs. 17-12.

Cyathidites minor Couper 1953, *in* Norton and Hall, 1969, p. 22, pl. 1, fig. 20.

Cyathidites diaphana (Wilson & Webster) Nichols & Brown, 1992, p. F14, pl. 3, figs. 3-5.

Description of North Dakota Specimens

Trilete spores, oblate, amb triangular, sides slightly concave, apices well rounded; equatorial diameter 28.5-(30.4)-33.5 μm (n = 5). Spore wall single layered, 0.5 to 1.0 μm thick, psilate. Laesurae extend one-half to three-fourths of radius, not bordered by distinct thickenings of spore wall.

Discussion

Comments. Nichols and Brown (1992) transferred this species to *Cyathidites* because the concave sides and rounded apices of the amb that characterize the species are diagnostic of *Cyathidites.* The amb in *Deltoidospora* tends to have straight sides and more pointed apices. Stanley's (1965) assignment of the species to *Cardioangulina* was rejected because that genus contains much larger spores than *Cyathidites*, and may be a junior synonym of *Cyathidites*.

Some workers (Norton and Hall, 1969) have classified similar spores into two species, assigning spores at the larger end of the size range to *Cyathidites diaphana* (as *Deltoidospora diaphana*), and smaller spores to *Cyathidites minor* Couper. The assignment of spores of this morphology to *C. minor* appears to be unwarranted, as that species has laesurae that extend nearly the full spore radius, whereas the laesurae in *C. diaphana* typically do not extend over two-thirds of the radius. A slight distinction based on size and length of the laesura appears to be evident in the spores here assigned to *C. diaphana*, but not enough specimens were encountered to determine if consistent differences can be diagnosed.

Anderson (1960) assigned spores that appear to be conspecific with *Cyathidites diaphana* to *Lygodiumsporites adriennis*. However, *L. adriennis* is described as being much larger (63-75 μm) and has an amb with convex sides. Therefore, Anderson's specimens are reassigned to *C. diaphana*.

Specimens encountered in this study are consistently smaller than is indicated by Wilson and Webster's (1946) original description (42-46 μm), but assignment to *Cyathidites diaphana* is consistent with the practice of other workers in the Western Interior.

Fleming (1990) noted that several fern families in the Polypodiales produce spores of similar morphology. Couper (1953) suggested possible affinities with the Cyatheaceae.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *Cyathidites diaphana* was recorded in about 75 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 13.1 percent.

Previous Records. Fort Union Formation, south-central Montana, (Wilson and Webster, 1946); Hell Creek and Fort Union Formations, northwestern South Dakota (Stanley, 1965); Fox Hills, Hell Creek, Tullock and Lebo Formations, northeastern Montana (including specimens assigned to *C. minor*) (Norton and Hall, 1969); Tullock Member of Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); Almond Formation, south-central Wyoming (Stone, 1973); Frenchman and Ravenscrag Formations, south-central Saskatchewan (Nichols *et al.*, 1986); Bearpaw, Hell Creek, and Tullock Formations, northeastern Montana (Oltz, 1969); Lewis Shale, eastern San Juan Basin of New Mexico (Anderson, 1960); and Raton Formation, Colorado and New Mexico (as *C. minor*) (Fleming, 1990).

Illustrated Specimens. Plate 10, Figure 4: UND-PC A2884-3, 12.8 mm across X 6.1 mm up. Plate 10, Figure 5: UND-PC A2919-4, 13.9 mm across X 4.9 mm up.

Cyathidites kerguelensis (Cookson) Kemp & Harris 1977

Plate 9, Figure 11

Trilites (Alsophilidites) kerguelensis Cookson, 1947, p. 136, pl. 16, fig. 69.

Alsophilidites kerguelensis Cookson ex Potonié, 1956 p. 14.

Cyathidites kerguelensis (Cookson) Kemp & Harris, 1977, p. 8, pl. 1, fig. 8.

Description of North Dakota Specimens

Trilete spores, amb triangular, sides straight to slightly convex, apices somewhat rounded; equatorial diameter 17.5-(20.3)-26.5 μm (n = 3). Spore wall single layered, about 1.0 μm thick, psilate. Laesurae long, reaching equator, unbordered.

Discussion

Comments. The spores assigned to *Cyathidites kerguelensis* are consistently smaller than the holotype, although they are in agreement with previous usage of the species within the northern Great Plains. Botanical affinities with the fern family Dicksoniaceae were suggested by Stanley (1965) and Norton and Hall (1969).

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2939, A2952, A2957, A2821, A2829, A2830, A2831, A2840, A2842, A2885, A2959, A2960, A2962, A2984, A2992, A2844, A2848, A2850, A2852, A2855, A2857, A2871. Uncommon; maximum abundance in any sample is 2.4 percent.

Previous Records. Tertiary, Kerguelen Islands (Cookson, 1947); Hell Creek and Fort Union Formations, northwestern South Dakota (Stanley, 1965); Lower Tertiary of Indian Ocean (Kemp and Harris, 1977); Lebo Formation, northeastern Montana (Norton and Hall, 1969); Tullock Formation, northeastern Montana (Oltz, 1969); Almond Formation, south-central Wyoming (Stone, 1973); Hell Creek Formation, North Dakota (Bergad, 1974); Hell Creek Formation, northwestern South Dakota (Kroeger, 1985); and Tuscaloosa, Raritan, and Magothy Formations (Upper Cretaceous), eastern U.S.A. (Groot, Penney, and Groot, 1961).

Illustrated Specimen. Plate 9, Figure 11: UND-PC A2919-4, 19.7 mm across X 4.4 mm up.

Genus *Dictyophyllidites* Couper 1958 emend. Dettmann 1963

Dictyophyllidites Couper, 1958, p. 140.

Dictyophyllidites Couper 1958 emend. Dettmann, 1963, p, 27.

Type Species: *Dictyophyllidites harrisii* Couper 1958

Generic Diagnosis

"Microspores trilete; amb triangular. Exine smooth to faintly patterned; thickened about the laesurate margins. Laesurae enclosed within membraneous, elevated lips" (Dettmann, 1963, p. 27).

Dictyophyllidites sp.

Plate 9, Figure 12

Description

Trilete spores, oblate, amb triangular, sides straight to slightly convex, corners well rounded; maximum equatorial diameter 20.0-(31.5)-39.5 μm (n = 6). Spore wall about 0.8 μm thick in interapical regions, thickening to about 1.5 μm at the apices; sculpture psilate. Laesurae extend nearly to equator; bordered by thickened margo about 2 μm wide, margo continues around radial ends of laesurae resulting in thickened wall at apices.

Discussion

Comments. *Dictyophyllidites* sp. is distinct from *D. harrisii* in its smaller size and in the continuation of the margos around the radial ends of the laesurae. Brenner (1963) and Singh (1971) described spores as *Dictyophyllidites* sp., but that species appears to have a much wider margo. Bergad (1974) described a species, *Dictyophyllidites* sp., from the Hell Creek Formation of North Dakota that appears to be conspecific with this species. Couper (1958) considered the genotype to represent spores produced by the Jurassic fern *Dictyophyllum*, and he compared them to spores produced by the fern family Cheiropleuriaceae.

Occurrences. Slope Formation, samples UND-PC A2818, A2819, A2831, A2960, A2977, A2844, A2845, A2862, A2865, and A3001. Uncommon; maximum relative abundance is 2.0 percent.

Previous Records. Hell Creek Formation, North Dakota (as *Dictyophyllidites* sp.) (Bergad, 1974).

Illustrated Specimens. Plate 9, Figure 12: UND-PC A2887.1-2, 4.3 mm across X 0.1 mm up.

Genus *Gleicheniidites* Ross 1949 emend. Skarby 1964.

Gleicheniidites Ross 1949, p. 31, 32.

Gleicheniidites Ross emend. Skarby 1964, p. 62.

See Skarby (1964, p. 61, 62) for generic synonymy.

Type species: *Gleicheniidites senonicus* Ross 1949

Generic Diagnosis

"Trilete spores, in polar view approximately triangular. Spore wall along or near the equator developed as a more or less distinct thickening, discontinuous at the corners. Surface smooth or faintly sculptured. The arms of the tetrad scar may or may not reach equator at the corners" (Skarby, 1964, p. 62).

Discussion

Two living genera of ferns, *Gleichenia* and *Dicranopteris* (Gleicheniaceae), produce spores with morphology similar to *Gleicheniidites* (Skarby, 1964).

Gleicheniidites senonicus Ross 1949

Plate 9, Figure 10

Gleicheniidites senonicus Ross, 1949, p. 31, 32, pl. 1, fig. 3.

See Skarby (1964, p. 65, 66) for specific synonymy.

Description of North Dakota Specimens

Trilete spores, amb triangular with straight to strongly concave sides, apices typically pointed; equatorial diameter 20.5-(29.4)-39 μm (n = 9). Exine about 1.0 μm thick at apices, equatorial crassitudes up to 1.6 μm thick present in interapical areas, crassitudes begin 6-7 μm from apex and are restricted to interior of the wall; sculpture psilate.

Laesurae nearly reaching equator, commonly bordered by narrow, thickened margo; distal surface commonly folded in triradiate pattern more or less parallel to laesurae.

Discussion

Comments. Skarby (1964) noted considerable variability in both size and shape of *Gleicheniidites senonicus*, even in specimens derived from a single sporangium. Considerable morphologic variability is also noted in specimens here assigned to the species. In addition to variability in size, the degree of concavity of the sides and roundness of the corners of the amb are quite variable. Specimens that could have been assigned to *Concavisporites jurienensis* were included in *Gleicheniidites*, as they appear to be abortive spores of *Gleicheniidites*. In the quantitative palynomorph counts, *Gleicheniidites senonicus* and *Gleicheniidites triangulus* were grouped as *Gleicheniidites* spp.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *Gleicheniidites* spp. was recorded in nearly every productive sample. Abundant; maximum relative abundance in any samples is 15.5 percent.

Previous Records. Upper Cretaceous (Senonian), Sweden (Ross, 1949; Skarby, 1964); Fort Union and Hell Creek Formations, northwestern South Dakota (as *Gleichenia circinidites* Cookson) (Stanley, 1965); Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988); Almond Formation, Rock Spring Uplift, Wyoming (Stone, 1973); Bearpaw, Fox Hills, Hell Creek, Tullock and Lebo Formations, northeastern Montana (Norton and Hall, 1969); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); upper Moreno Formation (Maastrichtian and Danian), Central California (as *G. circinidites*) (Drugg, 1967); Silverado Formation (upper Paleocene), southern California (Gaponoff, 1984); and Hell Creek, Ludlow, Cannonball, Tongue River, and Sentinel Butte

Formations, North Dakota (Robertson, 1975). See Skarby (1964, p. 68-72) for additional records of *Gleicheniidites senonicus*.

Illustrated Specimen. Plate 9, Figure 10: UND-PC A2884-2, 22.7 mm across X 1.8 mm up.

Gleicheniidites triangulus (Stanley) Habib 1970

Plate 10, Figure 6

Gleichenia triangula Stanley, 1965, p. 247, pl. 28, figs. 17-19.

Gleicheniidites triangulus (Stanley) Habib, 1970, p. 354, pl. 10, fig. 10.

Description of North Dakota Specimens

Trilete spores, amb triangular, sides slightly concave to slightly convex, apices rounded to slightly pointed; equatorial diameter 20.5-(28.2)-33 μm (n = 3). Wall single layered, up to 2.5 μm thick in equatorial interapical regions, thinning to about 0.8 μm at apices; exine psilate. Laesurae simple, extend to equator. Distal surface commonly with tri-radiate folds parallel to laesurae rays.

Discussion

Comments. *Gleicheniidites triangulus* (Stanley) Habib is distinguished from *G. senonicus* Ross by having apices that are more rounded. Stanley originally described this species as having a kyrtome paralleling the trilete rays. Specimens here attributed to *G. triangulus* do not have kyrtomes, but instead have folds on the distal surface that are parallel to the trilete rays, giving the appearance of exinal thickenings.

Occurrences. Separate records of the occurrence of *Gleicheniidites triangulus* were not maintained. In the quantitative counts, this species was combined with *G. senonicus* as *Gleicheniidites* spp.

Previous Records. Hell Creek Formation, northwestern South Dakota (Stanley, 1965); and Tullock Member of the Fort Union Formation, Powder

River Basin of Montana and Wyoming (as *Gleicheniidites* sp. cf. *Gleichenia triangula* Stanley) (Nichols and Brown, 1992).

Illustrated Specimen. Plate 10, Figure 6: UND-PC A2977-4, 11.7 mm across X 8.2 mm up.

Genus *Hydrosporis* Krutzsch 1962

Hydrosporis Krutzsch, 1962, p. 11.

Type species: *Hydrosporis azollaênsis* Krutzsch 1962

Generic Diagnosis

"Trilete microspores with a rigid Y mark with approximately straight rays with or without tecta; shape spherical or invaginated to a cup shape; size always small; surface laevigate or weakly sculptured" (Krutzsch, 1962, p. 11; translated in Jansonius and Hills, 1976).

Discussion

Krutzsch (1962) noted that spores of this type occur in *Salvinia* and *Azolla*, and possibly other genera of aquatic ferns. *Hydrosporis* differs from other spores encountered in this study by its consistently small size, circular amb, and lack of equatorial exinal thickenings.

Hydrosporis cf. *H. levis* Krutzsch 1962

Plate 10, Figure 8

Hydrosporis levis Krutzsch, 1962, p. 66, table 26, figs. 1-38.

Azolla cretacea Stanley 1965 (microspores) in Leffingwell, 1971, pl. 1, fig. 1.

Azolla cretacea Stanley 1965 (microspores) in Nichols and Brown, 1992, pl. 2, fig. 10.

Description of North Dakota Specimens

Trilete spores, amb nearly circular; maximum equatorial diameter 25 µm. Wall single layered, 0.5-0.7 µm thick, apparently slightly thicker adjacent to the laesurae, but well-defined margos lacking; psilate. Laesurae simple, about two-thirds spore radius.

Discussion

Comments. Spores here compared to *Hydrosporis levis* are distinguished from other species assigned to the genus by their psilate exine and simple laesurae. The present specimens appear to differ from *H. levis* in that they lack the two-layered wall described by Krutzsch (1962, p. 66). Isolated specimens of *Hydrosporis* cf. *H. levis* are rare, although similar spores are observed commonly within microspore massulae assignable to *Azolla* spp. In the quantitative counts, *Hydrosporis* cf. *H. levis* was combined with *Hydrosporis* sp. as *Hydrosporis* spp.

Previous Records. Spores conspecific with *Hydrosporis* cf. *H. levis* have been reported from the Lance and Fort Union Formations, east-central Wyoming (Leffingwell, 1971); Tullock Member of the Fort Union Formation, Powder River Basin, Montana and Wyoming (Nichols and Brown, 1992); probable record from the Almond Formation of south-central Wyoming (as *Todisporites* cf. *T. minor*) (Stone, 1973); and Ludlow Formation, North Dakota (Robertson, 1975).

Occurrences. Species assignable to *Hydrosporis* were recorded from the Ludlow and Slope Formations; samples UND-PC A2952, A2954, A2884, A2885, A2959, A2963, A2977, A2989, and A3000. Rare; maximum relative abundance in any sample is 3.6 percent.

Illustrated Specimen. Plate 10, Figure 8: UND-PC A2958-3, 3.2 mm across X 16.5 mm up.

Hydrosporis sp.

Plate 10, Figure 9

Description

Trilete spores, amb subcircular, equatorial dimensions 22-(22.4)-23 μm (3 specimens). Exine single layered, about 1 μm thick; sculpture weakly verrucate to granulate; verrucae 1-2 μm high, 1-3 μm in diameter, typically of equal size over entire specimen, closely spaced except in contact area where they are more sparsely dispersed. Laesurae about three-fourths radius, straight, margins slightly thickened.

Discussion

Comments. The sculpture of low verrucae or grana distinguishes *Hydrosporis* sp. from *Hydrosporis* cf. *H. levis*. This species most closely resembles *H. azollaënsis azollaënsis* Krutzsch 1962, which is of similar size and shape, but is described as extrapunctate, yielding a pseudoreticulate surface (Krutzsch, 1962, p. 64, 65). No species of *Hydrosporis* illustrated by Krutzsch has verrucate sculpture as distinct as that of specimens here assigned to *Hydrosporis* sp.

Occurrences. In the quantitative counts, *Hydrosporis* sp. was combined with *Hydrosporis* cf. *H. levis* as *Hydrosporis* spp. Therefore, separate records of the occurrence of *Hydrosporis* sp. were not maintained.

Previous Records. Hell Creek Formation, North Dakota (as *H. azollaënsis*) (Bergad, 1974).

Illustrated Specimen. Plate 10, Figure 9: UND-PC A2952-3, 18.8 mm across X 8.8 mm up.

Genus *Laevigatosporites* Ibrahim 1933 emend.
Schopf, Wilson & Bentall 1944

See Srivastava (1971, p. 252, 253) for synonymy of this genus.

Type Species: *Laevigatosporites vulgaris* (Ibrahim) Ibrahim 1933

Generic Diagnosis

Schopf, Wilson, and Bentall (1944) emended *Laevigatosporites* to include bean-shaped to oval monolete spores having psilate to finely punctate, apiculate or rugose sculpture.

Discussion

Although the emended diagnosis of Schopf, Wilson, and Bentall (1944) includes spores with reduced sculpture patterns, the name *Laevigatosporites* is typically applied only to psilate spores with or without punctae in the proximal region. The fern family Polypodiaceae produces diverse spore types including monolete, reniform spores such as those included in *Laevigatosporites*. However, these spores cannot be assigned unequivocally to the Polypodiaceae as other fern families also produce similar spores.

Laevigatosporites spp.

Plate 11, Figure 1

Description of North Dakota Specimens

Monolete spores, shape reniform to oval, size highly variable, ranging from about 30 u to greater than 70 u. Spore wall single layered, 0.5 to 1.5 u thick, commonly slightly thicker proximally; psilate, some specimens punctate or weakly scabrate in the contact area. Laesurae generally one-half to two-thirds length of spore.

Discussion

Comments. Species of *Laevigatosporites* are typically delineated on the basis of size and shape, although other characteristics such as laesura length and wall thickness have also been used. Most specimens encountered in this study are assignable to *Laevigatosporites haardtii* (Potonié & Venitz) Thomson & Pflug 1953 and *L. major* (Cookson) Krutzsch 1959.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation. *Laevigatosporites* spp. is the most abundant spore type encountered in this study and was recorded in about three-fourths of the productive samples. Maximum relative abundance in any sample is 54.6 percent.

Previous Records. Species of *Laevigatosporites* have been reported in nearly every palynologic study of Cretaceous and lower Tertiary rocks in the northern Great Plains.

Illustrated Specimen. Plate 11, Figure 1: UND-PC A2931-3, 23.5 mm across X 10.6 mm up.

Genus *Osmundacidites* Couper 1953

Osmundacidites Couper, 1953, p. 20.

Osmunda (Spores) Stanley, 1965, p. 250.

Type Species: *Osmundacidites wellmanii* Couper 1953

Generic Diagnosis

"Free, anisopolar, trilete, laesurae moderately long. Spores spherical to sub-spherical. Exine thin, granular-papillate, sculpture somewhat reduced on proximal face" (Couper, 1953, p. 20).

Discussion

Krutzsch (1967) emended the diagnosis of *Baculatisporites* Thomson & Pflug to include spores with echinate, baculate, rugulate and warty sculptural patterns. At this time, he proposed submerging *Osmundacidites* Couper within *Baculatisporites*. Norris (1986) redescribed the holotype of *O. wellmanii* and proposed to retain *Osmundacidites* Couper for granulate species without baculate or echinate sculpture. Norris's recommendation is followed here.

Osmundacidites cf. *O. wellmanii* Couper 1953

Plate 10, Figure 7

Plate 11, Figure 5

Osmundacidites wellmanii Couper, 1953, p. 20, pl. 1, fig. 5.

Osmundacidites sp. *in* Nichols and Brown, 1992, p. F16, pl. 2, fig. 11.

Osmunda comaumensis (Cookson) Stanley, 1965, in Stanley, 1965, p. 250, pl. 31, figs. 6-9.

Osmundacidites wellmanii Couper emend. Norris, 1986, p. 31.

Description of North Dakota Specimens

Trilete spores, amb more or less circular, but spores commonly folded or torn; maximum equatorial diameter 25.0-(38.72)-58.0 μm (n = 11). Spore wall, exclusive of sculptural elements, 0.7-1.0 μm thick, single layered, sculpture of coarse granulae and conae of various sizes, generally 0.7-2.0 μm in diameter and 1.5-2.0 μm high, some sculptural elements fused into irregular muri in a few specimens. Laesurae extend nearly full radius in most specimens, bordered by a narrow, thickened margo.

Discussion

Comments. Spores here assigned to *Osmundacidites* cf. *O. wellmanii* have somewhat coarser and more sparsely distributed sculptural elements than are described for *O. wellmanii* Couper (Norris, 1986). Thus these specimens are compared to *O. wellmanii*.

Stanley (1965) assigned specimens that appear conspecific with *O.* cf. *wellmanii* to *Osmunda comaumensis* (Cookson) Stanley. The sculpture pattern he described as "bacula, spinae and clavae" is not characteristic of *Trilites comaumensis*, as that species was originally described as possessing a sculpture of "blunt rod-like processes" (Cookson, 1953, p. 470). Therefore, the specimens described by Stanley are also here compared to *Osmundacidites wellmanii*.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *O.* cf. *O. wellmanii* was recorded in over 33 percent of the productive samples (see Plate 3). Common; maximum relative abundance in any sample is 4.8 percent.

Previous Records. Spores conspecific with *Osmundacidites* cf. *O. wellmanii* have been reported from the Fort Union and Hell Creek Formations, northwestern South Dakota (Stanley, 1965); and Tullock Member of Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols & Brown, 1992). *Osmundacidites wellmanii* is widely reported from Mesozoic and Tertiary deposits.

Illustrated specimens. Plate 10, Figure 7: UND-PC A2851-4, 11.1 mm across X 8.0 mm up. Plate 11, Figure 5: UND-PC A2923-2, 15.4 mm across X 4.1 mm up.

Genus *Reticuloidosporites* Pflug in Thomson & Pflug 1953.

Reticuloidosporites Pflug in Thomson & Pflug, 1953, p. 60.

Type Species: *Reticuloidosporites dentatus* Pflug in Thomson & Pflug 1953

Generic Diagnosis

Monolete spores, reniform; "with sculptural or structural elements arranged into a reticulum" (translated in Jansonius and Hills, 1976, card 2372).

Discussion

Srivastava (1971) erected the genus *Hazaria* to accommodate reticulate, monolete spores. The genus is probably a junior synonym of *Reticuloidosporites* Pflug in Thomson and Pflug 1953.

Reticuloidosporites pseudomurii Elsik 1968

Plate 11, Figure 2

Reticuloidosporites pseudomurii Elsik, 1968a, p. 290, pl. 7, fig. 2.

Description of North Dakota Specimens

Monolete spores, outline ovoid to reniform, dimensions 29.5-(39.5)-53.0 X 21.5-(29.2)-34.0 μm (n = 16). Spore wall 1.5-3.5 μm thick, thicker in proximal region in some specimens; single layered; sculpture weakly to strongly reticulate, lumina 2-3 μm in diameter, slightly smaller proximally in some specimens; muri triangular in optical section, 1-2 μm high, 2-3 μm wide at their base, narrowing outward to about 0.5 μm. Laesura, about one-half length of spore, commonly bordered by slightly thickened margo.

Discussion

Comments. The sculpture of spores assigned to *Reticuloidosporites pseudomurii* is quite variable, especially in the height of the muri and diameter of the lumina. However, the variability occurs on a more or less continuous scale and there do not appear to be discrete morphologic changes that could be used to further subdivide this species. The thickness of the spore wall displays more variability than is indicated in Elsik's (1968a) description of *R. pseudomurii* (0.5-1.0 μm thick), but these specimens are similar other aspects.

Other workers have assigned similar spores to *R. dentatus* Pflug in Thomson and Pflug 1953. That species appears distinct from *R. pseudomurii* by possessing sculptural elements that are smaller and more evenly spaced. *Hazaria canadiana* Srivastava 1971 is very similar in sculpture, but is described as having a two-layered spore wall.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *R. pseudomurii* was recorded in about 75 percent of the productive samples (See Plate 3). Abundant; maximum relative abundance in any sample is 41.0 percent.

Previous Records. Rockdale Formation (Paleocene), Texas (Elsik, 1968a); Lance and Fort Union Formations, Powder River Basin of Wyoming (Leffingwell, 1971); Tullock Member of the Fort Union Formation, Powder River Basin (Nichols and Brown, 1992); Hell Creek and Tullock Formations, northeastern Montana (as *R. dentatus*) (Hotton, 1988); Fort Union Formation, northwestern South Dakota (Stanley, 1960,); Frenchman and Ravenscrag Formations, south-central Saskatchewan (Nichols *et al.*, 1986); Wilcox Group (Paleocene), Texas (Nichols, 1970); and Tongue River Formation, eastern Montana (Spindel, 1975).

Illustrated Specimen. Plate 11, Figure 2: UND-PC A2887-2, 17.6 mm across X 1.1 mm up.

Genus *Stereisporites* Pflug in Thomson & Pflug 1953

emend. De Jersey 1964

See Krutzsch, 1963 for synonymy of this genus.

Type Species: *Stereisporites stereoides* (Potonié & Venitz) Thomson & Pflug 1953.

Generic Diagnosis

"Small spores (diameter less than 50 μm). Amb rounded triangular to subcircular. Trilete, laesurae straight, without conspicuous development of lips, tori or other features. Exine smooth or scabrate, relatively thick (1.5 to 2 μm or more), rigid, frequently with slight thickenings at angles of equator" (De Jersey, 1964, p. 4; cited in Jansonius and Hills, 1985, card 4343).

Discussion

Spores assignable to *Stereisporites* are morphologically similar to spores produced by the Sphagnaceae and are attributed to that family. Sphagnaceous spores encountered in this study exhibit considerable variability, especially in spore diameter, thickness of the spore wall at the equator, and sculpture.

Krutzsch (1963a) diagnosed several subgenera within *Stereisporites*. Although the subgenera have not typically been used by North American palynologists, they distinguish among various morphologies while maintaining the spores within a single genus, emphasizing their common origin within the Sphagnaceae. Because of the variability in morphology, spores here assigned to *Stereisporites* are lumped into groups that are approximately equivalent to the subgenera. Within the northern Great Plains, species of *Stereisporites* are common in Upper Cretaceous and lower Tertiary strata.

Stereisporites (Stereisporites) spp. and *Stereisporites (Distverrusporis)* spp.

Plate 10, Figure 10

Description of North Dakota Specimens

Trilete spores, amb generally subtriangular, sides convex, corners well rounded; equatorial diameter 20-26 μm. Spore wall thin, probably less than 1.0 μm, equatorial crassitude up to 3.0 μm thick present in most specimens, crassitude commonly slightly thicker on corners of amb; surface psilate; small circular boss may be present on distal pole. Laesurae about one-half spore radius, contact area distinctly defined in some specimens.

Discussion

Comments. This group includes specimens of *Stereisporites* that have psilate spore walls of variable thickness; a small circular boss may be positioned over the distal pole. Most specimens included in this group are assignable to *Stereisporites antiquasporites*, *S. steroides*, and *S. australis*.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *S. (Stereisporites)* and *S. (Distverrusporis)* spp. were recorded in about 67 percent of the productive samples (see Plate 3). Abundant; maximum relative abundance in any sample is 24.6 percent.

Illustrated specimens. Plate 10, Figure 10: UND-PC A2997-1, 16.1 mm across X 6.1 mm up.

Stereisporites (Distancoraesporis) spp.

Plate 11, Figures 3, 4

Description of North Dakota Specimens

Trilete spores, amb subtriangular, sides convex, corners well rounded; equatorial diameter 22.0-(27.5)-34 μm (n = 7). Wall thin, except for equatorial crassitude and distal polar thickened area; crassitude 1-5 μm thick, commonly slightly thicker at corners of amb; triradiate boss always present over distal pole, rotated about 60 degrees from the laesurae, shape of boss highly variable, ranging from three small thickened areas to three prominent Y-shaped thickenings. Laesurae about one-half spore radius, contact area commonly distinct.

Discussion

Comments. Spores of *S. (Distancoraesporis)* spp. are characterized by a triradiate boss on the distal pole. Within the northern Great Plains, spores of this group are commonly assigned to *Cingulatisporites dakotaensis* Stanley 1965, which is probably a junior synonym of *S. (Distancoraesporis) breviancoris* Krutzsch 1963. The amount of morphologic variability present in the specimens encountered in this study exceeds the circumscription of *C. dakotaensis*; thus they are assigned to the *S. (Distancoraesporis)* group. Srivastava (1972) raised *Distancoraesporis* to the rank of genus, but in his emended diagnosis he specified acingulate spores. Nearly all specimens encountered in this study have a thickened wall in the equatorial region and therefore are excluded from *Distancoraesporis sensu* Srivastava. Therefore, Krutzsch's usage is followed here.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *S. (Distancoraesporis)* spp. was recorded in about 33 percent of the productive samples (see Plate 3). Abundant; maximum relative abundance in any sample is 46.1 percent.

Previous Records. Hell Creek Formation and Ludlow Member of the Fort Union Formation, northwestern South Dakota (Stanley, 1965); Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988; Norton and Hall, 1967 & 1969); Edmonton Formation, Alberta, Canada (Snead, 1969); Tullock Formation, northeastern Montana (Oltz, 1969); and Lower Almond Formation, southwestern Wyoming (Stone, 1973).
Illustrated Specimens. Plate 11, Figure 3: UND-PC A2845.1-3, 19.7 mm across X 10.6 mm up. Plate 11, Figure 4: UND-PC A2878-3, 9.7 mm across X 1.7 mm up.

Stereisporites (Distancoraesporis) radiatus (Stanley) n. comb.

Plate 11, Figure 6

Cingulatisporites radiatus Stanley, 1965, p. 244, pl. 30, figs. 9-16 (basionym).

Stereisporites spp. (*pars*) in Nichols and Brown, 1992, pl. 4, figs. 2-4.

Description of North Dakota Specimens

Trilete spores, amb subtriangular, sides convex, apices rounded; equatorial diameter, 28.5-(31.2)-34 μm (n = 4). Spore wall probably relatively thin except at the equator where a distinct flange or zona is present; flange thickest at intersection with spore body, thins radially, 4-5 μm wide; slightly degraded specimens commonly have radially directed striae on flange. Y-shaped boss present on distal pole, oriented 60 degrees to the laesurae. Laesurae relatively short, commonly indistinct.

Discussion

Comments. *Stereisporites (Distancoraesporis) radiatus* (Stanley) n. comb. also possesses the distal, triradiate wall thickening that is present in the *S. (Distancoraesporis)* group, but the morphology of the spores is consistent enough to constitute a single species. Stanley (1965) interpreted the equatorial flange as a cingulum, but the illustration of the holotype (pl. 30, figs. 13, 14) shows that the flange thins to its margin, and should be considered a zona. In the North Dakota specimens, radially directed striae on the zona, considered by Stanley as diagnostic of the species, are only present on slightly degraded specimens. The zonate nature of the equatorial flange serves to distinguish this species from other spores assigned to the *S. (Distancoraesporis)* group.

Previous Records. Ludlow Member of the Fort Union Formation, northwestern South Dakota (Stanley, 1965); Tullock Formation, northeastern Montana (as *Cingulatisporites radiatus*) (Norton and Hall, 1967 & 1969); and Tullock Member of Fort Union Formation, Powder River Basin, Montana and Wyoming (Nichols & Brown, 1992).

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2939, A2940, A2958, A2819, A2821, A2822, A2876, A2877, A2878, A2919, A2885, A2991, A2845, A2846, A2850, A2851, A2855, A2857, A2858, A2859, A2860, A2861, A2862, A2864, and A2867. Uncommon; maximum relative abundance in any sample is 8.4 percent.

Illustrated Specimen. Plate 11, Figure 6: UND-PC A2876-6, 13.5 mm across X 4.8 mm up.

Stereisporites (Stereigranisporis) spp.

Plate 11, Figure 8

Description of North Dakota Specimens

Trilete spores, amb subtriangular, sides broadly convex, corners rounded; equatorial diameter 20.5-(24.0)-28.0 μm (n = 8). Spore wall single layered, about 1.5 μm thick, equatorial crassitude present in some specimens; sculpture coarsely granulate, grana up to 2.0 μm in diameter, sculpture commonly better developed on distal surface. Laesurae generally short, contact area well defined in some specimens.

Discussion

Comments. Specimens assigned to *S. (Stereigranisporis)* are characterized by coarsely granulate sculpture on the distal face or on both faces. Most specimens included within this group are assignable to *Stereisporites regius* (Drozhastchich) Drugg 1967.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *S. (Stereigranisporis)* spp. was recorded in about 33 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 5.1 percent.

Previous Records. Within the northern Great Plains and Canada, similar spores have been reported from the following strata: Ludlow Member of the Fort Union Formation, northwestern South Dakota (as *Sphagnum regium*) (Stanley, 1965); Eureka Sound Formation (Maastrichtian), Arctic Canada, (Felix and Burbridge, 1973); Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988); Fox Hills Formation, northeastern Montana (as *Converrucosisporites* sp.) (Norton and Hall, 1969); Paleocene portion of the Moreno Formation, California (Drugg, 1967); and Edmonton Formation, Alberta, Canada (Snead, 1969);

Illustrated Specimen. Plate 11, Figure 8: UND-PC A2919-4, 7.9 mm across X 11.6 mm up.

Stereisporites (Tripunctisporis) sp.

Plate 11, Figure 7

Description of North Dakota Specimens

Trilete spores, oblate, amb subtriangular, sides convex, apices rounded; equatorial diameter 31.5-(32.9)-36 μm (n = 9). Spore wall single layered, 1.2-1.4 μm thick at the equator, commonly slightly thicker on apices of amb, thinner on main body of spore; circular to triangular boss present on distal pole, boss contains 3 subcircular thin areas about 2.5 μm in diameter. Laesura short, about one-half spore radius, contact area distinct in some specimens.

Discussion

Comments. Specimens assigned to *S. (Tripunctisporis)* spp. are distinguished by a thickening of the spore wall, containing three small lumina, that is positioned over the distal pole. All specimens encountered appear to be assignable to a single species.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2821, A2822, A2876, A2878, A2919, A2881, A2885, A2993, A2994, and A2860. Rare; maximum relative abundance in any sample is 0.7 percent.

Previous Records. Ludlow Member of the Fort Union Formation, northwestern South Dakota (as *Sphagnum* sp.) (Trotter, 1963).

Illustrated Specimen. Plate 11, Figure 7: UND-PC A2923-1, 8.7 mm across X 3.6 mm up.

Genus *Toroisporis* Krutzsch 1959

Toroisporis Krutzsch, 1959, p. 90.

Type species: *Toroisporis torus* (Pflug) Krutzsch 1959

Generic Diagnosis

"Toriate azonotrilete microspores, mostly with triangular to subcircular amb, surface smooth or roughened, outline thus ± smooth; exine two or (often) more-layered, without significant equatorial thickenings either radial or interradial; ± faint structure may be present; tori always present, in different manifestations and in a number of different places" (Krutzsch, 1959, translated in Jansonius and Hills, 1976, card 1919).

Discussion

The presence of tori distinguishes *Toroisporis* Krutzsch from other psilate, trilete spore genera. *Dictyophyllidites* Couper emend. Dettmann 1963 appears to be distinct because the laesurae in spores of that genus are enclosed in membranous lips and the thickened margos border directly on the laesurae. However, Dettmann (1963) noted that many of the species that Krutzsch (1959; 1962) assigned to *Toroisporis* are probably comparable to *Dictyophyllidites*.

Toroisporis cf. *T. major* (Pflug) Stanley 1965

Plate 11, Figure 13

Sporites neddeni Potonié, 1931a, v. 30, pl. 1, fig. 5.

Sporites neddeni Potonié *in* Potonié, 1934, p. 36, pl. 1, fig. 12.

Concavisporites obtusangulus (Potonié) *major* Pflug *in* Thomson and Pflug, 1953, p. 50, pl. 1, fig. 42.

Toroisporis (*Toroisporis*) *torus* (Pflug) Krutzsch subfsp. *major* (Pflug) *in* Krutzsch, 1959, p. 95, pl. 9, figs. 68, 69.

Toroisporis major (Pflug) Stanley, 1965, p. 265, pl. 35, figs. 6-9.

Description of North Dakota Specimens

Trilete spores, amb triangular with slightly to broadly convex sides and well-rounded apices; equatorial diameter 43-(56.44)-82 μm (n = 9). Exine 1.5 to 2.0 μm thick, single layered, psilate. Laesurae about two-thirds of spore radius, bordered by arcuate tori.

Discussion

Comments. Specimens here assigned to *Toroisporis* cf. *T. major* are very similar to those ascribed to *T. major* by Stanley (1965), except that they tend to be larger (33-55 μm for *T. major*). Therefore, these specimens are compared to *Toroisporis major* (Pflug) Stanley 1965. Fleming (1990) noted that ferns in the Order Polypodiales produce spores of similar morphology.

Occurrences. Slope Formation; recorded only in sample UND-PC A2983. Rare.

Previous Records. *Toroisporis major* has been reported from the Fort Union Formation, northwestern South Dakota (Stanley, 1965); Tullock Member of the Fort Union Formation, Powder River Basin of Wyoming and

Montana (Nichols and Brown, 1992); and Raton Formation, Colorado and New Mexico (Fleming, 1990).

Illustrated Specimen. Plate 11, Figure 13: UND-PC A2884-3, 8.3 mm across X 3.2 mm up.

Toroisporis sp.

Plate 11, Figure 9

Description

Trilete spores, oblate, amb triangular, sides straight to slightly convex, apices well rounded to slightly pointed; equatorial diameter, 20.0-(27.2)-37.5 μm (n = 13). Spore wall single layered, about 0.5 μm thick, psilate. Laesurae simple, extend three-fourths to nearly full radius. Laesurae bordered by narrow band tori (Krutzsch, 1959) that tend to be located approximately midway between equator and proximal pole, thus appearing to delineate the contact area; in many specimens, a slight angulation on amb present where tori intersects equator, resulting in somewhat more pointed apices on amb.

Discussion

Comments. Spores here assigned to *Toroisporis* sp. appear to be distinct from previously described species of *Toroisporis* by the position of the tori and generally small size of the spores.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *Toroisporis* sp. was recorded in about 67 percent of the productive samples (see Plate 3). Common; maximum relative abundance in any sample is 19.4 percent.

Previous Records. No published records of spores similar to *Toroisporis* sp. have been noted.

Illustrated Specimen. Plate 11, Figure 9: UND-PC A2887-2, 6.2 mm across X 0.2 mm up.

Inaperturate Palynomorphs

Genus *Araucariacites* Cookson ex Couper 1953

Araucariacites Cookson ex Couper, 1953, p. 39.

Type Species: *Araucariacites australis* Cookson ex Couper 1953

Generic Diagnosis

"Spherical non-aperturate grains with granular exines of the type met with amongst recent members of the Araucariaceae" (Couper, 1953, p. 39).

Araucariacites australis Cookson 1947 ex Couper 1953

Plate 12, Figure 1

Granulonapites (*Araucariacites*) *australis* Cookson, 1947, p. 130, pl. 13, figs. 1-4.

Araucariacites australis Cookson 1947 ex Couper, 1953, p. 39.

Araucariacites sp. in Nichols and Brown, 1992, p. F17, pl. 5, fig. 1.

Description of North Dakota Specimens

Inaperturate pollen, outline circular to subcircular; maximum dimensions 41-(55.9)-68 μm (n = 11). Exine about 2 μm thick, highly folded in many specimens, stratification indistinct; sculpture uniformly and finely scabrate.

Discussion

Comments. The pollen grains here assigned to *Araucariacites australis* have a smaller average diameter than originally described for the species by Cookson (1947), but they are well within the given size range (39-[70]-93 μm).

As noted in the generic diagnosis, the botanical affinities of this genus are considered to be with the Araucariaceae, although the pollen morphology is probably too generalized to be certain. Stockey (1982) noted that *A. australis* is similar to the pollen of *Brachyphyllum* *mamillare*, an araucarian fossil. The modern Araucariaceae consists of two genera of tall, coniferous trees that are confined to the Southern Hemisphere. Based on megafossil remains, the family was more diverse and widespread during the Mesozoic, and extended into the Northern Hemisphere during the Jurassic (Stockey, 1982).

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2876, A2959, A2962, A2850, A2853, A2855, A2856, A2857, A2859, A2862, A2863, A2864, A2865, A2967, and A2868. Rare; maximum relative abundance in any sample is 1.5 percent.

Previous Records. Tertiary, Kerguelen Island (Cookson, 1947); Jurassic to Oligocene of New Zealand (as cf. *A. australis*) (Couper, 1953); Tullock Member of Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); Edmonton Formation, Alberta (Srivastava, 1966; 1967); Menefee Formation (Mesaverde Group), New Mexico (Jameossanaie, 1987); and Swan River Group (Lower Cretaceous), Manitoba and Saskatchewan (Playford, 1971). Stockey (1982) noted that *A. australis* is widespread in Jurassic, Cretaceous, and Tertiary rocks, including in the Northern Hemisphere.

Illustrated Specimen. Plate 12, Figure 1: UND-PC A2829-4, 23.6 mm across X 11.2 mm up.

Genus *Corollina* Malyavkina 1949
emend. Cornet & Traverse 1975

Corollina Malyavkina, 1949, p. 124.

Corollina Malyavkina 1949 emend. Cornet & Traverse, 1975, p. 17.

For synonymy of *Corollina*, see Cornet and Traverse (1975, p. 16, 17).

Type Species: *Corollina compacta* Malyavkina 1949

Generic Diagnosis

See Cornet and Traverse (1975, p. 17) for emended diagnosis of *Corollina*.

Discussion

Cornet and Traverse (1975) presented arguments that *Corollina* Malyavkina was validly published in 1949 and is the senior synonym for pollen grains commonly assigned to *Classopollis* Pflug 1953. Other workers, including Pocock and Jansonius (1961) and Srivastava (1976), asserted that *Classopollis* should be maintained in addition to *Corollina* because of uncertainty concerning the morphology of the genotype of *Corollina*. Although the original description and illustrations of *Corollina* Malyavkina are sketchy (see Traverse *et al.*, 1974, p. 38-124 to 38-129), they clearly indicate that the genus was erected to accommodate pollen of the *Classopollis* morphology; therefore the synonymy of Cornet and Traverse (1975) is followed here.

Corollina sp.

Plate 11, Figure 10

Description of North Dakota Specimens

Isolated pollen grains, amb circular, maximum dimension 19.0-(23.3)-27.5 μm (n = 7); exine two layered, about 1.0 μm thick, layers about equal thickness, faint separation between layers visible; sculpture finely scabrate except for a narrow band of equatorially directed striae in the equatorial region, individual striae about 0.5 μm wide. Single pseudopore about 6.5 μm diameter present on distal pole, exine continues over top of pseudopore. Distinct ring (rimula) about 0.7 μm wide, encircles grain on distal surface near equator. Some specimens have triangular-shaped area of thin exine on proximal pole, distinct trilete mark lacking.

Discussion

Comments. Alvin (1982) noted that *Corollina* sp. was produced by the extinct conifer family Cheirolepidiaceae, a predominantly Mesozoic family. However, numerous reports of *Corollina* in Paleocene deposits in

North America indicate that the family persisted into the early Tertiary. Specimens of *Corollina* encountered in the present study occur in a variety of lithologies, including lignite, suggesting that they are not reworked from Mesozoic deposits.

Alvin (1982) concluded that the Cheirolepidiaceae were thermophilous plants occupying habitats that varied within broad limits. Some species favored maritime habitats and may have formed extensive coastal forests, whereas others were probably associated with lakes and rivers. Jerzykiewicz and Sweet (1986) noted that, toward the end of the Cretaceous, the *Corollina*-bearing plants mainly occupied xeric habitats. However, it may be unreasonable to apply paleoautecological interpretations derived from the Mesozoic populations, when *Corollina* was commonly a dominant constituent of the palynoflora, to the last vestiges of the *Corollina*-producing plants during the Paleocene.

Occurrences. Ludlow and Slope Formations and the Boyce and 3-V Tongues of the Cannonball Formation; *Corollina* sp. was recorded in about 33 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 1.6 percent.

Previous Records. Tullock Member of Fort Union Formation, Powder River Basin, Montana and Wyoming (as *Corollina* sp.)(Nichols and Brown, 1992); Tongue River Member of Fort Union Formation, Powder River Basin (Pocknall and Nichols, unpublished, see Nichols and Brown, 1992, p. F17); Raton Formation Colorado and New Mexico (as *Corollina* sp.) (Fleming, 1990); lower Paleocene of the Atlantic and Gulf Coastal Plains (Frederiksen, 1980a); and Fort Union Formation, northwestern South Dakota (as *Classopollis torosus*) (Stanley, 1960); probable record as *Circulina parva* Brenner from the Bearpaw, Fox Hills, Hell Creek and Tullock Formations, northeastern Montana (Oltz, 1969).

Illustrated Specimen. Plate 11, Figure 10: UND-PC A2878-3, 23.7 mm across X 8.8 mm up.

Genus *Laricoidites* Potonié Thomson & Thiergart ex Potonié 1958

Laricoidites Potonié, Thomson, & Thiergart, 1951 [1950], p. 48 [nom. nud.].

Laricoidites Potonié, Thomson, & Thiergart ex Potonié, 1958, p. 76.

Type Species: *Laricoidites magnus* (Potonié) Potonié, Thomson, & Thiergart ex Potonié 1958

Generic Diagnosis

". . . Pollen with 'circular equator; exine smooth, barely intrapunctate, very thin, with numerous secondary folds'" (Potonié, 1958, p. 76, translated in Jansonius and Hills, 1976, card 1450).

Discussion

Potonié (1958) considered *Laricoidites* to differ from *Inaperturopollenites* Pflug & Thomson in Thomson & Pflug 1953 due to its larger size. The genera *Laricoidites* and *Laevigatasporites* Potonié & Gelletich 1933 both have the same type species and some difference of opinion exists concerning which genus has nomenclatural priority. Jansonius and Hills (1976) considered the assignment of a species to *Laevigatasporites* by Potonié and Gelletich (1933), as *Laevigatasporites* cf. *L. magnus*, to have validated that genus. The palynomorphs assigned to *Laevigatasporites* cf. *L. magnus* by Potonié and Gelletich are considerably smaller than the holotype of *Laricoidites magnus*, 30-40 μm versus 80-100 μm, and should be considered as a distinct species. Thus, the two genera do not truly share the same type species, although the genotype of *Laevigatasporites* could be considered to be, as yet, unnamed. Valid genera, such as *Inaperturopollenites* and *Psilainaperturites* Pierce 1961, already exist to accommodate smaller, inaperturate palynomorph species; therefore it seems best to abandon *Laevigatasporites*.

Laricoidites cf. *L. magnus*

(Potonié) Potonié, Thomson, & Thiergart 1951 ex Potonié 1958

Plate 12, Figure 2

Sporonites (?) *magnus* Potonié, 1931, p. 556, fig. 6.

Laricoidites magnus (Potonié) Potonié, Thomson, & Thiergart, 1951, p. 48.

Laricoidites magnus (Potonié) Potonié, Thomson, & Thiergart ex Potonié, 1958, p. 76, 77.

Description of North Dakota Specimens

Inaperturate palynomorphs, outline subcircular, specimens generally folded; shape probably originally spherical; diameter 62-(95.5)-140 μm (n = 4). Wall 0.5-1.5 μm thick, single layered; psilate to punctate, punctae less than 0.5 μm in diameter.

Discussion

Comments. *Laricoidites* cf. *L. magnus* is used here to accommodate all large (greater than 60 μm), inaperturate, weakly sculptured palynomorphs having a more or less circular outline. The size range of the specimens encountered here exceeds that described for *L. magnus* by Potonié (1934; cited in Jansonius and Hills, 1976). Many workers have considered the botanical affinities of this species to be with the Pinaceae in the genus *Larix*. However, Krutzsch and Vanhoorne (1977) included *Laricoidites* as algae or freshwater plankton.

Occurrences. Slope Formation and the Three V Tongue of the Cannonball Formation; samples UND-PC A2959, A2966, A2976, A2992, A2995, A2850, A2855, and A2871. Rare; maximum relative abundance in any sample is 1.2 percent.

Previous Records. *Laricoidites magnus* has been reported from the Kaiparowits Formation (Upper Cretaceous), Utah (Lohrengel, 1969); Hell Creek and Tullock Formations, northeastern Montana (Oltz, 1969); Almond Formation, south-central Wyoming (Stone, 1973); Cannonball Member of the

Fort Union Formation, northwestern South Dakota (Stanley, 1965); Tullock and Lebo Formations, northeastern Montana (Norton and Hall, 1969); Red Branch Member, Woodbine Formation (Cenomanian), Oklahoma (Hedlund, 1966); Fredricksburg Group (Albian), southern Oklahoma (Hedlund and Norris, 1968); Lance Formation, northeastern Montana (Farabee and Canright, 1986); Lower Cretaceous of northern Alberta (Singh, 1971); middle Miocene of offshore eastern U.S.A. (Bebout, 1980); and Potomac Group (Lower Cretaceous), Maryland (Brenner, 1963); probable record from the Hell Creek Formation, North Dakota (as *Magnosporites staplinii* Rouse) (Bergad, 1974);

Illustrated Specimens. Plate 12, Figure 2: UND-PC A2959-3, 22.0 mm across X 1.0 mm down.

Genus *Psilainaperturites* Pierce 1961

Psilainaperturites Pierce, 1961, p. 23, 44.

Type Species: *Psilainaperturites psilatus* Pierce 1961

Generic Diagnosis

"Psilate, inaperturate sporomorphs" (Pierce, 1961, p. 23).

Discussion

Psilainaperturites is used here in preference to *Inaperturopollenites* Pflug & Thomson in Thomson & Pflug 1953 emend. Krutzsch 1971 because the latter genus is intended for weakly sculptured palynomorphs that have a small ligula. *Laricoidites* Potonié Thomson & Thiergart ex Potonié 1958 is intended to accommodate larger palynomorphs.

Psilainaperturites sp. 1

Plate 12, Figures 5, 6

Description

Inaperturate palynomorphs; outline circular to subcircular, but specimens commonly folded; diameter about 20-50 μm. Wall about 0.5 μm thick, translucent to hyaline, single layered, psilate, rarely fissurate.

Discussion

Comments. *Psilainaperturites* sp. 1 has a size range similar to that of *Inaperturopollenites dubius* (Potonié & Venitz) Thomson & Pflug 1953, but has a psilate wall rather than the weakly granulate sculpture of the latter species. This species is commonly associated with algal palynomorphs and its thin, psilate wall is similar to other algal palynomorphs, suggesting a possible origin as resistant algal cysts. However, it is also possible that some specimens may be inaperturate pollen grains attributable to the Cupressaceae, Taxodiaceae, or Taxaceae. Traverse (1975) considered similar palynomorphs (Acritarch-8, pl. 1, figs. 12, 13) from Black Sea sediments to be of certain algal origin.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *Psilainaperturites* sp. 1 was recorded in over 75 percent of the productive samples (see Plate 3). Abundant; maximum relative abundance in any sample is 40.9 percent.

Illustrated Specimens. Plate 12, Figure 5: UND-PC A2995-3, 14.8 mm across X 11.2 mm up. Plate 12, Figure 6: UND-PC A2995.4, 12.3 mm across X 6.2 mm up.

Psilainaperturites sp. 2

Plate 11, Figures 11, 12

Description

Inaperturate palynomorphs, outline circular to subcircular; dimensions about 8-12 μm. Exine less than 0.5 μm thick, translucent to hyaline, single layered, psilate. Many specimens have short, straight fissura extending less than one-half of circumference.

Discussion

Comments. *Psilainaperturites* sp. 2 is distinguished from *P.* sp. 1 by its consistently smaller size. This species is of similar size to many psilate fungal palynomorphs; however, the fungal spores tend to have dark brown walls due to their chitinous composition. Traverse (1988) recorded nearly identical palynomorphs (Acritarch-10b, pl. 1, figs. 1-4) from Black Sea deposits, and noted either algal or fungal affinities. Thus, the botanical affinities of this species are uncertain, although wall composition appears more comparable to resistant algal cysts.
Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *Psilainaperturites* sp. 2 was recorded in over 75 percent of the productive samples (see Plate 3). Abundant; maximum relative abundance in any sample is 28.7 percent.
Previous Records. Hell Creek Formation, northeastern Montana (as "Incertae sedis Type A") (Oltz, 1969); and Kaiparowits Formation (Upper Cretaceous), Utah (as *Inaperturopollenites* n. sp. A) (Lohrengel, 1969).
Illustrated Specimens. Plate 11, Figure 11: UND-PC A2876-6, 7.4 mm across X 12.5 mm up. Plate 11, Figure 12: UND-PC A2876-6, 19.3 mm across X 2.9 mm up.

Genus *Sciadopityspollenites* Raatz ex Potonié 1958

Sciadopityspollenites Raatz, 1937, p. 13 (no diagnosis provided).
Sciadopityspollenites Raatz 1937 ex Potonié, 1958, p. 81.

Type Species: *Sciadopityspollenites serratus* (Potonié & Venitz) Potonié 1958

Generic Diagnosis

"Equator ± circular, germinal area not always distinctive, in part covered by secondary folds, not colpoid (as indicated by Thomson & Pflug 1953) but approximately circular to weakly oval; when it has opened, often a ± triangular rent is seen. Exine ornamented with small warts, in the type species usually with more than 30 protruding over the equator. These warts are rather uniform in size, each with a slightly uneven, yet ± rounded surface; their diameter about half of their height, their outline irregularly circular to polygonal, also elongate rugulate or irregularly triangular; they cover the whole exine, are reduced only in the germinal region" (Potonié, 1958, p. 81, translated in Jansonius and Hills, 1976, card 2547).

Sciadopityspollenites sp.

Plate 12, Figures 3, 4

Description

Inaperturate or zonaperturate(?) pollen. Outline circular to subcircular, diameter 31-(51.8)-75 μm (n = 9). Exine two layered, 2-3 μm thick; outer layer spongy with coarsely granulate to irregularly verrucate sculpture. Aperture generally indistinct; when evident, typically a triangular tear; triangular aperture surrounded by coarsely rugulate frill although aperture margins nearly sculptureless.

Discussion

Comments. These specimens are assigned to *Sciadopityspollenites* in preference to *Zonalapollenites* Pflug in Thomson & Pflug 1953 because they lack the marginal frill characteristic of *Zonalapollenites* and they commonly have a triangular tear in the apertural region.

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2942, A2956, A2958, A2829, A2842, A2976, A2877, A2883, A2885, A2970, A2972, A2851, A2852, A2858, A2862, A2871, and A2999. Rare; maximum relative abundance in any sample is 1.1 percent.

Illustrated Specimens. Plate 12, Figure 3: UND-PC A2942.1-1, 16.1 mm across X 14.9 mm up. Plate 12, Figure 4: UND-PC A2942.1-1, 22.6 mm across X 0.8 mm up.

Bisaccate and TCT Pollen

Bisaccate Pollen. Bisaccate pollen grains are relatively common in the strata included in this study. However, they are commonly torn, folded, or otherwise degraded, making confident identifications difficult. Although a number of species were recognized, the uncertainty in the identification of routine specimens makes the determination of the quantitative abundances of species unreliable. For this reason, the bisaccates are not further differentiated in this study.

Taxodiaceous-Cupressaceous-Taxaceous (TCT) Pollen. Pollen grains that were probably produced by the Taxodiaceae, Cupressaceaceae, or Taxaceae are very abundant, and dominate the palynomorph assemblages in most samples. These pollen grains are inaperturate, fissurate, or ligulate and have scabrate to granulate exines. Some specimens retain a thin perine that is typically wrinkled, giving the grains a rugulate appearance. The grains are between 15-30 um in diameter.

The high abundance of pollen assignable to the TCT complex tends to mask the occurrences of less common taxa. In order to emphasize trends in the occurrences of other taxa, the TCT group was deleted from the bulk of the quantitative analyses in this study (see Plate 4 for the relative abundance of TCT pollen).

Monosulcate Pollen

Genus *Arecipites* Wodehouse 1933 emend. Nichols *et al.* 1973

Arecipites Wodehouse 1933 p. 497, fig. 22.

Arecipites Wodehouse 1933 emend. Nichols *et al.*, 1973, p. 248.

Type Species: *Arecipites* punctatus Wodehouse 1933

Generic Diagnosis

"Monocolpate pollen, amb elongate-ellipsoidal; colpus tapered, not expanded or gaping at ends. Exine tectate in structure, but exine stratification often obscure; sometimes exhibiting columellae in optical section. Exine psilate to finely foveolate or scrobiculate, diameter of foveolae about 0.5 micron. Size variable in different species, ca. 20-50 microns" (Nichols et al., 1973, p. 248).

Arecipites tenuiexinous Leffingwell 1971

Plate 12, Figure 9

Arecipites tenuiexinous Leffingwell, 1971, p. 41, pl. 5, figs. 8, 9

Description of North Dakota Specimens

Monosulcate pollen, outline in polar view ovoid, dimensions 23.5-(29.2)-38.1 X 15.4-(19.1)-22.7 μm (n = 6). Exine tectate, about 0.7 μm thick, nexine very thin; sculpture foveo-reticulate in most specimens, microreticulate in others, lumina 0.5 to 0.7 μm diameter, muri from 0.5 to 1.0 μm wide, lumina commonly slightly smaller toward sulcus. Sulcus extends full length of grain, closed.

Discussion

Comments. Specimens here assigned to *Arecipites tenuiexinous* have a somewhat larger size range (25-30 X 18-23 μm in Leffingwell's (1971) description). Leffingwell describes the sculpture of the species as "reticulate, lumina about 0.5 u wide." However, measurements of Leffingwell's figured specimens suggest that the diameter of the lumina ranges up to about 1.0 μm, and the muri are about as wide as the lumina. The sculpture pattern of Leffingwell's figured specimens corresponds to grains assigned to *Arecipites tenuiexinous* in the present study.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *Arecipites tenuiexinous* was recorded in about 25 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 8.0 percent.

Previous Records. Lance Formation and Tullock Member of Fort Union Formation, east-central Wyoming (Leffingwell, 1971); Tullock Member of Fort Union Formation, Powder River Basin, Montana and Wyoming (Nichols & Brown, 1992); Paleocene portion of the Coalspur Formation, Alberta (Jerzykiewicz and Sweet, 1986); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); and Ravenscrag Formation, southern Saskatchewan (Jarzen, 1982).

Illustrated Specimen. Plate 12, Figure 9: UND-PC A2882-4, 17.6 mm across X 7.6 mm up.

Arecipites columellus Leffingwell 1971

Plate 12, Figure 7; Plate 13, Figure 2

Arecipites columellus Leffingwell, 1971, p. 40, pl. 7, figs. 1, 2.

Description of North Dakota Specimens

Monosulcate pollen, amb elliptical, ends somewhat pointed, dimensions 28.5-(35.0)-43 X 18.5-(23.5)-30 μm (n = 16). Exine tectate, about 1.2 μm thick, somewhat thinner toward ends of grain and toward sulcus; nexine very thin, columellate layer distinct in optical section, about 0.7 μm thick, tectum about 0.5 μm thick; sculpture foveo-reticulate to reticulate, lumina about 0.5 μm, muri 0.5-1.0 μm wide. Sulcus reaches ends of grain, not distinctly flared on ends.

Discussion

Comments. *Arecipites columellus* is distinguished from *A. tenuiexinous* by the presence of thick, stratified exine and from *A. punctatus* Wodehouse 1933 by its larger size (Leffingwell, 1971). *Arecipites plectilimuratus* Chmura 1973 is larger and has a coarser reticulum that has duplibaculate muri. Frederiksen (1980b) noted that this species is identical with the pollen of *Serenoa serrulata* (Michx.) of the Palmae.

Occurrences. Ludlow and Slope Formations and the Boyce Tongue of the Cannonball Formation; samples UND-PC A2942, A2953, A2956, A2838, A2834, A2873, A2841, A2874, A2877, A2880, A2881, A2883, A2885, A2964, A2968, A2987, A2989, A2993, A2870, A2871, A2872, A2996, A2999, A3000, and A3001. Common; maximum relative abundance in any sample is 26.3 percent.

Previous Records. Lance Formation and Tullock Member of Fort Union Formation, east-central Wyoming (Leffingwell, 1971); upper Claiborne and lower Vicksburg Groups (Eocene and Oligocene), Mississippi and Alabama (Frederiksen, 1980b); Lance Formation, northeastern Montana (Farabee and Canright, 1986); Ravenscrag Formation, southern Saskatchewan (Jarzen, 1982); and Maastrichtian portion of Coalspur Formation, Alberta (Jerzykiewicz and Sweet, 1986).

Illustrated Specimens. Plate 12, Figure 7: UND-PC A2996-1, 15.1 mm across X 13.7 mm up. Plate 13, Figure 2: UND-PC A2996-1, 7.9 mm across X 4.6 mm up.

Arecipites pertusus (Elsik in Stover *et al.* 1966) Nichols *et al.* 1973

Plate 13, Figure 1

Calamuspollenites pertusus Elsik in Stover, Elsik & Fairchild, 1966, p. 2, pl. 1, fig. 2.

Arecipites pertusus (Elsik in Stover *et al.*) Nichols *et al.*, 1973, p. 250, pl. 1, figs. 13, 14.

Description of North Dakota Specimens

Monosulcate pollen, outline in polar view elliptical to subcircular, dimensions 24.5-(33.0)-42.0 X 17.0-(24.9)-35.6 μm (n = 13). Exine tectate, about 1.5 μm thick, sexine about twice at thick as nexine; columellae closely spaced, distinct in optical section and plan view, about 0.4 μm in diameter; sculpture foveolate, foveolae about 0.5 μm in diameter, aligned in rows; linear arrangement of foveolae gives surface rugulate appearance; within a row, foveolae about 0.5 μm apart, rows are 1.5-2.0 μm apart; muri multibaculate. Sulcus extends four-fifths to full length of grain, tapered on ends.

Discussion

Comments. *Arecipites pertusus* is differentiated from *A. columellus* on the basis of the linear arrangement of the foveolae, giving the grains a superficially rugulate appearance. Stover *et al.* (1966) suggested botanical affinities with *Liriodendron tulipifera* or *Calamus*. Nichols *et al.* (1973) considered the affinities to be in the Palmae, but probably not with the modern genus *Calamus*.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2954, A2838, A2873, A2836, A2874, A2880, A2883, A2885, A2959, A2982, A2988, A2856, and A2866. Uncommon; maximum relative abundance in any sample is 8.0 percent.

Previous Records. Wilcox Group (upper Paleocene and lower Eocene), Texas (Stover, *et al.*, 1966; Nichols *et al.*, 1973; Elsik, 1968a); Midway and Wilcox Groups of the Gulf Coast region (Fairchild and Elsik, 1969); and Wilcox and Claiborne Groups (Eocene) of the Mississippi Embayment (R.H. Tschudy, 1973).

Illustrated Specimen. Plate 13, Figure 1: UND-PC A2923-2, 10.2 mm across X 5.0 mm up.

Genus *Clavamonocolpites* Gonzales Guzman 1967

Clavamonocolpites Gonzales Guzman, 1967, p. 49.

Type Species: *Clavamonocolpites terrificus* Gonzales Guzman 1967

Generic Diagnosis

"Pollen grains monocolpate with a conspicuous and prominent clavate sculpture. It differs from other monocolpate genera by its sculpture type" (Gonzales Guzman, 1967, p. 49, cited in Jansonius and Hills, 1990, card 4626).

Clavamonocolpites sp.

Plate 13, Figures 3, 4

Description

Monosulcate to trichotomosulcate pollen; outline typically ovoid, although grains readily folded; maximum dimension of monosulcate grains 21.0-(24.7)-31.0 um (n = 6); equatorial diameter of trichotomosulcate grains 24.5-26.5 um (n = 2). Exine intectate, stratification indistinct, about 0.7 um thick; sculpture clavate to gemmate, clavae about 0.8 um high; capita flattened, up to 1 um in diameter; clavae sparse, generally 1-2 um apart. Sulcus generally indistinct, extends full length of grain.

Discussion

Occurrences. Slope Formation, samples UND-PC A2942, A2821, A2877, A2846, A2848, and A2860. Rare; maximum relative abundance in any sample is 1.2 percent.

Previous Records. I have located no published records of fossil pollen conspecific with *Clavamonocolpites* sp.

Illustrated Specimens. Plate 13, Figure 3: UND-PC A2878-3, 11.4 mm across X 10.8 mm up. Plate 13, Figure 4: UND-PC A2878-3, 22.1 mm across X 13.3 mm up.

Genus *Cycadopites* Wodehouse 1933

Cycadopites Wodehouse, 1933, p. 483.

Type Species: *Cycadopites follicularis* Wilson & Webster 1946

Generic Diagnosis

"Essentially as in living species of *Cycas*, but larger. Ellipsoidal, about twice as long as broad, 25-45 μ long; provided with a single longitudinal furrow, reaching almost from end to end and always gaping open at its ends, even when tightly closed in the middle. Exine thin but firm, of various texture but generally quite smooth" (Wodehouse, 1933, p. 483).

Cycadopites scabratus Stanley 1965

Plate 13, Figure 7

Cycadopites scabratus Stanley, 1965, p. 271, pl. 37, figs. 10-15.

Description of North Dakota Specimens

Monosulcate pollen, amb ovate, ends pointed to rounded; dimensions 18.5-(26.0)-31 X 13.2-(14.8)-17 μm (n = 3). Exine single layered, about 0.5 μm thick; sculpture scabrate. Sulcus extends full length of grain, open at ends, overlapping in middle of grain in some specimens.

Discussion

Comments. The size and sculpture of *Cycadopites scabratus* is similar to that of pollen assignable to the Taxodiaceae-Cupressaceae-Taxaceae (TCT) complex. It is possible that distortion by compaction could result in folding of the TCT pollen (originally nearly spherical) into forms that approximate monosulcate pollen grains (see Harris, 1974). Thus, it is possible that *Cycadopites scabratus* is overrepresented in this study due to confusion with folded specimens of TCT pollen.

Occurrences. Ludlow and Slope Formations and Boyce Tongue of the Cannonball Formation. This species was recorded in about 25 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 4.1 percent.

Previous Records. Cannonball Member of Fort Union Formation, northwestern South Dakota (Stanley, 1965); Tullock Member of Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988); Bearpaw, Hell Creek, Tullock, and Lebo Formations, northeastern Montana (Norton and Hall, 1969); Bearpaw, Fox Hills, Hell Creek, Tullock, and Lebo Formations, northeastern Montana (Oltz, 1969); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); and Tongue River Formation, southeastern Montana (Spindel, 1975).

Illustrated Specimens. Plate 13, Figure 7: UND-PC A2957-3, 14.8 mm across X 9.6 mm up.

Genus *Liliacidites* Couper 1953 emend. Juhász and Góczán 1985

Liliacidites Couper, 1953 p. 56.

Liliacidites Couper 1953 emend. Juhász and Góczán, 1985, p. 157, 158.

Type Species: *Liliacidites kaitangataensis* Couper 1953

Generic Diagnosis

"In polar view irregularly boat-shaped or prolate, large and medium size, thin-walled, monosulcate, tectate-reticulate pollen, on which the diameters of lumina of the reticulum are larger in the central parts than at the ends. The sulcus opens in the sexine and in the nexine in an identical way, the sulcus is mostly a simple slit tapering at the ends. The nexine is smooth and the sexine is reticulate. The infratectum is formed by bacula emerging from the nexine, at the central part they stand farther from each other and are longer than at the polar parts where they are shorter and stand to each other nearer. The tectum consists of a generally irregular reticulum which is formed by the muri connecting the sometimes swollen outer ends of the bacula. PD:et > 15" (ratio of polar diameter to exine thickness greater than 15) (Juhász and Góczán, 1985, p. 157, 158).

Discussion

The emended diagnosis of Juhász and Góczán (1985) serves to separate *Liliacidites* from other monosulcate reticulate pollen on the basis of sculpture. Restricting the genus to pollen grains having finer reticulum at the ends of the grain is consistent with the sculpture of the genotype.

Liliacidites cf. *L. leei* Anderson 1960

Plate 13, Figure 6

Liliacidites leei Anderson, 1960, p. 18, 19, pl. 1, figs. 9-11, pl. 5, fig. 10, pl. 7, fig. 7, pl. 8, figs. 4, 5.

Description of North Dakota Specimens

Monosulcate pollen; outline ellipsoidal, ends generally somewhat pointed; dimensions 25.1-(33.2)-38.0 X 14.0-(19.5)-24.5 μm (n = 17). Exine semitectate, 1.0-1.5 μm thick, generally thinner at the ends of grains, sexine about twice as thick as nexine; columellate layer distinct in most specimens in optical section and plan view; sculpture reticulate to foveoreticulate, lumina about 1.5 μm in diameter in proximal region, decreasing gradually to 0.5-0.7 μm at grain ends, lumina commonly also decrease in diameter distally; muri from 0.7-1.5 μm wide, simplibaculate to duplibaculate. Sulcus extends full length of grain, tapered on ends, generally not gaping.

Discussion

Comments. The North Dakota specimens here compared to *Liliacidites leei* have a slightly larger size range and tend to have smaller lumina than was described for *L. leei* by Anderson (1960). Of the palynomorph species encountered in this study, this species is most similar to

Arecipites columellus, but can be distinguished on the basis of its larger lumina and the tendency of the lumina to decrease in diameter toward the ends of the grains. *Liliacidites* cf. *L. leei* also tends to have a more elongate outline and the ends of the grains tend to be more pointed. The botanical affinities of this species may be with the Liliaceae, a family of cosmopolitan distribution that occupies nearly all types of habitats (Nichols and Brown, 1992; Jarzen, 1982).

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2940, A2942, A2953, A2954, A2957, A2958, A2817, A2818, A2878, A2884, A2962, A2982, A2846, and A2856. Rare; maximum relative abundance in any sample is 2.2 percent.

Previous Records. *Liliacidites leei* has been reported from the Kirtland Shale, Ojo Alamo, and Nacimiento Formations, San Juan Basin of New Mexico (Anderson, 1960); Tullock Member of Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); Almond Formation, south-central Wyoming (Stone, 1973); and Lance Formation, northeastern Wyoming (Farabee and Canright, 1986). A probable record exists from the upper Paleocene of west-central Georgia (as *Liliacidites* sp. A) (Christopher *et al.*, 1980).

Illustrated Specimen. Plate 13, Figure 6: UND-PC A3001-2, 9.5 mm across X 17.3 mm up.

Liliacidites? sp.

Plate 12, Figure 8; Plate 13, Figure 5

Description

Monosulcate pollen, outline in polar view ovoid, ends generally somewhat pointed. Dimensions 22.5-(24.7)-27.0 X 15.5-(17.4)-20.0 μm (n = 5). Exine tectate, about 0.8 μm thick; columellate layer thin, but distinct; sculpture coarsely reticulate to foveoreticulate, lumina 0.8-1.6 μm in diameter, decreasing slightly toward ends of grain in some specimens; muri about 0.7-0.8 μm wide; very small spinules present upon muri; spinules about 0.3 μm long X 0.2 μm wide at their base, spaced 0.8-1.0 μm apart. Sulcus extends nearly full length of grain, ends tapered to slightly rounded.

Discussion

Comments. This species is only questionably assigned to *Liliacidites* because of the presence of supratectal spinules and a reticulum that fines only weakly to the ends of the grains. Bergad (1974) assigned similar specimens to *Monocolpopollenites*, but the tapered sulcus of this species makes that assignment inappropriate (see Nichols *et al.*, 1973). The genus *Brenneripollis* Juhász & Góczán 1985 contains monosulcate reticulate pollen that may have supratectal spinules, but that genus is described as having an irregular reticulum that is only loosely attached to the nexine. At present, no monosulcate pollen genus appears to encompass all the features expressed in this species.

Pollen grains that appear to be conspecific with this species have been described in several studies of Upper Cretaceous and Paleocene deposits of the Western Interior (see previous records), but no valid name has yet been applied to the species. Hotton (1988) suggested possible botanical affinities with *Aponogeton*.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2953, A2954, A2955, A2956, A2957, A2958, A2829, A2842, A2876, A2960, A2963, A2968, A2970, A2972, A2848, and A2859. Rare; maximum relative abundance is 1.6 percent.

Previous Records. Hell Creek Formation, North Dakota (as *Monocolpopollenites echinoreticulatus* [nom. nud.]) (Bergad, 1974); Hell Creek Formation, northeastern Montana (Hotton, 1988); Paleocene and Maastrichtian portions of Coalspur Formation, Alberta (as *Liliacidites* sp. (spinose)) (Jerzykiewicz and Sweet, 1986); and Hell Creek Formation, northwestern South Dakota (as *Monosulcites* cf. *M. tectatus*) (Kroeger, 1985); probable record as *Liliacidites* sp. from the Judith River Formation, north-central Montana (Tschudy, 1973).

Illustrated Specimens. Plate 12, Figure 8: UND-PC A2923-2, 21.1 mm across X 5.6 mm up. Plate 13, Figure 5: UND-PC A2957-3, 23.7 mm across X 0.6 mm up.

Genus *Longapertites* Van Hoeken-Klinkenberg 1964

Longapertites Van Hoeken-Klinkenberg, 1964, p. 213.

Type Species: *Longapertites marginatus* Van Hoeken-Klinkenberg 1964

Generic Diagnosis

"Monocolpate pollen grains with an aperture longer than half the greatest circumference of the grain" (Van Hoeken-Klinkenberg, 1964, p. 213, cited in Jansonius and Hills, 1985, card 4282).

Longapertites microfoveatus (Stanley) n. comb.

Plate 13, Figure 9

Schizosporis microfoveatus Stanley, 1965, p. 269, pl. 37, figs. 1-3 (basionym).

Description of North Dakota Specimens

Monosulcate pollen, amb ovoid; dimensions 26.5-(36.0)-42.0 X 17.0-(20.0)-25.0 μm (n = 5). Exine distinctly two layered, apparently tectate; about 1.0 μm thick, thickening slightly toward sulcus; sculpture foveoreticulate; lumina 0.3-0.5 μm in diameter, muri 0.5-0.8 μm wide. Sulcus long, extends slightly onto proximal surface; typically open on ends, overlapping in middle.

Discussion

Comments. The revised diagnosis of *Schizosporis* Cookson & Dettmann emend. Pierce 1976 restricted that genus to species possessing walls that are more complexly structured than is the wall of *Longapertites* *microfoveatus*. The aperture of *L. microfoveatus* is here interpreted to be a long sulcus rather than an elongate tear as originally interpreted (Stanley, 1965). *Arecipites microreticulatus* Anderson 1960 is very similar, but is described as having a thinner, structureless exine and larger size.

Occurrences. Ludlow and Slope Formations and the Boyce Tongue of the Cannonball Formation; samples UND-PC A2956, A2976, A2980, A2965, and A2980. Rare; maximum relative abundance in any sample is 1.1 percent.

Previous Records. Hell Creek Formation, northwestern South Dakota (Stanley, 1965); Hell Creek and Tullock Formations, northeastern Montana (Oltz, 1969); and Hell Creek Formation, North Dakota (Bergad, 1974).

Illustrated Specimen. Plate 13, Figure 9: UND-PC A2951-3, 19.0 mm across X 1.3 mm up.

Genus *Monocolpopollenites* Pflug & Thomson in Thomson & Pflug 1953 emend. Nichols *et al.* 1973

Monocolpopollenites Pflug & Thomson in Thomson & Pflug, 1953, p. 62.

Monocolpopollenites Pflug & Thomson in Thomson & Pflug 1953 emend. Nichols *et al.*, 1973, p. 251.

Type Species: *Monocolpopollenites tranquillus* (Potonié 1934) Thomson & Pflug 1953

Generic Diagnosis

"Monocolpate pollen, amb oval. Colpus with flared or rounded end or without margo. Exine psilate, scabrate, or reticulate, but not granulate or verrucate. Size variable in different species, ca. 20-50 μ" (Nichols *et al.*, 1973, p. 251).

Monocolpopollenites cf. *M. texensis* Nichols *et al.* 1973

Plate 13, Figure 8

Monocolpopollenites texensis Nichols *et al.*, 1973, p. 254, pl. 2, figs. 10-13.

Description of North Dakota Specimens

Monosulcate pollen; amb ovoid, ends rounded; dimensions 29.0-(34.4)-43.0 X 20.0-(22.1)-25.0 μm (n = 8). Exine two layered, apparently tectate, about 0.7 μm thick; psilate. Sulcus extends nearly full length of grain, flared on ends, meeting in center.

Discussion

Comments. These specimens agree well with the description of *Monocolpopollenites texensis* except they are consistently somewhat larger. They are similar in size to *Arecipites pseudotranquillus* Nichols *et al*. 1973, but differ in the shape of the sulcus. *M. texensis* has a rounded or flared sulcus, whereas *A. pseudotranquillus* has a sulcus with tapered ends.

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2873, A2842, A2875, A2876, A2884, A2959, A2960, A2963, A2964, and A2853. Uncommon; maximum relative abundance in any sample is 1.3 percent.

Previous Records. *Monocolpopollenites texensis* has been reported from the Wilcox Group (upper Paleocene), Texas (Nichols *et al*., 1973); and Menefee Formation (Mesaverde Group), New Mexico (as cf. *M. texensis*) (Jameossanie, 1987).

Illustrated Specimens. Plate 13, Figure 8: UND-PC A2952-3, 9.0 mm across X 12.3 mm up.

Genus *Monosulcites* Cookson ex Couper 1953

Monosulcites Cookson, 1947, p. 48 (no diagnosis provided).

Monosulcites Cookson ex Couper, 1953, p. 65.

Type Species: *Monosulcites minimus* Cookson ex Couper 1953

Generic Diagnosis

"Free, anisopolar, bilateral, monosulcate. Grain elongate to sub-circular. Exine variable in thickness and sculpture. Size variable" (Couper, 1953, p. 65).

Monosulcites sp.

Plate 13, Figures 10, 11

Description

Monosulcate pollen, outline ovoid to spindle shaped; dimensions 30.0-(34.9)-40.5 X 16.0-(21.5)-24.5 μm (n = 5). Exine single layered, about 0.5 μm thick, finely scabrate to punctate. Sulcus extends nearly full length of grain, tapered at ends; many specimens preserved in equatorial view, obscuring sulcus.

Discussion

Comments. *Monosulcites* sp. is differentiated from *Cycadopites scabratus* by the shape of the sulcus. *Monosulcites crecentus* Norton & Hall 1969 is somewhat smaller, has densely granulate exine, and is described as having crescentic folds on each side of sulcus.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2838, A2829, A2840, A2841, A2836, A2842, A2871, A2882, A2962, A2963, A2965, A2972, A2979, A2987, A2853, A2860, and A2863. Rare; maximum relative abundance in any sample is 2.1 percent.

Illustrated Specimens. Plate 13, Figure 10: UND-PC A2829-4, 10.1 mm across X 7.1 mm up. Plate 13, Figure 11: UND-PC A2836.0-3, 3.0 mm across X 17.4 mm up.

Genus *Rossipollis* Krutzsch 1970

Rossipollis Krutzsch, 1970, p. 40.

Type Species: *Rossipollis reticulatus* (Ross) Krutzsch 1970

Generic Diagnosis

"A small, longisulcoid pollen genus with subcircular outline and compressed to stubby oval-lenticular shape; wall relatively thick, with several layers, the outer one of these with various fine sculpture (or structure), such as punctate, densely gemmate-baculate-pilate, minutely reticulate, intrabaculate-punctate, etc. The sulcus-like structure extends only little beyond the 'equator' onto the other face (which further lacks a sulcus) and is developed by lack of the outer wall layer. Therefore, it is not fully open, but covered with a sort of membrane (= inner wall layer), which in turn may show some fine sculpture which, however, is clearly different from that surrounding it" (Krutzsch, 1970, p. 40, translated in Jansonius and Hills, 1976, card 2439).

Rossipollis scabratus (Stanley) n. comb.

Plate 13, Figure 12

Schizosporis scabratus Stanley, 1965, p. 269, 270, pl. 35, figs. 10-17 (basionym).

non *Monosulcites scabratus* (Stanley) Stone, 1973, p. 77, pl. 15, figs. 80, 81.

Description of North Dakota Specimens

Monosulcate pollen grains, outline in polar view circular-ovoid to nearly circular; maximum dimension 18.5-(24.6)-25.0 μm (n = 7). Exine 1.5-2.0 μm thick, thickness generally uneven throughout grain; exine structure difficult to determine in many specimens, other specimens appear to be tectate; sculpture scabrate to weakly rugulate, many specimens have punctate tectum. Sulcus extends full length of grain, typically extending slightly onto proximal hemisphere; tapered on ends, not gaping.

Discussion

Comments. Stanley (1965) interpreted the aperture of this species to be a fissura that extends nearly completely around the grain, hence the original assignment to *Schizosporis*. Stone (1973) interpreted the aperture to be a sulcus and transferred the species to *Monosulcites* Cookson ex Couper 1953. Although I agree that the aperture is a sulcus, the extension of the sulcus of this species onto the proximal hemisphere makes assignment to *Rossipollis* more appropriate. In addition, the specimens assigned to the species by Stone (1973) do not appear to be conspecific with the protologue specimens as they have an ovoid amb and a shorter sulcus with flared ends.

The exine structure of most specimens is difficult to determine, and often appears to be "spongy." However, specimens are occasionally encountered that appear to have a tectate-columellate exine structure, suggesting angiosperm affinities. This nomenclatural combination has been proposed previously by Hotton (1988), but is not yet validly published.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2942, A2953, A2956, A2818, A2821, A2829, A2839, A2840, A2841, A2836, A2842, A2874, A2875, A2876, A2877, A2878, A2919, A2879, A2881, A2883, A2884, A2965, A2969, A2988, A2992, A2993, A2844, A2849, A2851, A2857, A2858, A2859, A2860, A2861, A2862, and A2869. Uncommon; maximum relative abundance in any sample is 3.7 percent.

Previous Records. Hell Creek Formation, northwestern South Dakota (Stanley, 1965); Hell Creek Formation, North Dakota (Bergad, 1974); Hell Creek Formation, northwestern South Dakota (Kroeger, 1985); Hell Creek Formation, northeastern Montana (Hotton, 1988); and Menefee Formation (Mesaverde Group), northern New Mexico (Jameossanaie, 1987).

Illustrated Specimen. Plate 13, Figure 12: UND-PC A2878-3, 12.4 mm across X 3.3 mm up.

Obligate Dyads and Tetrads

Genus *Dicotetradites* Couper 1953 emend. Crosbie & Clowes 1980

Dicotetradites Couper, 1953, p. 63.

Simplicepollis Harris, 1965, p. 94, 95.

Dicotetradites Couper emend. Crosbie & Clowes, 1980, p. 459.

Type species: *Dicotetradites clavatus* Couper 1953

Generic Diagnosis

"Pollen grains in tetrahedral tetrads, individual grains triporate, pores on or slightly distally displaced from equator, pores arranged according to Fisher's Law (Erdtman, 1952; pores arranged 'two and two at six points' on the tetrad) (Crosbie and Clowes, 1980, p. 459).

Dicotetradites rallus (Stanley) n. comb.

Plate 14, Figures 1, 2

Ericaceoipollenites rallus Stanley, 1965, p. 296, pl. 44, figs. 15-18 (basionym).

Ericipites rallus (Stanley) Farabee & Canright, 1986, p. 48, pl. 17, fig. 10.

Simplicepollis rallus (Stanley) Nichols and Brown, 1992, p. F29, pl. 10, figs. 1-6.

Description of North Dakota Specimens

Tetrahedral pollen tetrads, diameter of tetrads 30.5-(34.9)-40 μm (n = 4), individual grains oblate, 18.5-26.5 μm in diameter. Exine very thin, stratification indistinct, sculpture finely scabrate. Apertures weakly developed oroids arranged according to Fisher's rule. Sculpture typically more strongly expressed in vicinity of oroids.

Discussion

Comments. Crosbie and Clowes (1980) examined topotypes of the species *Dicotetradites clavatus* Couper 1953 using scanning electron and light microscopy. They determined that the topotype specimens are triporate rather than tricolpate or triorate as was specified in Couper's original diagnosis. Their emended diagnosis placed *Simplicepollis* Harris into synonymy with *Dicotetradites*.

Nichols and Brown (1992) interpreted the apertural condition of *Ericaceoipollenites rallus* Stanley as trioroid rather than tricolpate, and transferred the species to the genus *Simplicepollis*. Crosbie and Clowes' (1980) study indicates that the species should now be assigned to *Dicotetradites*.

No specimens of *D. rallus* encountered in this study are tricolpate or even tricolpoid, but rather, they are trioroid with weakly developed apertures consisting of relatively large ora. The apertures are typically indistinct, but several specimens were located that have clearly defined apertures.

B.D. Tschudy (1973) described a similar species, *Inaperturotetradites scabratus*, from the Judith River Formation (Campanian) of north-central Montana. Individual grains of this species are described as inaperturate, but she commented that they may be synonymous with *Dicotetradites rallus* (*Ericaceoipollenites rallus*), which was originally described as inaperturate to weakly tricolpate (Stanley, 1965). The specimens that Tschudy illustrated (pl. 1, figs. 18, 19) appear to be more coarsely and uniformly scabrate than specimens here assigned to *D. rallus*, but she noted that the sculpture of *I. scabratus* is variable, even between the grains within a tetrad.

Stanley (1965) suggested an affinity for *D. rallus* with *Kalmia* in the Ericaceae. Nichols and Brown (1992) considered the botanical affinities to be uncertain, but probably not with the Ericaceae. In this study, *Dicotetradites rallus* commonly occurs in association with algal palynomorphs, suggesting an aquatic habitat for the producing plant.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *D. rallus* was recorded in about three-fourths of the productive samples. Abundant; maximum relative abundance in any sample is 42.6 percent.

Previous Records. Ludlow and Cannonball Members of the Fort Union Formation, northwestern South Dakota (Stanley, 1965); Tullock Member of the Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); Ludlow Formation, southwestern North Dakota (Johnson *et al.*, 1989); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); Almond Formation, south-central Wyoming (Stone, 1973); Paleocene and Maastrichtian portions of the Coalspur Formation, Alberta (Jerzykiewicz and Sweet, 1986); Hell Creek Formation, North Dakota (Bergad, 1974); probable record from Hell Creek and Tullock Formations, northeastern Montana (as *Virgo granulatus*) (Hotton, 1988); probable record from the Bearpaw, Hell Creek, Tullock and Lebo Formations, northeastern Montana (as *Dicotetradites granulatus*) (Norton and Hall, 1969); and Kaiparowits Formation (Upper Cretaceous), Utah (Lohrengel, 1970);

Illustrated Specimen. Plate 14, Figure 1: UND-PC A2931-3, 5.9 mm across X 8.1 mm up. Plate 14, Figure 2: UND-PC A2996-1, 11.4 mm across X 91.5 mm up.

Genus *Dyadonapites* Erdtman 1947 ex B.D. Tschudy 1973

Dyado-nyapites Erdtman, 1947, p. 111.

Dyadites Pant, 1954, p. 54.

Dyadities van der Hammen, 1956, p. 79. (Invalid name, modern pollen grain designated as type specimen.)

Dyadonapites Erdtman 1947 ex B.D. Tschudy, 1973, p. 32.

Type species: *Dyadonapites reticulatus* B.D. Tschudy 1973

Generic Diagnosis

"Inaperturate palynomorphs united in dyads, greatest dimension of dyad less than 60 μm; individual cells of dyad alike or very similar, their shape spherical, oval, or irregular; surface ornamentation various" (Tschudy, 1973, p. 32).

Discussion

The generic synonymy listed above is from B.D. Tschudy (1973); see her paper for additional discussion on *Dyadonypites*.

Dyadonapites reticulatus B.D. Tschudy 1973

Plate 14, Figures 4, 5

Dyadonapites reticulatus B.D. Tschudy, 1973, p. 32, pl. 11, figs. 15-17.

Emended Description

Inaperturate pollen grains generally occurring as dyads, rarely monads; outline of individual grains circular to slightly ovoid, maximum dimension of individual grains 19-(21.9)-23 μm (n = 7); when occurring in dyads, one grain typically distinctly larger than the other. Exine semitectate, about 1 μm thick, nexine very thin, columellae distinct in plan view, giving beaded appearance to muri; sculpture reticulate, lumina of irregular shape and size, lumina diameter 0.5-1.0 μm; muri narrow and sharply ridged, about 0.3 μm wide. Grains occurring as monads are typically folded.

Discussion

Comments. Tschudy (1973) did not allow for the inclusion of monads in her original description of *D. reticulatus*, although in her remarks, she noted that palynomorphs were present that appeared to be individual cells of the species. The emended description provided here allows for such monads to be included within *D. reticulatus*.

Samples bearing *D. reticulatus* commonly contain monads that appear to be individual grains of the species. They are very similar to grains assigned to *Sparganiaceaepollenites* in size and sculpture, but they are inaperturate. Because the pore of *Sparganiaceaepollenites* is commonly indistinct, some specimens of *D. reticulatus* may be assigned incorrectly to *Sparganiaceaepollenites* or *vice versa*. The botanical affinities of *D. reticulatus* are uncertain, although a possible relationship to the Typhaceae and Sparganiaceae was suggested by Nichols and Brown (1992)

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2818, A2829, A2830, A2836, A2875, A2876, A2963, A2965, A2976, A2977, A2981, A2982, A2988, A2991, A2992, A2994, A2848, A2852, A2853, A2854, and A2996. Uncommon; maximum relative abundance in any sample is 18.0 percent.

Previous Records. Judith River Formation of north-central Montana (B.D. Tschudy, 1973); Tullock Member of Fort Union Formation, Powder River Basin of Wyoming and Montana (Nichols and Brown, 1992); Frenchman and Ravenscrag Formations, south-central Saskatchewan (Nichols *et al.* 1986); Tongue River Member of Fort Union Formation in the Powder River Basin of Wyoming (Pocknall and Nichols cited in Nichols and Brown, 1992); and Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988).

Illustrated Specimens. Plate 14, Figure 4: UND-PC A2818-2, 16.3 mm across X 4.6 mm up. Plate 14, Figure 5: UND-PC A2818-2, 10.9 mm across X 0.7 mm up.

Monoporate Pollen

Genus *Pandaniidites* Elsik 1968

?*Pandanus* Simpson, 1961, p. 430.

Pandaniidites Elsik, 1968a, p. 314.

Spinamonoporites Norton in Norton and Hall, 1969, p. 36.

Type species: *Pandaniidites texus* Elsik 1968

Generic Diagnosis

"Monoporate, spherical, spinose pollen. Pore annulate or nearly so. Spines sparse and irregularly distributed. Exine of two layers, tightly appressed, tectate-psilate" (Elsik, 1968a, p. 314).

Pandaniidites typicus (Norton) Farabee & Canright 1986

Plate 14, Figure 3

Spinamonoporites typicus Norton in Norton & Hall, 1969, p. 36, pl. 5, fig. 22.

Pandanus cf. *P. shiabensis* Simpson in Snead, 1969, p. 40, pl. 7, fig. 13.

Pandaniidites typicus (Norton) in Leffingwell *et al.*, 1970, p. 254 (invalid combination, no basionym stated).

Pandaniidites radicus Leffingwell, 1971, p. 42, pl. 5, figs. 3-5.

Pandanus (pollen) in Jarzen, 1976, p. 49, pl. 1, fig. 11.

Pandanus (pollen) in Jarzen, 1978, p. 35, pl. 1, fig. 9.

Pandaniidites typicus (Norton) Farabee & Canright, 1986, p. 1382, pl. 2, fig. 12.

Pandaniidites typicus (Norton) Sweet, 1986, p. 1380, pl. 2, fig. 12.

Description of North Dakota Specimens

Monoporate pollen, grains generally folded, outline typically ovoid to pear-shaped; maximum dimension of grain 22.0-(23.8)-26.0 μm (n = 5). Exine less than 0.5 μm thick, stratification indistinct; sculpture of echinae 1.5-2.5 μm long by 0.9 μm wide at their bases; echinae 2-5 μm apart, commonly slightly curved, exine thickens at base of spines to about 1.0 μm. Pore about 2-3 μm in diameter, more or less circular, annulate, annulus diffuse, about 1.5 μm wide.

Discussion

Comments. Three species assignable to *Pandaniidites* have been described from North America: *P. typicus* (Norton) Farabee and Canright, *P.*

radicus Leffingwell, and *P. texus* Elsik. Sweet (1986) noted that *Pandaniidites typicus*

> ". . . encompasses specimens exhibiting the combined wall thickness ascribed to *P. texus* and *P. radicus* and both annulate and nonannulate specimens" (p. 1382).

Although this statement implies synonymy of the three species, he did not place *P. texus* and *P. radicus* into synonymy with *P. typicus*. Only minor differences in exine thickness and spine length distinguish *Pandaniidites typicus* from *P. radicus*; thus they appear to be conspecific. Elsik (1968a) described *P. texus* as having a tectate exine, a feature that is not discernable in *P. typicus*.

Several workers have suggested that the botanical affinities of *Pandaniidites* lie with *Pandanus* (Pandanaceae) (Elsik, 1968a; Norton and Hall, 1969; Simpson, 1961; Leffingwell, 1971; Muller, 1981; Jarzen, 1983; Nichols and Brown, 1992) while others have suggested a relationship to *Lemna* (Lemnaceae) (Ke & Shi, 1978; Sweet, 1986). Affinities with *Pandanus* appear to be most likely as the pollen of that genus has inwardly thickened exine below the echinae, similar to that in *Pandaniidites* (Fleming, 1990).

Jarzen (1978) noted that *Pandanus* is at present entirely paleotropical in distribution. The pandans or screwpines are typical of seacoasts and marshes where they are part of a mangrove floral association.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation. *Pandaniidites typicus* was recorded in about 33 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 3.0 percent.

Previous Records. Bearpaw, Fox Hills, Hell Creek, Tullock and Lebo Formations, northeastern Montana (Norton and Hall, 1969); Hell Creek and Fort Union Formations, northeastern Montana (Nichols *et al.*, 1982); Lance and Fort Union Formations, east-central Wyoming (Leffingwell, 1971); Frenchman and Ravenscrag Formations, south-central Saskatchewan

(Nichols *et al.*, 1986); Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988); Tullock Member of Fort Union Formation, Powder River Basin, Montana and Wyoming (Nichols and Brown, 1992); Hell Creek and Tullock Formations, northeastern Montana (Oltz, 1969); Paskapoo Formation, Alberta (Snead, 1969); Paleocene and Maastrichtian portions of Coalspur Formation, Alberta, (Jerzykiewicz and Sweet, 1986); Frenchman Formation, south-central Saskatchewan (Jarzen, 1978); Maastrichtian and Paleocene of south-central Saskatchewan (Jarzen, 1976); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); and Ravenscrag Formation, southern Saskatchewan (Jarzen, 1982).

Illustrated Specimen. Plate 14, Figure 3: UND-PC A2982-4, 15.6 mm across X 11.5 mm up.

Genus *Sparganiaceaepollenites* Thiergart 1937 emend. Krutzsch 1970

Sparganiaceaepollenites Thiergart, 1937, p. 307.

Sparganiaceaepollenites Thiergart emend. Krutzsch, 1970, p. 19.

Type Species: *Sparganiaceaepollenites polygonalis* Thiergart 1937

Generic Diagnosis

"± roundish, monoporate pollen; pore ± roundish, usually only a few microns in diameter, without an anulus or without a distinct delineation but rather bounded irregularly by the sculptural elements surrounding the pore. Sculpture finely reticulate, usually with columellae underneath the reticulum-tectum. Mostly small to medium-large forms, rarely larger" (Krutzsch, 1970, translated in Jansonius and Hills, 1976, card 2627).

Sparganiaceaepollenites cf. *S. globipites*

(Wilson & Webster) Krutzsch 1970

Plate 14, Figure 6

Sparganium globipites Wilson & Webster, 1946, p. 276, fig. 18.

Sparganiaceaepollenites globipites (Wilson & Webster 1946) Krutzsch, 1970, p. 19.

Description of North Dakota Specimens

Monoporate pollen grains, shape variable due to readily folded exine, commonly elongate-triangular or pear-shaped; maximum dimension of grains 18.5-(27.3)-36.5 μm (n = 20). Exine semitectate, about 1.0 μm thick, nexine very thin; sculpture reticulate, muri distinctly simplibaculate, lumina 0.5-1.0 μm in diameter, of equal size over entire grain. Pore 3-4 μm in diameter, circular to slightly elongate, not bordered by exine thickening; pore indistinct in many grains.

Discussion

Comments. Fossil pollen grains here compared to *Sparganiaceaepollenites globipites* differ from that species by possessing a smaller pore (7-8 μm in diameter in original description) and lacking a circular outline. *Sparganiaceaepollenites polygonalis* Thiergart and *S. neogenicus* Krutzsch are also similar, but tend to have pores that are more distinct and thicker, less easily folded exine. Krutzsch (1970) illustrated a very similar form as *Sparganiaceaepollenites* sp. C.

The commonly indistinct nature of the pores in this species may be attributable to the pore being hidden within an exinal fold. The exine is relatively weak and many specimens have elongate tears in addition to pores. *Dyadonypites reticulatus* B.D. Tschudy has similar sculpture to *Sparganiaceaepollenites* cf. *S. globipites*, and monad grains of that species might readily be confused with grains of *S.* cf. *S. globipites* that have indistinct pores. The Sparganiaceae and the Typhaceae produce pollen grains of similar morphology, but grains of the Typhaceae tend to remain in tetrads.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2957, A2842, A2878, A2969, A2976, A2985, A2987, A2988, A2848, A2851, A2855, A2856, A2857, A2858, A2859, A2863, A2864, A2865, and A2866. Uncommon; maximum relative abundance in any sample is 2.0 percent.

Previous Records. Fossil pollen grains that appear to be conspecific with *Sparganiaceaepollenites* cf. *S. globipites* have been reported from the Tullock Member of Fort Union Formation, Powder River Basin of Wyoming and Montana (as *Sparganiaceaepollenites* cf. *S. globipites*) (Nichols and Brown, 1992); and Paleocene portion of the Coalspur Formation, Alberta (as *Sparganium* sp.) (Jerzykiewicz and Sweet, 1986).

Illustrated Specimen. Plate 14, Figure 6: UND-PC A3157-2, 21.3 mm across X 1.9 mm up.

Sparganiaceaepollenites sp.

Plate 14, Figures 7-9

Description

Monoporate pollen grains, outline ovoid to circular, probably a compressed sphere, diameter 15.0-(24.5)-30.0 μm (n = 8). Exine semitectate, 1.0-1.5 μm thick, sexine about equal in thickness to the nexine; exine structure of clavae; heads of clavae fused to form reticulate sculpture, commonly clavae incompletely fused, yielding an imperfect reticulum with many incompletely closed lumina; muri about 0.5 μm wide, simplibaculate to duplibaculate (rarely); lumina irregular, commonly elongate, 1.0-1.5 μm in diameter. Pore about 4 μm diameter, unbordered, ulcerate in some grains.

Discussion

Comments. *Sparganiaceaepollenites* sp. is distinct from *S.* cf. *S. globipites* on the basis of the coarser reticulum with wider muri and the lumina that are commonly incompletely closed. This species appears to be conspecific with pollen grains described as *Sculptomonoporites varireticulatus* (nom. nud.) by Bergad (1974) and Hotton (1988).

Some differences are present in the character of the reticulum within this species. Some grains have relatively smooth muri and completely surrounded lumina whereas others have prominent structural elements visible beneath the muri and commonly have incompletely surrounded lumina. However, insufficient specimens were encountered to determine if these differences are consistent enough to constitute separate species.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2951, A2952, A2953, A2954, A2955, A2956, A2822, A2834, A2839, A2931, A2842, A2885, A2960, A2962, A2963, A2964, and A2980. Uncommon; maximum relative abundance in any sample is 7.1 percent.

Previous Records. Hell Creek Formation, south central North Dakota (Bergad, 1974); and Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988).

Illustrated Specimens. Plate 14, Figure 7: UND-PC A2955-3, 15.9 mm across X 4.6 mm up. Plate 14, Figure 8: UND-PC A2952-3, 12.5 mm across X 3.4 mm up. Plate 14, Figure 9: UND-PC A2879-2, 2.6 mm across X 5.2 mm up.

Sparganiaceaepollenites? sp.

Plate 14, Figures 10, 11

Description

Monoulcerate(?) or inaperturate(?) palynomorphs; outline circular to ovoid, readily folded, maximum dimension 18.0-(25.5)-28.5 μm

(n = 13). Wall very thin, about 0.5 μm thick, stratification not evident; sculpture evenly microreticulate, lumina 0.5 μm or less in diameter; muri narrow. Apertures indistinct, many specimens appear inaperturate, or with numerous openings that appear to be due to secondary deterioration of wall; some specimens with single, irregular, unbordered ulcus.

Discussion

Comments. The apertural condition of these palynomorphs cannot be determined with certainty; therefore the generic assignment is questioned. They are questionably assigned to *Sparganiaceaepollenites* on the basis of their reticulate wall and apparent single pore-like aperture. This species is distinct from *Sparganiaceaepollenites* cf. *S. globipites* by the absence of any evident wall stratification and the presence of a finer reticulum.

Occurrences. Slope Formation and the Boyce and Three V Tongues of the Cannonball Formation. *Sparganiaceaepollenites*? sp. was recorded in about 25 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 3.9 percent.

Illustrated Specimens. Plate 14, Figure 10: UND-PC A2877.0-1, 14.1 mm across X 16.7 mm up. Plate 14, Figure 11: UND-PC A2880-2, 13.6 mm across X 20.1 mm up.

Triporate and Tetraporate Pollen

Genus *Cricotriporites* Leidelmeyer 1966

Cricotriporites Leidelmeyer, 1966, p. 54.

Type Species: *Cricotriporites guianensis* Leidelmeyer 1966

Generic Diagnosis

"Triporate pollen grains with a psilate sculpture and with a circular circumference. The grains are provided with distinct circular to oval pores with annulus and/or costae pori" (Leidelmeyer, 1966, p. 54).

Cricotriporites plektosus (Anderson 1960) n. comb.

Plate 14, Figure 12

Triporopollenites plektosus Anderson, 1960, p. 27, pl. 4, fig. 14; pl. 8, fig. 16 (basionym).

Description of North Dakota Specimens

Triporate pollen, shape probably oblate or globose although generally indeterminate due to folding, specimens in polar view tend to have irregularly subcircular to subtriangular ambs; dimensions 23.0-(26.7)-31.0 μm (n = 10). Exine about 0.5 μm thick, tectate, columellate layer rarely observable except adjacent to pores; sculpture finely scabrate to nearly psilate. Pores 2-3 μm in diameter, more or less circular, commonly subequatorial due to folding. Pores bordered by narrow annuli typically less than 1 μm wide.

Discussion

Comments. Anderson (1960) proposed this species to accommodate randomly folded, triporate pollen with an annulus. The species is interpreted here to include thin-walled, annulate, triporate pollen that are commonly folded.

The genus *Triporopollenites* as emended by Potonié (1960) contains triporate pollen with a rigidly triangular amb. Transfer of this species to *Cricotriporites* is consistent with its more circular amb and annulate pores. Fleming (1990, Ph. D. dissertation) has previously proposed the combination *Cricotriporites plektosus*, but his work is not yet published.

Triporopollenites praetenuis Chmura 1973 is very similar to *Cricotriporites plektosus* and may be a junior synonym. The species is identical in all aspects except that the exine is described as about 1.0 μm thick compared to 0.5 μm in Anderson's original description of *C. plektosus*.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongue of the Cannonball Formation; *C. plektosus* was recorded in about 67 percent of the productive samples (see Plate 3). Common; maximum relative abundance in any sample is 9.5 percent.

Previous Records. Ojo Alamo and Nacimiento Formations, San Juan Basin of New Mexico (Anderson, 1960); Lance Formation and Tullock and Lebo Members of the Fort Union Formation, east-central Wyoming (Leffingwell, 1971); and Hell Creek and Tullock Formations, northeastern Montana (as *Annutriporites plektosus*, (invalid combination, unpublished)) (Hotton, 1988); Maastrichtian and Paleocene portions of the Coalspur Formation, Alberta (Jerzykiewicz and Sweet, 1986); Tullock Member of the Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); Maastrichtian and Paleocene portions of the Raton Formation, Colorado and New Mexico (Fleming, 1990).

Illustrated Specimen. Plate 14, Figure 12: UND-PC A2976-2, 11.8 mm across X 5.1 mm up.

Genus *Jarzenipollenites* Kedves 1980

Jarzenipollenites Kedves, 1980, p. 24.

Type Species: *Jarzenipollenites trinus* (Stanley) Kedves 1980

Generic Diagnosis

"The equatorial contour is triangular, with convex sides. There are three germinal apertures, these are pores, and there is a small centripetal annulus. Germinalia are connected with one another by arcus. The surface is smooth or punctate" (Kedves, 1980, p. 24).

Discussion

Kedves (1980) did not provide a differential diagnosis to emphasize the differences between *Jarzenipollenites* and previously existing form- or organ- genera for "*Alnus*-type" fossil pollen grains. However, *Alnipollenites* Potonie ex Potonie 1960 and *Polyvestibulopollenites* Pflug in Thomson & Pflug 1953 are both diagnosed as having vestibulate pores whereas *Jarzenipollenites* lacks vestibulate pores. Therefore, *Jarzenipollenites* Kedves is retained for the non-vestibulate specimens encountered in this study.

Kedves' diagnosis places undue emphasis on pore number, as many modern species produce porate pollen with variable pore numbers. Therefore, the diagnosis should be emended to include pollen grains with a variable number of pores. At the specific level, it is probably useful to maintain pore number as a diagnostic feature. Some workers (Stanley, 1965; Frederiksen, 1980a) have noted that the pore number of *Alnus*-type pollen grains appears to have some stratigraphic significance.

Jarzenipollenites trinus (Stanley) Kedves 1980

Plate 14, Figure 14

Alnus trina Stanley, 1965, p. 289, pl. 43, figs. 4, 5 (non fig. 6).

Alnipollenites trinus (Stanley) Norton in Norton & Hall, 1969, p. 42, pl. 5, fig. 20.

Alnipollenites trinus (Stanley) Oltz, 1969, p. 240, pl. 41, fig. 97.

Jarzenipollenites trinus (Stanley) Kedves, 1980, p. 172, pl. 2, figs. 4-6.

Polyvestibulopollenites trinus (Stanley) Norris, 1986, p. 41, pl. 10, figs. 46, 53.

Emended Description

Triporate pollen, amb triangular, sides straight to slightly convex, angulaperturate; equatorial diameter 15.5-(19.4)-22.0 μm (n = 13). Exine of two layers closely appressed, about 0.5 μm thick in equatorial interporia; columellate layer indistinct except near pores where short, peg-like columellae are present; grain surface psilate. Distinct arcus 1.5-2.0 μm wide present on both polar surfaces; arcus generally parallel to the edges of amb, but may be convex poleward.

Pores 1-2 μm in diameter, lolongate; sexine thickens at pores forming tumescence as much as 1.0 μm thick, endexine stops 2-3 μm from pores, forming atria; short interloculum present at atria margins.

Discussion

Comments. Specimens of *Jarzenipollenites trinus* encountered in this study agree well in size and gross general morphology with Stanley's (1965) original description of the species and the illustration of the holotype (pl. 43, fig. 4). It is evident that Stanley included more than one morphotype in his original circumscription of the species, as one of the paratypes illustrated (pl. 43, fig. 6) appears to be a specimen of *Ulmipollenites krempii* (Anderson) Frederiksen 1979. *Jarzenipollenites trinus* is distinct from the ulmaceous species encountered in the present study by having thinner exine and lacking sculpture of low verrucae or rugulae.

Stanley (1965) did not describe *J. trinus* as atriate, and the structure of the pores is not very clear in the illustrated specimens. Because these specimens agree in all other aspects with *J. trinus* and the present study is geographically and stratigraphically close to the strata from which this species was originally described, they are considered to be conspecific, and the description is emended to include atriate pores. The assignment of this species to *Alnipollenites* or *Polyvestibulipollenites* (Oltz, 1969; Norris, 1986) is inappropriate, as both of those genera are diagnosed as possessing vestibulate pores.

Occurrences. Ludlow and Slope Formations and the Three V Tongue of the Cannonball Formation; *J. trinus* was recorded in about 33 percent of the productive samples (see Plate 3). Common; maximum relative abundance in any sample is 8.3 percent.

Previous Records. Ludlow Member of Fort Union Formation, northwestern South Dakota (Stanley, 1965); Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988); Tullock Formation, northeastern Montana (Norton and Hall, 1969); Bearpaw, Hell Creek, and Tullock

Formations, northeastern Montana (Oltz, 1969); Paskapoo and Edmonton Formations, Alberta (Snead, 1969); Paleocene portion of Coalspur Formation, Alberta (Jerzykiewicz and Sweet, 1986); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); and Ravenscrag Formation, southern Saskatchewan (Jarzen, 1982).

Illustrated Specimens. Plate 14, Figure 14: UND-PC A2931-4, 23.0 mm across X 10.5 mm up.

Genus *Labrapollis* Krutzsch 1968

Labrapollis Krutzsch, 1968, p. 62.

Type Species: *Labrapollis labraferus* (Potonié) Krutzsch 1968

Generic Diagnosis

"Small to very small, flat-lenticular pollen with rounded to over-rounded sides, with three equatorial germinals; the latter with labrum, weak anulus or without differentiation around the vertical oval to slit-shaped exopores and with usually large to very large half-circular or more-than-half-circular atria as endopores; on both hemispheres with 'plicae' running over the pole from one interradial side to another; surface may vary from smooth to finely verrucate" (Krutzsch, 1968, p. 62, translated in Jansonius and Hills, 1976, card 1423).

Discussion

The small size, shape of the amb, germinal structures, and the presence of plicae differentiate *Labrapollis* Krutzsch from *Triatriopollenites* Pflug in Thomson & Pflug and *Triporopollenites* Pflug in Thomson & Pflug. The shape of the amb and germinal structures differentiate the genus from juglandaceous pollen (Krutzsch, 1968).

Labrapollis granulatus (Simpson) n. comb.

Plate 14, Figure 13

Engelhardtia granulata Simpson, 1961, p. 445, pl. 14, figs. 3, 4 (basionym).

Triatriopollenites granulatus (Simpson) Leffingwell, 1971, p. 51, pl. 10, figs. 8, 9.

Engelhardtioidites granulatus (Simpson) Srivastava, 1975a, p. 139, pl. 8, fig. 10, pl. 9, figs. 1-3.

Description of North Dakota Specimens

Triporate pollen, oblate, amb circular to weakly subtriangular, when amb is subtriangular, grains tend to be planaperturate; equatorial diameter 17.0-(19.5)-21.0 μm (n = 12). Exine tectate, about 0.7 μm thick, sexine and nexine about equal in thickness, columellate layer indistinct; sculpture scabrate, scabrae about 0.5 μm diameter, evenly spaced about 0.5 μm apart. Pores lolongate, equatorial, slightly aspidate about 2.0 μm in latitudinal diameter, extend about 2 μm onto each polar hemisphere. Pores atriate, atria begin 1.5-2.0 μm from the pore, nexine thickens slightly adjacent to atrium. On one polar hemisphere, ovoid areas of thin nexine(?) 5-6 μm in diameter are positioned directly poleward of each pore, normally thickened exine at the pole results in a triradiate pattern on hemisphere.

Discussion

Comments. Specimens here assigned to *Labrapollis granulatus* are all somewhat smaller than originally described for the species by Simpson (1961), a feature also noted by Leffingwell (1971) for specimens from east-central Wyoming. *Triatriopollenites* Pflug in Pflug & Thomson is diagnosed as having a triangular amb with equatorial pores located at the corners. *Labrapollis granulatus* never meets those criteria, and therefore assignment to *Triatriopollenites* (Leffingwell, 1971) is inappropriate.

Srivastava (1975a) transferred this species to *Engelhardtioidites* Potonié, Thomson & Thiergart 1950. However, that genus is angulaperturate and is not diagnosed as having "plicae" over one of the poles. Also, *Engelhardtioidites* has been considered a junior synonym of *Momipites* (Nichols, 1973). Thus, *Labrapollis* appears to be a more appropriate assignment.

Krutzsch (1968) assigned pollen of similar morphology to *Labrapollis globosus* (Pflug in Thomson & Pflug 1953) Krutzsch 1968. The original illustrations of *L. globosus* (Thomson and Pflug, 1953, pl. 8, figs. 76, 77) indicate pollen of similar size and outline and possessing similar atria, but the areas of thinned exine on one pole are not evident and the exine is described as smooth. However, two of the specimens illustrated by Krutzsch (1968, pl. 1, figs. 32-34) appear to be conspecific with *L. granulatus*.

Triporopollenites tectus Newman, 1965 is similar in many respects to *L. granulatus*, but is reported as being somewhat smaller (range 14-16 μm, average 15 μm). Leffingwell (1971) reported a size range for *L. granulatus* of 15.5-24.0 μm. If the greater size range is considered, *T. tectus* is probably a junior synonym of *L. granulatus*.

Simpson (1961) considered this species to have affinities with *Engelhardtia* (Juglandaceae). However, Nichols & Brown (1992) considered the species to lack typical juglandaceous characters.

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation; *Labrapollis granulatus* was recorded in about 33 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 3.2 percent.

Previous Records. Tertiary, western Scotland (Simpson, 1961); Tullock Member of Fort Union Formation, Powder River Basin, Wyoming (Nichols and Brown, 1992); Fort Union Formation of northwestern South Dakota (as *Tiliapollenites indubitabilis* Potonié 1934) (Gerhardt, 1958); upper Lance Formation and Fort Union Formation, east-central Wyoming (Leffingwell, 1971); Paleocene portion of the Raton Formation, Colorado and New Mexico (Fleming, 1990); Maastrichtian of Scotland (Srivastava, 1975); and Tongue River Formation, Powder River Basin of Montana and Wyoming (Pocknall, 1987).

Illustrated Specimen. Plate 14, Figure 13: UND-PC A2879-1, 15.6 mm across X 17.6 mm up.

Labrapollis sp.

Plate 14, Figure 17

Description of North Dakota Specimens

Triporate pollen, oblate, amb nearly circular, diameter 10.0-(11.0)-12.2 μm (n = 8). Exine about 0.5 μm thick, stratification of two layers closely appressed although indistinct in some specimens. Plicae present on both polar hemispheres, plicae about 1.5 μm wide, extend across the poles, join at equatorial interporia, central non-thickened polar island about 2.8 μm in diameter present. Pores equatorial, about 1.6 μm in diameter; annulate, annuli about 1.0 μm thick, extend about 1.5 μm from apertures, appear to be formed by thickening of both sexine and nexine; nexine stops 0.5-1.0 μm from pores, forming a small atrium.

Discussion

Comments. *Engelhardtioidites minutus* Newman 1965 is triporate and of similar size to *Labrapollis* sp., but it appears to have more distinctly notched pores that lack an annulus, and lacks distinct plicae and the area of thinned polar exine.

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2822, A2873, A2829, A2830, A2841, A2874, A2919, A2880, A2883, A2984, A2985, A2851, A2852, A2853, A2857, A2858, A2861, and A2862. Uncommon; maximum relative abundance in any sample is 7.4 percent.

Previous Records. I have not noted any published records of fossil pollen conspecific with *Labrapollis* sp.

Illustrated Specimen. Plate 14, Figure 17: UND-PC A2879-2, 9.9 mm across X 13.2 mm up.

Genus *Momipites* Wodehouse 1933 emend. Nichols 1973

Momipites Wodehouse, 1933, p. 511.

Engelhardtiapollenites Raatz, 1937, p. 20 (*nom. nud.*).

Engelhardtioidites Potonié, Thomson, & Thiergart, 1950, p. 51 (*nom. nud.*).

Triatriopollenites Thomson and Pflug, 1953, p. 76 (*pars*).

Engelhardtioidites Potonié, Thomson, & Thiergart ex Potonié, 1960, p. 118.

Maceopolipollenites Leffingwell, 1971, p. 29.

Momipites Wodehouse emend. Nichols, 1973, p. 106.

Plicatopollis Krutzsch 1962 emend. Frederiksen & Christopher, 1978, p. 133 (*pars*).

Type species: *Momipites coryloides* Wodehouse 1933

Generic Diagnosis

"Triporate pollen, rarely with two or four pores; oblate to suboblate; amb generally semiangular to subangular. Pores located equatorially, circular to meridionally elongate, with distinct atrium, non-aspidate. Exine about 1-1.5 microns in thickness; psilate to faintly scabrate or foveolate. Exine with or without various structural modifications; thinning or triradiate thickening at poles, random or non-random folding. Size variable in different species, about 15-40 microns" (Nichols, 1973, p. 106).

Discussion

Nichols (1973) emended *Momipites* Wodehouse to include juglandaceous pollen bearing general similarities to the modern *Engelhardtia-Alfaroa* group, specifically including species that have exinal thickening or thinning on one pole. The genus *Maceopolipollenites* Leffingwell 1971, which had been erected to contain species with polar exinal thin areas, was absorbed within *Momipites* by this emendation. Frederiksen and Christopher (1978) emended *Plicatopollis* Krutzsch to include those species, previously within *Momipites*, that have triradiate polar exinal modifications. Their emendation, which specifies triatriate pollen with granulate sculpture, may exclude *Plicatopollis plicatus* (Potonié 1934) Krutzsch 1962, the type species of *Plicatopollis*, as Potonié's original description indicates punctate sculpture. Nichols and Ott (1978) considered the species assigned to *Plicatopollis* by Frederiksen and Christopher (1978) to be members of a morphologic continuum within *Momipites* and argued for their retention within *Momipites*, especially with regard to the uncertainty of the holotype of *Plicatopollis*. Their recommendation is followed here.

Momipites waltmanensis Nichols & Ott 1978

Plate 14, Figure 20

Momipites waltmanensis Nichols & Ott, 1978, p. 102, pl. 1, figs. 5-8.

Description of North Dakota Specimens

Triporate pollen, oblate, amb triangular, apices rounded, sides slightly to distinctly concave, angulaperturate; equatorial diameter 19.5-(21.6)-25.0 μm (n = 6). Exine 0.8 to 1.0 μm thick, two-layered, columellate layer not resolvable, nexine very thin; exine may thicken slightly toward apertures, but distinct annulus or tumescence lacking; sculpture of sparse, evenly distributed scabrae about 0.5 μm in diameter and about 1.0 μm apart; diffuse thinning of exine present on at least one pole. Pores equatorial, lolongate, well notched into amb, 1.0 to 1.5 μm in equatorial dimension, extending poleward about 2.0 μm; pores atriate, atria 8-12 μm in diameter.

Discussion

Comments. *Momipites waltmanensis* is distinguished from *M. wyomingensis* by having a concave to straight-sided amb and smaller modal diameter. Nichols and Ott (1978) specifically stated that no exinal polar modifications are present in this taxon, but their illustrations, including the holotype, show diffuse polar thinnings such as are evident in specimens encountered in this study. *M. waltmanensis* is distinguished from *M. leffingwellii* by the distinct circumpolar ring of thinned exine that is present in *M. leffingwellii*.

The holotype of *Momipites microfoveolatus* (Stanley 1965) Nichols 1973 (originally described as *Engelhardtia microfoveolata* by Stanley, 1965, pl. 45, figs. 8-10) is very similar to *Momipites waltmanensis* with the exception that it is described as having foveolate sculpture. The sculpture pattern is not discernible on the illustrations of the holotype, although one of the isotypes appears to have scabrate sculpture. The strata included in this study are geographically and stratigraphically close to the stratum from which the holotype of *M. microfoveolatus* was recovered (Cannonball Member of the Fort Union Formation in northwestern South Dakota). No specimens assignable to *Momipites* having foveolate sculpture have been discovered yet, suggesting that the sculpture of *M. microfoveolatus* may have been misinterpreted, or possibly based upon degraded specimens. Reinspection of the holotype and isotypes, or at the very least a topotypic study of *M. microfoveolatus*, is in order. Because of the uncertainty of the morphology of *M. microfoveolatus*, *M. waltmanensis* is not placed into synonymy with it at this time.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *M. waltmanensis* was recorded in over 25 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 2.4 percent.

Previous Records. Fort Union Formation, central Wyoming (Nichols and Ott, 1978); Tongue River and Sentinel Butte Formations of North Dakota (as *Momipites coryloides*) (Robertson, 1975); Tullock Member of Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); probable record from the Ludlow and Cannonball Members of the Fort Union Formation of northwestern South Dakota (Stanley, 1965) (see comments above); probable record from the Paleocene portion of the Coalspur Formation, Alberta (as *M. microfoveolatus*) (Jerzykiewicz and Sweet, 1986); and Tongue River Formation, Powder River Basin of Wyoming and Montana (Pocknall, 1987).

Illustrated Specimen. Plate 14, Figure 20: UND-PC A2817-3, 7.0 mm across X 4.4 mm up.

Momipites leffingwellii Nichols & Ott 1978

Plate 14, Figures 15, 16

Maceopolipollenites tenuipolus (Anderson) auct. non Leffingwell, 1971, p. 31, pl. 7, fig. 4.

Momipites leffingwellii Nichols & Ott, 1978, p. 103, 104, pl. 1, figs. 27-30.

Description of North Dakota Specimens

Triporate pollen, oblate, angulaperturate, amb triangular, broadly rounded apices, sides straight to slightly concave; equatorial diameter 19.0-(21.3)-24.0 μm (n = 34). Exine about 0.7 μm thick, endexine very thin, columellate layer not evident; sculpture sparsely scabrate, scabrae less than 0.5 μm in diameter; ring-shaped area of thinned exine present on one pole, entire ring about 9 μm in diameter, thinned area about 1.7 μm wide. Pores lolongate, about 1.2 μm wide, well notched into amb; pores atriate, atria begin about 5 μm from pores.

Discussion

Comments. *Momipites leffingwellii* is distinguished from similar species of *Momipites* by its straight- to concave-sided amb and the circumpolar ring of thinned exine that is present on one pole. Nichols and Ott

(1978) assigned the specimen ascribed to *Momipites* (*Maceopolipollenites*) *tenuipolus* by Leffingwell (1971) to *Momipites leffingwellii*. Leffingwell included an illustration of a single specimen that is conspecific with *M. leffingwellii* (see additional comments under *M. tenuipolus*).

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *M. leffingwellii* was recorded in about 50 percent of the productive samples (see Plate 3). Common; maximum relative abundance in any sample is 7.3 percent.

Previous Records. Fort Union Formation, zones P1 to P3, Wind River Basin of Wyoming (Nichols and Ott, 1978); and Fort Union Formation of east-central Wyoming (as *Maceopolipollenites tenuipolus*) (Leffingwell, 1971); probable record from the Ludlow and Cannonball Members of Fort Union Formation, northwestern South Dakota (as *Engelhardtia microfoveolata*, pl. 45, fig. 13 only) (Stanley, 1965).

Illustrated Specimens. Plate 14, Figure 15: UND-PC A2958-4, 14.7 mm across X 6.5 mm up. Plate 14, Figure 16: UND-PC A2829-4, 7.7 mm across X 13.5 mm up.

Momipites tenuipolus Anderson 1960

Plate 14, Figure 18

Momipites tenuipolus Anderson, 1960, p. 25, pl. 7, fig. 14, pl. 8, figs. 14, 15.

Maceopolipollenites tenuipolus (Anderson) auct. non Leffingwell, 1971, p. 31, pl. 7, fig. 4.

Engelhardtia tenuipolus (Anderson) Elsik, 1968b, p. 600, pl. 16, figs. 3, 4, 6, 8.

Engelhardtioidites tenuipolus (Anderson) Srivastava, 1972, p. 248, pl. 11, figs. 7, 8.

Description of North Dakota Specimens

Triporate pollen, oblate, angulaperturate, amb triangular, sides slightly convex, apices well rounded, equatorial diameter 20.5-(22.5)-26.0 μm (n = 7). Exine tectate, about 1.0 μm thick, sexine about twice the thickness of nexine, columellate layer not clearly evident; sculpture sparsely scabrate, scabrae 0.5-1.0 μm apart, about 0.3 μm in diameter. Pores lolongate, deeply notched into amb, about 1.5 μm wide; endexine stops about 5 μm from pore, forming broad, arcuate atrium about 9 μm in diameter. Area of thinned exine present on one pole, ranging in shape from circular with diffuse margins, to trilobate, to ring shaped.

Discussion

Comments. *Momipites anellus* Nichols & Ott has a larger modal equatorial diameter and the polar ring is more distinct, *M. leffingwellii* Nichols & Ott has concave sides, and *M. marylandicus* (Groot & Groot) Nichols 1973 appears to have more distinctly scabrate sculpture and more convex sides (see re-illustration of holotype in Frederiksen and Christopher [1978, pl. 1, fig. 32]) (Nichols and Ott, 1978).

Nichols and Ott (1978) stated that *Momipites tenuipolus* may have a polar thinning or a diffuse polar ring, but never a distinct polar ring. Specimens assigned to *M. tenuipolus* by Nichols and Brown (1992) are similar to specimens here assigned to the species in both convexity of the amb and distinctness of polar ring. Nichols (1973, pl. 1, figs. 20, 21) included specimens possessing a trilobate polar thin area.

Occurrences. *Momipites tenuipolus* was combined with the morphologically similar *Momipites* cf. *M. anellus* in the numerical analysis. These species were recorded in the Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation. The two species were recorded in nearly 50 percent of the productive samples, but generally not in high relative abundance (see Plate 3). Uncommon; maximum relative abundance in any sample is 11.8 percent.

Previous Records. Ludlow Member of the Fort Union Formation, northwestern South Dakota (as *Momipites coryphaeus* (Potonié)) (Gerhard, 1958); Nacimiento Formation, New Mexico (Anderson, 1960); Ludlow Member of the Fort Union Formation, northwestern South Dakota (as Juglandaceae, *Incertae sedis* [Th-29], pl. X, figs. 114, 115) (Trotter, 1963); Wilcox Group (Paleocene) of Texas (Nichols, 1973); Tullock Member of Fort Union Formation, Powder River Basin of Wyoming (Nichols and Brown, 1992); upper Moreno Formation (Maastrichtian-Danian), California (Drugg, 1967); Tullock Formation, northeastern Montana (Hotton, 1988); Hell Creek Formation of North Dakota (Bergad, 1974); Edmonton and Paskapoo Formations, Alberta (Snead, 1969); Oak Hill Member of Naheola Formation (Paleocene), Alabama (Srivastava, 1972); Paleocene portion of Raton Formation, Colorado and New Mexico (Fleming, 1990); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); Silverado Formation (Paleocene), California (Gaponoff, 1984); Ravenscrag Formation, southern Saskatchewan (Jarzen, 1982); Paleocene of the Mississippi Embayment (Tschudy, 1971); and Paleocene and lower Eocene of the Mississippi Embayment (R. Tschudy, 1973).

The *Momipites tenuipolus* group of Frederiksen and Christopher (1978) included specimens with a polar ring of thinned exine. Specimens that are probably conspecific with *M. tenuipolus* Anderson (see plate 1, fig. 28) are present in the lower Paleocene interval (Midwayan) from South Carolina. The specimen illustrated by Leffingwell (1971, pl. 7, fig. 4) as *Maceopolipollenites tenuipolus* is assignable to *Momipites leffingwellii* (Nichols and Ott, 1978). However, Nichols and Brown (1992) acknowledged that *M. tenuipolus* was probably also present in Leffingwell's study of the Fort Union Formation in east-central Wyoming.

Illustrated specimens. Plate 14, Figure 18: UND-PC A2954-4, 13.8 mm across X 11.0 mm up. Plate 14, Figure 19: UND-PC A2998-1, 15.6 mm across X 17.8 mm up.

Momipites ventifluminis Nichols & Ott 1978

Plate 15, Figure 1

Momipites ventifluminis Nichols & Ott 1978, p. 102, pl. 1, figs. 9-14.

Description of North Dakota Specimens

Triporate pollen, oblate, amb subtriangular, sides convex, angulaperturate; equatorial diameter 21.0-(23.6)-24.5 μm (n = 4). Exine of two layers closely appressed, about 1.0 μm thick, endexine very thin, distinct columellate layer lacking; sculpture or sparse scabrae less than 0.5 μm in diameter, scabrae spaced 1.0-1.2 μm apart; three circular areas of thinned exine present on one(?) pole, each thinned area 7-8 μm in diameter, partially coalesced over pole; thinned areas located in interporia regions, oriented about 60 degrees from pores. Pores lolongate, equatorial, well notched into amb, about 1.5 μm wide; atriate, atria about 11 μm in diameter; pores bordered by slight tumescence.

Discussion

Comments. Specimens here assigned to *Momipites ventifluminis* agree in nearly all respects with the original description of Nichols and Ott (1978), except that the polar thinned areas are somewhat larger.

Occurrences. Slope Formation, sample UND-PC A2998. Rare.

Previous Records. Fort Union Formation, central Wyoming (Nichols and Ott, 1978); upper portion (Paleocene) of Raton Formation, Colorado and New Mexico (Fleming, 1990).

Illustrated Specimens. Plate 15, Figure 1: UND-PC A2998-1, 12.9 mm across X 8.9 mm up.

Momipites cf. *M. anellus* Nichols & Ott 1978

Plate 15, Figures 2-4

Momipites anellus Nichols & Ott 1978, p. 103, pl. 1, figs. 22-25.

Description of North Dakota Specimens

Triporate pollen, oblate, amb subtriangular, sides convex, angulaperturate; equatorial diameter 19.5-(23.2)-29.0 μm (n = 32). Exine of two layers closely appressed, about 1.0 μm thick, endexine very thin, columellate layer not evident; sculpture sparsely scabrate, scabrae about 0.5 μm in diameter, spaced 0.5-1.0 μm apart; a ring of thinned exine present on one(?) pole, ring about 12 μm in diameter, 2-3 μm wide, polar island of normally thickened exine about 7 μm in diameter. Pores equatorial, lolongate, notched into amb, about 2 μm in wide; atriate, atria about 10 μm in diameter; slight tumescence borders pores.

Discussion

Comments. *Momipites anellus* is distinguished from similar species of *Momipites* by its modal diameter, convex-sided amb, and distinct circumpolar ring of thinned exine (Nichols and Ott, 1978). The North Dakota specimens are comparable in size and shape of the amb, but the circumpolar ring tends to be somewhat more diffuse and is commonly triangular. In some specimens, the circumpolar ring appears to consist of thinned areas, such as are present in *M. ventifluminis*, that are interconnected by diffuse exinal thin areas.

Occurrences. *Momipites* cf. *M. anellus* was combined in the quantitative analysis with *M. tenuipolus*. Separate records of the occurrence of this species were not maintained.

Previous Records. *Momipites anellus* has been reported from the Fort Union Formation, central Wyoming (Nichols and Ott, 1978); and Paleocene portion of the Raton Formation, Colorado and New Mexico (Fleming, 1990).

Illustrated Specimens. Plate 15, Figure 2: UND-PC A2846.1-4, 11.2 mm across X 6.8 mm up. Plate 15, Figure 3: UND-PC A3001-1, 14.4 mm across X 16.1 mm up. Plate 15, Figure 4: UND-PC A2954-4, 13.8 mm across X 11.0 mm up.

Genus *Triatriopollenites* Pflug in Thomson & Pflug 1953

Triatriopollenites Pflug in Thomson & Pflug, 1953, p. 76.

Type Species: *Triatriopollenites rurensis* Pflug in Thomson & Pflug 1953

Generic Diagnosis

"Triporate pollen; amb triangular, corners ± rounded, but never circular; pores equatorial, at the corners; pores always with atrium, never with vestibulum or postvestibulum; isopolar; pore canal index less than 0.3; pore canal cylindrical, never beak-shaped; no interloculum or solutions-meridium, oculus praevestibulum or endanulus; often with anulus or labrum" (Thomson and Pflug, 1953, p. 76, translated in Jansonius and Hills, 1983).

Triatriopollenites subtriangulus (Stanley) Frederiksen 1979

Plate 15, Figure 6

Carpinus subtriangula Stanley, 1965, p. 291, pl. 43, figs. 12-16.

Triporopollenites subtriangula (Stanley) Oltz, 1969, p. 141, pl. 41, fig. 101.

Triatriopollenites subtriangulus (Stanley) Frederiksen, 1979, p. 151, pl. 2, figs. 19-22.

Description of North Dakota Specimens

Triporate (rarely tetraporate or pentaporate) pollen, oblate, amb subtriangular, sides distinctly convex; equatorial diameter 18.0-(28.9)-36.5 μm (n = 17). Exine tectate, about 1.0 μm thick, sexine about twice as thick as nexine, columellate layer thin, but distinct in optical section; sculpture psilate to finely infrascabrate. Pores circular to slightly lolongate, 3-4 μm in diameter, slightly labrate, some specimens with weak ektannulus that appears to consist primarily of thickening of the footwall layer; endexine stops about 3-4 μm from pore, forming an atrium about 8 μm in diameter; in some specimens, endexine separates slightly from ektexine at edge of atrium, forming small interloculum; due to folding, one or more pores appear slightly subequatorial in some specimens.

Discussion

Comments. *Triatriopollenites subtriangulus* is distinguished from similar species of triporate pollen by its convex triangular amb, nearly smooth sculpture, and pore structure. Although Stanley (1965, p. 292) made no mention of atriate pore structures and excluded grains with thickened pore margins, his illustrated specimens (pl. 43, figs. 12-16) appear to have pore structures similar to those of specimens here assigned to *T. subtriangulus*.

Triporopollenites maximus Norton in Norton & Hall 1969 is very similar to *Triatriopollenites subtriangulus* but is described as having a smaller size range (18-24 μm). Specimens assigned by Norton and Hall (1969) to *Triporopollenites granilabratus* (Stanley) Nichols & Brown 1992 (as *Triatriopollenites granilabrata* (Stanley) Norton) are probably conspecific with *T. subtriangulus*.

Nichols and Brown (1992) considered this species to compare with the pollen of the Myricaceae. Frederiksen (1979) compared this species to the pollen of *Comptonia* (Myricaceae).

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation; *T. subtriangulus* was recorded in about 90 percent of the productive samples (see Plate 3). Abundant; maximum relative abundance in any sample is 25.1 percent.

Previous Records. Cannonball and Ludlow Members of Fort Union Formation, northwestern South Dakota (Stanley, 1965); Aquia Formation and Marlboro Clay (Paleocene), northeastern Virginia (Frederiksen, 1979); Tullock Member of Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); Paskapoo Formation, Alberta (Snead, 1969); Paleocene and Maastrichtian portions of the Coalspur Formation, Canada (as part of Betulaceae-Myricaceae pollen; illustrated specimen, pl. 3, fig. 3, appears conspecific) (Jerzykiewicz and Sweet, 1986); and Tullock and Lebo Formations, northeastern Montana (Oltz, 1969); probable record from the Porters Creek Clay (Paleocene), south-central Arkansas (as *Triatriopollenites* sp., pl. 1, fig. 13) (Jones, 1962).

Illustrated Specimen. Plate 15, Figure 6: UND-PC A2931-3, 16.1 mm across X 8.1 mm up.

Genus *Triporopollenites* Pflug & Thomson in Thomson & Pflug 1953

Triporopollenites Pflug & Thomson in Thomson & Pflug, 1953, p. 82.

Type Species: *Triporopollenites coryloides* Pflug & Thomson in Thomson & Pflug 1953

Generic Diagnosis

"Triporate pollen; amb ± triangular-rounded triangular, never circular; pores equatorial, at the corners, never with atrium, vestibulum or post-vestibulum; endexine and ektexine always tightly appressed; endoporus less than three times the exoporus; isopolar; pore canal less than 0.3, cylindrical, never beak-shaped; no interloculum, solutions-wedge, oculus, praevestibulum endanulus; occasionally with anulus or labrum" (Thomson and Pflug, 1953, p. 82, translated in Jansonius and Hills, 1976, card 3962).

Triporopollenites granilabratus (Stanley) Nichols & Brown 1992

Plate 15, Figures 5, 7, 10

Corylus granilabrata Stanley, 1965, p. 293, pl. 43, figs. 17-28.

non *Triatriopollenites granilabratus* (Stanley) Norton in Norton & Hall, 1969, p. 40, pl. 5, fig. 18.

Casuarinidites granilabratus (Stanley) Srivastava, 1972, p. 243, 244, pl. 9, figs. 1-12, pl. 10, figs. 1-4.

Triporopollenites granilabratus (Stanley) Nichols & Brown, 1992 p. 26, pl. 9, figs. 1, 2.

Description of North Dakota Specimens

Triporate pollen, oblate, amb triangular with convex sides; equatorial diameter 17.0-(23.6)-30.5 μm (n = 18). Exine tectate, 0.5-1.0 μm thick; nexine very thin, recognizable only near apertures; sculpture densely scabrate. Pores equatorial, 1.5-2.0 μm diameter, distinctly labrate, slight annulus present in some specimens; columellate layer thickens in labrum, lengthened columellae push footwall and endexine inward. Endopore the same size or slightly larger than exopore, but distinct atrium lacking in most specimens.

Discussion

Comments. *Triporopollenites granilabratus* is distinct from *Triporopollenites infrequens* by possessing pores with smaller (rather than well developed) annuli and less pronounced labra. *Casuarinidites pulcher* (Simpson) Srivastava 1972 is similar, but lacks distinctly labrate pores. Specimens attributable to *C. pulcher* were encountered in this study, but are rare and are combined with *T. granilabratus* in the quantitative results.

Srivastava (1972) transferred this species to *Casuarinidites*, but Frederiksen (1988) concluded that the North American species of this morphology are inappropriately assigned to *Casuarinidites* and should be transferred to *Triatriopollenites* and *Triporopollenites*. Frederiksen and Christopher (1978) considered *T. granilabratus* to be a junior synonym of *Triatriopollenites convexus* Groot & Groot 1962. However, the pores of *T. convexus* are described as atriate and the illustrated specimens do not show the presence of elongated columellae within the labra. Frederiksen (1988) considered *T. granilabratus* to be atriate, a feature that is not consistently present in the specimens encountered in this study. The nexine of this species is very thin, and the presence of atriate pores in some specimens can probably be attributed to differences in preservation. The primary condition of the grains is interpreted to be non-atriate, and the assignment by Nichols & Brown

(1992) to *Triporopollenites* is followed here. Fleming (1990) suggested possible botanical affinities with the Betulaceae and noted that the species is likely to occur in most palynomorph assemblages, consistent with anemophilous pollen distribution.

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation. This species was recorded in about 75 percent of the productive samples (see Plate 3). Abundant; maximum relative abundance in any sample is 15.9 percent.

Previous Records. Ludlow Member of Fort Union Formation, northwestern South Dakota (Stanley, 1965); Tullock Member of the Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); Oak Hill Member of the Naheola Formation (Paleocene), Alabama (Srivastava, 1972); Cretaceous and Paleocene portions of the Raton Formation, Colorado and New Mexico (Fleming, 1990); and Rockdale Formation, Texas (as *Triporopollenites bituitus* Potonié [in part]) (Elsik, 1968b); probable record from the Porters Creek Clay (Paleocene), south-central Arkansas (as *Triatriopollenites* sp., pl. 1, fig. 15) (Jones, 1962).

Illustrated Specimen. Plate 15, Figure 5: UND-PC A2860-4, 11.2 mm across X 12.1 mm up. Plate 15, Figure 7: UND-PC A2876-1, 22.0 mm across X 7.6 mm up. Plate 15, Figure 10: UND-PC A2878-3, 9.1 mm across X 7.6 mm up.

Triporopollenites infrequens (Stanley) Frederiksen 1988

Plate 15, Figure 9

Betula infrequens Stanley, 1965, p. 290, pl. 43, figs. 7-11.

Betulaceoipollenites infrequens (Stanley) Oltz, 1969, p. 140, pl. 41, fig. 115.

Betulaecoipollenites infrequens (Stanley) Rouse & Srivastava, 1972, p. 1179, fig. 64.

Triporopollenites infrequens (Stanley) Frederiksen, 1988, p. 49.

Description of North Dakota Specimens

Triporate pollen, oblate, amb nearly circular, pores strongly aspidate; equatorial diameter 19.0-(23.5)-27.0 μm (n = 12). Exine tectate, about 1.5 μm thick; nexine and columellate layers thin, columellae lengthen and become distinct in labrum; tectum about 1.0 μm thick; sculpture finely scabrate. Pores circular to lolongate, about 1.5-2.0 μm in equatorial diameter; sexine flexes out to form strong labrum and reflexes into pore, weak annulus typically present; some specimens atriate.

Discussion

Comments. Stanley (1965) described *Triporopollenites infrequens* as being vestibulate, although the illustrated specimens do not clearly show vestibulae, but rather have labrae containing elongated columellae. Frederiksen (1988, p. 49) considered the genotype of *Betulaceoipollenites* Potonié 1960 to be triatriate, and therefore a probable synonym of *Triatriopollenites*.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; recorded in about 33 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 2.1 percent.

Previous Records. Ludlow Member of Fort Union Formation, northwestern South Dakota (Stanley, 1965); Aquia, Marlboro and Nanjemoy Formations (Paleocene and Eocene), northeastern Virginia (Frederiksen, 1979); Tullock Member of Fort Union Formation, Powder River Basin (Nichols and Brown, 1992); Tullock Formation, northeastern Montana (Oltz, 1969); Eocene of the eastern Gulf Coast (as part of *Triporopollenites palaeobetuloides* group) (Frederiksen, 1988); upper and lower Paleocene of South Carolina (Frederiksen, 1980); and Rockdale Formation (Paleocene), Texas (as *Triporopollenites bituitus* [in part]) (Elsik, 1968b).

Illustrated Specimen. Plate 15, Figure 9: UND-PC A2878-3, 6.7 mm across X 0.4 mm up.

Genus *Ulmipollenites* Wolff 1934 emend. Srivastava 1969

Ulmi-pollenites Wolff, 1934, p. 75.

Ulmus-pollenites Raatz, 1937, p. 17.

Ulmoidites Potonié, Thomson, and Thiergart, 1950, p. 57.

Polyporopollenites Pflug in Thomson and Pflug, 1953, p. 90, 91.

Ulmipollenites Wolff 1934 emend. Potonié, 1960, p. 131.

Ulmoideipites Anderson, 1960, p. 20.

Ulmipollenites Wolff 1934 emend. Srivastava, 1969a, p. 981, 982.

Type species: *Ulmipollenites undulosus* Wolff 1934, p. 75.

Generic Diagnosis

Pollen "having slightly undulate to rugulate sexine" (Srivastava, 1969, p. 47).

Discussion

Srivastava (1969) placed *Ulmoideipites* into synonymy with *Ulmipollenites* because the two genera do not differ significantly. His emendation did not completely reformulate the diagnosis of the genus, and he apparently intended the diagnosis to include pollen grains with 5 pores as in Wolff's (1934) original diagnosis. In addition, pollen having weakly verrucate sculpture are not specifically included in the diagnosis. Thus, *Ulmipollenites* remains in need of further emendation. Sweet (1986) retained the two genera, noting that *Ulmoideipites* included pollen with verrucate sculpture that are not included in *Ulmipollenites*. The pollen grains here assigned to *Ulmipollenites* have sculpture that grades from weakly and irregularly rugulate to verrucate. Specimens having weakly rugulate sculpture appear to derive the rugulate pattern by local joining of verrucae. In view of the gradational nature of the sculpture, it seems best to include all of these specimens within a single genus.

Ulmipollenites krempii (Anderson) Frederiksen 1979

Plate 15, Figures 8, 14

Ulmoideipites krempii Anderson, 1960, p. 20, pl. 4, fig. 12; pl. 6, figs. 2, 3; pl. 10, fig. 8.

Carya paleocenica Stanley, 1965, p. 299, pl. 45, figs. 3-7.

Ulmipollenites verrucatus Norton in Norton & Hall, 1969, p. 41, pl. 5, fig. 24.

Ulmipollenites krempii (Anderson) Frederiksen, 1979, p. 154, pl. 3, figs. 6-8.

Description of North Dakota Specimens

Triporate to tetraporate pollen, oblate, amb circular to quadrate with convex sides; equatorial diameter 24-(25.1)-29 μm (4 specimens). Exine about 1 μm thick, tectate, sexine thick, nexine not resolvable, columellate layer thin, but may be evident in optical section along entire wall or only adjacent to pores; sculpture of low verrucae about 2 μm in diameter, verrucae locally joined in some specimens, forming weak, irregular rugulate pattern; pores connected by distinct to diffuse inwardly curving arcus. Pores equatorial, lolongate, about 1.5 X 3 μm in diameter, bordered by slight tumescence.

Discussion

Comments. Anderson (1960) distinguished *Ulmipollenites krempii* from *U. tricostatus* by the more triangular outline and distinct beaded arcus in *U. tricostatus*. Both species were recorded in this study and were combined as *Ulmipollenites* spp. in the quantitative analysis.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *Ulmipollenites* spp. was recorded in about 67 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 14.0 percent.

Previous Records. Ojo Alamo and Naciemiento Formations, New Mexico (Anderson, 1960); Hell Creek and Fort Union Formations, northwestern South Dakota (as *Polyporopollenites ambiguipites*, invalid combination, unpublished) (Stanley, 1960); Cannonball Member of the Fort Union Formation of northwestern South Dakota (as *Carya paleocenica*) (Stanley 1965, p. 299); Marlboro and Nanjemoy Formations of Virginia (Frederiksen, 1979); Tullock Member of Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); Lance and lower Fort Union Formations, east central Wyoming (Leffingwell, 1971); Ravenscrag Formation, southern Saskatchewan (Jarzen, 1982); Tongue River Member of the Fort Union Formation and Wasatch Formation, Powder River Basin of Montana and Wyoming (Pocknall, 1987); Hell Creek Formation, northeastern Montana (as *U. undulosus* Wolff and *U. verrucatus* Norton)(Norton and Hall, 1969); Fox Hills, Hell Creek, Tullock and Lebo Formations, northeastern Montana (as *U. undulosus*) (Oltz, 1969); Paleocene and Maastrichtian portions of the Coalspur Formations (as *U. krempii* and *U. herbridicus*) (Jerzykiewicz and Sweet, 1986); Raton Formation, Colorado and New Mexico (Fleming, 1990); Elko Formation (Eocene), Nevada (as *U. tricostatus*) (Wingate, 1983); Lower Sabinian of South Carolina (Frederiksen, 1980a); Hell Creek Formation, North Dakota (as *U. undulosus*) (Bergad, 1974); Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988); and the Hell Creek, Ludlow, Cannonball, Tongue River, and Sentinel Butte, and Golden Valley Formations, North Dakota (Robertson, 1975).

Illustrated Specimens. Plate 15, Figure 8: UND-PC A2879-2, 3.6 mm across X 14.9 mm up. Plate 15, Figure 14: UND-PC A2970-1, 4.1 mm across X 6.8 mm up.

Tricolpate Pollen

Genus *Cranwellia* Srivastava 1967 emend. Srivastava 1969

Cranwellia Srivastava 1967, p. 537.

Cranwellia Srivastava 1967 emend. Srivastava 1969b, p. 50.

Type Species: *Cranwellia striata* (Couper) Srivastava 1967

Generic Diagnosis

"Isopolar; colpate or colporate pollen, apertures 3 or more than three, angulaperturate, pores conspicuous to inconspicuous, amb triangular with mostly concave or straight and sometimes slightly convex sides, colpi short or long, sometimes reaching the polar area; poles flattened, polar axis compressed, equatorial angular projections well developed giving pollen grains the effect of a three-armed body; sexine tectate, granulate, granules arranged in a linear pattern giving a striate appearance, in polar view striation starting from the middle of each mesocolpium and running across to the middle of the adjacent mesocolpia, striations parallel to each other and perpendicular to the radius, from pole to the apex of each equatorial angular projection (i.e. striae circumbaculate)" (Srivastava, 1969b, p. 50).

Discussion

Scanning-electron microscope studies of Maastrichtian species of *Cranwellia* by Farabee and Canright (1986) showed that the striate sculpture consists of a regular series of smooth ridges or striae, not aligned granules as indicated in Srivastava's emended diagnosis. The diagnosis of the genus should be emended to reflect their observations.

Cranwellia subtilis Sweet 1986

Plate 15, Figures 11, 12

Cranwellia subtilis Sweet, 1986, p. 1379, pl. 1, figs. 11-13.

Description of North Dakota Specimens

Tricolpate pollen grains, subprolate to suboblate; amb triangular, sides slightly concave to slightly convex; in equatorial view, outline more or less rhomboidal; angulaperturate; equatorial diameter of specimens in polar view 24.0-(28.2)-31.0 μm (n = 7); dimensions of specimens in equatorial view 23.5-(24.8)-26.5 (polar diameter) X 16.5-(21.4)-28.4 μm (n = 5). Exine semitectate; about 1.0 μm thick, slightly thicker at poles, nexine very thin; columellae evident in optical section and plan view, more distinct at poles; columellae joined to form striate sculpture, striae predominantly radially directed except in equatorial mesocolpia where they are more or less random in orientation; muri simplibaculate, about 0.5 μm wide, tapering on both ends, individual striae 3-5 μm long; some specimens with granulate sculpture at poles, colpi extend two-thirds to three-fourths of grain radius, gaping in polar view; bordered by band of slightly thickened nexine about 2.5 μm wide, thickened nexine corroded in some specimens.

Discussion

Comments. Specimens of *Cranwellia subtilis* encountered in this study are slightly larger than indicated in Sweet's (1986) original description, but agree well in all other aspects. This species is distinct from other species of the genus by its extremely fine, striate sculpture and generally small size.

Srivastava (1969) compared *Cranwellia* to the extant genus *Elytranthe* of the Loranthaceae. Muller (1981) rejected the comparison to the Loranthaceae and Farabee and Canright (1986) cited additional morphologic evidence for rejecting a botanical affinity with *Elytranthe*.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2939, A2954, A2955, A2956, A2957, A2836, A2842, A2883, A2885, A2960, A2974, A2976, A2977, A2978, A2979, A2982, A2988, A2992, A2994, A2995, A2848, and A2997. Rare; maximum relative abundance in any sample is 2.0 percent.

Previous Records. Paleocene portion of the Coalspur Formation, Alberta (Jerzykiewicz and Sweet, 1986).

Illustrated Specimens. Plate 15, Figure 11: UND-PC A2995-3, 13.0 mm across X 9.4 mm up. Plate 15, Figure 12: UND-PC A2995-3, 26.7 mm across X 15.6 mm up.

Genus *Cupuliferoidaepollenites* Potonié, Thomson & Thiergart 1950 ex Potonié 1960

Cupuliferoidaepollenites Potonié, Thomson & Thiergart, 1950, p. 55, 66.

Cupuliferoidaepollenites Potonié, Thomson & Thiergart 1950 ex Potonié, 1960, p. 92.

Type Species: *Cupuliferoidaepollenites liblarensis* (Thomson in Potonié, Thomson & Thiergart 1950) Potonié 1960

Generic Diagnosis

"Slender ovoid to barrel-shaped (± cylindrical) tricolpate pollen; poles well rounded; exine hyaline, exoexine ± laevigate with faint infratexture" (Potonié, 1960, p. 92; translated in Jansonius and Hills, 1976, card 684).

Cupuliferoidaepollenites microscabratus (Norton) n. comb.

Plate 15, Figures 13, 15

Tricolpopollenites microscabratus Norton in Norton & Hall, 1969, p. 47, pl. 7, fig. 8 (basionym).

Tricolpopollenites nadirus Oltz, 1969, p. 151, pl. 42, fig. 142.

Description of North Dakota Specimens

Tricolpate to tricolporoidate (rarely tetracolpate) pollen, prolate; polar diameter 15.5-(22.8)-26.5 µm, equatorial diameter 14.5-(18.1)-19.5 µm (n = 8). Exine two layered, about 1.0 µm thick, sexine and nexine about equal thickness, but columellate layer not evident; sculpture psilate to weakly infrascabrate. Colpi long, reach well into polar regions, many specimens with slight equatorial flexure and absence or thinning of exine on colpi floors in equatorial area.

Discussion

Comments. Specimens here attributed to *Cupuliferoidaepollenites microscabratus* have a somewhat larger size range than is indicated by the original description (21-23 µm polar diameter). Most specimens have indistinctly two-layered exine, whereas the original description noted that endexine and ektexine were indistinguishable (Norton and Hall, 1969).

The genus *Tricolpopollenites* Pflug & Thomson in Thomson & Pflug 1953 was proposed for prolate to spheroidal, tricolpate pollen grains of variable sculpture. Krutzsch (1959b) contended that the type species *T. parmularius* (Potonié 1934) Thomson & Pflug 1953 is tricolporate. However, ora are not readily evident on the illustrated specimens in Potonié (1934b) and Thomson and Pflug (1953), and some question remains concerning the morphology of the genotype. As other genera are available to accommodate the species included in *Tricolpopollenites*, it seems best to follow the suggestion of Srivastava (1975) and avoid the use of that genus.

Numerous species have been proposed to accommodate prolate, psilate, tricolpate pollen similar to *C. microscabratus*. *Cupuliferoidaepollenites liblarensis* is smaller and tends to be more barrel shaped. *Tricolpopollenites liblarensis fallax* (Potonié) Thomson & Pflug 1953 and *Tricolpopollenites parvulus* Groot & Penney 1960 are also smaller.

Tricolpopollenites leviculus Chmura 1973 is larger and has colpi with ragged margins and expanded ends.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *C. microscabratus* was recorded in most of the productive samples (see Plate 3). Common; maximum relative abundance in any sample is 9.8 percent.

Previous Records. Hell Creek Formation, northeastern Montana (Norton and Hall, 1969); Tullock and Lebo Formations, northeastern Montana (Oltz, 1969); Hell Creek and Tullock Formations, northeastern Montana (as *Cupuliferoidaepollenites* cf. *C. microscabratus*) (Hotton, 1988); Almond Formation, south central Wyoming (Stone, 1973); and the Yazoo Clay (Eocene) of Mississippi (as *Tricolpopollenites* sp.) (Tschudy and Van Loenen, 1970, pl. 4, figs. 1, 7); probable record from the Claiborne, Jackson and Vicksburg Groups (Eocene-lower Oligocene) of Mississippi and Alabama (as cf. *C. liblarensis* [pl. 9, fig. 24]) and cf. *C. selectus*) (Frederiksen, 1980b); Wilcox Group (Paleocene) of Texas (as *Cupuliferoidaepollenites* n. sp. A) (Nichols, 1970).

Illustrated Specimens. Plate 15, Figure 13: UND-PC A2931-3, 11.5 mm across X 13.7 mm up. Plate 15, Figure 15: UND-PC A2820.1-3, 4.7 mm across X 2.6 mm up.

Cupuliferoidaepollenites mutabilis (Leffingwell) Jameossanaie 1987

Plate 15, Figure 16

Tricolpites mutabilis Leffingwell, 1971, p. 44, 45, pl. 8, figs. 1-3.

Cupuliferoidaepollenites mutabilis (Leffingwell) Jameossanaie, 1987, p. 25, pl. 14, figs. 42-44.

Description of North Dakota Specimens

Tricolporoidate (rarely hexacolporoidate) pollen, oblate; equatorial diameter 14.5-(19.2)-25.9 µm (n = 10). Exine tectate, about 0.8 µm thick, sexine and nexine about equal thickness in the mesocolpia; exine distinctly thins to less than 0.5 µm toward colpi, area of thinned exine about 2.5 μm wide at equator, narrower toward poles. Columellate layer distinct in mesocolpia, absent or indistinct toward colpi; sculpture weakly to moderately scabrate in mesocolpia, colpi margins smooth. Colpi reaching about two-thirds distance to poles, closed to gaping; some specimens with narrow costae colpi.

Discussion

Comments. Leffingwell (1971) originally described this species as having tricolpate apertures. Most of the North Dakota specimens assigned to *Cupuliferoidaepollenites mutabilis* are tricolporoidate, and rare specimens have more distinct pores.

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2939, A2940, A2951, A2953, A2954, A2955, A2957, A2958, A2817, A2822, A2873, A2842, A2875, A2882, A2962, A2995, A2862, A2997, and A2999. Uncommon; maximum relative abundance in any sample is 2.3 percent.

Previous Records. Lance and Fort Union Formations, east-central Wyoming (Leffingwell, 1971); Menefee Formation (Mesaverde Group), northern New Mexico (Jameossanaie, 1987); Albian of northern California (Jameossanaie and Lindsley-Griffen, 1993); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988); and Almond Formation, south-central Wyoming (Stone, 1973).

Illustrated Specimen. Plate 15, Figure 16: UND-PC A2871-2, 24.2 mm across X 12.0 mm up.

Genus *Fraxinoipollenites* Potonié 1951 ex Potonié 1960

Fraxinoipollenites Potonié, 1951, p. 277 (nom. nud.).

Fraxinoipollenites Potonié 1951 ex Potonié, 1960, p. 94.

Type Species: *Fraxinoipollenites pudicus* (Potonié) Potonié 1951 ex Potonié 1960

Generic Diagnosis

"Shape elongated ovoid to fusiform; three long colpi without a geniculus or pore; exine granulate to reticulate; outline crenate" (Potonié, 1960, p. 94, translated).

Discussion

Pollen grains here assigned to *Fraxinoipollenites* are distinguished from species of *Tricolpites* by their pronouncedly prolate shape.

Fraxinoipollenites variabilis Stanley 1965

Plate 16, Figure 4

Fraxinoipollenites variabilis Stanley, 1965, p. 306, pl. 45, figs. 29-35.

Description of North Dakota Specimens

Tricolpate to tricolporoidate pollen grains, prolate; dimensions 18.0-(23.9)-30.0 X 10.0-(15.1)-19.5 μm (n = 11). Exine semitectate, about 1.0 μm thick, nexine thin; exine structure of fused clavae; sculpture microreticulate, lumina about 0.5 μm in diameter, circular, evenly sized over entire grain. Colpi long, reach into polar regions, tend to be slightly sinuous, especially at the equator.

Discussion

Comments. *Fraxinoipollenites variabilis* is distinguished from *Tricolp ites hians* on the basis of its more prolate shape and long colpi that reach well into polar regions. Stanley (1965) appears to have included two morphotypes in the original description of the species. The holotype (pl. 45, figs. 29, 30) is prolate with relatively thin exine showing short clavae and straight, slightly open colpi. The isotypes are subprolate with thicker, more distinctly clavi-reticulate exine and long, narrow colpi that are typically sinuous in the equatorial region. The species is used here in the sense of the holotype.

Tricolpopollenites sinuosus Norton in Norton & Hall 1969 may be a junior synonym. That species is described as 28-33 x 15-21 μm, clavireticulate, sinuous colpi with margo; the illustrated specimen does not show adequate detail for confident comparison. Oltz (1969) erected the species *Tricolpopollenites uniformis* for pollen that he admitted are probably conspecific with *F. variabilis*. Stanley (1965) suggested botanical affinities with *Fraxinus*, but Muller (1981) considered this relationship to be unconfirmed. On the basis of DECORANA analysis, Fleming (1990) considered this species to be a common constituent of coal assemblages.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formations. *Fraxinoipollenites variabilis* was recorded in about 50 percent of the palyniferous samples (see Plate 3). Common; maximum relative abundance in any sample is 28.6 per cent.

Previous Records. Ludlow Member of Fort Union Formation, northwestern South Dakota (Stanley, 1965); Lance Formation and Tullock Member of Fort Union Formation, Powder River Basin, Montana and Wyoming (Nichols and Brown, 1992); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); upper Claiborne, Jackson, and lower Vicksburg Groups (Eocene and Oligocene), Alabama and Mississippi (Frederiksen, 1980b); Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988); Fort Union Formation, east-central Wyoming, (Leffingwell, 1971); Tullock and Lebo Formations, northeastern Montana (as *Tricolpopollenites uniformis*) (Oltz, 1969); Maastrichtian and Paleocene portions of the Raton, Colorado and New Mexico (Fleming, 1990); Almond Formation, south-central Wyoming (Stone, 1973); Fredericksburg Group (Albian), Texas and Oklahoma (Srivastava, 1975b); Edmonton Formation, Alberta (Srivastava, 1970); and Paleocene portion of Bonnet Plume Formation, Yukon (Rouse and Srivastava, 1972); probable record from Lebo Formation, northeastern Montana (as *Tricolpopollenites sinuosus*) (Norton and Hall, 1969); probable record from the Ravenscrag Formation, southern Saskatchewan (as *Tricolpopollenites* sp. A) (Jarzen, 1982).

Illustrated Specimen. Plate 16, Figure 4: UND-PC A2972-4, 20.3 mm across X 7.9 mm up.

Fraxinoipollenites turonicus (Mtchedlishvili) n. comb.

Plate 16, Figures 1, 2

Menispermum turonicum Mtchedlishvili in Samoilovitch *et al.*, 1961, p. 197, 198, pl. 25, figs. 1-3 (basionym).

Tricolpopollenites turonicus (Mtchedlishvili) Chmura, 1973, p. 119, pl. 25, figs. 1-3.

Tricolpites turonicus (Mtchedlishvili) Rouse and Srivastava, 1972, p. 1179.

Description of North Dakota Specimens

Tricolpate to tricolporoidate pollen, shape subprolate to prolate; dimensions 21.0-(24.8)-27.5 X 14.0-(17.2)-23.0 μm (n = 12). Exine semitectate, about 1.5 μm thick, slightly thicker in polar regions, sexine about equal thickness to nexine; sexine structure of fused clavae; columellate layer distinct in optical section and plan view, about 0.5 μm thick; sculpture reticulate, lumina 0.8-1.0 μm in diameter, circular to elongate; muri about 0.5 μm wide, simplibaculate; sculpture in most specimens fines slightly toward colpi, but not to the poles. Colpi long, extend nearly to poles; equatorial regions of colpi typically have indistinct ragged floors suggestive of oroids, oroids about 4-5 μm in meridional dimension.

Discussion

Comments. The specimens here assigned to *Fraxinoipollenites turonicus* are slightly larger than Siberian protologue specimens (12.7-20.6 X 17.3-22.6 μm) (see Traverse and Ames, 1969, p. 30-79). The North Dakota specimens appear identical to those assigned to the species by Chmura (1973). This species is differentiated from *Fraxinoipollenites variabilis* by its coarser reticulum, slightly larger sexinal structural elements, and the tendency for the exine to thicken at the poles. The reticulum of most specimens grows slightly finer toward the colpi, but not so distinctly as to warrant assignment to the genus *Satishia* Ward 1986.

Occurrences. Slope Formation and the Three V Tongue of the Cannonball Formation; samples UND-PC A2964, A2843, A2846, A2855, A2857, A2861, A2863, A2865, A2868, A2870, A2999, and A3001. Rare; maximum relative abundance in any sample is 2.8 percent.

Previous Records. Upper Cretaceous to Paleocene, western Siberian lowlands (Samoilovitch *et al.*, 1961); Moreno Formation (Maastrichtian), central California (Chmura, 1973); and Maastrichtian portion of the Bonnet Plume Formation, Yukon (Rouse and Srivastava, 1972).

Illustrated Specimens. Plate 16, Figure 1: UND-PC A2843.1-4, 6.9 mm across X 18.9 mm up. Plate 16, Figure 2: UND-PC A2995-1, 11.8 mm across X 8.5 mm up.

Genus *Quercoidites* Potonié, Thomson & Thiergart 1950
ex Potonié 1960 emend. Frederiksen 1980

Quercoidites Potonié, Thomson & Thiergart, 1950, p. 54 (nom. nud.).

Quercoidites Potonié, Thomson & Thiergart 1950 ex Potonié, 1960, p. 92.

Quercoidites Potonié, Thomson & Thiergart 1950 ex Potonié 1960, emend. Frederiksen, 1980a, p. 160.

Type Species: *Quercoidites henrici* Potonié, Thomson & Thiergart 1950 ex Potonié 1960

Generic Diagnosis

"Prolate to subprolate pollen grains, tricolpate, tricolporoidate, or indistinctly tricolporate; exine typically granulate, often finely so; surface of exine rough; columellae often only weakly expressed" (Frederiksen, 1980a, p. 160).

Quercoidites cf. *Q. spissus* Leffingwell 1971

Plate 16, Figure 3

Quercoidites spissus Leffingwell, 1971, p. 45, pl. 8, figs. 6, 7.

Description of North Dakota Specimens

Tricolporoidate to tricolporate pollen, oblate to subprolate; equatorial diameter 15.0-(17.4)-20.5 μm (n = 5). Exine tectate, about 1.0 μm thick in mesocolpia, thinning gradually toward colpi, sexine about twice thickness of nexine; columellae very prominent, up to 1.0 μm in diameter and 0.5 μm high; columellae absent in broad band on colpi margins; tectum very thin, appears as a thin film stretched over ends of columellae, supratectal sculpture psilate; large columellae give grains a granulate appearance; exine surface generally crenulate in optical section. Colpi reach about three-fourths of grain radius, margins smooth. Distinct ora generally lacking although equatorial flexure present in most specimens.

Discussion

Comments. The specimens here referred to *Quercoidites spissus* Leffingwell differ in several aspects from the original description of the species. Leffingwell (1971) described the species as tricolpate although the illustrated specimens are tricolporoidate. The exine of the protologue specimens does not clearly thin toward the colpi, although the sculpture is somewhat reduced, although not as distinctly as in the North Dakota specimens. The thin tectum described here is not evident in the protologue specimens, but that feature is indistinct, and may have been overlooked.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2873, A2841, A2836, A2842, A2876, A2881, A2960, A2967, A2968, A2977, A2978, A2983, A2984, A2985, A2987, A2988, A2992, A2848, A2849, A2853, A2856, A2860, A2864, A2866, A2997, A2998, and, A3000. Uncommon; maximum relative abundance in any sample is 4.5 percent.

Previous Records. *Quercoidites spissus* has been reported from the Lance and Fort Union Formations, east-central Wyoming (Leffingwell, 1971); and Tullock Member of Fort Union Formation, Powder River Basin of Montana (Nichols and Brown, 1992).

Illustrated Specimens. Plate 16, Figure 3: UND-PC A2876-6, 18.6 mm across X 6.8 mm up.

Genus *Retitrescolpites* Sah 1967

Retitrescolpites Sah, 1967, p. 56.

Type Species: *Retitrescolpites typicus* Sah 1967

Generic Diagnosis

"Grains tricolpate or -colporoidate, spheroidal to subspheroidal to rounded triangular; exine retipila(ria)te to sometimes reticulate" (Sah, 1967, p. 56).

Discussion

Sah (1967) differentiated *Retitrescolpites* from *Tricolpites* Cookson emend. Potonié 1960 on the basis of retipilate or retipilariate, coarsely reticulate sculpture in the former genus.

Retitrescolpites anguloluminosus (Anderson) Frederiksen 1979

Plate 16, Figures 5, 6

Tricolpites anguloluminosus Anderson, 1960, p. 26, pl. 6, figs. 15-17, pl. 8, fig. 17.

Tricolpites bathyreticulatus Stanley, 1965, p. 320, 321, pl. 47, figs. 18-23.

Salixipollenites cf. *S. bathyreticulatus* (Stanley) Snead, 1969, p. 34, pl. 1, fig. 8.

Tricolpopollenites anguloluminosus (Anderson) Elsik, 1968b, p. 624, pl. 24, figs. 15, 16, pl. 25, fig. 1.

Retitrescolpites anguloluminosus (Anderson) Frederiksen, 1979, p. 139, pl. 1, figs. 17, 18.

Description of North Dakota Specimens

Tricolpate (rarely tricolporoidate) pollen, oblate to globose, amb subcircular to circular; equatorial diameter 16.0-(26.4)-33.0 μm (n = 15). Exine semi-tectate, 1.0-2.5 μm thick; nexine less than 0.5 μm thick, sexine at least twice as thick as nexine; sculpture coarsely reticulate, lumina typically polygonal, 1.5-3.5 μm in diameter; muri narrow, simplibaculate; muri border colpi such that lumina do not open into the colpi. Colpi gaping, extend one-half to two-thirds grain radius.

Discussion

Comments. Many North American palynologists have maintained *Tricolpites bathyreticulatus* Stanley as a species distinct from *Retitrescolpites anguloluminosus* (Anderson) Frederiksen on the basis that the lumina are smaller in *R. anguloluminosus* (described as "about 2 microns") than in *T. bathyreticulatus* (described as "up to 3 μm"). Measurement of the lumina of the illustrated holotypes and paratypes of both species shows little difference between their diameters. The specimens encountered in the present study show a gradation in size of the lumina from 1.5 to about 3.5 μm with most specimens possessing lumina about 2 μm in diameter. Thus there appears to be no basis on which the two species can be consistently differentiated. The North Dakota specimens suggest that some distinction may be possible based on the height and structure of the muri, but based on the original descriptions, these features cannot be used to differentiate *T. bathyreticulatus* from *R. anguloluminosus*. Further study is required to determine if the type of muri will permit the recognition of two species.

DECORANA analysis by Fleming (1990) determined that *R. angulolumin osus* is characteristic of coal seams, indicating that the parent plant lived in or close to swamps. A similar mode of occurrence is noted in the current study. Jarzen (1982) noted a very close similarity of this form species to *Exbucklandia* of the Hamamelidaceae. *Exbucklandia* is presently restricted in distribution to Asia, Malaysia, and Sumatra. An affinity with *Fraxinus excelsior* Linnaeus was suggested by Stanley (1965), and Farabee and Canright (1986) noted that some members of the Cruciferae produce similar pollen types.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation, *R. anguloluminosus* was recorded in about three-fourths of the productive samples. Abundant; maximum relative abundance in any sample is 33.3 percent.

Previous Records. Ojo Alamo Formation, San Juan Basin, New Mexico (Anderson, 1960); Ludlow and Cannonball Members of Fort Union Formation, northwestern South Dakota (Stanley, 1965); Maastrichtian and Paleocene portions of the Raton Formation, Colorado and New Mexico (Fleming, 1990); Tullock and Lebo Formations, northeastern Montana (Norton and Hall, 1969; Oltz, 1969); Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988); Lance and Fort Union Formations, east-central Wyoming (Leffingwell, 1971); Almond Formation, south-central Wyoming (as *T.* cf. *anguloluminosus*) (Stone, 1973); Ravenscrag Formation, southern Saskatchewan (Jarzen, 1982); upper Moreno Formation (Paleocene), central California (Drugg, 1967); Rockdale Formation (Paleocene), Texas (Elsik, 1968b); Tullock Member of Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); Edmonton Formation, Alberta, Canada (Snead, 1969); Moreno Formation (Maastrichtian), central California (Chmura, 1973); Cimarron Ridge Formation (Upper Cretaceous or younger), Colorado (Dickinson *et al.*, 1978); Wilcox Group (Paleocene), Texas (Nichols, 1970); Silverado Formation (upper Paleocene), southern California (Gaponoff, 1984); upper Paleocene of west-central Georgia (Christopher *et al.*, 1980); upper and lower Paleocene, South Carolina

(Frederiksen, 1980a); and Lance Formation, northeastern Wyoming (Farabee and Canright, 1986).

Illustrated Specimen. Plate 16, Figure 5: UND-PC A2887-2, 18.4 mm across X 19.2 mm up. Plate 16, Figure 6: UND-PC A2878-3, 14.3 mm across X 13.7 mm up.

Genus *Rousea* Srivastava 1969

Rousea Srivastava, 1969b, p. 52.

Type Species: *Rousea subtilis* Srivastava 1969

Generic Diagnosis

"Tricolpate, angulaperturate, colpi, reaching polar area; amb subtriangular or rounded, sides convex; sexine thick, reticulate, lumina larger in mesocolpia becoming smaller at colpi margins and apocolpia" (Srivastava, 1969b, p. 52).

Rousea cf. *R. parvicolpata* (Norton) n. comb.

Plate 16, Figures 7, 8

Tricolpopollenites parvicolpatus Norton in Norton & Hall, 1969, p. 48, pl. 7, fig. 13 (basionym).

Description of North Dakota Specimens

Tricolpate pollen grains, subprolate; dimensions of grains in equatorial view 14.5-(18.5)-21.0 (polar diameter) X 11.0-(15.2)-18.0 μm (n = 9); equatorial diameter of grains in polar view 18.0-(19.3)-20.5 (n = 3). Exine semitectate, about 1.0 μm thick, sexine about twice as thick as nexine; sculpture reticulate, lumina polygonal, up to 1.2 μm in diameter, typically decreasing in diameter toward poles and colpi; exine structure baculate, columellae distinct in plan view; muri narrow, relatively delicate, simplibaculate. Colpi relatively short, one-half to three-fourths of grain length, commonly bordered by smooth, thinned margo.

Discussion

Comments. Specimens here compared to *Rousea parvicolpata* (Norton) n. comb. appear to differ from that species in having a reticulum with more or less equidimensional lumina (originally described as 0.5 X 1 μm wide). The holotype appears to have a very narrow thickened margo, a feature that is present in only a few specimens in the present study. However, the short colpi and relatively coarse sculpture suggest that this species is correctly ascribed. Lack of detail in the original illustration precludes a more confident comparison. *Rousea* cf. *R. parvicolpata* differs from *Rousea* sp. 4 in having short colpi with smooth margins and by lacking a heterobrochate reticulum.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *R. parvicolpata* was recorded in about 80 percent of the productive samples (see Plate 3). Abundant; maximum relative abundance in any sample is 24.5 percent.

Previous Records. *Rousea parvicolpata* has been reported from the Tullock Formation, northeastern Montana (Norton and Hall, 1969; Oltz, 1969); and Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988); probable record from the Edmonton Formation of Alberta (as *Salixipollenites* sp. B) (Snead, 1969, p. 35, pl. 6, figs. 8, 9).

Illustrated Specimens. Plate 16, Figure 7: UND-PC A2878-3, 9.0 mm across X 5.0 mm up. Plate 16, Figure 8: UND-PC A2931-4, 14.4 mm across X 2.3 mm up.

Rousea sp. 1

Plate 16, Figures 9, 10

Description

Tricolpate to tricolporoidate (rarely hexarugate) pollen, most specimens prolate, although polar compressions common; dimensions of prolate specimens 19.5-(22.8)-27.5 X 11.5-(16.2)-20.2 μm (n = 10), equatorial diameter of specimens in polar compression 20.0-(23.0)-28 μm (n = 7). Exine semitectate, about 1.7 μm thick, sexine about twice as thick as nexine; in polar view, exine thins gradually toward colpi; sculpture reticulate, lumina 1.5 to 2.0 μm in diameter in mesocolpia, meridionally elongated; lumina decrease in size to 0.5 μm toward colpi and poles, meridionally oriented striate-reticulate sculpture pattern more pronounced toward colpi and poles; muri about 0.4 μm wide, simplibaculate, narrower adjacent to colpi. Colpi long, reach well into polar area; oroids evident by equatorial flexure and disruption in reticulate-striate pattern.

Discussion

Comments. *Rousea* sp. 1 differs from similar species in its distinctive striate-reticulate sculpture pattern. *Tricolpites hypanthos* Farabee and Canright 1986 has a similar sculpture pattern, but has smaller lumina that fine toward the poles, and not toward the colpi. *Tricolpites obliquimuratus* Chmura 1973 has a similar sculpture pattern of meridionally elongated lumina, but the lumina do not fine toward the poles and the occurrence of colporoidate apertures was not mentioned in the description. Hotton (1988) illustrated specimens that may be conspecific with these as *Tricolpites* cf. *T. obliquimuratus*; however, the illustrated specimens do not clearly show the lumina fining toward the poles.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *Rousea* sp. 1 was recorded in about 25 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 12.5 percent.

Previous Records. Probable record from the Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988).

Illustrated Specimens. Plate 16, Figure 9: UND-PC A2882-4, 5.9 mm across X 10.6 mm up. Plate 16, Figure 10: UND-PC A2943.1-4, 11.2 mm across X 14.3 mm up.

Rousea sp. 2

Plate 16, Figures 11-13

Description

Tricolpate pollen, globose to subprolate, dimensions 14.5-(21.9)-28 X 10.5-17.5)-22.0 μm (n = 20). Exine semi-tectate, about 1.5-2.0 μm thick, thinning gradually toward colpi; sexine 3-4 times as thick as nexine, reti-pilate, pilae distinct, relatively large; lumina diameter up to 2.0 μm in equatorial mesocolpia, decreasing to poles and colpi, generally decreasing to poles only past the ends of colpi; muri 0.5-0.7 μm wide, simplibaculate, columellae distinct in plan view. Colpi long, reaching nearly to poles.

Discussion

Comments. *Rousea* sp. 2 of the present study bears some similarity to *Rousea* sp. 2 in Farabee and Canright (1986), but that species is described as having exine that thins toward the poles. *Rousea georgensis* (Brenner) Dettmann has less distinct pilate exine structure and also has thinner exine at the poles. *Tricolpopollenites clavireticulatus* Norton in Norton & Hall 1969 also has similar size and exine structure, but is more prolate and is characterized by exine that thins at the poles.

This taxon may be divisible into two species. One form (Plate 16, Figures 11, 13) tends to be more prolate and have less distinct reti-pilate exine structure and a distinct fining of the lumina toward the colpi. The other form (Plate 16, Figure 12) tends to be globose to subprolate, has less distinct fining of the lumina toward the colpi, and has more pronounced reti-pilate exine structure.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *Rousea* sp. 2 was recorded in about 33 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 9.3 percent.

Previous Records. I have not noted any published records of fossil pollen conspecific with *Rousea* sp. 2.

Illustrated Specimens. Plate 16, Figure 11: UND-PC A2878-2, 19.1 mm across X 9.1 mm up. Plate 16, Figure 12: UND-PC A2988-3, 20.5 mm across X 1.8 mm up. Plate 16, Figure 13: UND-PC A2846.1-4, 12.3 mm across X 8.5 mm up.

Rousea sp. 3

Plate 16, Figure 14

Description

Tricolpate to tricolporoidate pollen, prolate; polar diameter 22.5-(31.4)-48.0 μm, equatorial diameter 14.0-(19.9)-26.5 μm (n = 17). Exine tectate, about 1.2 μm thick, nexine about 0.5 μm thick; sculpture reticulate to foveoreticulate; typically strongly heterobrochate in mesocolpia, larger lumina in equatorial mesocolpia up to 1.2 μm in diameter, completely bordered by smaller lumina about 0.4 μm in diameter, large lumina gradually decrease in size to about 0.5 μm at poles; lumina also fine abruptly at colpi margins. Colpi long, nearly reaching poles, weak equatorial flexure present in some specimens.

Discussion

Comments. *Rousea* sp. 1 in Farabee and Canright (1986) is of similar size and is heterobrochate, but the size of the lumina does not decrease so distinctly toward the poles. One of the specimens illustrated as *Rousea* spp. by Nichols and Brown (1992, pl. 17, fig. 2) has similar sculpture pattern, but has a distinctly rhomboidal outline in equatorial view.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2959, A2876, A2880, A2885, A2965, A2968, A2978, A2985, A2988, A2989, A2991, A2992, A2994, A2995, A2843, A2855, A2857, A2858, A2865, A2872, A2999, and A3000. Rare; maximum relative abundance in any sample is 1.9 percent.

Previous Records. I have not located any published records of fossil pollen conspecific with *Rousea* sp. 3.

Illustrated Specimen. Plate 16, Figure 14: UND-PC A2978-1, 22.9 mm across X 3.5 mm up.

Rousea sp. 4

Plate 16, Figure 15

Description

Tricolpate pollen, prolate; dimensions of specimens in equatorial view 16.0-(18.9)-25.0 X 12-(14)-17.5 μm (n = 21), equatorial diameter of specimens in polar view 14.0-(17.0)-19.5 μm (n = 7). Exine semitectate, about 1.5 μm thick, sexine slightly thicker than nexine; sculpture reticulate, lumina generally polygonal, up to about 1.5 μm in diameter in equatorial mesocolpia; many specimens slightly heterobrochate with smaller lumina of about 0.5 μm diameter present at junctions of muri; diameter of lumina decreases abruptly adjacent to colpi forming narrow band of small, evenly sized lumina at colpi margins; diameter of lumina decreases slightly to the poles in most specimens, but is difficult to confirm for specimens in equatorial view. Muri narrow, simplibaculate; baculae distinct in plan view, tack-shaped in optical section. Colpi long, reach well into polar regions.

Discussion

Comments. Specimens assigned to *Rousea* sp. 4 may be divided into two species based on the presence or absence of heterobrochate reticulum. However, too few specimens lacking the heterobrochate reticulum were encountered to be able to determine if they constitute a distinct species.

This species may be conspecific with *Tricolpites* sp. 2 in Farabee and Canright (1986), although their description indicates a much larger range in the size of the lumina (4.8-0.3 μm) than is present in specimens encountered in the present study. The reticulum of *Salixipollenites discoloripites* (Wodehouse) Srivastava and *S. eximius* Srivastava has smaller lumina and is not described as heterobrochate. *Tricolpopollenites clavireticulatus* Norton in Norton & Hall 1969 is of similar size and sculpture, but is described as having clavate exine structure and a reticulum that fines more distinctly toward the colpi and poles.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *Rousea* sp. 4 was recorded in about 50 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 7.7 percent.

Previous Records. Tullock Formation of eastern Montana (as *Rousea heterobrochata* [nom. nud.]) (Hotton, 1988).

Illustrated Specimen. Plate 16, Figure 15: UND-PC A2882-4, 12.5 mm across X 16.7 mm up.

Rousea sp. 5

Plate 16, Figure 16; Plate 17, Figure 1

Description

Tricolpate to tricolporoidate pollen, subprolate to oblate, dimensions of specimens in equatorial view 22.5-(25.0)-27.0 X 14.0-(18.7)-22.7 μm (n = 6); equatorial diameter of grains in polar view 23.0-27.0 μm (n = 2). Exine tectate, 1.0-1.6 μm thick, thinner at colpi margins and toward poles in most specimens; sexine about equal to or slightly thicker than nexine; tectum about 0.5 μm thick; sculpture foveo-reticulate, lumina up to 1.0 μm in diameter in mesocolpia, decreasing abruptly to less than 0.5 μm adjacent to the colpi and poles, some specimens smooth on colpi margins; many specimens heterobrochate in mesocolpia; muri 0.7-1.0 μm wide in mesocolpia, ridged, appearing wider at lower focus; generally simplibaculate. Colpi long, rounded on ends in some specimens, reaching to polar regions. Distinct ora lacking although most specimens colporoidate.

Discussion

Comments. *Rousea* sp. 5 is differentiated from similar pollen grains by its foveo-reticulate sculpture and smooth colpi margins. Hotton (1988) described two species that are somewhat similar as *Rousea* sp. 6 and *Dryadopollis* sp. 1. Both of those species are reticulate rather than foveo-reticulate.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *Rousea* sp. 5 was recorded in about 33 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 3.0 percent.

Previous Records. I have not located any published records of fossil pollen conspecific with *Rousea* sp. 5.

Illustrated Specimens. Plate 16, Figure 2: UND-PC A2842-4, 13.3 mm across X 15.7 mm up. Plate 17, Figure 1: UND-PC A2878-3, 12.2 mm across X 12.6 mm up.

Genus *Striatopollis* Krutzsch 1959

Striatopollis Krutzsch, 1959b, p. 142.

See Ward (1986, p. 50) for synonymy and discussion of *Striatopollis*.

Type Species: *Striatopollis sarstedtensis* Krutzsch 1959

Generic Diagnosis

"With three colpi; sideview oval-rhombic, amb subcircular but with rather deep and up to 5 u wide gaping colpi; figura fusiform; wall outside the colpi relatively thick (ca. 2 u or more); wall two-layered, outer layer 2-3 as thick as inner one, the outer layer with a coarse rib sculpture (see fig.), the ribs being separated by narrow, deep incisions; the ribs are not smooth, but have an extrapunctate sculpture (which is not a "corrosion sculpture," but a primary feature); the ribs are vertical (meridians), about 5-8 per sector crossing the equator; their number reduces toward the poles in such a manner, that those of two sections are continuous, those of the third section butting and joining them, or ending before reaching the polar area. The colpus area is free of sculpture, and has a very thin inner wall layer; probably each germinal has a narrow opening or slit of 6-8 u length; differentiation of the inner layer in the equatorial plane could not be observed. Polar axis, so far measured, 18-20 u" (Krutzsch, 1959, p. 142, translated in Jansonius and Hills, 1976, card 2775). Monotypic genus, combined description.

Striatopollis trochuensis (Srivastava) Farabee & Canright 1986
Plate 17, Figures 4, 5

Salixipollenites trochuensis Srivastava, 1967, p. 529, pl. 7, figs. 13, 5.

Rutihesperipites trochuensis (Srivastava) Srivastava, 1977, p. 536, p. 1, figs. 1-8.

Striatopollis trochuensis (Srivastava) Farabee & Canright, 1986, p. 64, pl. 22, fig. 71.

Tricolpites sp. A in Snead, 1969, p. 51, pl. 5, fig 14.

Description of North Dakota Specimens

Tricolpate (rarely tricolporoidate) pollen grains, prolate; in polar view, amb trilobed, fossaperturate; dimensions in equatorial view 22.5-(23.4)-24.5 x 12.0-(14.8)-17.0 μm (n = 5); equatorial diameter of grains in polar view 14.0-(15.5)-17.0 μm (n = 2). Exine about 1.5 μm thick, nexine about 0.5 μm thick; semitectate, columellate layer distinct; sculpture striate, striae with predominant meridional orientation, individual striae generally less than 5 μm long, commonly bifurcating; striae consist of baculae fused at distal ends; muri and vallae about equal in width, about 0.5 μm wide. Colpi long, reaching nearly to the poles, narrow; weak equatorial flexure present in some specimens.

Discussion

Comments. The North Dakota specimens of *Striatopollis trochuensis* agree well with Srivastava's (1977) emended description of the species except that they tend to be more prolate than the holotype or paratypes. *Striatopollis tectatus* Leffingwell 1971 is similar in size and gross sculpture, but the striae are described resting on the tectum. *Striatopollis trochuensis* is not fully tectate and the striae consist of aligned baculae that are fused to form the striae. Some specimens that are probably assignable *S. tectatus* were encountered, but they are included with *S. trochuensis* in the quantitative analysis.

Tricolpites striatus Couper 1954 has a sculpture pattern similar to this species, but is much larger. The specimens assigned to *T. striatus* by Norton and Hall (1969) are within the size range of *R. trochuensis* and are probably conspecific with this species. *Tricolpites bacu striatus* Norton in Norton & Hall 1969 is described as having a similar sculpture pattern and is probably a junior synonym of *Striatopollis trochuensis*. Srivastava (1977) noted morphologic similarity of this species to the pollen produced by the Aceraceae.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2953, A2822, A2830, A2841, A2842, A2884, A2960, A2963, A2975, A2979, A2985, A2849, A2850, A2851, A2852, A2853, A2855, A2857, A2860, A2861, A2865, A2866, A2867, and A2996. Uncommon; maximum relative abundance in any sample is 3.2 percent.

Previous Records. Edmonton Formation, south-central Alberta (Srivastava, 1967, 1977); Edmonton Formation, Alberta (Snead, 1969); Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988); Kiowa Formation (Albian), Kansas (Ward, 1986); Maastrichtian and Paleocene portions of the Coalspur Formation, Alberta (Jerzykiewicz and

Sweet, 1986); and Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); probable record from the Hell Creek Formation, northeastern Montana (as *T. striatus* and *T. bacustriatus*) (Norton and Hall, 1969).

Illustrated Specimens. Plate 17, Figure 4: UND-PC A2865-3, 12.7 mm up X 14.3 mm across. Plate 17, Figure 5: UND-PC A2939-2, 20.9 mm across X 4.8 mm up.

Genus *Tricolpites* Cookson ex Couper 1953 emend. Jarzen & Dettmann 1990

Tricolpites Cookson 1947, p. 134.

Tricolpites Cookson ex Couper 1953, p. 61.

Tricolpites Cookson ex Couper 1953, emend. Jarzen & Dettmann, 1990, p. 99.

Type Species: *Tricolpites reticulatus* Cookson ex Couper 1953

Generic Diagnosis

"Pollen grains free, tricolpate, isopolar, oblate to subprolate; amb circular to trilobate with convex mesocolpia. Colpi meridionally aligned, parallel-sided, but often gaping, margins entire; membrane absent or reduced, without free-standing bacula. Exine stratified; sexine baculate semitectate with reticulate surface. Reticulum regular, composed of smooth-crested muri and elongate to equidimensional lumina that are of uniform size and less than 1 μ in diameter over entire surface of grain" (Jarzen and Dettmann, 1990, p. 99).

Tricolpites hians Stanley 1965

Plate 17, Figures 2, 3

Tricolpites hians Stanley, 1965, p. 321, pl. 47, fig. 24-27.

Tricolpopollenites hians (Stanley) Elsik, 1968b, p. 622 (pars).

Tricolpites parvus Stanley, 1965, p. 322, pl. 47, pl. 28-31.

Description of North Dakota Specimens

Tricolpate (rarely tetracolpate or hexarugate) pollen, oblate to subprolate, amb more or less circular; equatorial diameter of grains in polar view 15.5-(19.1)-23.5 μm (n = 23); dimensions of grains in equatorial view 15.5-(20.0)-25.0 (polar diameter) X 12.0-(16.2)-22.0 μm (n = 33). Exine semitectate, 1.0-2.0 μm thick, sexine generally 0.7-1.0 μm thick; nexine 0.5-1.1 μm thick, commonly variable within a single specimen; ektexine structure of fused clavae, columellate layer distinct in optical section, columellae not visible in plan view; sculpture evenly microreticulate; diameter of lumina 0.5 μm or less, circular; muri very narrow. Colpi extend one-half to two-thirds grain radius, open and V-shaped in polar view, typically narrow in specimens in equatorial view; colpi of many specimens bordered by costae colpi about 2 μm wide.

Discussion

Comments. *Tricolpites hians* is interpreted rather broadly in this present study, and *Tricolpites parvus* Stanley 1965 is regarded as a junior synonym. Stanley (1965) distinguished *T. hians* from *T. parvus* on the basis of the thick nexine in the latter species. This criterion proved to be questionable in the present study as the nexine thickness in otherwise identical specimens appears to intergrade from less than 0.5 μm to greater than 1.0 μm and some specimens exhibit both thick and thin nexine. Nexine thickness may be affected by palynomorph preservation. The presence of costae colpi also appears to be affected by the quality of pollen grain preservation, as they are more typical of specimens in samples that contain very well preserved palynomorphs.

Norton and Hall (1969) and Oltz (1969) did not recognize *T. hians* from the Upper Cretaceous and Paleocene of northeastern Montana. The taxa that they erected to accommodate microreticulate, tricolpate pollen grains are at least partly conspecific with *Tricolpites hians* as interpreted in the present study. Included are *Tricolpopollenites* *microreticulatus* Norton in Norton & Hall 1969, *Tricolpites varius* Norton in Norton & Hall 1969, and *Tricolpopollenites parviluminosus* Oltz 1969. Chmura (1973) assigned similar pollen to *Tricolpopollenites sparsus* (Martynova) Chmura 1973, but further study is needed to determine if that species is conspecific with *T. hians*. Several angiosperm families produce pollen grains similar in morphology to *T. hians*, including the Platanaceae, Cruciferae and Resedaceae.

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation. *Tricolpites hians* was recorded in all but three of the palyniferous samples (see Plate 3). Abundant; maximum relative abundance in any sample is 48.2 percent.

Previous Records. Fort Union Formation, northwestern South Dakota (Stanley, 1965); Tullock Member of the Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); Judith River Formation, north-central Montana (B.D. Tschudy, 1973); Rockdale Formation (Paleocene), Texas (Elsik, 1968b); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); Silverado Formation (upper Paleocene), southern California (in part) (Gaponoff, 1984); Hell Creek Formation, North Dakota (as *Tricolpopollenites nexidentatus* [nom. nud.] and *Pericolpites* sp.) (Bergad, 1974); Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988); Ludlow, Cannonball, Tongue River, and Sentinel Butte, and Golden Valley Formations, North Dakota (Robertson, 1975); Menefee Formation (Mesaverde Group), New Mexico (Jameossanaie, 1987); Claiborne Formation (Eocene), Tennessee (Potter, 1976). Probable records from the Hell Creek Formation, northeastern Montana (as *Tricolpopollenites microreticulatus*) (Norton and Hall, 1969); Almond Formation, south-central Wyoming (as *Tricolpopollenites microreticulatus*) (Stone, 1973); upper Moreno Formation (Maastrichtian and Paleocene), central California (as *Tricolpopollenites micromunus*) (Drugg, 1967); Oak Hill Member of Naheola Formation (Paleocene), Alabama (as *T. parvus*) (Srivastava, 1972); and

Hell Creek Formation, northeastern Montana (as *Tricolpopollenites parviluminosus*) (Oltz, 1969);

Illustrated Specimens. Plate 17, Figure 2: UND-PC A2828.1-5, 6.6 mm across X 11.2 mm up. Plate 17, Figure 3: UND-PC A2876-6, 9.5 mm across X 10.2 mm up.

Tricolpites cf. *T. minutus* (Brenner) Dettmann 1973

Plate 17, Figure 6

Tricolpopollenites minutus Brenner, 1963, p. 93, pl. 40, figs. 5, 6.

Cornaceoipollenites minutus (Brenner) Norris, 1967, p. 107, pl. 17, figs. 7-11.

Cupuliferoidaepollenites minutus (Brenner) Singh, 1971, p. 194, pl. 29, figs. 8, 9.

Tricolpites minutus (Brenner) Dettmann, 1973, p. 12, pl. 4, figs. 1-4.

Description of North Dakota Specimens

Tricolpate pollen, subprolate to globose; dimensions of grains in equatorial view 11.0-(11.7)-13.0 μm (polar diameter) X 8.0-(9.9)-10.5 μm (n = 17); equatorial diameter of specimens in polar view 8.0-(11.3)-14.0 μm (n = 7). Exine semitectate, about 1.0 μm thick, sexine about twice as thick as nexine; structure of clavae with heads fused to form microreticulate sculpture, lumina less than 0.5 μm in diameter, regular; muri narrow. Colpi typically extend two-thirds to three fourths of grain length, closed.

Discussion

Comments. *Tricolpites minutus* (Brenner) Dettmann tends to have a more prolate shape and is not described as having a reti-clavate exine structure. Thus, the specimens encountered in this study are only compared to *T. minutus*. *Tricolpites minutus* is distinguished from *T. hians* by its very small size and relatively longer colpi. *Tricolpites micromunus* (Groot & Penny) Singh and *Tricolpites tersus* Oltz are of similar size but have a reticulum with somewhat larger lumina. Chmura (1973) assigned similar pollen grains to *Tricolpopollenites sparsus* (Martynova) forma vescus (Samoilovitch) Chmura 1973, but additional study is required to determine if that species is conspecific with *Tricolpites* cf. *T. minutus*. Pigg and Stockey (1991) noted that similar pollen grains are found in *Platanathus potamacensis*, a late Albian platanaceous male inflorescence.

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation. *Tricolpites* cf. *T. minutus* was recorded in over three-fourths of the productive samples. Abundant; maximum relative abundance in any sample is 48.4 per cent.

Previous Records. *Tricolpites minutus* has been reported from the Potomac Group (Lower Cretaceous) of Maryland (Brenner, 1963); Peace River Formation (Albian), Alberta (Singh, 1971); lower Colorado Group (Albian-Cenomanian), Alberta (Norris, 1967); Albian to Cenomanian(?), Alberta (Jarzen and Norris, 1975); and Cheyenne and Kiowa Formations (Albian), Kansas (Ward, 1986). B.D. Tschudy (1973) reported a similar specimen from the Judith River Formation of north-central Montana (as *Tricolpites* sp., pl. 8, fig. 36).

Illustrated Specimen. Plate 17, Figure 6: UND-PC A2878-3, 17.2 mm across X 3.9 mm up.

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

Plate 17, Figure 7

Retitricolpites vulgaris Pierce, 1961, p. 50, pl. 3, figs. 101, 102.

Tricolpites vulgaris (Pierce) Srivastava, 1969, p. 57, pl. 1, figs. 20-22.

Description of North Dakota Specimens

Tricolpate to tricolporoidate pollen, shape oblate to subprolate, amb nearly circular; dimensions of specimens in equatorial view 18.5-(20.0)-24.5 X 15.5-(16.5)-20 μm (n = 5); equatorial diameter of specimens in polar view 16.5-(19.9)-22 μm (n = 6). Exine semitectate, about 1.5 μm thick in mesocolpia, thinner at colpi margins; sexine about equal in thickness to nexine; exine structure of baculae fused at distal ends; sculpture reticulate, lumina about 1.0 μm in diameter in mesocolpia, fining slightly toward colpi and poles; muri narrow, simplibaculate, baculae beneath muri yield a slightly beaded appearance. Colpi short, in polar view extend about one-half grain radius, gaping, colpi not bordered by thickened or muri. Nexinal thickenings commonly present near polar ends of colpi.

Discussion

Comments. The specimens here compared to *Tricolpites vulgaris* differ from that species by commonly having tricolporoidate apertures. The North Dakota specimens also commonly have a reticulum that fines slightly toward the poles and colpi. This sculptural feature is not evident on Pierce's (1961) protologue specimens, but the original illustrations are lacking in detail. Scanning electron photomicrographs of pollen grains assigned to the species by Srivastava (1975) and Farabee and Canright (1986) showed that the reticulum fines slightly to the colpi, but apparently not toward the poles. Pierce (1961) suggested botanical affinities with *Hamamelis* or *Corylopsis*.

Occurrences. Slope Formation and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2836, A2967, A2977, A2981, A2984, A2988, A2989, A2992, A2843, A2844, A2846, A2853, A2856, A2863, A2869, A2871, A2996, A2997, A2999, and A3001. Rare; maximum relative abundance in any sample is 1.5 percent.

Previous Records. *Tricolpites vulgaris* has been reported from the Dakota Formation (Cenomanian), Minnesota (Pierce, 1961); Fredericksburg Group (Albian) of Oklahoma (Hedlund and Norris, 1968; Srivastava, 1975); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); Peace River and Shaftesbury Formations (Albian), Alberta (Singh, 1971); Colorado Group (Albian-Cenomanian(?)), Alberta (Norris, 1967); Edmonton

Formation (Maastrichtian), Alberta (Srivastava, 1969b); Menefee Formation (Mesaverde Group), New Mexico (Jameossanaie, 1987); upper Albian to lower Senonian, Alberta (Jarzen and Norris, 1975); Cheyenne and Kiowa Formations (Albian), Kansas (Ward, 1986); Swan River Formation, Saskatchewan and Manitoba (Albian) (Playford, 1971); and Paleocene(?) and Eocene, Baltimore Canyon, eastern U.S.A. offshore (Bebout, 1980).

Illustrated Specimen. Plate 17, Figure 7: UND-PC A2967-4, 11.9 mm across X 5.0 mm up.

Tricolpites sp. 1

Plate 17, Figure 9

Description

Tricolpate pollen, shape oblate; equatorial diameter 26.0-(28.5)-32.5 μm (n = 11). Exine semitectate, about 1.2 μm thick, thinning gradually toward colpi, sexine about twice thickness of nexine in mesocolpia; exine structure of fused clavae; columellate layer distinct in mesocolpia, very thin or absent at colpi margins; sculpture microreticulate, lumina about 0.3 μm in diameter, sculpture diminished on colpi margins. Colpi moderately long, extend about two-thirds grain radius, typically gaping widely.

Discussion

Comments. *Tricolpites* sp. 1 is differentiated from other microreticulate tricolpate pollen species by its extremely fine reticulum, the exine that thins gradually to the colpi margins, and the nearly smooth borders of the colpi. Hotton (1988) described a pollen species, *Tricolpites* sp. 10, that has similar form and sculpture, but is much larger (47 μm).

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation. *Tricolpites* sp. 1 was recorded in about 33 percent of the productive samples (see Plate 3). Rare; maximum relative abundance in any sample is 1.9 percent.

Previous Records. I am unaware of any previously published records of fossil pollen conspecific with *Tricolpites* sp. 1.

Illustrated Specimen. Plate 17, Figure 9: UND-PC A2879-1, 11.9 mm across X 14.7 mm up.

Tricolpites sp. 2

Plate 17, Figure 8

Description

Tricolpate to tricolporoidate pollen, oblate to subprolate; amb subtriangular, angulaperturate; equatorial diameter 15.5-(18.4)-21.0 μm (n = 11). Exine semitectate, about 1 μm thick in mesocolpia, thinning to 0.3 μm near colpi, sexine about twice as thick as nexine; exine structure of clavae fused at their heads; sculpture microreticulate, diameter of lumina about 0.5 μm in mesocolpia, decreasing toward colpi to form smooth or nearly smooth margos. Colpi long, nearly reaching poles, closed; distinct pores lacking although equatorial flexure is commonly present.

Discussion

Comments. *Tricolpites* sp. 2 is differentiated from *Tricolpites* sp. 1 by its triangular amb, slightly larger lumina in the reticulum, and commonly tricolporoidate apertures. The exines of *Tricolpites hians* and *Tricolpites* cf. *T. minutus* do not thin toward the colpi.

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2818, A2877, A2978, A2979, A2981, A2987, A2989, A2991, A2994, A2843, and A2863. Uncommon; maximum relative abundance in any sample is 2.3 percent.

Previous Records. I am unaware of any previously published records of fossil pollen conspecific with *Tricolpites* sp. 2.

Illustrated Specimen. Plate 17, Figure 8: UND-PC A2818-2, 4.5 mm across X 10.1 mm up.

Syncolpate and Syncolporate Pollen

Genus *Cupanieidites* Cookson and Pike 1954 emend. Chmura 1973

Cupanieidites Cookson and Pike, 1954, p. 210.

Cupanieidites Cookson and Pike 1954 emend. Chmura, 1973, p. 133, 134.

Type Species: *Cupanieidites major* Cookson and Pike 1954

Generic Diagnosis

"Pollen grains clearly isopolar to clearly heteropolar. Outline in polar view triangular; sides concave to convex. Tricolporate; angulaperturate; colpi non-syncolpate, syncolpate or parasyncolpate; pores relatively inconspicuous. Ektexine and endexine of approximately equal thickness. Surface scabrate to reticulate. Grain size variable" (Chmura, 1973, p. 134).

Cupanieidites cf. *C. reticularis* Cookson & Pike 1954

Plate 17, Figure 10

Cupanieidites reticularis Cookson & Pike, 1954, p. 214, pl. 2, figs. 87-89.

Description of North Dakota Specimens

Syncolporate pollen, isopolar to heteropolar; oblate, amb triangular, sides straight to slightly convex, apices slightly rounded; equatorial diameter 21.5-(24.1)-27.5 μm (n = 10). Exine semitectate, about 1.0-1.5 μm thick, nexine 0.5 μm thick; sculpture microreticulate, lumina about 0.5-0.8 μm in diameter, commonly slightly elongate; muri about 0.5 μm wide. Always syncolporate on one pole, colpi do not always reach pole of opposite hemisphere; rarely parasyncolporate; if present, polar island small and present on only one pole; colpi bordered by costae colpi 2-3 μm wide. Exopores always indistinct, endopores distinct to indistinct, about 2.5-5 μm wide.

Discussion

Comments. The North Dakota specimens differ from *Cupanieidites reticularis* by being commonly heteropolar and by possessing a finer reticulum. Although the apertures are somewhat variable, other characters encountered in this species remain relatively constant. Several similar species of *Cupanieidites* have been described, including *C. inaequalis* Leffingwell 1971 and *C. carlquistii* (Drugg) Chmura 1973, both of which differ by always being parasyncolporate on at least one pole. Specimens that may be conspecific with *Cupaneidites* cf. *C. reticularis* were assigned to *C. reticularis* by Drugg (1967). Those grains were described as very finely reticulate in sculpture and are nonsyncolpate on one pole in some specimens. Cookson and Pike (1954) considered the botanical affinities of *Cupanieidites* to be with the Sapindaceae, a family of tropical and subtropical lianas, trees, or shrubs.

Occurrences. Slope Formation; samples UND-PC A2940, A2942, A2953, A2817, A2820, A2841, A2882, A2963, A2965, A2970, A2978, A2979, A2980, A2995, A2848, A2850, A2860, A2862, A2997. Rare; maximum relative abundance in any sample is 1.0 percent.

Previous Records. *Cupanieidites reticularis* has been reported from the Eocene of Australia (Cookson and Pike, 1954); Kirtland Shale, San Juan Basin, New Mexico (as *C.* cf. *reticularis*) (Anderson, 1960); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); Silverado Formation (Paleocene), California (Gaponoff, 1984); and Chuckanut Formation (Upper Cretaceous through Eocene(?), Washington (Griggs, 1971). Drugg (1967) recorded specimens that may be conspecific with this species (as *C. reticularis*) from the Maastrichtian and Paleocene portions of the Moreno Formation, California.

Illustrated Specimen. Plate 17, Figure 10: UND-PC A2884-3, 6.7 mm across X 8.9 mm up.

Genus *Syncolporites* van der Hammen 1954

Syncolporites van der Hammen, 1954, p. 83.

Type Species: *Syncolporites lisamae* van der Hammen 1954

Generic Diagnosis

"Syncolporate (tricolporate with the colpi united in the polar areas)" (van der Hammen, 1954, translation).

Discussion

Krutzsch (1969) regarded *Myrtaceidites* Cookson & Pike 1954 to be a senior synonym of *Syncolporites* van der Hammen 1954. However, *Myrtaceidites* was not formally designated until 1960 (Potonié, 1960), and if Krutzsch's synonymy is accepted, the genus is a junior synonym. Krutzsch (1969) considered the presence of annuli and an arcus to be diagnostic of *Myrtaceidites*, whereas the genotype of *Syncolporites* is described as annulate, but an arcus is not described, nor is one evident in the figured specimen. Thus, the two genera may not be synonymous.

Specimens encountered in this study suggest that the presence of an arcus (probably more properly considered to be costae colpi) and endannulus may not be reliable diagnostic criteria, as their presence or absence may be related to differences in palynomorph preservation. Rather than recognize two genera on somewhat dubious grounds, all specimens are included here under *Syncolporites*.

Syncolporites cf. *S. minimus* Leffingwell 1971

Plate 17, Figure 12

Syncolporites minimus Leffingwell, 1971, p. 49, 50, pl. 9, figs. 6-8.

Description of North Dakota Specimens

Trisyncolporate pollen, anisopolar; oblate, amb triangular, sides slightly convex, apices typically slightly protruding; equatorial diameter 15.5-(18.2)-23.5 μm (n = 13). Exine tectate, about 0.7 μm

thick in intercolpia, thinning to about 0.3 μm toward apertures, columellate layer thin but evident in intercolpia, diminishes 4-5 μm from colpi; sculpture irregularly punctate to microreticulate, reduced on colpi margins. Syncolporate to parasyncolporate on one polar hemisphere, colpi extend only a short distance onto the opposite polar hemisphere; exine thinned along margins of syncolpi. Pores indistinct.

Discussion

Comments. *Syncolporites minimus* Leffingwell is described as having granular sculpture, and is not described as anisopolar. The specimens here compared to *S. minimus* are anisopolar and have micropunctate to microreticulate sculpture. *Cupaneidites cloudi* Chmura 1973 has an anisopolar apertural condition similar to that of *Syncolporites* cf. *S. minimus*. However, that species appears distinct by having a straight- to concave-sided amb, somewhat larger size, and a more distinct and variable reticulate sculpture.

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation; *S. minimus* was recorded in about 67 percent of the productive samples (see Plate 3). Common; maximum relative abundance in any sample is 12.3 percent.

Previous Records. *Syncolporites minimus* has been reported from the following rock units: uppermost Lance Formation and Tullock Member of the Fort Union Formation, east-central Wyoming (Leffingwell, 1971); Paleocene and Maastrichtian portions of Coalspur Formation, Alberta (Jerzykiewicz and Sweet, 1986); Tullock Member of Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); and upper Maastrichtian and lower Paleocene, Alberta and Saskatchewan (Sweet and Braman, 1992). Pollen grains that may be conspecific with *Syncolporites* cf. *S. minimus* have also been reported from the Edmonton Formation of Alberta (as *Myrtaceidites* sp. A) (Snead, 1969, p. 35, pl. 6, fig. 5) and the Ravenscrag Formation of southern Saskatchewan (as Myrtaceae cf. *Metrosideros*) (Jarzen, 1978, p. 35, pl. 1, fig. 12.).

Illustrated Specimen. Plate 17, Figure 12: UND-PC A2931-3, 16.3 mm across X 11.3 mm up.

Syncolporites sp. 1

Plate 17, Figures 13, 14

Description

Trisyncolporate pollen, anisopolar, angulaperturate; amb triangular, sides convex; equatorial diameter 17.0-(19.2)-21.0 μm (n = 7). Exine tectate, about 0.7 μm thick; columellate layer thin, but evident; sexine about twice as thick as nexine; sculpture micropunctate, punctae less than 0.5 μm in diameter; muri 0.5-1.0 μm wide, surface of muri rounded, giving grain surface a scabrate appearance. Syncolpate to parasyncolpate on one polar hemisphere, colpi extend only a short distance onto opposite hemisphere. Exopores indistinct or lacking; endopores 5-6 μm in diameter, bordered by distinct endannulus, endannulus triangular in optical section, 0.5-0.8 μm thick; pore region commonly slightly labrate. Syncolpi bordered by costae colpi (arcus) 1.5-2.0 μm wide, costae colpi merge with endannuli; small, triangular polar island may be defined by syncolpi.

Discussion

Comments. *Syncolporites* sp. 1 differs from *Syncolporites* cf. *S. minimus* by the presence of endannuli and costae colpi. Some degree of gradation of morphologic features exists between the two species, and if the endannuli and costae colpi of *Syncolporites* sp. 1 were to be removed by taphonomic processes, the two species could prove to be the same. However, lacking further evidence, two species are maintained at the present.

Specimens here assigned to *Syncolporites* sp. 1 are differentiated from *Myrtaceidites solidus* Sweet 1986 by the presence of syncolpi on both polar hemispheres and intectate exine with granulate sculpture in the latter species. Specimens assigned to several species of *Myrtaceidites* by Cookson and Pike (1954) all appear to have less distinct endannuli and less distinctly sculptured exine. Snead (1969) assigned three species to *Myrtaceidites* (*M.* sp. A, sp. B, and sp. C). Both *Myrtaceidites* sp. B and sp. C have some features in common with the specimens encountered in this study, but they are described as having granulate sculpture. The illustrated specimens lack suffiecient detail to determine if they are isopolar or anisopolar.

Occurrences. Slope Formation; recorded only in sample UND-PC A2982 with relative abundance of 40.9 percent.

Previous Records. I have not yet located any published records of fossil pollen conspecific with *Syncolporites* sp. 1.

Illustrated Specimens. Plate 17, Figure 13: UND-PC A2982-4, 16.1 mm across X 9.6 mm up. Plate 17, Figure 14: UND-PC A2982-4, 16.2 mm across X 9.4 mm up.

Syncolporites sp. 2

Plate 17, Figure 11

Description

Isopolar syncolporate pollen, oblate, amb triangular, sides slightly convex; equatorial diameter 13.5-(14.6)-17.0 um (n = 4). Exine 2-layered, about 0.8 um thick in mesocolpia increasing gradually to about 2.0 um toward apertures; sculpture granulate to coarsely scabrate. Polar islands lacking. Pores with annuli and endannuli 3-4 um wide; pores vestibulate, vestibulum extends 3-4 um either side of pores. Colpi bordered by raised area about 4 um wide suggesting separation of ektexine and endexine continues along colpi margins.

Discussion

Comments. *Syncolporites* sp. 2 differs from other species of *Syncolporites* encountered in this study by its granulate/scabrate sculpture and the presence of annuli and vestibulae. *Syncolporites minimus* Leffingwell 1971 is of similar size and sculpture, but lacks annuli and vestibulae. Bergad (1974) assigned similar, but parasyncolporate grains, to *Myrtaceidites eucalyptoides* Cookson & Pike 1954.

Occurrences. Slope Formation and the Boyce Tongue of the Cannonball Formation; samples UND-PC A2842, A2970, A2971, A2988, and A2991. Rare; maximum relative abundance in any sample is 1.6 percent.

Previous Records. I have not noted any published records of fossil pollen conspecific with *Syncolporites* sp. 2.

Illustrated Specimen. Plate 17, Figure 11: UND-PC A2842-4, 14.2 mm across X 4.8 mm up.

Tricolporate Pollen

Genus *Brevicolporites* Anderson 1960 emend. Elsik 1970

Brevicolporites Anderson, 1960, p. 24.

Brevicolporites Anderson 1960 emend. Elsik, 1970, p. 100.

Type Species: *Brevicolporites colpella* Anderson 1960

Generic Diagnosis

"Oblate to spherical, tricolporate pollen bearing faint to conspicuous arci. Outline circular to subtriangular. Aperture construction various but ektexinous aperture is a colpus bounded by ektexinous ridges or arci. Arci pass over the poles from aperture to aperture in a syncolpate fashion, leaving an irregularly triangular area at each pole. Arci are irregular and scabrate to warty. Equatorial and polar areas between arci are psilate, scabrate, granulose, weakly verrucose or vermiculate-rugulose. Ektexine is tectate; columellae are discernible under arci or ektexinous thickenings. Ektexine and endexine are otherwise tightly appressed and undifferentiated except at the aperture. Endexine is continuous; apparently invaginate at equatorial pores which may be as wide or wider than the overlying colpus and bounding arci" (Elsik, 1970, p. 100).

Discussion

Elsik (1970) further noted that a truly syncolpate or syncolporate condition is not present, but the syncolporate appearance is due to the presence of an arcus.

Brevicolporites colpella Anderson 1960

Plate 17, Figures 15, 16

Brevicolporites colpella Anderson, 1960, p. 24, pl. 6, figs. 11-14.

Tricolporopollenites intergranulatus Norton in Norton & Hall, 1969, p. 51, pl. 7, fig. 23.

Tricolporopollenites sp. C. in Jarzen, 1982, p. 139, pl. 1, fig. 6.

Description of North Dakota Specimens

Tricolporate, brevicolpate pollen, shape oblate to globose, amb triangular, sides straight to slightly convex; angulaperturate, apices well-rounded, apertures slightly recessed; equatorial diameter 13.5-(18.2)-21.0 μm (n = 10). Exine tectate, about 1.3 μm thick in intercolpia, thickening to about 1.7 μm near apertures; endexine distinct, about 0.3 μm thick, stops about 3.5 μm from colpi; foot layer(?) of constant thickness except it tapers to pores; columellate layer distinct, about 0.3 μm thick, thickening distinctly at margins of colpi, thickening forms arcus that connects apertures, individual columellae not resolvable in optical section; sculpture psilate except for equatorial intercolpia and poles where sculpture is weakly foveolate or fossulate. Colpi short, extend about one-fourth of grain radius. Pores lalongate, commonly only a latitudinal slit.

Discussion

Comments. The specimens of *Brevicolporites colpella* Anderson encountered in this study tend to have more rigidly triangular ambs than those illustrated by Anderson (1960). Fleming (1990) noted that this species does not appear to have any clear similarity to the pollen of any modern family.

Occurrences. Ludlow and Slope Formations and the Three V Tongue of the Cannonball Formation; samples UND-PC A2940, A2952, A2953, A2954, A2955, A2956, A2818, A2821, A2822, A2959, A2963, A2965, A2968, A2969, A2970, A2971, A2972, A2974, A2976, A2977, A2981, A2982, A2987, A2988, A2989, A2991, A2992, A2847, A2850, A2856, A2860, A2861, A2868, A2871, and A2996. Common to abundant; maximum relative abundance in any sample is 21.8 percent.

Previous Records. Ojo Alamo Formation, eastern San Juan Basin, New Mexico (Anderson, 1960); Fort Union Formation of northwestern South Dakota (as *Tricolpites psilatus* [nom. nud.] (Stanley, 1960, p. 167); Tullock Member of Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); Tullock Formation, northeastern Montana (Norton and Hall, 1969); Maastrichtian and Paleocene portions of the Raton Formation, Colorado and New Mexico (Fleming, 1990); Paleocene portion of the Coalspur Formation, Alberta, Canada (Jerzykiewicz and Sweet, 1986); and Ravenscrag Formation, southern Saskatchewan (Jarzen, 1982).

Illustrated Specimens. Plate 17, Figure 15: UND-PC A2963-3, 19.7 mm across X 13.2 mm up. Plate 17, Figure 16: UND-PC A2879-2, 17.1 mm across X 16.5 mm up.

Genus *Caprifoliipites* Wodehouse 1933

Caprifoliipites Wodehouse, 1933, p. 518.

Type Species: *Caprifoliipites viridifluminis* Wodehouse 1933

Generic Diagnosis

"Pollen grains very small, ellipsoidal, tricolpate with furrows long and pointed, with conspicuous internally projecting furrow rims and pore rims; exine coarsely reticulate" (Wodehouse, 1933, p. 518).

Caprifoliipites cf. *C. microreticulatus* (Pflug & Thomson) Potonié 1960

Plate 18, Figures 1, 2

Tricolporopollenites microreticulatus Pflug & Thomson in Thomson & Pflug, 1953, p. 106, pl. 14, figs. 27-42.

Caprifoliipites microreticulatus (Pflug & Thomson) Potonié, 1960, p. 98.

Description of North Dakota Specimens

Tricolporate to tricolporoidate pollen, globose to oblate, amb triangular with straight to convex sides; dimensions of specimens in equatorial view 16.0-(18.9)-26.5 (polar diameter) X 13.5-(16.7)-21.0 μm ($n = 6$); equatorial diameter of specimens in polar view 20.5-(22.3)-26.5-μm ($n = 5$). Exine semitectate, about 1.0 μm thick, sexine about 2 to 3 times as thick as nexine; exine structure of baculae that are more-less tack shaped; sculpture reticulate, lumina diameter about 1.0 μm in mesocolpia, decreasing toward apertures and poles, colpi bordered by smooth margo about 1.5 μm wide; muri about 0.5 μm wide. Colpi long, nearly reaching poles, not gaping. Pores indistinct in most specimens, up to 6.0 μm in equatorial diameter, shape indeterminate, specimens in equatorial view typically geniculate.

Discussion

Comments. The protologue specimens of *Caprifoliipites microreticulatus* differ from the North Dakota specimens in several aspects. In the protologue specimens, the lumina of the reticulum do not distinctly become finer toward the poles and colpi, a distinct geniculus is lacking, and the amb is more circular. Thomson and Pflug (1953) described two forms of this species, forma *elongata* and forma *globosa*. The specimens described here more closely resemble the former.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2940, A2942, A2955, A2821, A2873, A2878, A2919, A2967, A2968, A2969, A2970, A2976, A2978, A2980, A2984, A2987, A2993, A2847, A2860, A2862, A2863, A2866, A2868, and A2998. Rare; maximum relative abundance in any sample is 4.5 percent.

Previous Records. *Caprifoliipites microreticulatus* has been reported from the upper Oligocene to lower Miocene, Germany (Thomson and Pflug, 1953) and the Moreno Formation (Maastrichtian and Paleocene), California (Drugg, 1967).

Illustrated Specimens. Plate 18, Figure 1: UND-PC A2878-4, 12.2 mm across X 11.5 mm up. Plate 18, Figure 2: UND-PC A2879-2, 11.8 mm across X 8.4 mm up.

Genus *Cupuliferoipollenites* Potonié 1951 ex Potonié 1960

Cupuliferoipollenites Potonié, 1951, p. 145.

Cupuliferoipollenites Potonié 1951 ex Potonié, 1960, p. 98.

Type Species: *Cupuliferoipollenites pusillus* (Potonié) Potonié 1960

Generic Diagnosis

"Shape stiffly elongated ovoid; poles rounded; tricolporate; exolamella smooth, infratexture ± faint; rugae long; short equatorial rugae distinguishable" (Potonié, 1960, p. 98, translated in Jansonius and Hills, 1976, card 685).

Cupuliferoipollenites pusillus (Potonié) Potonié 1960

Plate 17, Figure 19

Pollenites quisqualis pusillus Potonié, 1934b, p. 71, pl. 3, fig. 21.

Cupuliferoipollenites pusillus (Potonié) Potonié, 1960, p. 145.

Description of North Dakota Specimens

Tricolporate pollen, prolate; dimensions 12.5-(15.9)-19.5 X 8.5-(10.4)- 12.0 μm (n = 7). Exine about 0.6 μm thick, stratification indistinct, but probably of two layers closely appressed; sculpture psilate to weakly scabrate. Colpi long, reaching to the polar areas, narrow costae colpi present in some specimens. Pores lalongate, about 3 X 2 μm.

Discussion

Comments. *Cupuliferoipollenites pusillus* is distinguished from similar pollen grains by its small size and distinct pores. Frederiksen (1980) considered the botanical affinities of the genus to be with the Fagaceae, in the genera *Dryophyllum*, *Castaneae*, or *Castanopsis*.

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2940, A2956, A2879, A2962, A2963, A2984, A2991, A2992, A2995, A2844, A2849, A2858, and A2861. Uncommon; maximum relative abundance in any sample is 3.0 percent.

Previous Records. Eocene of Germany (Potonié, 1934b); Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988); Brightseat Formation (Paleocene), Maryland (Groot and Groot, 1962); Almond Formation, south-central Wyoming (Stone, 1973); upper Moreno Formation (Paleocene) California (Drugg, 1967); Edmonton Formation, Alberta (Snead, 1969); Richards Formation (Eocene to early Oligocene), Mackenzie Delta region, Northwest Territories (Norris, 1986); Ravenscrag Formation, southern Saskatchewan (Jarzen, 1982); and Moreno Formation (Maastrichtian), central California (Chmura, 1973).

Illustrated Specimen. Plate 17, Figure 19: UND-PC A2919-1, 5.4 mm across X 4.9 mm up.

Cupuliferoipollenites cingulum (Potonié) Song & Zheng 1981

Plate 17, Figure 18

Pollenites cingulum Potonié, 1931b, pl. 1, figs. V61c, 60d, 45a, 62c, 52b, 61b, 46c, 68a, 60a, 48b, 46b, 46a.

Tricolporopollenites cingulum (Potonié) Thomson & Pflug, 1953, p. 100.

Cupuliferoipollenites cingulum (Potonié) Song & Zheng, 1981, p. 117, pl. 40, figs. 21-24.

Description of North Dakota Specimens

Tricolporate pollen, prolate; dimensions 16.5-(18.1)-21.0 X 11.5-(12.7)-14.5 μm (n = 6). Exine tectate, about 1.0 μm thick, sexine about twice thickness of nexine; columellate layer distinct in optical section; sculpture psilate to weakly scabrate. Colpi long, bordered by costae colpi about 1.0 μm wide. Pores distinct, lalongate, 3-4 μm long by 1.5 μm wide, constricted at intersection with colpi.

Discussion

Comments. *Cupuliferoipollenites cingulum* is differentiated from similar pollen grains by its distinctly lalongate pores and weakly sculptured surface.

Occurrences. Slope Formation and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2883, A2963, A2964, and A2851. Rare; maximum relative abundance in any sample is 1.1 percent.

Previous Records. Miocene of Germany (Potonié, 1931b); Fort Union Formation, northwestern South Dakota (Stanley, 1960); Cape Searle Formation (Paleocene), Baffin Island, northeastern Canada (Burden and Langille, 1991); Rockdale Formation (Paleocene), Texas (Elsik, 1968b); Claiborne Formation (Eocene) western Tennessee (Potter, 1976); Maastrichtian and Paleocene of northwestern Canada, (Wilson, 1978); and Wilcox, Claiborne, and Jackson Groups (Eocene-Oligocene), Mississippi Embayment (R.H. Tschudy, 1973).

Illustrated Specimen. Plate 17, Figure 18: UND-PC A2963-3, 20.4 mm across X 14.9 mm up.

Genus *Cyrillaceaepollenites* Mürriger & Pflug 1951 ex Potonié 1960

Cyrillaceaepollenites Mürriger & Pflug, 1951, p. 90 (nom. nud).

Cyrillaceaepollenites Mürriger & Pflug 1951 ex Potonié, 1960, p. 102.

Type Species: *Cyrillaceaepollenites megaexactus* (Potonié) Potonié 1960

Generic Diagnosis

"Shape somewhat rigid, suboblate to more or less spherical, tricol-porate, colpi long, pores distinct, exine surface smooth infratexture weak" (Potonié, 1960, p. 102, translated in Jansonius and Hills, 1976, card 727).

Cyrillaceaepollenites cf. *C. megaexactus* (Potonié) Potonié 1960

Plate 17, Figure 17

Pollenites megaexactus Potonié, 1931b, p. 26, pl. 1, fig. V 42b.

Cyrillaceaepollenites megaexactus (Potonié) Potonié, 1960, p. 102.

Description of North Dakota Specimens

Tricolporate to tricolporoidate pollen, subprolate, outline in equatorial view ovoid; dimensions 16.0-(17.5)-19.5 X 11.5-(13.0)-15.5 μm (n = 8). Exine tectate, about 1.5 μm thick; in polar view, exine thins gradually to colpi; nexine thin, columellate layer thin, but distinct in most specimens; sculpture weakly scabrate to psilate, grain surface in optical section smooth to weakly undulate. Colpi long, infolded, no distinct costae colpi; pores distinct to indistinct, 2-3 μm in diameter, pronounced geniculus present.

Discussion

Comments. The specimens here compared to *Cyrillaceaepollenites megaexactus* tend to be somewhat more prolate in shape than the specimens illustrated by Potonié (1931b) (see Kremp *et al.*, 1958, p. 4-154) and Thomson and Pflug (1953) (as *Tricolporopollenites megaexactus* subsp. *brühlensis*). The original illustrations and descriptions lack sufficient detail to be fully confident in this specific determination.

Occurrences. Slope Formation and Three V Tongue of the Cannonball Formation; samples UND-PC A2940, A2954, A2957, A2820, A2883, A2977, A2843, A2853, A2863, A2997, and A3000. Rare; maximum relative abundance in any sample is 4.6 percent.

Previous Records. *Cyrillaceaepollenites megaexactus* has been reported from the Oligocene and Miocene, Germany (Potonié, 1931b); Paleocene to lower Pliocene of Germany (Thomson and Pflug, 1953); Eocene of Gulf

Coast (Frederiksen, 1988); uppermost Paleocene through Oligocene, South Carolina (Frederiksen, 1980a); and Claiborne Group (Eocene), Mississippi Embayment (R.H. Tschudy, 1973).

Illustrated Specimen. Plate 17, Figure 17: UND-PC A2843.1-4, 13.8 mm across X 6.9 mm up.

Cyrillaceaepollenites cf. *C. exactus* (Potonié 1931) Potonié 1960

Plate 18, Figures 13, 14

Pollenites exactus Potonié, 1931, p. 26, pl. 1, fig. V46b[2] or V49b[2] (printer's error in figure number).

Tricolporopollenites megaexactus (Potonié) Thomson & Pflug 1953 subsp. *exactus* (Potonié) Thomson & Pflug, 1953, p. 101, pl. 12, figs. 87-92.

Cyrillaceaepollenites exactus (Potonié 1931) Potonié, 1960, p. 102.

Description of North Dakota Specimens

Tricolporate pollen, subprolate to slightly oblate, amb circular to sub-triangular, angulaperturate; equatorial diameter of specimens in polar view 11.5-(13.3)-15.5 μm (n = 14), dimensions of specimens in equatorial view 12.0-(12.6)-13.0 (polar diameter) X 8.5-(10.2)-11.5 μm (n = 3). Exine two layered, probably tectate, sexine and nexine separated by dark line in most specimens; in other specimens, columellate(?) layer barely resolvable; exine 0.7-1.0 μm thick in mesocolpia, nexine about equal to, or slightly thicker than sexine; exine, especially nexine, thins toward apertures; sculpture psilate. Some specimens with distinct costae colpi about 1.5 μm wide, narrowing toward poles; specimens lacking costae colpi are otherwise identical, and presumably costae colpi have degraded. Colpi closed to open, extend about three-fourths grain radius. Pores small, circular, about 1.5 μm in diameter; specimens lacking distinct pores have pronounced flexure in equatorial region of colpi; exine slightly thickened around pores.

Discussion

Comments. The specimens here compared to *Cyrillaceaepollenites exactus* are quite similar to the specimens illustrated by Potonié (1931) and Thomson and Pflug (1953). However, the illustrations and descriptions provided in their reports lack adequate detail to allow fully confident assignment of the present specimens to *C. exactus*. Nichols (1970) noted a general similarity of this fossil species to the modern *Cyrilla* and *Vitis*.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *Cyrillaceaepollenites* cf. *C. exactus* was recorded in about 33 percent of the productive samples (see Plate 3). Common; maximum relative abundance in any sample is 31.8 percent.

Previous Records. *Cyrillaceaepollenites exactus* has been reported from the lower and middle Tertiary of Europe (Potonié 1931b; 1934; 1951; Thomson and Pflug, 1953); Wilcox Group (Paleocene) of Texas (Nichols, 1973); and Fort Union Formation of northwestern South Dakota (Stanley, 1960).

Illustrated Specimens. Plate 18, Figure 13: UND-PC A2995-3, 11.1 mm across X 11.0 mm up. Plate 18, Figure 14: UND-PC A2995-3, 16.0 mm across X 11.3 mm up.

Genus *Foveotricolporites* Pierce 1961

Foveotricolporites Pierce, 1961, p. 52.

Type Species: *Foveotricolporites rhombohedralis* Pierce 1961

Generic Diagnosis

"Foveolate, tricolporate pollen" (Pierce, 1961, p. 52).

Discussion

Foveotricolporites Pierce is similar in form and sculpture to *Rhoipites* Wodehouse 1933 and both genera are perhaps somewhat inadequately defined. In this study, *Foveotricolporites* is used for pollen grains that have foveolate to foveo-reticulate sculpture and weak to absent costae colpae. *Rhoipites* is applied to foveo-reticulate to reticulate pollen grains that have distinctive costae colpi and tend to have lalongate pores.

Foveotricolporites pachyexinous (Leffingwell) n. comb.

Plate 18, Figures 3, 4

Fraxinoipollenites pachyexinous Leffingwell, 1971, p. 45, pl. 9, figs. 1, 2 (basionym).

Description of North Dakota Specimens

Tricolporate to tricolporoidate pollen, prolate, outline in equatorial aspect slightly rhomboid; dimensions 15.0-(20.0)-24.5 X 11.0-(16.1)-19.0 μm (n = 17). Exine tectate, about 1.0 μm thick, sexine about twice as thick as nexine; columellate layer distinct in optical section; in polar view, sexine and nexine thin markedly toward colpi; sculpture foveolate to foveo-reticulate, lumina about 0.7 μm in diameter in intercolpia, lumina decrease in diameter toward colpi, some specimens smooth adjacent to colpi; muri about 0.8 μm wide. Colpi extend nearly full length of grain, commonly bordered by narrow costae colpi. Pores indistinct, restricted to nexine, in many specimens evident only by equatorial buckling, most distinct in lateral colpi or by gap in colpi costae; shape of pores not evident; nexine commonly slightly separated from sexine near pores.

Discussion

Comments. Leffingwell (1971) described *Fraxinoipollenites pachyexinous* as tricolpate. The illustrated specimens are distinctly tricolporoi date, but distinct ora are not evident. Specimens here assigned to the species appear to be identical to Leffingwell's specimens with the exception that some specimens are indistinctly tricolporate.

Fraxinoipollenites Potonié ex Potonié 1960 is diagnosed as tricolpate without a geniculus or pore; thus the genus is inappropriate for this species. *Rhoipites* Wodehouse 1933 is distinctly tricolporate and tends to have lalongate ora. Transfer to *Foveotricolporites* is based on the presence of foveolate to foveo-reticulate sculpture. *Tricolporopollenites argaleus* Chmura 1973 is larger and has thicker, more coarsely sculptured exine.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *Foveotricolporites pachyexinous* was recorded in about 67 percent of the productive samples (see Plate 3). Common; maximum relative abundance in any sample is 4.0 percent.

Previous Records. Fort Union Formation, east-central Wyoming (Leffingwell, 1971); and Tongue River Member of Fort Union Formation, southeastern Montana (Spindel, 1975).

Illustrated Specimens. Plate 18, Figure 3: UND-PC A2931-3, 17.0 mm across X 12.5 mm up. Plate 18, Figure 4: UND-PC A2931-4, 13.5 mm across X 10.5 mm up.

Foveotricolporites spp.

Plate 18, Figures 5-7; Plate 19, Figure 5

Description

Relatively large tricolporate pollen, prolate to globose. Polar diameter about 40 μm, equatorial diameter 30-35 μm. Exine tectate, foveolate to foveoreticulate; fovea uniform in size or decreasing to colpi. Colpi long, costae colpi lacking in most forms. Pores distinct to indistinct, relative large (about 5 μm).

Discussion

Comments. *Foveotricolporites* spp. contains at least three discrete morphologies, specimens of which are relatively rare. Several fossil pollen taxa have been described are probably conspecific with some of the specimens assigned here to *Foveotricolporites* spp., including *Tricolporopollenites explanatus* (Anderson) Elsik 1968, *T. confossus* Newman 1965, *T. foveotectatus* Norton in Norton & Hall 1969, and *Caprifoliipites longus* Stanley 1965. Specimens having distinct costae colpi and endannuli may have nyssoid affinities.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2939, A2942, A2957, A2834, A2873, A2836, A2883, A2884, A2885, A2963, A2972, A2979, A2991, A2992, A2995, A2844, A2851, A2856, A2862, and A3001. Rare; maximum relative abundance in any sample is 1.6 percent.

Illustrated specimens. Plate 18, Figure 5: UND-PC A2919-4, 22.0 mm across X 17.9 mm up. Plate 18, Figure 6: UND-PC A2883-3, 16.4 mm across X 5.1 mm up. Plate 18, Figure 7: UND-PC A2997-1, 18.4 mm across X 14.4 mm up. Plate 19, Figure 5: UND-PC A2997-1, 12.9 mm across X 6.8 mm up.

Genus *Kurtzipites* Anderson 1960 emend. Srivastava 1981

Kurtzipites Anderson, 1960, p. 24.

Aenigmapollis Stanley, 1965, p. 311.

Coriaripites Srivastava, 1969b, p. 49.

Kurtzipites Anderson 1960 emend. Srivastava, 1981, p. 869.

Type Species: *Kurtzipites trispissatus* Anderson 1960

Generic Diagnosis

"Pollen tricolporate or tricolporoidate(?); colpi short on somewhat aspidate or narrowly rounded amb corners; length from colpi tip to amb one-fourth to one-half amb radius; pores atriate, situated at colpi center; amb subtriangular to subcircular, rarely triangular, oblate, sides convex or straight, rarely concave; exine two-layered; nexine normally thicker around pores; sexine very thin, tectate; infratectal layer generally not seen; supratectal sculpture fine granulose, spinulose" (Srivastava, 1981, p. 868).

Discussion

All species of *Kurtzipites* encountered in this study are tricolporate, although the pores appear to be restricted to the nexine. In species lacking distinct nexinal thickenings around the pores, the endopores are indistinct due to the thin nexine that is characteristic of the genus.

Kurtzipites trispissatus Anderson 1960 emend. Srivastava 1981

Plate 18, Figure 10

Kurtzipites trispissatus Anderson, 1960, p. 25, pl. 2, figs. 15-17.

Aquilapollenites minutus Srivastava, 1967, p. 542, pl. 10, figs. 2, 3.

Coriaripites alienus Srivastava, 1969b, p. 50, pl. 1, fig. 1.

Fibulapollis mirificus auct. non (Chlonova) Chlonova 1961 in Felix and Burbridge 1973, pl. 3, figs. 14, 15.

Description of North Dakota Specimens

Tricolporate, brevicolpate pollen, oblate, amb subtriangular with convex sides to slightly hexagonal, apertural areas slightly aspidate; equatorial diameter 18.0-(24.4)-31.0 μm (n = 7). Exine tectate, about 0.7 μm thick; sexine and nexine indistinguishable except in center of equatorial intercolpia where exine thickens to about 1.0 μm and columellate layer is distinct; sculpture minutely and sparsely scabrate, scabrae less than 0.5 μm in diameter and spaced about 1 μm apart. Colpi short, one-fourth to one-third radius, exopores lacking, endopores distinct, about 5 μm in equatorial diameter and extending about 2.5 μm poleward; a triangular nexinal thickening about 5 u across present on both hemispheres just poleward of endopore, an apex of triangle is oriented toward poles.

Discussion

Comments. The specimens of *Kurtzipites trispissatus* encountered in this study agree well with the emended description of Srivastava (1981). However, no prior description of *K. trispissatus* has noted the presence of thickened exine in the equatorial intercolpia. This exinal thickening results in an angulation of the amb in the intercolpia, giving the amb the more or less hexagonal shape that was noted in Anderson's (1960) original description of the species.

McIver *et al.* (1991) recovered pollen assignable to *Kurtzipites trispissatus* from fossil flowers that were discovered in the Ravenscrag Formation of southwestern Saskatchewan. However, the morphology of the fossil flowers did not reveal definite clues to their botanical affinities. Based on pollen morphology, they considered *Kurtzipites* to be an anemophilous member of the extinct triprojectate pollen complex, a group that is thought to be primarily zoophilous. Detrended correspondence analysis by Fleming (1990) indicated an affiliation of this species with marsh environments.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *K. trispissatus* was recorded in about 33 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 7.6 percent.

Previous Records. Kirtland Shale, San Juan Basin of New Mexico (Anderson, 1960); Lance and Fort Union Formations, east-central Wyoming (Leffingwell, 1971); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); Tullock Member of Fort Union Formation, Powder River Basin of Wyoming and Montana (Nichols and Brown, 1992); Hell Creek Formation, northeastern Montana (Norton and Hall, 1969); Hell Creek and Tullock Formations, northeastern Montana (Oltz, 1969); Edmonton Formation, Alberta, (Snead, 1969; Srivastava, 1967, 1969, 1970); Frenchman and Ravenscrag Formations, south-central Saskatchewan (Nichols *et al.*, 1986); Ravenscrag Formation, southern Saskatchewan (Jarzen, 1982; McIver *et al.*, 1991); Paleocene and Maastrichtian portions of the Coalspur Formation, Alberta, (Jerzykiewicz and Sweet, 1986); Maastrichtian and Paleocene portions of the Raton Formation), Colorado and New Mexico (Fleming, 1990); Eureka Sound Formation (Maastrichtian), Arctic Canada (Felix and Burbridge, 1973); Kincaid Formation

(Maastrichtian), Texas (Evitt, 1973); and Hell Creek and Fort Union Formations, northeastern Montana (Nichols *et al.*, 1982).

Nichols and Sweet (1993) noted that *K. trispissatus* has been reported from throughout the Western Interior of North America. They considered the first appearance of the genus *Kurtzipites* to mark the base of the Maastrichtian throughout that region.

Illustrated Specimen. Plate 18, Figure 10: UND-PC A2960-4, 18.1 mm across X 14.1 mm up.

Kurtzipites parvus (Norton) n. comb.

Plate 18, Figure 11

Momipites parvus Norton in Norton & Hall, 1969, p. 37, pl. 5, figs. 6, 7 (basionym).

Momipites circularis Norton in Norton & Hall, 1969, p. 37, pl. 5, fig. 8.

Kurtzipites simplex Leffingwell, 1971, p. 51, pl. 10, figs. 2-4.

Unidentified palynomorph, Jarzen, 1976, p. 49, pl. 1, fig. 7.

Engelhardtia/Oreomunnea pollen in Jarzen, 1978, p. 35, pl. 1, fig. 19.

Kurtzipites circularis (Norton) Srivastava, 1981, p. 874-876.

Description of North Dakota Specimens

Tricolporate, brevicolpate pollen, oblate, amb subcircular, apertures slightly aspidate; equatorial diameter 20.0-(23.7)-27.0 μm (n = 10). Exine about 0.5 μm thick, of two layers closely appressed, nexine very thin; sculpture finely and sparsely scabrate. Colpi short, generally gaping, extend one-third to one-fourth of grain radius. Exopores lacking; endopores distinct to obscure, about 5 μm in diameter.

Discussion

Comments. Norton (in Norton and Hall, 1969) described pollen grains having this morphology as two species, *Momipites parvus* and *Momipites circularis*. Neither species possesses morphologic features typical of the genus *Momipites* Wodehouse (Nichols, 1973) and the transfer to *Kurtzipites* is based on their brevicolpate, tricolporate apertures and the distinctive shape of the amb. Both of Norton's species appear to be referable to a single species, of which *Kurtzipites parvus* is the senior synonym based on page priority.

Fleming (1990) has previously proposed this nomenclatural combination for this species, but his study is not yet published. He noted that this species tends to occur in assemblages that are interpreted to represent marsh paleoenvironments. A similar habitat is interpreted for species of *Kurtzipites* in the present study.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *K. parvus* was recorded in about 50 percent of the productive samples (see Plate 3). Common; maximum relative abundance in any sample is 40.9 percent.

Previous Records. Hell Creek, Tullock, and Lebo Formations, northeastern Montana (Norton and Hall, 1969); Lance Formation and Tullock Member of the Fort Union Formation, east-central Wyoming (Leffingwell, 1971); Fort Union Formation (Zone I of the Cave Hills section), northwestern South Dakota, (as *Momipites findus* [nom. nud.]) (Stanley, 1960, p. 118); Hell Creek, Lebo and Tullock Formations, northeastern Montana (Oltz, 1969); Tullock Member of the Fort Union Formation, Powder River Basin of Montana and Wyoming (Nichols and Brown, 1992); Frenchman and Ravenscrag Formations, south-central Saskatchewan (Nichols *et al.*, 1986); Maastrichtian and Paleocene portions of the Raton Formation, Colorado and Wyoming (Fleming, 1990); Cretaceous and Paleocene portions of the Coalspur Formation, Alberta, (Jerzykiewicz and Sweet, 1986); Ravenscrag Formation, southern Saskatchewan (Jarzen, 1982); and Frenchman Formation, south-central Saskatchewan (Jarzen, 1978).

Illustrated Specimen. Plate 18, Figure 11: UND-PC A2892-3, 10.6 mm across X 5.3 mm up.

Kurtzipites polyformis (Stanley) n. comb.

Plate 18, Figure 12

Aenigmapollis polyformis Stanley, 1965, p. 312, pl. 46, figs. 22-25.

Porocolpopollenites spp. Elsik, 1968b, p. 34, pl. 28, figs. 15a, b, and c only.

Kurtzipites annulatus Norton in Norton & Hall, 1969, p. 39, pl. 5, fig. 13.

Kurtzipites sp. Penny, 1969, pl. 16-3, fig. 18.

Kurtzipites sp. Snead, 1969, p. 52, pl. 5, figs. 15, 16.

Kurtzipites sp. Leffingwell, 1971, p. 51, pl. 10, figs. 6, 7.

Kurtzipites cf *K. trispissatus* Anderson 1960, in R.H. Tschudy, 1971, p. 86, pl. 4, fig. 20.

Kurtzipites sp. Jarzen, 1976, p. 49, pl. 1, fig. 12.

Description of North Dakota Specimens

Tricolporate, brevicolpate pollen, oblate, amb subcircular, apertures slightly aspidate; equatorial diameter 20.0-(23.8)-27.0 μm (n = 8). Exine tectate, 0.5-1.0 μm thick, thickening slightly near apertures; columellate layer indistinct in optical section except for equatorial intercolpia; sculpture finely and sparsely scabrate. Colpi short, generally less than one-third of grain radius, slightly gaping. Exopores lacking, endopores about 3-4 μm in diameter, more or less circular; endopores surrounded by arcuate nexinal thickenings that are best developed just poleward of endopores, where they form a triangular-shaped patch.

Discussion

Comments. Srivastava (1981) recognized that *Aenigmapollis polyformis* Stanley was assignable to *Kurtzipites* Anderson, although he considered *A. polyformis* to be a junior synonym of *K. trispissatus*. Stanley (1965) described *A. polyformis* as tricolporate with pores that are surrounded by an annulus that is widest on the meridional portion. The illustrated specimens show that the annulus extends completely around the pore, a diagnostic feature of *Kurtzipites annulatus* Norton. Therefore, *A. polyformis* is transferred to *Kurtzipites* and *K. annulatus* becomes a junior synonym.

Fleming (1990) has previously proposed this nomenclatural combination, but his work is not yet validly published. He noted that detrended correspondence analysis placed *K. polyformis* in a group that is interpreted to represent marsh assemblages, suggesting that the producing plant was a marsh inhabitant.

Occurrences. Ludlow and Slope Formations and the Boyce Tongue of the Cannonball Formation; samples UND-PC A2952, A2954, A2955, A2956, A2957, A2958, A2822, A2877, A2919, A2881, A2883, A2960, A2963, A2964, A2965, A2976, A2981 and A2982. Common; maximum relative abundance in any sample is 47.9 percent.

Previous Records. Hell Creek and Fort Union Formations, northwestern South Dakota (Stanley, 1965); Hell Creek Formation, northeastern Montana (Norton and Hall, 1969); Hell Creek Formation, eastern Montana (R.H. Tschudy, 1971); Hell Creek and Tullock Formations, northeastern Montana (Oltz, 1969); Fort Union Formation, Montana (Penny, 1969); Edmonton Formation, Alberta (Snead, 1969); Lance Formation and Tullock Member of Fort Union Formation, east-central Wyoming (Leffingwell, 1971); Maastrichtian-Paleocene boundary interval, Morgan Creek, Saskatchewan (Jarzen, 1977); Maastrichtian and Paleocene portions of the Raton Formation, Colorado and New Mexico (Fleming, 1990); Frenchman Formation, Saskatchewan (Sweet, 1978); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); Ravenscrag Formation, southern Saskatchewan (Jarzen, 1982); Rockdale Formation (Paleocene), Texas (Elsik, 1968b); and Fort Union Formation, northwestern South Dakota (as *Triporopollenites falcatus* [nom. nud.] (Gerhard, 1958).

Illustrated Specimen. Plate 18, Figure 12: UND-PC A2923-1, 7.7 mm across X 3.6 mm up.

Genus *Myrtipites*? Norton & Hall 1969

Myrtipites Norton & Hall, 1969, p. 54.

Type Species: *Myrtipites granulatus* Norton in Norton & Hall 1969

Generic Diagnosis

"Tricolporate grains; colpi short, never meeting at the poles; shape subtriangular to triangular; size variable; exine structure tectate, a vestibulum beneath the pore always present; exine sculpture variable" (Norton and Hall, 169, p. 54).

Discussion

Norton and Hall (1969) considered the presence of a vestibulum to be a diagnostic feature of *Myrtipites*. Pollen grains here assigned to *Myrtipites*? have distinct vestibuli only in exceptional cases. In most grains, the endexinal wall of the vestibulum is missing, presumably through degradation, and only a small interloculum remains. All grains exhibit pronounced endexinal thickening around the endopores. In addition, most specimens have a weakly developed nexinal arcus connecting the pores. The arcus appears to be a continuation of the nexinal thickening about the pores.

Several additional tricolporate genera have short colpi and pores that have vestibuli or interloculi. These genera include *Senipites* Srivastava 1969, *Myrtacidites* Chiataley ex Belsky, Boltenhagen & Potonié 1965, and *Brevicolporites* Anderson 1960. However, none of the aforementioned genera encompass all of the morphologic features present in these pollen grains.

Myrtipites? sp 1

Plate 18, Figure 15; Plate 19, Figure 1

Description

Tricolporate pollen, oblate to globose, amb triangular, sides slightly convex, apices well rounded; specimens in equatorial or subequatorial aspect typically pentagonal in outline; equatorial diameter 14.2-(20.4)-24.7 μm (n = 15). Exine tectate, about 0.5 μm thick in the interapertural areas, thickening to 2.5 μm at the apertures; columellate layer distinct adjacent to apertures, not evident elsewhere; tectum about 0.5 μm thick; nexine about 0.5 μm thick, thickening to form an endannulus about 1.3 μm thick around the endopores, endannulus triangular in optical section; sculpture finely granulate to infragranulate. Weak arcus on both polar hemispheres present in most specimens. Colpi extend about one-half grain radius, closed, commonly rounded at their ends. Exopores small to lacking, endopores distinct, 4-5 μm in diameter. Vestibulum present in some specimens, most specimens have only small interloculum.

Discussion

Comments. Most specimens of *Myrtipites*? sp. 1 have distinctly granulate sculpture. However, some specimens appear to have a smooth tectum, but the relatively large columellae yield an infragranulate sculpture. The distinction between the two sculpture types is probably due to differences in preservation. This species appears to be somewhat similar in size and general morphology to *Myrtipites granulatus* Norton in Norton & Hall 1969. *M. granulatus* exhibits the lengthening of the columellate layer adjacent to the apertures, but it was described as having vestibulate pores and also lacks an arcus.

Occurrences. Ludlow and Slope Formations and the Boyce Tongue of the Cannonball Formation; samples UND-PC A2942, A2822, A2919, A2879, and A2885. Rare; maximum relative abundance in any sample is 1.2 percent.

Previous Records. No prior records of fossil pollen conspecific with this species have been located.

Illustrated Specimens. Plate 18, Figure 15: UND-PC A2887-2, 10.8 mm across X 6.4 mm up. Plate 19, Figure 1: UND-PC A2887-2, 10.6 mm across X 11.4 mm up.

Myrtipites? sp. 2

Plate 19, Figures 2-4

Description

Tricolporate pollen grains, shape oblate to globose, amb triangular, sides convex; most specimens oriented in three-fourths polar view with rigidly pentagonal outline; diameter 14.0-(17.0)-23.0 μm (n = 35). Exine tectate, 1 to 3 μm thick on same specimen, thinnest in the interapertural areas where columellate layer is not evident; tectum relatively constant in thickness; columellate layer and nexine thicken near apertures; nexine thickness 0.5-2.0 μm. Exinal thickenings around pores are connected by distinct to indistinct arcus that involves thickening of nexine and columellate layers; a Y-shaped exinal thickening present on poles, rotated 60 degrees from apertures; polar thickening connects to arcus, a circular exinal thickening 4-5 μm in diameter present at junction of arcus and Y-mark, orientation of arcus and polar thickening difficult to ascertain in most specimens; sculpture finely scabrate to weakly granulate. Colpi narrow, extend about one-half grain radius; exopores lacking, endopores circular to lolongate, about 2.0 to 5.0 μm in diameter, distinctly endannulate, vestibuli lacking.

Discussion

Comments. *Myrtipites*? sp. 2 is differentiated from *Myrtipites*? sp. 1 by its distinctly smaller diameter, finer sculpture, and unusual exinal thickenings that tend to orient the grains such that the outline is pentagonal. *Myrtipites*? sp. 2 appears to be distinguished from *Myrtipites scabratus* Norton in Norton & Hall 1969 by its smaller diameter, larger pores, and exinal thickenings.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2939, A2834, A2873, A2878, A2883, A2960, A2844, A2846, A2847, A2849, A2851, A2852, A2853, A2857, A2858, A2859, and A2962. Common; maximum relative abundance in any sample is 8.7 percent.

Previous Records. I have not yet noted any published records of fossil pollen conspecific with *Myrtipites*? sp. 2.

Illustrated Specimens. Plate 19, Figure 2: UND-PC A2939-3, 13.32 mm across X 16.6 mm up. Plate 19, Figure 3: UND-PC A2939-3, 8.7 mm across X 3.1 mm up. Plate 19, Figure 4: UND-PC A2939-3, 15.1 mm across X 0.5 mm up.

Genus *Nyssapollenites* Thiergart 1937 ex Potonié 1960

Nyssapollenites Thiergart, 1937 (preprint), 1938, p. 322.

Nyssapollenites Thiergart 1937 ex Potonié, 1960, p. 103.

Type Species: *Nyssapollenites pseudocruciatus* (Potonié) Thiergart 1937

Generic Diagnosis

"Pollen with 'suboblate shape, round ovoid or almost spherical; meridian often rhombic; equator ± rounded triangular; tricolporate, equatorial rugae ± distinct, rugae meridional (= colpi) with ± thickened border; exine infrapunctate'" (Potonié, 1960, p. 103, translated in Jansonius and Hills, 1976, card 1794).

Nyssapollenites sp.

Plate 19, Figures 6-8

Description

Tricolporate pollen, subprolate to globose, amb circular to triangular with convex sides, outline in equatorial view oval to slightly rhombic; dimensions of specimens in equatorial view 14.0-(17.1)-20.5 X 8.5-(12.9)-17.0 μm (n = 9); equatorial diameter of grains in polar view 13.0-(19.5)-20.0 μm (n = 3). Exine tectate, 0.7-1.0 μm thick, sexine generally slightly thicker than nexine; columellate layer thin, but evident in optical section; sculpture psilate to infrascabrate. Colpi long, reaching well into polar area; colpi bordered by costae colpi that range from distinct to indistinct, costae colpi generally about 1.0 μm wide, interrupted by pores. Pores distinct in equatorial view, less distinct in polar view, lalongate, 1.5-2.0 μm in meridional diameter; distinct exinal thickening around pores lacking.

Discussion

Comments. *Nyssapollenites* sp. is distinct from other species of tricolporate pollen encountered in this study by its small size, weak sculpture, and the presence of costae colpi. *Tricolporopollenites incomptus* Chmura 1973 has smaller, less distinct pores and more deeply inset colpi. *Tricolporites rhomboides* Anderson 1960 tends to have thicker exine (1.5 μm), is somewhat smaller and lacks distinct costae colpi.

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation. *Nyssapollenites* sp. was recorded in about 33 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 10.9 per cent.

Previous Records. I have not yet noted any published records of a fossil pollen species conspecific with *Nyssapollenites* sp. 1.

Illustrated Specimens. Plate 19, Figure 6: UND-PC A2982-4, 8.9 mm across X 18.6 mm up. Plate 19, Figure 7: UND-PC A2982-4, 17.6 mm across X 13.7 mm up. Plate 19, Figure 8: UND-PC A2878-2, 20.1 mm across X 5.1 mm up.

Genus *Polotricolporites* González Guzmán 1967

Polotricolporites González Guzmán, 1967, p. 42.

Type Species: *Polotricolporites mocinnii* González Guzmán 1967

Generic Diagnosis

"Pollen grains with three furrows and three pores. The furrows are 'connected' by thickenings (ridges) of the exine in the polar areas.

Sculpture types; foveolate-reticulate-fossulate" (González Guzmán, 1967, p. 42, cited in Jansonius and Hills, 1976, card 2071).

Polotricolporites rotundus Sweet 1986

Plate 19, Figure 10

Polotricolporites rotundus Sweet, 1986, p. 1383, pl. 1 & 2, figs. 20, 21.

Description of North Dakota Specimens

Tricolporate pollen, prolate; outline rhomboidal in equatorial view, amb triangular, angulaperturate; dimensions 24.0-(35.5)-40.0 X 19.0-(30.0)-35.0 μm (n = 6). Exine semitectate; about 1.5 μm thick on the apocolpia, thinning slightly to equatorial apertural areas, sexine about twice as thick as nexine; columellae distinct in optical section and plan view; sculpture reticulate; lumina reach maximum diameter of about 1.3 μm in mesocolpia, decreasing toward colpi, commonly elongate, may be heterobrochate; some specimens with distinctly finer reticulum; muri simplibaculate, narrow. Colpi long, nearly reaching poles, exine infolded into colpi. Exopores lacking, endopores distinct, 3-5 μm in meridional diameter, probably lalongate; endexine thickens and separates slightly from ektexine at endopore.

Discussion

Comments. These specimens appear to agree well with the original description and illustrations of *Polotricolporites rotundus*. Sweet (1986) described two varieties, *P. rotundus rotundus* and *P. rotundus pumilus*. The North Dakota specimens appear to be assignable to the *rotundus* variety. *Caprifoliipites longus* Stanley 1965 is similar in size and sculpture, but lacks the rhomboidal outline in equatorial view.

Occurrences. Ludlow and Slope Formations and the Boyce Tongue of the Cannonball Formation; samples UND-PC A2940, A2952, A2957, A2818, A2820, A2822, A2838, A2875, A2982, A2995, and A2868. Rare; maximum relative abundance in any sample is 1.8 percent.

Previous Records. Maastrichtian and Paleocene portions of the Coalspur Formation, Alberta and Saskatchewan (Sweet, 1986); Hell Creek and Tullock Formations, northeastern Montana (Hotton, 1988); and Hell Creek Formation, North Dakota (as *Tricolpites geranioides*) (Bergad, 1974).

Illustrated Specimens. Plate 19, Figure 10: UND-PC A2887-2, 5.2 mm across X 0.4 mm up.

Genus *Rhoipites* Wodehouse 1933

Rhoipites Wodehouse, 1933, p. 513.

Type Species: *Rhoipites bradleyi* Wodehouse 1933

Generic Diagnosis

"Ellipsoidal, tricolpate pollen, with furrows long and pointed; furrow and pore thickenings conspicuous, projecting deeply inwards; exine rather finely reticulate-pitted" (Wodehouse, 1933, p. 513).

Rhoipites pisinnus Stanley 1965

Plate 19, Figure 9

Rhoipites pisinnus Stanley, 1965, p. 286, pl. 42, figs. 14-23.

Description of North Dakota Specimens

Tricolporate pollen, shape prolate, outline in equatorial aspect oval; dimensions 15.5-(19.8)-22.0 X 11.5-(16)-18.5 μm (n = 17). Exine tectate, about 1.0-1.5 μm thick, slightly thicker on poles; nexine about equal in thickness to sexine, columellate layer distinct; sculpture foveo-reticulate to microreticulate; lumina 0.5 μm or less in diameter, smaller toward colpi; muri typically 0.5-0.8 μm wide. Colpi long, reaching into polar areas, closed, bordered by distinct costae colpi about 1.5 μm wide; pores equatorial, lalongate, about 4 X 2 μm.

Discussion

Comments. Pollen grains here assigned to *Rhoipites pisinnus* agree with Stanley's original description in nearly every respect. Stanley (1965) described the sculpture as "faintly reticulate with lumina 0.2-0.3 μ wide." The sculpture on the illustrated specimens shows that the lumina and muri are about of equal width, and the lumina decrease in size toward the colpi. This sculpture pattern is consistent with the foveo-reticulate pattern of the specimens noted in the present study.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; *R. pisinnus* was recorded in about 33 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 3.4 percent.

Previous Records. Hell Creek Formation and Ludlow Member of Fort Union Formation, northwestern South Dakota (Stanley, 1965); Bearpaw, Hell Creek, and Tullock Formations, northeastern Montana (Oltz, 1969); Tullock Member of Fort Union Formation, Powder River Basin of Wyoming and Montana (as *Rhoipites* spp., pl. 7, fig. 22) (Nichols and Brown, 1992); Lance Formation, northeastern Wyoming (Farabee and Canright, 1986); Ravenscrag Formation, southern Saskatchewan (Jarzen, 1982); and Edmonton Formation (Maastrichtian and Paleocene), Alberta (Snead, 1969).

Illustrated Specimen. Plate 19, Figure 9: UND-PC A2982-4, 18.2 mm across X 19.6 mm up.

Genus *Simpsonipollis* Srivastava 1975

Simpsonipollis Srivastava, 1975a, p. 142.

Type Species: *Simpsonipollis mullensis* (Simpson) Srivastava 1975

Generic Diagnosis

"Pollen, tricolporate or tetracolporate, prolate to subprolate; colpi long; pores large or small, well defined; exine subtectate, clavate; sculpture reticulate, meshes arranged more or less in meridional (linear) lattices" (Srivastava, 1975, p. 142).

Discussion

Simpsonipollis is differentiated from *Aesculiidites* Elsik 1968b by having a meridional rather than circumstriate orientation to the striate sculpture elements.

Simpsonipollis sp. 1

Plate 19, Figures 11, 15

Description

Tricolporate pollen, prolate to subprolate; dimensions of grains in equatorial view 22.0-(22.9)-26.0 X 14.0-(16.5)-19.0 μm (n = 5) equatorial diameter of grains in polar view 20.5-23.5 μm (n = 2). Exine semitectate, about 1.0 μm thick, sexine 2-3 times as thick as nexine, columellae short but distinct in optical section and plan view; sculpture of meridionally oriented striae; striae commonly slightly sinuous, striae about 0.5-0.8 μm wide, simplibaculate; vallae 0.5 or less in width. Colpi long, commonly bordered by costae colpi about 1.5 μm wide. Pores equatorial, distinct to indistinct, circular to lalongate; pore size variable, up to 4 μm in meridional diameter.

Discussion

Comments. Pollen grains here assigned to *Simpsonipollis* sp. 1 express considerable variability in the size of the pores and the distinctness of the costae colpi. Specimens possessing distinct costae colpi and small pores (Plate 19, Figure 15) may represent a distinct species. However, the number of specimens encountered was insufficient to document the degree of gradation between the two forms.

Some of the specimens assigned to *Simpsonipollis* sp. 1 may be conspecific with *Tricolporopollenites striatus* Norton in Norton & Hall 1969. However, Norton did not specify whether the striate sculpture *T. striatus* had a meridional or circumstriate orientation, and the illustrated specimen lacks sufficient detail to resolve this question.

Occurrences. Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation; samples UND-PC A2951, A2953, A2818, A2842, A2883, A2965, A2979, A2845, A2863, A2969, and A2972. Rare; maximum relative abundance in any sample is 1.0 percent.

Previous Records. Hell Creek Formation, northeastern Montana (Norton and Hall, 1969); and Hell Creek and Tullock Formations, northeastern Montana (as *Simpsonipollis* cf. *S. striatus*) (Hotton, 1988).

Illustrated Specimens. Plate 19, Figure 11: UND-PC A2979-3, 24.9 mm across X 13.1 mm up. Plate 19, Figure 15: UND-PC A2919-1, 20.9 mm across X 3.2 mm up.

Simpsonipollis sp. 2

Plate 19, Figures 12-14

Description

Tricolporate to tricolporoidate pollen, suboblate to subprolate; in equatorial view, outline ovoid to rhomboid; amb triangular, sides convex; dimensions 12.0-(16.6)-18.0 X 12.1-(14.0)-15.5 μm (n = 7). Exine tectate, about 0.8 μm thick, thins abruptly about 1.5 μm from colpi; sexine and nexine about equal thickness; columellate layer thin, but resolvable; sculpture finely strio-reticulate to striate, commonly indistinct; striae supratectal, predominantly diagonally oriented, commonly yielding a swirling or chevron pattern; muri and vallae each about 0.5 μm wide. Colpi long, reaching polar regions, bordered by narrow costae colpi; pores distinct to indistinct; if distinct pores lacking, equatorial flexure present; pores about 1.5 to 2.5 μm in meridional diameter.

Discussion

Comments. These specimens are assigned to *Simpsonipollis* with some hesitation, as the striae do not have a predominantly meridional orientation. At present, a more suitable genus has not been identified.

Although the pores of most specimens are indistinct, a small equatorial break in the costae colpi is present in nearly every specimen.

Occurrences. Ludlow and Slope Formations; samples UND-PC A2957, A2958, A2817, and A2994. Rare; maximum relative abundance in any sample is 1.4 percent.

Previous Records. Probable record from Hell Creek and Tullock Formations, northeastern Montana (as ?*Simpsonipollis* sp. 3) (Hotton, 1988).

Illustrated Specimens. Plate 19, Figure 12: UND-PC A2957-3, 10.5 mm across X 7.2 mm up. Plate 19, Figures 13 and 14: UND-PC A2957-3, 8.3 mm across X 7.9 mm up.

Genus *Tricolporopollenites* Pflug & Thomson in Thomson & Pflug 1953

Tricolporopollenites Pflug & Thomson in Thomson & Pflug, 1953, p. 98.

Type Species: *Tricolporopollenites dolium* (Potonié) Thomson & Pflug 1953

Generic Diagnosis

"Pollen with three symmetrically distributed germinals, that each consist of a meridional colpus with an equatorial pore" (Thomson and Pflug, 1953, p. 98, translated in Jansonius and Hills, 1976, card 2999).

Discussion

Thomson and Pflug's (1953) diagnosis of *Tricolporopollenites* included tricolporate pollen of all sculptural types. Since other genera are available to accommodate pollen having sculpture differing from the genotype, *Tricolporopollenites dolium*, such broad circumscription is unnecessary. As used here, the genus is restricted to tricolporate pollen having scabrate to granulate sculpture similar to that of the genotype.

Potonié (1960) considered *Tricolporopollenites* to be a junior synonym of *Rhoipites* Wodehouse 1933. However, *Rhoipites* is diagnosed as having a finely reticulate-pitted exine and would not appear to apply to the pollen here assigned to *Tricolporopollenites*.

Tricolporopollenites cf. *T. dolium* (Potonié) Thomson & Pflug 1953

Plate 19, Figures 16, 17

Pollenites dolium Potonié, 1931b, p. 26, pl. 1, fig. V38a.

Tricolporopollenites dolium (Potonié) Thomson & Pflug, 1953, p. 98, pl. 12, figs. 114-117.

Description of North Dakota Specimens

Tricolporate pollen, prolate; outline in equatorial view ovoid to slightly rhomboid, amb subtriangular to somewhat trilobate; dimensions 12.5-(16.3)-21.5 X 10.5-(13.0)-20.0 μm (n = 13). Exine tectate, about 1.0 μm thick, may thicken slightly at poles; nexine about as thick as sexine; columellate layer distinct, 0.3-0.4 μm thick; sculpture scabrate to weakly granulate. Colpi long, narrow costae colpi present in many specimens. Pores equatorial, distinct in most specimens, about 2.0 μm in meridional diameter.

Discussion

Comments. *Tricolporopollenites* cf. *T. dolium* differs from *T. dolium* by its smaller size and somewhat more indistinct pores. The specimens assigned to the species by Thomson and Pflug (1953) are notably larger (30-40 μm). *Tricolporopollenites inductorius* Chmura 1973 is of similar size, but is described as finely reticulate. Hotton (1988) included scabrate pollen very similar to these North Dakota specimens in *Tricolporopollenites* cf. *T. inductorius*.

Occurrences. Ludlow and Slope Formations and the Three V Tongue of the Cannonball Formation; samples UND-PC A2822, A2968, A2995, A2846, A2848, A2857, A2858, and A2868. Rare; maximum abundance in any sample is 3.1 percent.

Previous Records. A probable record of fossil pollen conspecific with *Tricolporopollenites* cf. *T. dolium* exists from Hell Creek and Tullock Formations, northeastern Montana (as *Tricolporopollenites* cf. *T. inductorius*) (Hotton, 1988).

Illustrated Specimens. Plate 19, Figure 16: UND-PC A2919-1, 3.1 mm across X 2.1 mm up. Plate 19, Figure 17: UND-PC A2845.1-3, 15.8 mm across X 16.5 mm up.

Genus *Wilsonipites* Srivastava 1969

Wilsonipites Srivastava, 1969b, p. 63.

Type Species: *Wilsonipites nevisensis* Srivastava 1969

Generic Diagnosis

"Tricolporate, oblate to spherical, angulaperturate; colpi long, reaching poles, meridional, narrow; pores equatorial, small, inconspicuous; amb subtriangular to circular, sides convex; sexine very thin, scabrate, reticulations less than 1 μ" (Srivastava, 1969b, p. 63).

Wilsonipites sp.

Plate 19, Figures 18, 19

Description

Tricolporate pollen, subprolate to globose; dimensions 11.0-(12.1)-15.5 X 9.0-(10.5)-14.5 μm (n = 17). Exine semitectate, about 1.2 μm thick, sexine slightly thicker than nexine; structure of fused clavae; sculpture microreticulate, lumina about 0.5 μm diameter; muri narrow. Colpi long, reaching to polar regions, generally bordered by colpi costae, colpi margins psilate in some specimens. Pores distinct to indistinct, 2.0-3.0 μm in meridional diameter, circular to lolongate.

Discussion

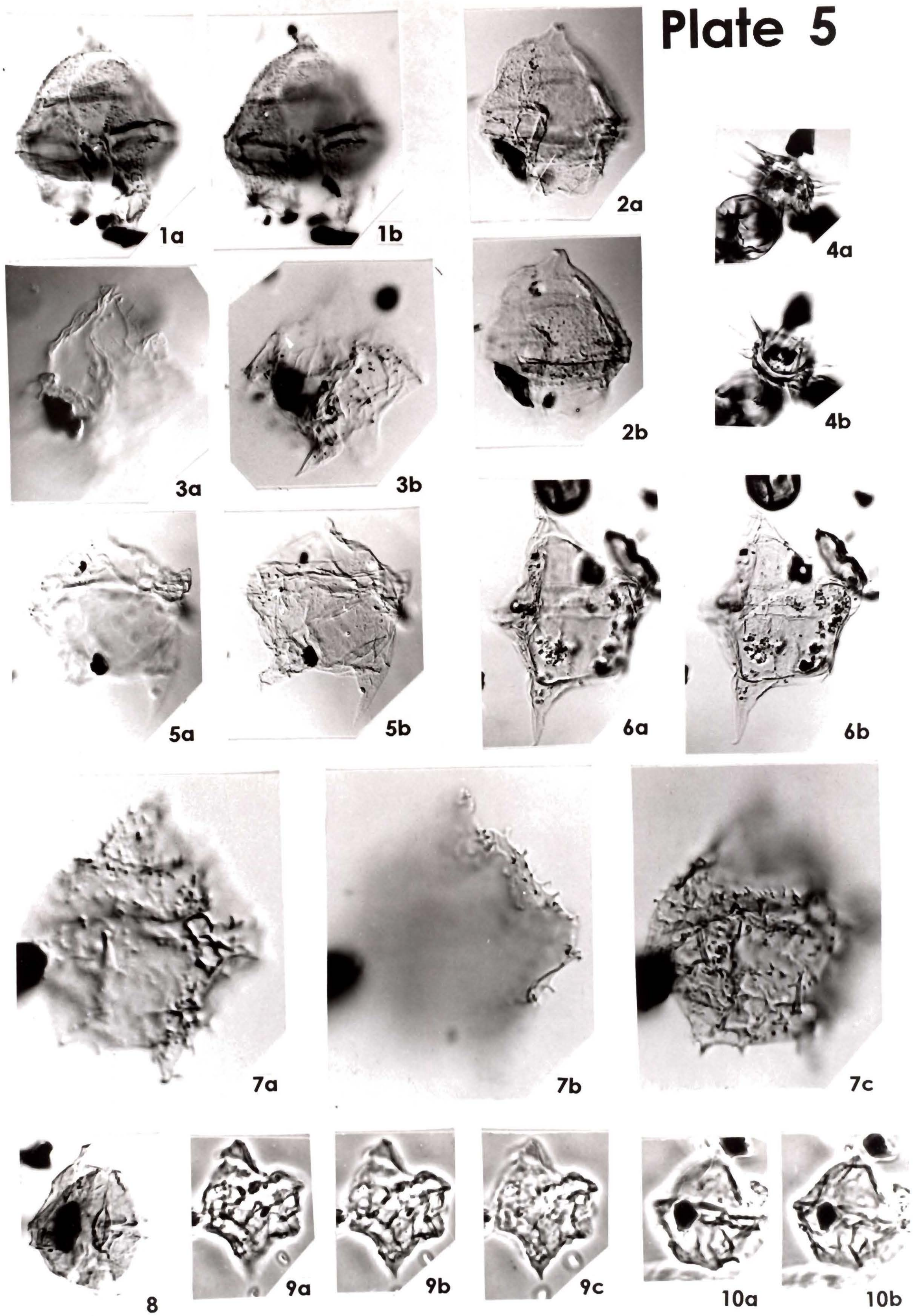
Comments. *Wilsonipites* sp. is nearly identical in size and sculpture to pollen grains assigned to *Tricolpites* cf. *T. minutus*. The pores and the presence of costae colpi serve to differentiate the two species.

Occurrences. Ludlow and Slope Formations and Boyce and Three V Tongues of the Cannonball Formation; *Wilsonipites* sp. 1 was recorded in about 33 percent of the productive samples (see Plate 3). Uncommon; maximum relative abundance in any sample is 8.2 percent.

Previous Records. I have not noted any published records of fossil pollen that is conspecific with *Wilsonipites* sp. 1.

Illustrated Specimens. Plate 19, Figure 18: UND-PC A2878-3, 6.9 mm across X 6.2 mm up. Plate 19, Figure 19: UND-PC A2963-1, 24.2 mm across X 14.3 mm up.

Plate 5



Explanation of Plate 5

Figures 1a-b, 2a-b: *Deflandrea* cf. *D. flounderensis* Stover 1974. 400X. Figure 1, brightfield (BF) illumination; Figure 2, differential interference contrast (DIC) illumination.

Figures 3a-b: *Phelodinium magnificum* (Stanley) Stover & Evitt 1978. 400X. DIC illumination.

Figures 4a-b: *Diphyes colligerum* (Deflandre & Cookson) Cookson emend. Davey & Williams 1966. 400X. DIC illumination.

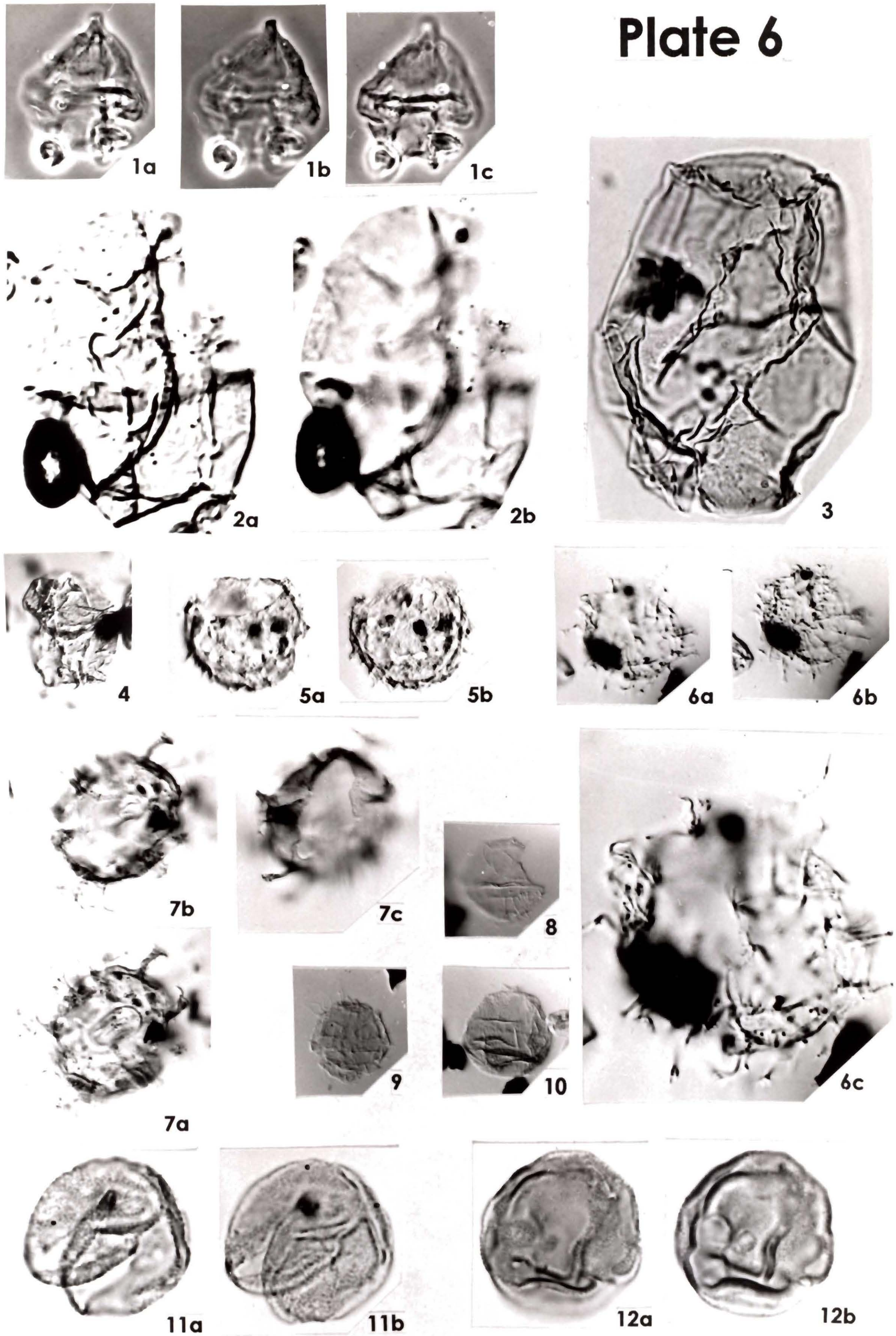
Figures 5a-b, 6a-b: *Phelodinium* sp. 400X. DIC illumination.

Figures 7a-c: *Spinidinium? pilatum* (Stanley) Costa & Downie 1979. 1000X. Figure 7a, DIC illumination; Figure 7b, 7c, BF illumination.

Figure 8: *Senegalinium microgranulatum* (Stanley) Stover & Evitt 1978. 400x. DIC illumination.

Figures 9a-c, 10a-b: Peridinioid sp. 1. 400X. Phase contrast illumination.

Plate 6



Explanation of Plate 6

Figures 1a-c: Peridinioid sp. 1. 400X. Phase contrast illumination.

Figures 2a-b, 3, 4: Dinoflagellate? sp. 1. Figures 2 and 3, 1000X; Figure 4, 400X. Figures 2 and 4, DIC illumination; Figure 3, BF illumination.

Figures 5a-b: Dinoflagellate sp. 2. 400X. DIC illumination.

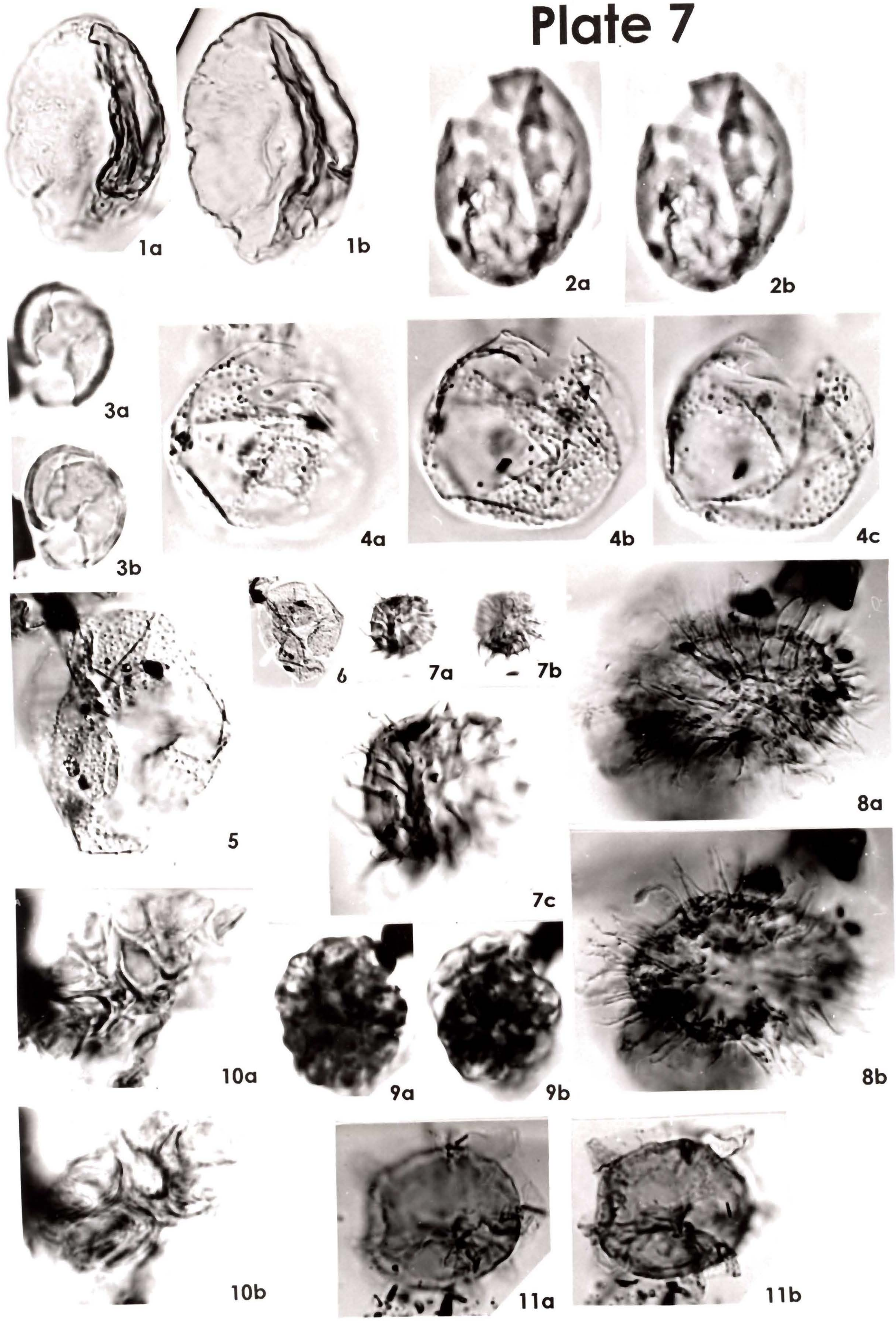
Figures 6a-c: Dinoflagellate sp. 3. Figures 6a and 6b, 400X; Figure 6c, same specimen 1000X, showing details of processes. DIC illumination.

Figures 7a-c: Dinoflagellate sp. 4. 400X. DIC illumination.

Figures 8, 9, 10: Dinoflagellate sp. 5. 400X. DIC illumination.

Figures 11a-b, 12a-b: Acritarch Type-1. 1000X. Brightfield illumination.

Plate 7



Explanation of Plate 7

Figures 1a-b, 2a-b: Acritarch Type-2. 1000x. Figures 1a and 1b BF illumination; Figures 2a and 2b, phase contrast illumination.

Figures 3a-b: Acritarch Type-3. 1000X. BF illumination.

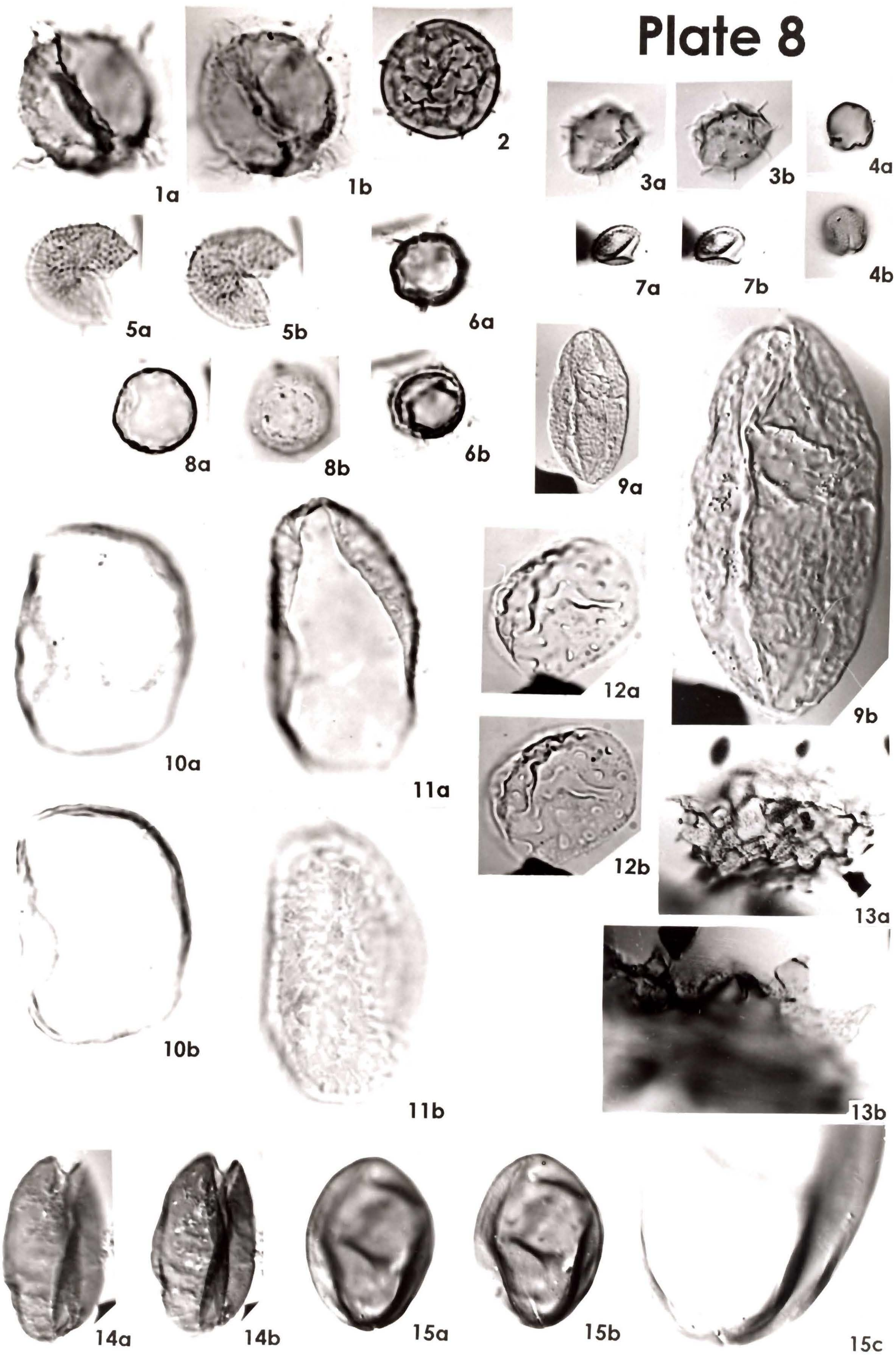
Figures 4a-c, 5, 6: Acritarch Type-4. Figures 4a, 4b, 4c, and 5, 1000X; Figure 6, same specimen as Figure 5, 400X. DIC illumination.

Figures 7a-c, 8a-b: *Baltisphaeridium* spp. Figures 7a and 7b, 400X; Figures 7c, 8a, 8b, 1000X. DIC illumination.

Figures 9a-b, 10a-b: *Botryococcus* sp. 1000X. BF illumination.

Figure 11a-b: *Cymatiosphaera* spp. 1000X. BF illumination.

Plate 8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Explanation of Plate 8

Figures 1a-b, 2: *Cymatiosphaera* spp. 1000X. BF illumination.

Figures 3a-b, 4a-b, 5a-b, 7a-b: *Micrhystridium* Type-1. 1000X. Figures 3a, 3b, 4a, 4b, DIC illumination; Figures 5a, 5b, 7a, 7b, BF illumination.

Figures 6a-b, 8a-b: *Micrhystridium* Type-2. 1000X. BF illumination.

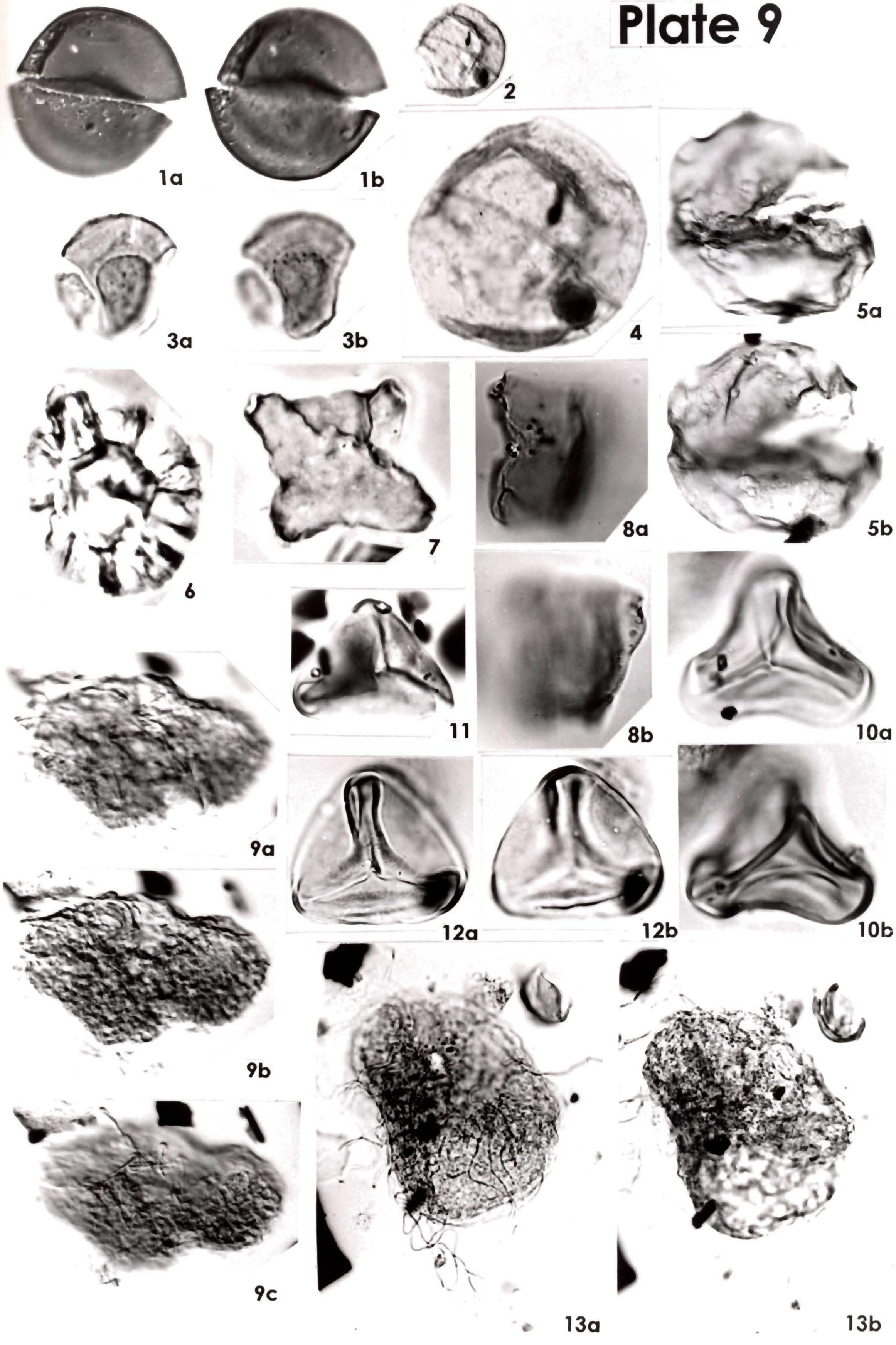
Figures 9a-b, 10a-b, 11a-b: *Ovoidites* cf. *O. ligneolus*. Figure 9a, 400X; Figure 9b, same specimen, 1000X; Figures 10a, 10b, 11a, 11b, 1000X. Figures 9a, 9b, DIC illumination; Figures 10a, 10b, 11a, 11b, BF illumination.

Figures 12a-b: *Polyporina* sp. 1000X. BF illumination.

Figures 13a-b: *Pediastrum* spp. Figure 13a, 400X; Figure 13b, same specimen, 1000X. DIC illumination.

Figures 14a-b, 15a-c: *Psiloschizosporis laevigatus* (Stanley) n. comb. Figures 14a, 14b, 15a, 15b, 400X; Figure 15c, same specimen as 15a and 15b, 100X, showing detail of spore wall.

Plate 9



Explanation of Plate 9

Figures 1a-b, 2, 4, 5a-b: *Psiloschizosporis* cf. *P. spriggii*. Figures 1a, 1b, 2, 5a, and 5b, 400X; Figure 4, same specimen as Figure 2, 1000X. Figures 1a, 1b, and 4, BF illumination; Figures 2, 5a, and 5b, DIC illumination.

Figures 3a-b: *Sigmopollis hispidus* Hedlund 1965. 1000X. BF illumination.

Figure 6: *Pterospermella australiensis* (Deflandre & Cookson) Eisenack *et al.* 1973. 1000X. Phase contrast illumination.

Figure 7, 8a-b: *Tetraporina* sp. 1000X. Figure 7, phase contrast illumination; Figure 8a, 8b, DIC illumination.

Figures 9a-c: *Azolla cretacea* Stanley, 1965. 400X. DIC illumination.

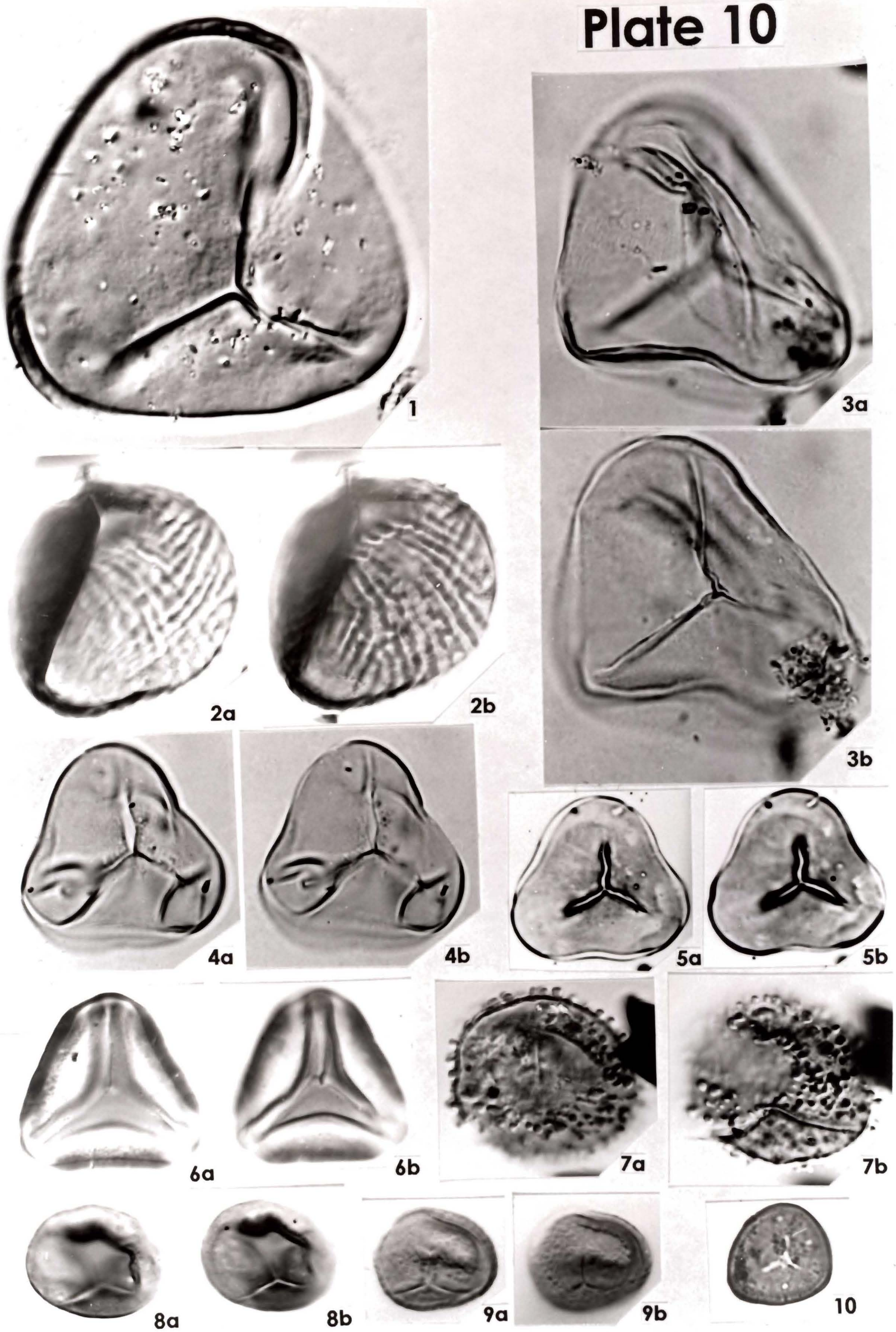
Figures 10a-b: *Gleicheniidites senonicus* Ross 1949. 1000X, DIC illumination.

Figure 11: *Cyathidites kerguelensis* (Cookson) Kemp & Harris 1977. 1000X. BF illumination.

Figures 12a-b: *Dictyophyllidites* sp. 1000X. BF illumination.

Figures 13a-b: *Azolla* spp. 400X. BF illumination.

Plate 10



Explanation of Plate 10

Figures 1, 3a-b: *Biretisporites furcosus* (Stanley) n. comb. 1000X. Figure 1, DIC illumination; Figure 3a, and 3b, BF illumination.

Figures 2a-b: *Cicatricosisporites* spp. 1000X. DIC illumination.

Figures 4a-b, 5a-b: *Cyathidites diaphana* (Wilson & Webster) Nichols & Brown 1992. 1000X. BF illumination.

Figures 6a-b: *Gleicheniidites triangulus* (Stanley) Habib 1970. 1000X. DIC illumination.

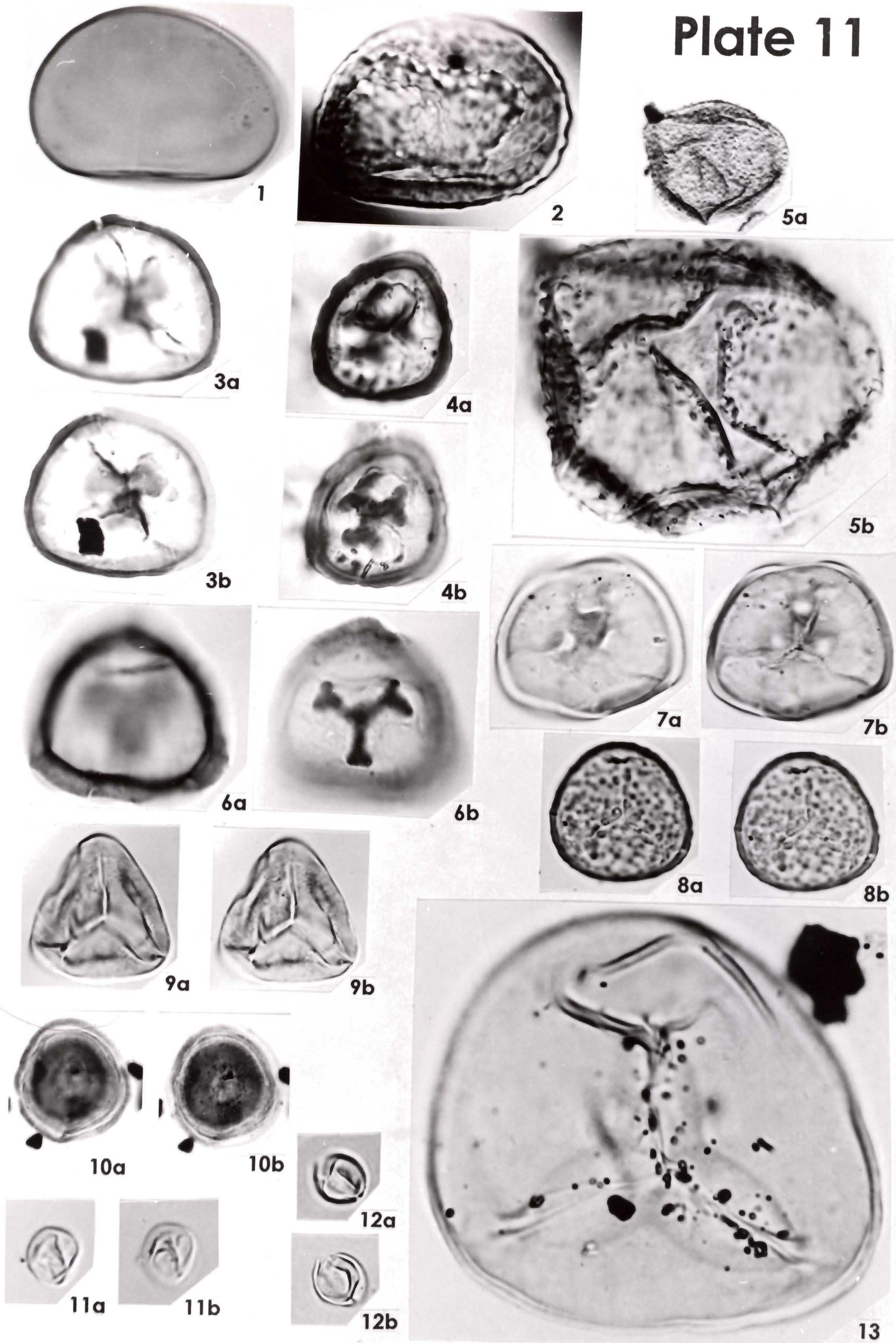
Figures 7a-b: *Osmundacidites* cf. *O. wellmanii* Couper 1953. 1000X. DIC illumination.

Figures 8a-b: *Hydrosporis* cf. *H. levis* Krutzsch 1962. 1000X, DIC illumination.

Figures 9a-b: *Hydrosporis* sp. 1000X. DIC illumination.

Figure 10: *Stereisporites* (*Stereisporites*) spp. and *Stereisporites* (*Distverrusporis*) spp. 1000X. BF illumination.

Plate 11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Explanation of Plate 11

Figure 1: *Laevigatosporites spp.* 1000X. BF illumination.

Figure 2: *Reticuloidosporites pseudomurii* Elsik 1968. 1000X. BF illumination.

Figures 3a-b, 4a-b. *Stereisporites (Distancoraesporis)* spp. 1000X. BF illumination.

Figures 5a-b: *Osmundacidites* cf. *O. wellmanii*. Figure 5a, 400X; Figure 5b, same specimen, 1000X. DIC illumination.

Figures 6a-b: *Stereisporites (Distancoraesporis) radiatus* (Stanley) n. comb. 1000X. BF illumination.

Figures 7a-b: *Stereisporites (Tripunctisporis)* sp. 1000X. BF illumination.

Figures 8a-b: *Stereisporites (Stereigranisporis)* spp. 1000X. BF illumination.

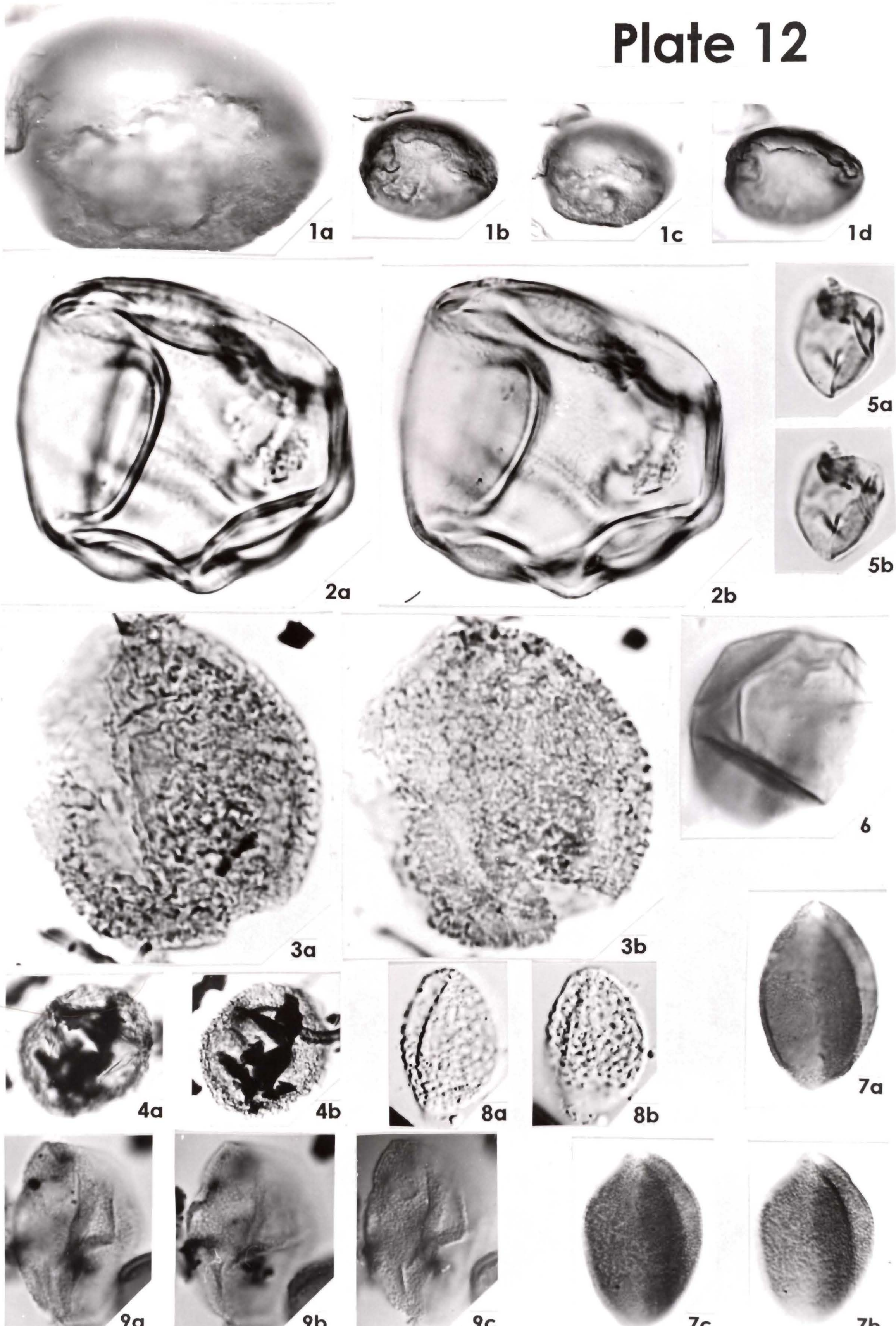
Figures 9a-b: *Toroisporis* sp. 1000X. DIC illumination.

Figures 10a-b: *Corollina* sp. 1000X. BF illumination.

Figures 11a-b, 12a-b: *Psilainaperturites* sp. 2. 1000X. Figure 11a and 11b, DIC illumination; Figure 12a and 12b, BF illumination.

Figure 13: *Toroisporis* cf. *T. major*. 1000X. BF illumination.

Plate 12



Explanation of Plate 12

Figures 1a-d: *Araucariacites australis* Cookson 1947 ex Couper 1953. Figure 1a, 1000X; Figures 1b, 1c, and 1d, same specimen, 400 X.

Figures 2a-b: *Laricoidites* cf. *L. magnus* (Potonié) Potonié, Thomson, & Thiergart 1951 ex Potonié 1958. 1000X. BF illumination.

Figures 3a-b, 4a-b: *Sciadopityspollenites* sp. Figures 3a and 3b, 1000X; Figures 4a and 4b, 400X. BF illumination.

Figures 5a-b, 6: *Psilainaperturites* sp. 1. 1000X. BF illumination.

Figures 7a-c: *Arecipites columellus* Leffingwell 1971. 1000X. Figures 7a and 7c, BF illumination; Figure 7b, DIC illumination.

Figures 8a-b: *Liliacidites*? sp. 1000X. DIC illumination.

Figures 9a-c: Arecipites tenuiexinous Leffingwell 1971. 1000X. Figures 9a and 9b, BF illumination; Figure 9c, DIC illumination.

Plate 13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Explanation of Plate 13

Figures 1a-c: *Arecipites pertusus* (Elsik in Stover *et al.*) Nichols *et al.* 1973. 1000X. Figures 1a and 1b, DIC illumination; Figure 1c, BF illumination.

Figures 3a-b, 4a-c: *Clavamonocolpites* sp. 1000X. Figures 3a, 4a, 4b, and 4c, BF illumination; Figure 3b, DIC illumination.

Figures 5a-c: *Liliacidites*? sp. 1000X. Figures 5a and 5c, BF illumination; Figure 5, DIC illumination.

Figures 6a-b: *Liliacidites* cf. *L. leei* Anderson 1960. 1000X. DIC illumination.

Figures 7a-b: *Cycadopites scabratus* Stanley 1965. 1000X. BF illumination.

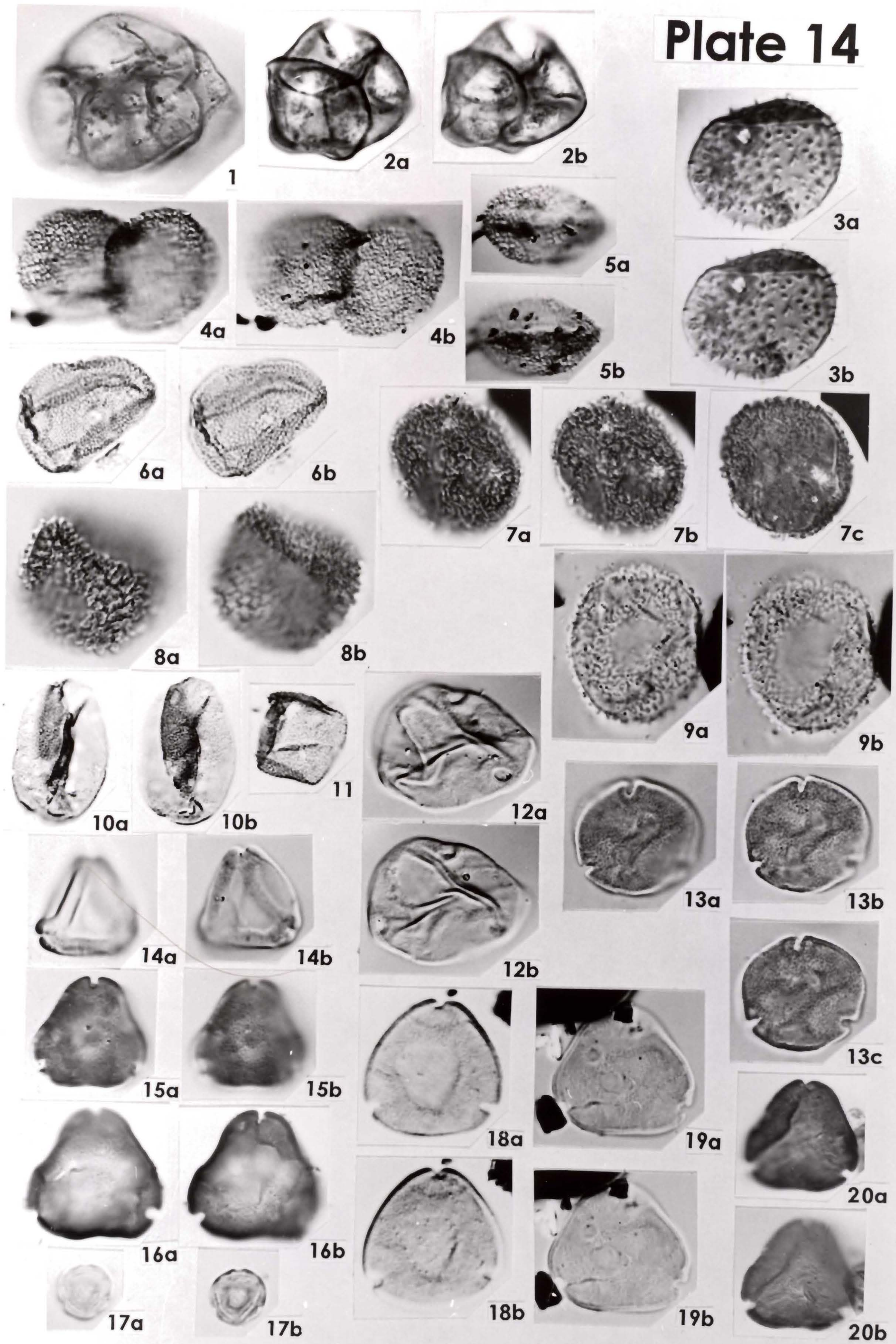
Figures 8a-b: *Monocolpopollenites* cf. *M. texensis* Nichols *et al.* 1973. 1000X. BF illumination.

Figures 9a-d: *Longapertites microfoveatus* (Stanley) n. comb. 1000X. DIC illumination.

Figures 10a-b, 11a-b: *Monosulcites* sp. 1000X. DIC illumination.

Figures 12a-c: *Rossipollis scabratus* (Stanley) n. comb. 1000X. Figure 12a, DIC illumination; Figures 12b and 12c, BF illumination.

Plate 14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Explanation of Plate 14

Figures 1, 2a-b: *Dicotetradites rallus* (Stanley) n. comb. 1000X. DIC illumination. Figure 1 is a more typical specimen; specimen in Figure 2 displays distinct pores.

Figures 3a-b: *Pandaniidites typicus* (Norton) Farabee and Canright 1986. 1000X. DIC illumination.

Figure 4a-b, 5a-b: *Dyadonapites reticulatus* B.D. Tschudy 1973. 1000X. DIC illumination. Figure 4 is a typical specimen; Figure 5 is a monad specimen from the same sample.

Figures 6a-b: *Sparganiaceaepollenites* cf. *S. globipites* (Wilson & Webster) Krutzsch 1970. 1000X. BF illumination.

Figures 7a-c, 8a-b, 9a-b: *Sparganiaceaepollenites* sp. 1000X. Figures 7a, 7b, 8a, 9a, and 9b, DIC illumination; Figures 7c and 8b, BF illumination.

Figures 10a-b, 11: *Sparganiaceaepollenites*? sp. 1000X. BF illumination.

Figures 12a-b: *Cricotriporites plektosus* (Anderson) n. comb. 1000X. DIC illumination.

Figures 13a-c: *Labrapollis granulatus* (Simpson) n. comb. 1000X. DIC illumination.

Figures 14a-b: *Jarzenipollenites trinus* (Stanley) Kedves 1980. 1000X. Figure 14a, BF illumination; Figure 14b, DIC illumination.

Figures 15a-b, 16a-b: *Momipites leffingwellii* Nichols & Ott 1978. 1000X. DIC illumination.

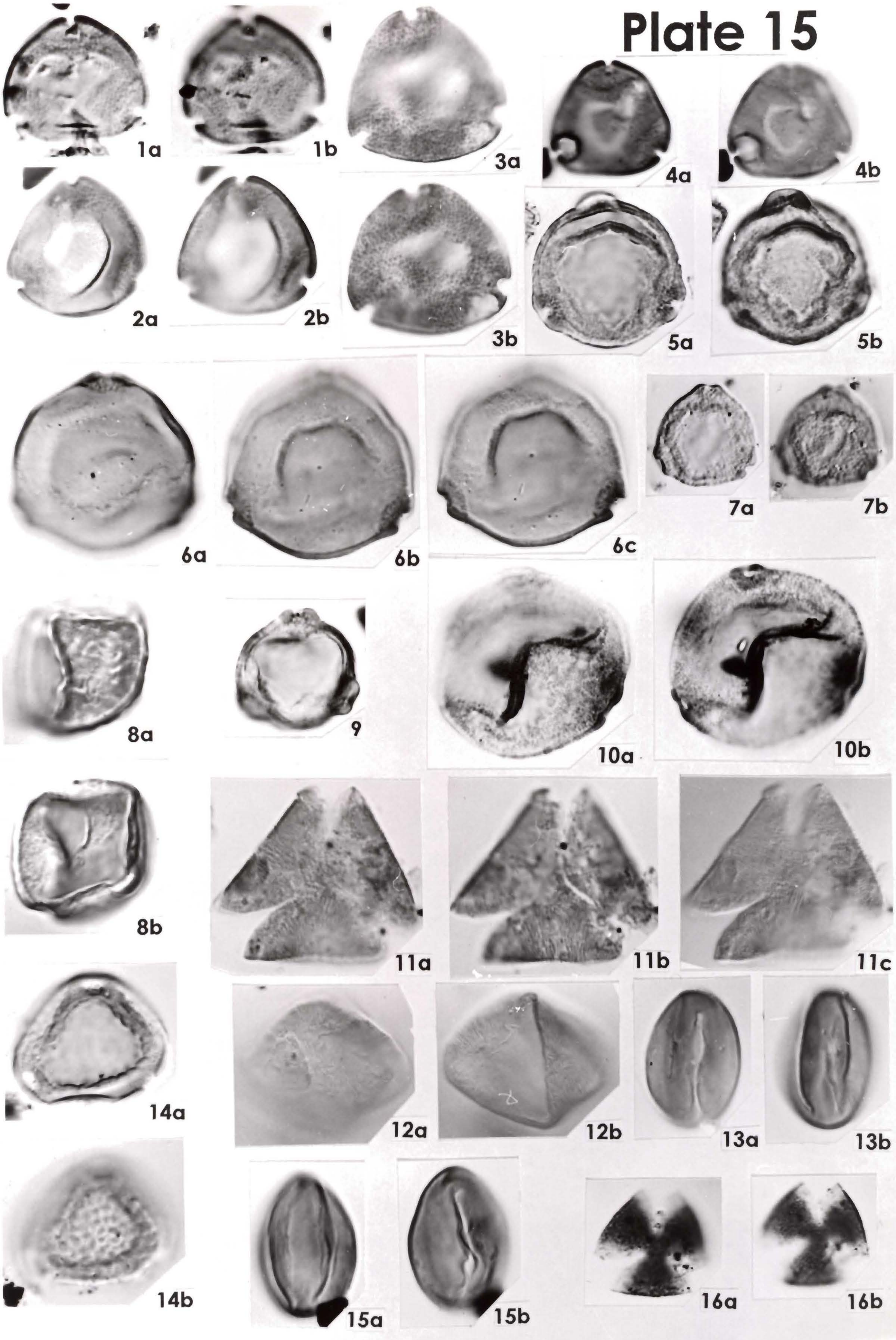
Figures 17a-b: *Labrapollis* sp. 1000X. Figure 17a, DIC illumination; Figure 17b, BF illumination.

Figure 18a-b: *Momipites tenuipolus* Anderson 1960. 1000X. DIC illumination.

Figure 19a-b: *Momipites* species indeterminate. 1000X, DIC illumination.

Figures 20a-b: *Momipites waltmanensis* Nichols & Ott 1978. 1000X. DIC illumination.

Plate 15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Explanation of Plate 15

Figures 1a-b: *Momipites ventifluminis* Nichols & Ott 1978. 1000X. DIC illumination.

Figures 2a-b, 3a-b, 4a-b: *Momipites* cf. *M. anellus* Nichols & Ott 1978. 1000X. DIC illumination.

Figures 5a-b, 7a-b, 10a-b: *Triporopollenites granilabratus* (Stanley) Nichols & Brown 1992. 1000X. Figures 5a, 5b, 10a, and 10b, BF illumination; Figures 7a and 7b, DIC illumination. Figure 10 is photomicrograph of a swollen, partially degraded specimen that has a pitted exine.

Figures 6a-c: *Triatriopollenites subtriangulus* (Stanley) Frederiksen 1979. 1000X. Figures 6a and 6b, BF illumination; Figure 6c, DIC illumination.

Figure 9: *Triporopollenites infrequens* (Stanley) Frederiksen 1988. 1000X. BF illumination.

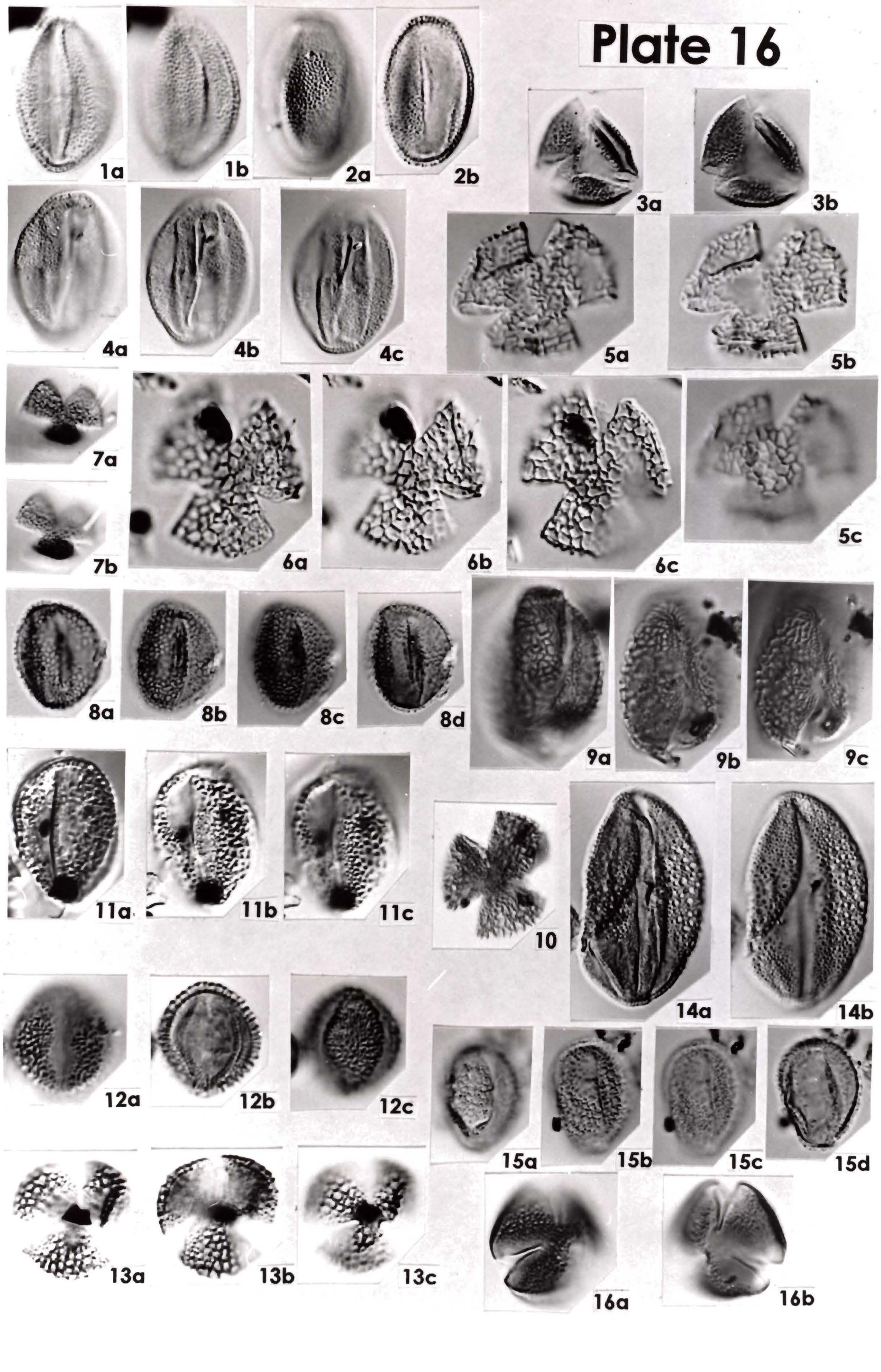
Figures 8a-b, 14a-b: *Ulmipollenites krempii* (Anderson) Frederiksen 1979. 1000X. DIC illumination.

Figures 11a-c, 12a-b: *Cranwellia subtilis* Sweet 1986. 1000X. Figures 11a and 11b, BF illumination; Figures 11c, 12a, and 12b, DIC illumination.

Figures 13a-b, 15a-b: *Cupuliferoidaepollenites microscabratus* (Norton) n. comb. 1000X. Figures 13a and 13b, DIC illumination; Figures 15a and 15b, BF illumination.

Figures 16a-b: *Cupuliferoidaepollenites mutabilis* (Leffingwell) Jameossanaie 1987. 1000X. BF illumination.

Plate 16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Explanation of Plate 16

Figures 1a-b, 2a-b: *Fraxinoipollenites turonicus* (Mtchedlishvili) n. comb. 1000X. DIC illumination.

Figures 3a-b: *Quercoidites* cf. *Q. spissus* Leffingwell 1971. 1000X. DIC illumination.

Figures 4a, 4b, 4c: *Fraxinoipollenites variabilis* Stanley 1965. 1000X. DIC illumination.

Figures 5a-c, 6-c: *Retitrescolpites anguloluminosus* (Anderson) Frederiksen 1979. 1000X. Figures 5a, 5b, 5c, 6b, and 6c, DIC illumination; Figure 6a, BF illumination.

Figures 7a-b, 8a-d: *Rousea* cf. *R. parvicolpata* (Norton) n. comb. 1000X. Figure 8a, BF illumination; Figures 7a, 7b, 8b, 8c, and 8d, DIC illumination.

Figures 9a-c, 10: *Rousea* sp. 1. 1000X. Figure 9a, BF illumination; Figures 9b, 9c, and 10, DIC illumination.

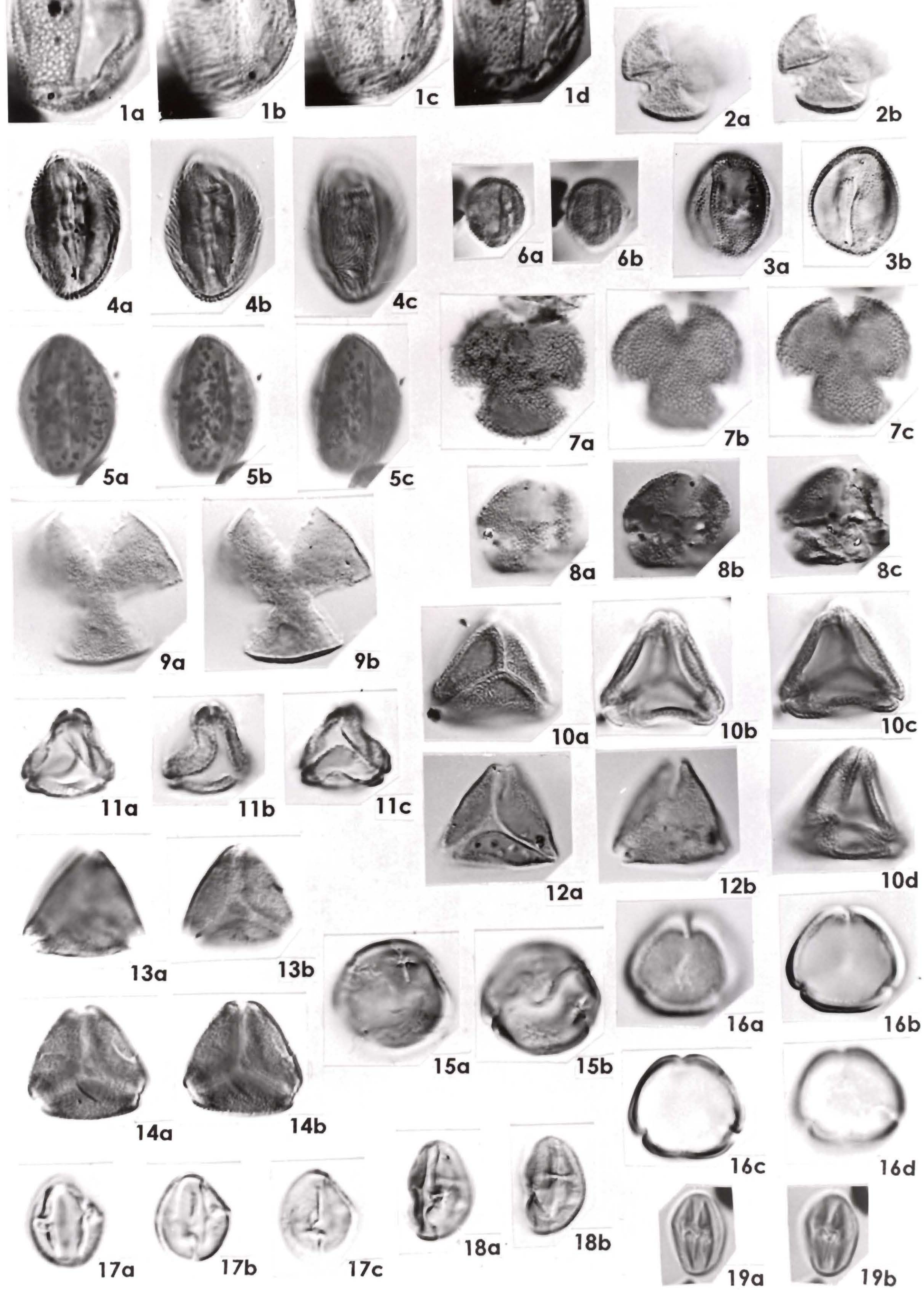
Figures 11a-c, 12a-c, 13a-c: *Rousea* sp. 2. 1000X. DIC illumination.

Figures 14a-b: *Rousea* sp. 3. 1000X. DIC illumination.

Figures 15a-c: *Rousea* sp. 4. 1000X. Figures 15a-b and 15d, DIC illumination; Figure 15c, BF illumination.

Figures 16a-c: *Rousea* sp. 5. 1000X. DIC illumination.

Plate 17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Explanation of Plate 17

Figure 1a-d: *Rousea* sp. 1. 1000X. Figure 1a, BF illumination; Figures 1b-d, DIC illumination.

Figures 2a-b, 3a-b: *Tricolpites hians* Stanley 1965. 1000X. DIC illumination.

Figures 4a-c, 5a-c: *Striatopollis trochuensis* (Srivastava) Farabee & Canright 1986. 1000X. Figures 4a and 5a-b, BF illumination; Figures 4b-c and 5c, DIC illumination.

Figures 6a-b: *Tricolpites* cf. *T. minutus* (Brenner) Dettmann 1973. 1000X. Figure 6a, BF illumination; Figure 6b, DIC illumination.

Figures 7a-c: *Tricolpites* cf. *T. vulgaris* (Pierce) Srivastava 1969. 1000X. Figure 7a, DIC illumination; Figure 7b-c, BF illumination.

Figures 8a-c: *Tricolpites* sp. 2. 1000x. DIC illumination.

Figures 9a-b: *Tricolpites* sp. 1. 1000X. DIC illumination.

Figures 10a-d: *Cupanieidites* cf. *C. reticularis* Cookson & Pike 1954. 1000X. DIC illumination.

Figures 11a-c: *Syncolporites* sp. 2. 1000X. DIC illumination.

Figures 12a-b: *Syncolporites* cf. *S. minimus* Leffingwell 1971. 1000X. DIC illumination.

Figures 13a-b, 14a-b: *Syncolporites* sp. 1. 1000X. DIC illumination.

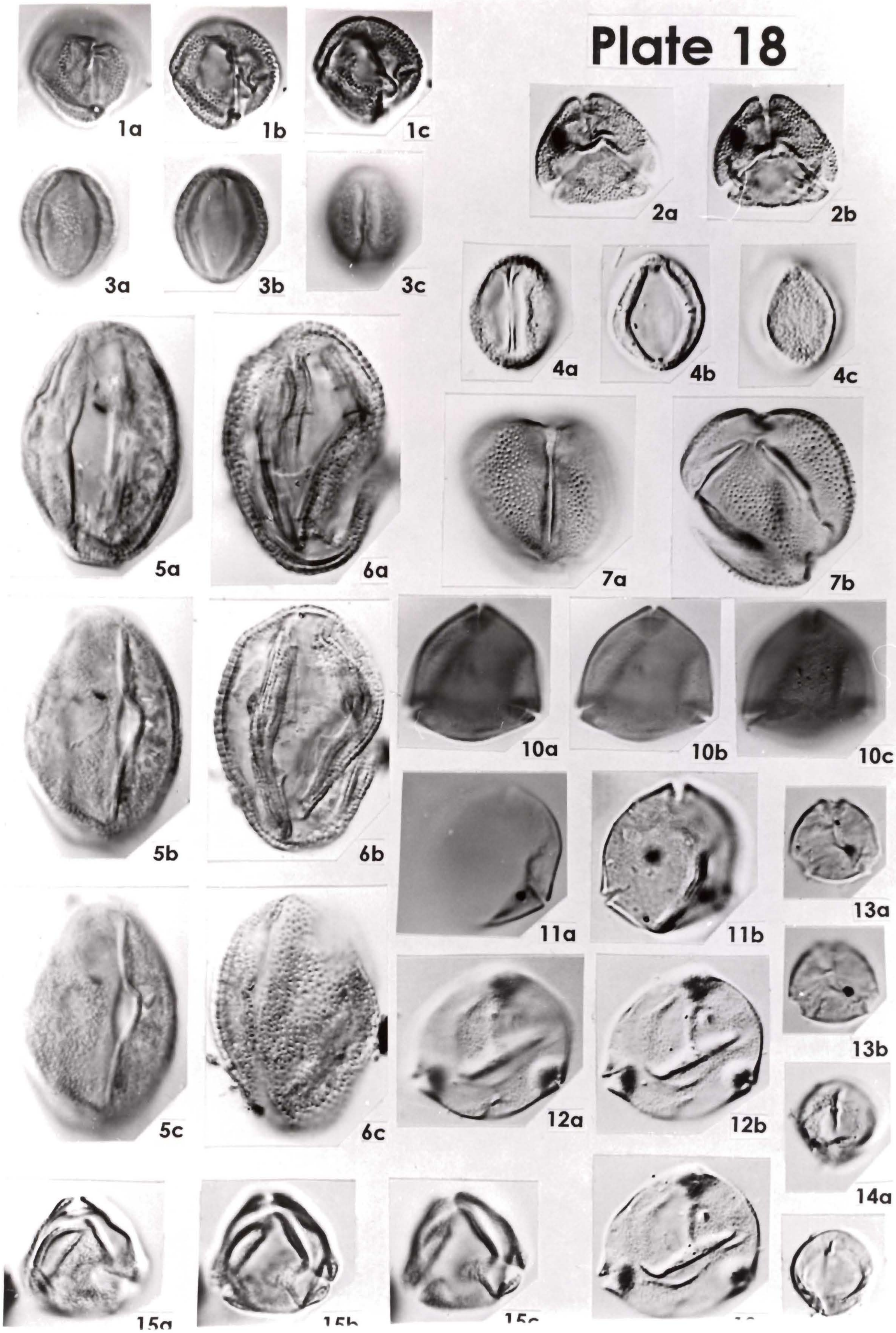
Figures 15a-b, 16a-d: *Brevicolporites colpella* Anderson 1960. 1000X. Figures 15a-b and 16a-b, DIC illumination; Figures 16c-d, BF illumination.

Figures 17a-c: *Cyrillaceaepollenites* cf. *C. megaexactus* (Potonié) Potonié 1960. 1000X. DIC illumination.

Figures 18a-b: *Cupuliferoipollenites cingulum* (Potonié) Song& Zheng 1981. 1000X. DIC illumination.

Figures 19a-b: *Cupuliferoipollenites pusillus* (Potonié) Potonié 1960. 1000X. DIC illumination.

Plate 18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Explanation of Figure 18

Figures 1a-c, 2a-b: *Caprifoliipites* cf. *C. microreticulatus* (Pflug & Thomson) Potonié 1960. 1000X. Figure 1a and 2a-b, DIC illumination; Figure 1b-c, BF illumination.

Figures 3a-c, 4a-c: *Foveotricolporites pachyexinous* (Leffingwell) n. comb. 1000X. DIC illumination.

Figures 5a-c, 6a-c: *Foveotricolporites* spp. 1000X. DIC illumination.

Figures 10a-c: *Kurtzipites trispissatus* Anderson emend. Srivastava 1981. 1000X. DIC illumination.

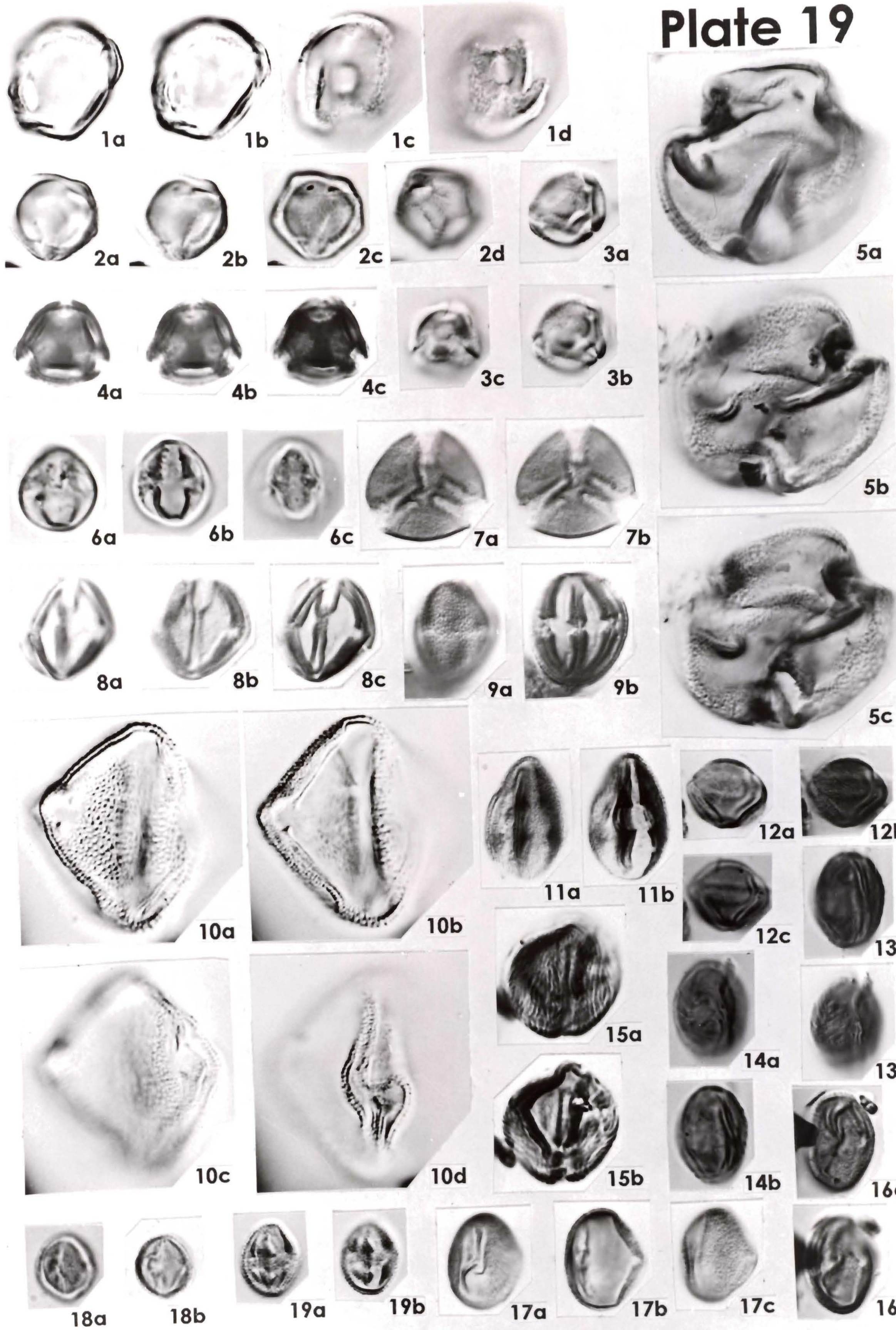
Figures 11a-b: *Kurtzipites parvus* (Norton) n. comb. 1000X. BF illumination.

Figures 12a-c: *Kurtzipites polyformis* (Stanley) n. comb. 1000X. DIC illumination.

Figures 13a-b, 14a-b: *Cyrillaceaepollenites* cf. *C. exactus* (Potonié) Potonié 1960. 1000X. Figures 13a and 14a-b, DIC illumination; Figure 13b, BF illumination.

Figures 15a-c: *Myrtipites*? sp. 1. 1000X. Figures 15a and 15c, DIC illumination; Figure 15b, BF illumination.

Plate 19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Explanation of Plate 19

Figures 1a-d: *Myrtipites*? sp. 1. 1000X. Figures 1a-c, BF illumination; Figure 1d, DIC illumination.

Figures 2a-d, 3a-c, 4a-c: *Myrtipites*? sp. 2. 1000X. DIC illumination.

Figures 5a-5c: *Foveotricolporites* spp. 1000X. DIC illumination.

Figures 6a-c, 7a-b, 8a-c: *Nyssapollenites* sp. 1000X. Figures 6a-c, BF illumination; Figures 7a-b and 8a-c, DIC illumination.

Figures 9a-b: *Rhoipites pisinnus* Stanley 1965. 1000X. DIC illumination.

Figures 10a-d: *Polotricolporites rotundus* Sweet 1986. 1000X. DIC illumination.

Figures 11a-b, 15a-b: *Simpsonipollis* sp. 1. 1000X. DIC illumination.

Figures 12a-c, 13a-b, 14a-b: *Simpsonipollis* sp. 2. 1000X. Figures 12a, 12c, 14a, and 14b, BF illumination; Figures 12b, 13a, and 13b, DIC illumination.

Figures 16a-b, 17a-c: *Tricolporopollenites* cf. *T. dolium* (Potonié) Thomson & Pflug 1953. 1000X. DIC illumination.

Figures 18a-b, 19a-b: *Wilsonipites* sp. 1000X. Figures 18a-b, BF illumination; Figures 19a-b, DIC illumination.

APPENDICES

APPENDIX 1

DESCRIPTIONS OF THE LOCATIONS OF THE MEASURED SECTIONS

Information pertaining to all of the stratigraphic sections was entered into the geologic section cataloging system (M-number system) that is maintained by Dr. Joseph H. Hartman of the Energy and Environmental Research Center of the University of North Dakota.

M0043. Reference: E.S. Belt (1981-83, unpublished field notes). Field information compiled by J.H. Hartman (1990, unpublished)
Date Measured: 1981
County: Slope County, North Dakota
Quadrangle: Williams Lake
Location, base of section: E half, SE¼, NE¼, SE¼, Sec., 8, T. 135 N., R. 105 W.
Location, top of section: unknown
Elevation, top of section: estimated at 862.6 m (2830 feet).
Section thickness: about 78.2 m (256.5 feet).
Comments: Location given above is only location listed in M-number catalog.

M0047. Reference: E.S. Belt (1981-83, unpublished field notes). Field information compiled by J.H. Hartman (1988, unpublished)
Date Measured: 1981
County: Slope County, North Dakota
Quadrangle: Pretty Butte
Location, base of section: Center, SW¼, SW¼, Sec., 16, T. 135 N., R. 105 W.
Location, top of section: unknown
Elevation, top of section: estimated at 832.1 m (2730 feet).
Section thickness: about 29.4 m (96.5 feet).
Comments: Location given above is only location listed in M-number catalog.

M0048. Reference: E.S. Belt (1981-83, unpublished field notes). Field information compiled by J.H. Hartman (1988, unpublished)
Date Measured: 1981
County: Slope County, North Dakota
Quadrangle: Pretty Butte
Location, base of section: W edge, NW¼, SE¼, SW¼, Sec., 16, T. 135 N., R. 105 W.
Location, top of section: unknown
Elevation, top of section: 840.4 m (2757.1 feet).
Section thickness: 29.6 m (97.1 feet)
Comments: Location listed above is only location listed.

M747. Reference: Van Alstine (1974, p. 86-89).
Date Measured: July 28, 1972
County: Slope County, North Dakota
Quadrangle: Three V Crossing

Location, base of section: NE¼, SW¼, Sec., 14, T. 135 N., R. 105 W.
Location, top of section: unknown
Elevation, top of section: unknown
Section thickness: 50.9 m (167 feet)
Comments: "Section measured on northwest-facing cutbank exposure, east side of Little Missouri River" (Van Alstine, 1974, p. 86). Location listed above is only location given.

M1720. Reference: Kroeger (1988, unpublished field notes, p. 192-210).
Date Measured: August 5-7, 1988
County: Slope County, North Dakota
Quadrangle: Three V Crossing
Location, base of section: SW¼, NW¼, SW¼, SW¼, Sec. 2, T. 135 N., R. 105 W.
Location, top of section: SE¼, NE¼, SW¼, SW¼, Sec. 2, T. 135 N., R. 105 W.
Elevation, top of section: about 830.6 m (2725 feet)
Section thickness: about 41.1 m (134.8 feet)
Comments: Section measured along an east-west trending ridge. Lowest coal is locally burned, forming clinker.

M1721a. Reference: Kroeger (1988, unpublished field notes, p. 218-235).
Date Measured: August 9-10, 1988
County: Slope County, North Dakota
Quadrangle: Three V Crossing
Location, base of section: NW¼, SW¼, SE¼, NW¼, NW¼, Sec. 15, T. 135 N., R. 105 W.
Location, top of section: NW¼, NW¼, SE¼, NW¼, NW¼, Sec. 15, T. 135 N., R. 105 W.
Elevation, top of section: about 823.0 m (2700 feet)
Section thickness: about 39.0 m (128 feet)
Comments: Section measured up a steep, south-facing, cutbank of the Little Missouri River. Base of section is approximately at river bed. Uppermost bed, calcareous sandstone ("east yellow marker" of Moore (1976)) was traced northward to the base of section M1721b.

M1721b. Reference: Kroeger (1988, unpublished field notes, p. 235-256).
Date Measured: August 11-14, 1988.
County: Slope County, North Dakota
Quadrangle: Three V Crossing
Location, base of section: NE¼, SW¼, SE¼, SW¼, SW¼, Sec. 10, T. 135 N., R. 105 W.
Location, top of section: NE¼, NE¼, SE¼, SW¼, SW¼, Sec. 10, T. 135 N., R. 105 W.
Elevation, top of section: about 870.2 m (2855 feet)
Section thickness: about 53.1 m (174.2 feet)
Comments: Base of section is just below the level of the two-track ranch road. Section measured up a steep southwest-facing slope; continues to top of hill.

M1722. Reference: Kroeger (1988, unpublished field notes, p. 45-50)
Date Measured: June 23, 1988
County: Slope County, North Dakota
Quadrangle: Williams Lake

Location, base of section: SE¼, NW¼, NE¼, NW¼, Sec. 17, T. 135 N., R. 105 W.
Location, top of section: NE¼, NE¼, SE¼, NW¼, Sec. 17, T. 135 N., R. 105 W.
Elevation, top of section: about 855.0 m (2805 feet)
Section thickness: about 21.3 m (70 feet)
Comments: Section measured up a northwesterly facing slope. Line of section approximately south to north.

M1729. Reference: Kroeger (1988, unpublished field notes, p. 262-266).
Date Measured: August 13, 1988
County: Slope County, North Dakota
Quadrangle: Three V Crossing
Location, base of section: SW¼, SW¼, NW¼, NW¼, SW¼, Sec. 14, T. 135 N., R. 105 W.
Location, top of section: SW¼, SW¼, NW¼, NW¼, SW¼, Sec. 14, T. 135 N., R. 105 W.
Elevation, top of section: about 786.4 m (2680 feet)
Section thickness: about 2.4 m (8 feet)
Comments: Section includes only the uppermost T Cross lignite, the Boyce Tongue of the Cannonball Formation, and the basal portion of the overlying bed.

M1733. Reference: Kroeger (1988, unpublished field notes, p. 282-295; Kroeger, 1989, unpublished field notes, p. 26-40).
Date Measured: August 16, 1988; May 28, 1989.
County: Slope County, North Dakota
Quadrangle: Pretty Butte
Location, base of section: NE¼, SW¼, NW¼, SE¼, Sec. 30, T. 135 N., R. 105 W.
Location, top of section: SW¼, NE¼, SE¼, SW¼, Sec. 30, T. 135 N., R. 105 W.
Elevation, top of section: about 887.0 m (2910 feet)
Section thickness: about 83.8 m (275 feet)
Comments: Base of section is lowest exposed coal bed. Section measured up a northeast-facing slope, continues to the top of hill.

M1958. Reference: Kroeger (1989, unpublished field notes, p. 10-24).
Date Measured: May 24-26, 1989
County: Slope County, North Dakota
Quadrangle: Williams Lake
Location, base of section: NW¼, NW¼, NW¼, NE¼, Sec. 17, T. 135 N., R. 105 W.
Location, top of section: NW¼, NE¼, NE¼, NW¼, Sec. 17, T. 135 N., R. 105 W.
Elevation, top of section: about 853.4 m (2800 feet)
Section thickness: about 39.3 m (129.1 feet)
Comments: Section was measured up a steep east-facing slope. Base of section is in deep ravine in drainage.

M1959. Reference: Kroeger (1989, unpublished field notes, p. 42-57).
Date Measured: May 28 and May 31, 1989
County: Slope County, North Dakota
Quadrangle: Pretty Butte
Location, base of section: NE¼, SE¼, SE¼, SE¼, Sec. 30, T. 135 N., R. 105 W.
Location, top of section: SE¼, NE¼, SE¼, SE¼, Sec. 30, T. 135 N., R. 105 W.
Elevation, top of section: about 861.0 m (2825 feet)

Section thickness: about 59.3 m (161.7 feet)
Comments: Section measured up a steep south-facing slope.

M1960. Reference: Kroeger (1989, unpublished field notes, p. 61-66).
Date Measured: May 30, 1989
County: Slope County, North Dakota
Quadrangle: Pretty Butte
Location, base of section: NE¼, SW¼, NW¼, NW¼, Sec. 34, T. 135 N., R. 106 W.
Location, top of section: SE¼, NW¼, NW¼, NW¼, Sec. 34, T. 135 N., R. 106 W.
Elevation, top of section: about 861.0 m (2825 feet)
Section thickness: about 43.8 m (143.7 feet)
Comments: Base of section at water level of Cannonball Creek. Section measured up a south-facing cutbank on north side of Cannonball Creek.

M1961. Reference: Kroeger (1989, unpublished field notes, p. 105-110).
Date Measured: June 5, 1989
County: Slope County, North Dakota
Quadrangle: Williams Lake
Location, base of section: NE¼, NE¼, NE¼, SW¼, Sec. 8, T. 135 N., R. 105 W.
Location, top of section: NE¼, NE¼, NE¼, SW¼, Sec. 8, T. 135 N., R. 105 W.
Elevation, top of section: about 854.9 m (2805 feet)
Section thickness: about 18.8 m (61.8 feet)
Comments: Section measured up a west-facing slope.

M2187. Reference: Hartman in Schmitt *et al.*, 1991; Kroeger (1990, unpublished field notes).
Date Measured: September 7,
County: Slope County, North Dakota
Quadrangle: Three V Crossing
Location, base of section: NW¼, SE¼, NE¼, SE¼, Sec. 9, T. 135 N., R. 105 W.
Location, top of section: NW¼, SE¼, NE¼, SE¼, Sec. 9, T. 135 N., R. 105 W.
Elevation, top of section: about 868.6 m (2850 feet)
Section thickness: about 323.1 m (1060 feet)
Comments: Section interpreted from lithologic and geophysical data collected from stratigraphic test well. Well bottomed out in the Pierre Shale. Only upper portion of section included in cross sections.

APPENDIX 2

INDEX TO THE SAMPLE NUMBERS, UND-PC ACCESSION NUMBERS, AND FIELD SAMPLE NUMBERS.

Sample Number	UND PC Accession Number	Field Sample Number	Stratigraphic Section (M-Number)
1	A2939	TS-88-015	M1721
2	A2940	TS-88-016	M1721
3	A2942	TS-88-018	M1721
4	A2951	TS-88-027	M1721
5	A2952	TS-88-028	M1721
6	A2953	TS-88-029	M1721
7	A2954	TS-88-030	M1721
8	A2955	TS-88-031	M1721
9	A2956	TS-88-032	M1721
10	A2957	TS-88-033	M1721
11	A2958	TS-88-034	M1721
12	A2817	TS-88-035	M1721
13	A2818	TS-88-036	M1721
14	A2819	TS-88-037	M1721
15	A2820	TS-88-038	M1721
16	A2821	TS-88-039	M1721
17	A2822	TS-88-040	M1721
18	A2838	TS-88-056	M1721
19	A2834	LT-88-165	M1729
20	A2873	LT-88-166	M1729
21	A2829	TS-88-047	M1721
22	A2830	TS-88-048	M1721
23	A2839	TS-88-057	M1721
24	A2831	TS-88-049	M1721
25	A2832	TS-88-050	M1721
26	A2840	TS-88-058	M1721
27	A2833	TS-88-051	M1721
28	A2816	TS-88-052	M1721
29	A2841	TS-88-059	M1721
30	A2836	TS-88-054	M1721
31	A2842	TS-88-060	M1721
32	A2874	LT-88-167	M1729
33	A2875	LT-88-168	M1729
34	A2876	LT-88-169	M1729
35	A2877	LT-88-170	M1729
36	A2878	LT-88-171	M1729
37	A2919	LT-88-196	M1729
38	A2879	LT-88-172	M1729
39	A2880	LT-88-173	M1729
40	A2881	LT-88-174	M1729
41	A2882	LT-88-175	M1729
42	A2883	LT-88-176	M1729
43	A2884	LT-88-177	M1729
44	A2885	LT-88-178	M1729
45	A2959	TS-88-061	M1721
46	A2960	TS-88-062	M1721
47	A2962	TS-88-064	M1721

Sample Number	UND PC Accession Number	Field Sample Number	Stratigraphic Section (M-Number)
48	A2963	TS-88-065	M1721
49	A2964	TS-88-066	M1721
50	A2965	TS-88-067	M1721
51	A2966	TS-88-068	M1721
52	A2967	TS-88-069	M1721
53	A2968	TS-88-070	M1721
54	A2969	TS-88-071	M1721
55	A2970	TS-88-072	M1721
56	A2971	TS-88-073	M1721
57	A2972	TS-88-074	M1721
58	A2974	TS-88-076	M1721
59	A2976	TS-88-078	M1721
60	A2977	TS-88-079	M1721
61	A2978	TS-88-080	M1721
62	A2979	TS-88-081	M1721
63	A2980	TS-88-082	M1721
64	A2981	TS-88-083	M1721
65	A2982	TS-88-084	M1721
66	A2983	TS-88-085	M1721
67	A2984	TS-88-086	M1721
68	A2985	TS-88-087	M1721
69	A2987	TS-88-089	M1721
70	A2988	TS-88-090	M1721
71	A2989	TS-88-091	M1721
72	A2991	TS-88-093	M1721
73	A2992	TS-88-094	M1721
74	A2993	TS-88-095	M1721
75	A2994	TS-88-096	M1721
76	A2995	TS-88-097	M1721
77	A2843	TS-88-098	M1721
78	A2844	TS-88-099	M1721
79	A2845	TS-88-100	M1721
80	A2846	TS-88-101	M1721
81	A2847	TS-88-102	M1721
82	A2848	TS-88-103	M1721
83	A2849	TS-88-104	M1721
84	A2850	TS-88-105	M1721
85	A2851	TS-88-106	M1721
86	A2852	TS-88-107	M1721
87	A2853	TS-88-108	M1721
88	A2854	TS-88-109	M1721
89	A2855	TS-88-110	M1721
90	A2856	TS-88-111	M1721
91	A2857	TS-88-112	M1721
92	A2858	TS-88-113	M1721
93	A2859	TS-88-114	M1721
94	A2860	TS-88-115	M1721
95	A2861	TS-88-116	M1721
96	A2862	TS-88-117	M1721
97	A2863	TS-88-118	M1721
98	A2864	TS-88-119	M1721
99	A2865	TS-88-120	M1721
100	A2866	TS-88-121	M1721
101	A2867	TS-88-122	M1721
102	A2868	TS-88-123	M1721
103	A2869	TS-88-124	M1721
104	A2870	TS-88-125	M1721
105	A2871	TS-88-126	M1721
106	A2872	TS-88-127	M1721

Sample Number	UND PC Accession Number	Field Sample Number	Stratigraphic Section (M-Number)
107	A2996	TS-88-128	M1721
108	A2997	TS-88-129	M1721
109	A2998	TS-88-130	M1721
110	A2999	TS-88-131	M1721
111	A3000	TS-88-131.5	M1721
112	A3001	TS-88-132	M1721

APPENDIX 3

DESCRIPTION OF STRATIGRAPHIC SECTION M1721

Formation: Slope
Unit number: 080; Description: Top of outcrop.

Formation: Slope; Informal unit name: Channel 11 (of Belt, 1984); Unit number: 079; Thickness of unit: 2.200 m (7.218 feet).
Description: Interbedded silts and silty claystone, light moderate brown, silts commonly rippled, no roots at base. Upper portion of unit is similar, does not fine-upwards and does not contain evidence of intense rooting. Palynological samples collected (field numbers): TS-88-203/204.
Stratigraphic position of samples: -203 from base; -204 from 30 cm below top of outcrop.

Formation: Slope; Informal unit name: Channel 11 (of Belt, 1984); Unit number: 078; Thickness of unit: 2.950 m (9.678 feet).
Description: Sandstone, fine-grained to upper very fine-grained, fining upwards, large trough or tabular cross beds at base, clayball layers common on reactivation surfaces. Parallel laminae below suggest episodic deposition. Upper portion if fine-grained with smaller sedimentary structures, including small scale tabular or trough sets and small ripples. Basal contact covered, upper sharp.
Palynological samples collected (field numbers): none.

Formation: Slope; Unit number: 077; Thickness of unit: 2.800 m (9.186 feet); Description: Covered interval.

Formation: Slope; Unit number: 076; Thickness of unit: 1.400 m (4.593 feet).
Description: Claystone, silty, dusky yellow green, bentonitic, only a few relatively large sub-horizontal roots found in lower portion, other root traces absent or rare throughout. Sideritic concretions at top.
Rock color: 10GY 3/2.
Palynological samples collected (field numbers): TS-88-202.
Stratigraphic position of samples: -202 from near base.

Formation: Slope; Unit number: 075; Thickness of unit: 2.000 m (6.562 feet).
Description: Siltstone, tan, interbedded with clayey silts, very weathered, locally concretionary, no roots observed. Overlying bentonitic clay slops down over outcrop in many areas making determination of upper contact questionable.
Palynological samples collected (field numbers): none.

Formation: Slope; Unit number: 074; Thickness of unit: 0.600 m (1.968 feet).
Description: Claystone, slightly silty, bentonitic, olive gray, sparsely rooted at base, extremely weathered at top. Rock color: 5Y 4/1.
Palynological samples collected (field numbers): TS-88-164.
Stratigraphic position of samples: -164 from near base.

Formation: Slope; Unit number: 073; Thickness of unit: 0.600 m (1.968 feet).
Description: Siltstone, clayey, bentonitic, light yellow brown, parallel laminated, sparsely rooted.
Palynological samples collected (field numbers): TS-88-163.
Stratigraphic position of samples: -163 from middle.

Formation: Slope; Unit number: 072; Thickness of unit: 1.200 m (3.937 feet).
Description: Sandstone, very fine-grained, ripple and small trough cross-bedded, commonly calcareously cemented, siderite concretions at 1.0 m above base.
Palynological samples collected (field numbers): TS-88-162.
Stratigraphic position of samples: -162 from sideritic concretion zone.

Formation: Slope; Unit number: 071; Thickness of unit: 0.200 m (0.656 feet).
Description: Lignite, crumbly, not woody.
Palynological samples collected (field numbers): TS-88-161.
Stratigraphic position of samples: -161 from middle.

Formation: Slope; Unit number: 070; Thickness of unit: 0.400 m (1.312 feet).
Description: Claystone, silty, medium gray brown, fines upward to dark brown carbonaceous shale, rooted throughout.
Palynological samples collected (field numbers): TS-88-159/160.
Stratigraphic position of samples: -159 from base; -160 from top.

Formation: Slope; Unit number: 069; Thickness of unit: 0.450 m (1.476 feet).
Description: Interbedded claystone and siltstone at base, vertical burrows present, coarsens upward to rooted, fine-grained, light-brown sandstone.
Palynological samples collected (field numbers): TS-88-158.
Stratigraphic position of samples: -158 from base.

Formation: Slope; Unit number: 068; Thickness of unit: 0.950 m (3.117 feet).
Description: Sandstone, fine-grained, light brown, friable, sparsely rooted at top, bedding indistinct, but is apparently small rippled and trough laminated.
Palynological samples collected (field numbers): none.

Formation: Slope; Unit number: 067; Thickness of unit: 1.700 m (5.577 feet).
Description: Base is very clayey, parallel laminated siltstone, pale yellow brown, roots sparse to absent, fissile weathering, plant fossils and seeds abundant. Fines upward to dark gray green claystone. Upper 0.3 m is a second fining upward cycle with a bioturbated silt at the base and a red oxidized clay at the top. Top of lower sequence has abundant horizontal roots 2-3 mm diameter. Rock color: 10YR 6/2.
Palynological samples collected (field numbers): TS-88-156/157.
Stratigraphic position of samples: -156 from base; -157 from about 0.4 m below top.

Formation: Slope; Unit number: 066; Thickness of unit: 0.950 m (3.117 feet).
Description: Clayey silt, light olive gray, roots and plant fossils common in upper half. Roots up to 0.5 cm thick and rhizomes present. Unit is resistant, holds up a notable cliff, indistinctly bedded, lower contact sharp and nonerosional. Rock color: 5Y 5/2.
Palynological samples collected (field numbers): TS-88-154/155.
Stratigraphic position of samples: -154 from base; -155 from top.

Formation: Slope; Informal unit name: Yule lignite; Unit number: 065;
Thickness of unit: 1.350 m (4.429 feet).
Description: Lignite, 5 cm thick shale split at 0.8 m. woody chunks common, clayey horizons common.
Palynological samples collected (field numbers): TS-88-151/153.
Stratigraphic position of samples: -151 from 0.4 m above base; -152 from clay split at 0.8 m; -153 from uppermost, carb shale.

Formation: Slope; Unit number: 064; Thickness of unit: 0.700 m (2.297 feet).
Description: Claystone, grayish olive green at base, abundantly rooted with small roots, slickensides abundant. Top is dusky-brown claystone, roots abundant, including large, coalified, horizontal roots? Upper contact gradational. Rock color: 5GY 3/2 (base) to 5YR 2/2 (top).
Palynological samples collected (field numbers): TS-88-149/150.
Stratigraphic position of samples: -149 from 0.1 m above base; -150 from top.

Formation: Slope; Unit number: 063; Thickness of unit: 0.150 m (0.492 feet).
Description: Carbonaceous shale and lignite.
Palynological samples collected (field numbers): TS-88-148.

Formation: Slope; Unit number: 062; Thickness of unit: 0.750 m (2.461 feet).
Description: Lignitic shale, dark brown at base, grades upward to grayish olive green, clayey silt about 5 cm above base. Root traces abundant. Well preserved leaf fossils at base. Rock color: 5GY 3/2.
Palynological samples collected (field numbers): TS-88-145/147.
Stratigraphic position of samples: -145 from base; -146 from middle; -147 from top.

Formation: Slope; Informal unit name: Yule lignite; Unit number: 061;
Thickness of unit: 1.000 m (3.281 feet).
Description: Lignite.
Palynological samples collected (field numbers): TS-88-142/144.
Stratigraphic position of samples: -142 from base; -143 from middle; -144 from top.

Formation: Slope; Unit number: 060; Thickness of unit: 0.250 m (0.820 feet).
Description: Carbonaceous shale, dark brown, abundant plant fossils.
Palynological samples collected (field numbers): TS-88-140/141.
Stratigraphic position of samples: -140 from bottom; -141 from top.

Formation: Slope; Unit number: 059; Thickness of unit: 2.300 m (7.546 feet).
Description: Interbedded very fine-grained sandstones, silts and mudstones. Clay interbeds about 5-10 mm thick, sand beds up to 0.5 m. Roots absent in lower portion, but become more abundant near top.
Palynological samples collected (field numbers): TS-88-139.
Stratigraphic position of samples: -139 from well rooted sandy mudstone 0.4 m below top.

Formation: Slope; Unit number: 058; Thickness of unit: 0.300 m (0.984 feet).
Description: Claystone, gray green, interbedded with silty clays. Very thin silt stringers present. Coarsens upward, plant fragments rare, few vertical, silt-filled burrows about 2 mm diameter present. Rock color: 10G 4/2.
Palynological samples collected (field numbers): TS-88-138.
Stratigraphic position of samples: -138 from middle.

Formation: Slope; Unit number: 056; Thickness of unit: 1.100 m (3.609 feet).
Description: Sandstone, very fine-grained, light brown, fining upward, sparsely rooted at base, although relatively large (1 cm diameter) subhorizontal root traces are present. Roots are more abundant upward, including those that appear to originate from this horizon. Uppermost of unit is dark-moderate brown, clayey sandstone with very abundant root traces, including some larger than 2 cm diameter.
Palynological samples collected (field numbers): TS-88-134/135.
Stratigraphic position of samples: -134 from 0.5 m above base; -135 from top.

Formation: Slope; Informal unit name: Number 1 lignite; Unit number: 055; Thickness of unit: 0.100 m (0.328 feet).
Description: Lignite, gradational with below, upper contact sharp.
Palynological samples collected (field numbers): TS-88-133.

Formation: Slope; Unit number: 054; Thickness of unit: 0.150 m (0.492 feet).
Description: Gradational with unit 53, very silty, lignitic mudstone, intensely rooted, moderate brown. Rock color: 5YR 3/4.
Palynological samples collected (field numbers): TS-88-132.

Formation: Slope; Unit number: 053; Thickness of unit: 1.000 m (3.281 feet)
Description: Sandstone, very fine-grained, light brown, friable, interbedded with clays and silts, silty beds rippled, sand-filled burrows common, very small root traced common.
Palynological samples collected (field numbers): TS-88-131.5.
Stratigraphic position of samples: -131.5 from 10 to 20 cm above base.

Formation: Slope; Informal unit name: Number 1 lignite; Unit number: 052; Thickness of unit: 0.450 m (1.476 feet).
Description: lignite.
Palynological samples collected (field numbers): TS-88-129/131.
Stratigraphic position of samples: -129 from base; -130 from middle; -131 from top.
Formation: Slope; Unit number: 051; Thickness of unit: 0.250 m (0.820 feet).
Description: Lignitic shale, dark brown.
Palynological samples collected (field numbers): TS-88-128.
Stratigraphic position of samples: -128 from middle.

Formation: Slope; Unit number: 050; Thickness of unit: 0.500 m (1.640 feet).
Description: Sandstone, light brown, ripple laminated, burrowed or rooted at base, fines upward, clayey interbeds abundant in upper half, upper portion contains relatively large root traces and locally bears large (0.5 m diameter) calcareous concretions. Lower contact sharp.
Palynological samples collected (field numbers): none.

Formation: Slope; Unit number: 049; Thickness of unit: 0.200 m (0.656 feet).
Description: Mudstone, moderate brown, plant fragments abundant, extensively burrowed, bedding disrupted. Rock color: 5YR 3/4.
Palynological samples collected (field numbers): TS-88-127.

Formation: Slope; Unit number: 048; Thickness of unit: 1.800 m (5.905 feet).
Description: Interbedded clay, silt, and fine to lower medium-grained sandstone. Silts are generally parallel laminated although small ripples are present. Burrows common in silty beds. Plant debris abundant on laminae. Upper contact sharp, jarositic nodules common.
Palynological samples collected (field numbers): TS-88-125/126.
Stratigraphic position of samples: -125 from 0.6 m; -126 from 1.5 m.

Formation: Slope; Unit number: 047; Thickness of unit: 0.350 m (1.148 feet).
Description: Silty claystone, dusky brown, moderate brown at top where distinct silt interbeds are present. Upper contact gradational. Rock color: 5YR 2/2.
Palynological samples collected (field numbers): TS-88-124.
Stratigraphic position of samples: -124 from lower 0.1 m.

Formation: Slope; Unit number: 046; Thickness of unit: 1.100 m (3.609 feet).
Description: Interbedded silts and very fine-grained sandstone and moderate brown clays. Silt predominates, generally small-ripple laminated. very fine-grained sandstone beds about 10 cm thick present at 30 cm and at top. Clayey, finely interbedded siltstones commonly have horizontal and vertical silt-filled burrows 3-5 mm diameter.
Palynological samples collected (field numbers): TS-88-123.
Stratigraphic position of samples: -123 from 0.4 m above base.

Formation: Three V Tongue of Cannonball Formation; Informal unit name: upper brackish tongue; Unit number: 045; Thickness of unit: 0.800 m (2.625 feet).
Description: Claystone, silty, dusky yellow brown, finely interbedded with light brown siltstone, bentonitic, silts may be small ripple laminated, sideritic concretions from 0.5-0.6 m. Rock color: 10YR 2/2.
Palynological samples collected (field numbers): TS-88-121/122.
Stratigraphic position of samples: -121 from middle; -122 from concretionary zone.

Formation: Three V Tongue of Cannonball Formation; Informal unit name: upper brackish tongue; Unit number: 044; Thickness of unit: 2.800 m (9.186 feet).
Description: Claystone, slightly silty, brownish black, coarsens upward to clayey silt, no fossils evident, although laterally mollusks have been found, burrows common. Rock color: 5YR 2/1.
Palynological samples collected (field numbers): TS-88-114/120.
Stratigraphic position of samples: -114 from base; -115 from 0.5 m; -116 from 1.0 m; -117 from 1.5 m; -118 from 2.0 m; -119 from 2.5 m; -120 from top.

Formation: Three V Tongue of Cannonball Formation; Informal unit name: upper brackish tongue; Unit number: 043; Thickness of unit: 0.200 m (0.656 feet).
Description: Black marker bed, carbonaceous mudstone, brownish black, gypsiferous; weathers blocky, forming a slight ridge; bedding indistinct. Channel sample collected through unit. Rock color: 5YR 2/1.
Palynological samples collected (field numbers): TS-88-113.
Stratigraphic position of samples: -113 collected as a channel sample through unit.

Formation: Three V Tongue of Cannonball Formation; Informal unit name: upper brackish tongue; Unit number: 042; Thickness of unit: 2.300 m (7.546 feet).
Description: Claystone, grayish black, horizontal burrows present, silty layers common. Samples collected as channel samples on 20 cm intervals. Oyster bed present from 1.1-1.2 m, although laterally they are present at almost any horizon. Rock color: N2.
Palynological samples collected (field numbers): TS-88-102/112.
Stratigraphic position of samples: -102 from lower 20 cm; -103 from 20-40 cm above base; -104 from 40-60 cm above base; -105 from 60-80 cm above base; -106 from 80-100 cm above base; -107 from 1.0-1.2 m above base (includes oyster bed); -108 from 1.4-1.4 m above base; -109 from 1.4-1.6 m above base; -110 from 1.6-1.8 m above base; -111 from 1.8-2.0 m above base; -112 from 2.0 m above base.

Formation: Slope; Informal unit name: oyster lignite; Unit number: 041;
Thickness of unit: 0.700 m (2.297 feet).
Description: Lignite, woody in middle, jarositic-gypsiferous layer in middle, upper and lower contacts distinct.
Palynological samples collected (field numbers): TS-88-97/101.
Stratigraphic position of samples: -97 from basal 4 cm; -98 from 20 cm above base; -99 from 30 cm above base; -100 from 0.5 m above base; -101 from uppermost.

Formation: Slope; Unit number: 040; Thickness of unit: 6.700 m (21.981 feet).
Description: Interbedded thin, friable, very fine-grained sandstones, siltstones, and claystones. Claystones are bentonitic, sands are small ripple laminated, silts and clays are parallel bedded. Jarositic horizons common. Fresh colors range from dusky yellow-brown in the clays and clayey silts to light brown, for sands. Upper 1.6 m is grayish olive, clayey silt with small root traces. Rock color: 5YR 6/4 to 10Y 4/2.
Palynological samples collected (field numbers): TS-88-93/96.
Stratigraphic position of samples: -93 from 0.5 m above base; -94 from 1.0 m below top; -95 from 0.5 m below top; -96 from uppermost.

Formation: Slope; Unit number: 039; Thickness of unit: 1.300 m (4.265 feet).
Description: Claystone, slightly silty, dusky yellow green, bentonitic, plant remains rare, capped by concretionary horizon about 4 cm thick.
Rock color: 10GY 3/2.
Palynological samples collected (field numbers): TS-88-91/92.
Stratigraphic position of samples: -91 from 0.5 m above base; -92 from concretionary horizon at top.

Formation: Slope; Unit number: 038; Thickness of unit: 1.100 m (3.609 feet).
Description: Claystone, slightly silty, dusky brown, not bentonitic. Plant fragments abundant on bedding planes, 5-8 cm wide coalified flattened stems or horizontal roots common. In the upper 30 cm, plant fossils are rare or absent and color darkens to dark dusky brown, fissile in upper. Jarosite fills fractures, lower contact distinct.
Rock color: 5YR 2/2 TO 5YR 2/2.
Palynological samples collected (field numbers): TS-88-89/90.
Stratigraphic position of samples: -89 from middle; -90 from uppermost 20 cm.

Formation: Slope; Unit number: 037; Thickness of unit: 1.000 m (3.281 feet).
Description: Siltstone, clayey, interbedded with siltstone, plant fragments abundant, lignite blebs common in lower portion, bentonitic, weathers pale brown.
Palynological samples collected (field numbers): none.

Formation: Slope; Unit number: 037; Thickness of unit: 1.000 m (3.281 feet).
Description: Siltstone, clayey, interbedded with siltstone, plant fragments abundant, lignite blebs common in lower portion, bentonitic, weathers pale brown.
Palynological samples collected (field numbers): none.

Formation: Slope; Informal unit name: Glasswort clay (Moore, 1976); Unit number: 036; Thickness of unit: 1.250 m (4.101 feet).
Description: Claystone, brownish black, weathers olive gray, Slightly silty, bearing distinct very thin silt stringers at the base. Bentonitic, jarositic and gypsiferous at base, uppermost 8 cm is grayish brown, sideritic concretion layer containing abundant pyrite. Unit is extensively weathered. Root traces near top. Rock color: 5YR 2/1 to 10GY 5/2.
Palynological samples collected (field numbers): TS-88-87/88.
Stratigraphic position of samples: -87 from base; -88 from concretionary horizon.

Formation: Slope; Informal unit name: Upper coal pair; Unit number: 035; Thickness of unit: 0.950 m (3.117 feet).
Description: Lignite, carbonaceous shale at base, very woody.
Palynological samples collected (field numbers): TS-88-84/86.
Stratigraphic position of samples: -84 from carb shale at base; -85 from thin detrital horizon in middle; -86 from uppermost.

Formation: Slope; Unit number: 034; Thickness of unit: 1.500 m (4.921 feet).
Description: Interbedded clayey silts and siltstone, light brown to light grayish brown on weathered surfaces. Clayey beds are moderate brown, Silty beds are lighter colored. Fines upward to dark yellow-brown, silty clay directly beneath lignite. Extensively weathered with limited outcrop. Location of section beginning with unit 34 is upper exposures of type Slope. Rock color: 5YR 3/4 to 10YR 4/2.
Palynological samples collected (field numbers): TS-88-83.
Stratigraphic position of samples: -83 from uppermost.

Formation: Slope; Informal unit name: East yellow marker; Unit number: 033; Thickness of unit: 2.500 m (8.202 feet).
Description: Sandstone, fine to medium grained, cliff forming, capped by a 0.5 m thick calcareous layer showing small ripple, wave and climbing ripple laminae, base not obviously erosive. Weathers to light yellow-brown. Uppermost cemented layer is laterally continuous.
Palynological samples collected (field numbers): none.

Formation: Slope; Informal unit name: East yellow marker; Unit number: 032; Thickness of unit: 2.250 m (7.382 feet).
Description: Siltstone, interbedded with clayey siltstone, weathered color, light yellow-brown.
Palynological samples collected (field numbers): TS-88-82.
Stratigraphic position of samples: -82 from 1.5 m above base.

Formation: Slope; Informal unit name: lower coal pair; Unit number: 031; Thickness of unit: 0.550 m (1.804 feet).
Description: Lignite.
Palynological samples collected (field numbers): TS-88-81.
Stratigraphic position of samples: -81 from middle.

Formation: Slope; Informal unit name: lower coal pair; Unit number: 030; Thickness of unit: 0.450 m (1.476 feet).
Description: Lignite, interbedded with black carbonaceous shale. Brown clay layers common, upper contact distinct.
Palynological samples collected (field numbers): TS-88-80.
Stratigraphic position of samples: -80 from 0.1 m above base.

Formation: Slope; Unit number: 029; Thickness of unit: 1.750 m (5.741 feet).
Description: Siltstone, light olive gray, winnowed, parallel and small ripple laminated, organic laminae common, 5 cm thick lignitic horizon at 0.3 m above base, a thick concretionary horizon at 0.7 m above base. Fines upward to light gray-brown silty clay, root traces at top. Upper contact distinct. Rock color: 5Y 6/1.
Palynological samples collected (field numbers): TS-88-76/79.
Stratigraphic position of samples: -76 from lignitic layer; -77 from concretionary layer; -78 from 0.2 m below top; -79 from uppermost of unit.

Formation: Slope; Informal unit name: lower coal pair; Unit number: 028;
Thickness of unit: 0.380 m (1.247 feet).
Description: Lignite.
Palynological samples collected (field numbers): TS-88-75.
Stratigraphic position of samples: -75 from middle.

Formation: Slope; Unit number: 027; Thickness of unit: 0.330 m (1.083 feet).
Description: Mudstone, brown, with abundant silt stringers. Plant fossils abundant, vertical root traces rare, horizontal roots? abundant, contacts distinct.
Palynological samples collected (field numbers): TS-88-74.
Stratigraphic position of samples: -74 from middle.

Formation: Slope; Informal unit name: lower coal pair; Unit number: 026; Thickness of unit: 0.250 m (0.820 feet).
Description: Lignite, several clay splits.
Palynological samples collected (field numbers): none.

Formation: Slope; Unit number: 025; Thickness of unit: 0.150 m (0.492 feet).
Description: Lignitic shale, dark brown, horizontal roots present.
Palynological samples collected (field numbers): TS-88-73.

Formation: Slope; Unit number: 024; Thickness of unit: 0.450 m (1.476 feet).
Description: Sandstone, very fine-grained, light gray brown, rooted throughout, 7 cm thick gray claystone bed in middle.
Palynological samples collected (field numbers): TS-88-70/72.
Stratigraphic position of samples: -70 from basal sand; -71 from clay split; -72 from upper sand.

Formation: Slope; Informal unit name: ; Unit number: 023;
Thickness of unit: 0.850 m (2.789 feet); Description: Lignite, 2 cm thick split near base, several thin splits in upper 30 cm, contacts sharp. Palynological samples collected (field numbers): TS-88-69.
Stratigraphic position of samples: -69 from middle.

Formation: Slope; Unit number: 022; Thickness of unit: 0.150 m (0.492 feet).
Description: Claystone, silty, pale yellow-brown, abundant darker organic laminae. Plant fossils extremely abundant. Few larger roots (2-3 mm diameter) present. Rock color: 10YR 6/2.
Palynological samples collected (field numbers): TS-88-68.

Formation: Slope; Unit number: 021; Thickness of unit: 0.900 m (2.953 feet).
Description: Clayey siltstone, light moderate brown, fines upward to gray green claystone.
Palynological samples collected (field numbers): TS-88-66/67.
Stratigraphic position of samples: -66 from near base; -67 from gray green claystone about 0.6 m above base.

Formation: Slope; Unit number: 020; Thickness of unit: 0.900 m (2.953 feet).
Description: Clayey siltstone, coarsens upward to light gray-brown very fine-grained sandstone, upper contact distinct.
Palynological samples collected (field numbers): none.

Formation: Slope; Unit number: 019; Thickness of unit: 0.800 m (2.625 feet).
Description: Siltstone to very fine-grained sandstone, light grayish-brown, fines upward to gray-green claystone, upper contact gradational, lower contact distinct. Palynological samples collected (field numbers): TS-88-65.
Stratigraphic position of samples: -65 from top of unit.

Formation: Slope; Unit number: 018; Thickness of unit: 1.200 m (3.937 feet).
Description: Clayey siltstone at base, coarsens upward to very fine-grained sandstone with small ripple laminae. Claybeds and organic laminae common in lower portion. Sideritic concretionary layer at 0.4 m.
Palynological samples collected (field numbers): TS-88-64.
Stratigraphic position of samples: -62 from 0.2 m.

Formation: Slope; Unit number: 018; Thickness of unit: 1.200 m (3.937 feet).
Description: Clayey siltstone at base, coarsens upward to very fine-grained sandstone with small ripple laminae. Claybeds and organic laminae common in lower portion. Sideritic concretionary layer at 0.4 m.
Palynological samples collected (field numbers): TS-88-64.
Stratigraphic position of samples: -62 from 0.2 m.

Formation: Slope; Unit number: 017; Thickness of unit: 1.050 m (3.445 feet).
Description: Clayey silt, laminated, coarsens upward to very fine-grained sandstone with abundant organic laminae, sands are light, grayish brown, silts are dark brown. Silts commonly small ripple laminated, siltstones intensely burrowed.
Palynological samples collected (field numbers): TS-88-63.
Stratigraphic position of samples: 63 from 0.4m above base.

Formation: Slope; Unit number: 016; Thickness of unit: 0.700 m (2.297 feet).
Description: Siltstone, dark yellow-brown, silty blebs (burrows?) common, 0.1 m thick claystone bed present about 0.3 m from top, olive black. Rock color: 10YR 4/2 to 5Y 2/1.
Palynological samples collected (field numbers): TS-88-61/62.
Stratigraphic position of samples: -61 from lower 0.2m; -62 from claystone 0.3 to 0.4 m above base.

Formation: Boyce Tongue of Cannonball Formation; Unit number: 015; Thickness of unit: 1.500 m (4.921 feet).
Description: Claystone, silty, grayish olive green, lower contact sharp, mollusk impressions common, fractures blocky, jarosite filled bedding plane burrows and fractures common. Samples collected from three localities 15 to 20 m apart. Rock color: 5GY 3/2.
Palynological samples collected (field numbers): TS-88-42/60.
Stratigraphic position of samples: -42/45 from locality 1; -46/55 from locality 2; -56/-60 from locality 3; see notes for sample horizons.

Formation: Ludlow; Informal unit name: T Cross lignite; Unit number: 014; Thickness of unit: 2.350 m (7.710 feet).
Description: Lignite, 3 clay splits 2 cm or thinner within the lower .35 m.
Palynological samples collected (field numbers): TS-88-35/41.
Stratigraphic position of samples: -35 from base; -36 from 25 cm above base (clay split); -37 from 0.5m above base; -38 from 1.0 m above base; -39 from 1.5 m above base; -40 from 2.0 m above base; -41 from uppermost 0.05 m.

Formation: Ludlow; Unit number: 013; Thickness of unit: 1.900 m (6.234 feet).
Description: Mudstone, dark yellow-brown to grayish brown, leaf fossils common as are stem or horizontal root imprints. Upper contact gradational, fines upward in the upper 15 cm. Rock color: 10YR 4/2 to 5YR 3/2.
Palynological samples collected (field numbers): TS-88-31/34.
Stratigraphic position of samples: -31 from 0.3 m above base; -32 from 1.0 m above base; -33 from top 20 cm; -34 from uppermost of unit.

Formation: Ludlow; Unit number: 012; Thickness of unit: 0.650 m (2.133 feet).
Description: Sandstone, fine-grained, interbedded clays and silts at base, coarsens upward, jarositic nodules throughout.
Palynological samples collected (field numbers): none.

Formation: Ludlow; Unit number: 011; Thickness of unit: 0.950 m (3.117 feet).
Description: Claystone, silty, dark yellow-brown, concretionary in lower 3 cm, gradational contact at top, distinct below. Fragmented plant fossils common on bedding planes, root traces absent, silt stringers common. Rock color: 10YR 4/2.
Palynological samples collected (field numbers): TS-88-29/30.
Stratigraphic position of samples: -29 from basal 0.1 m; -30 from 0.2 m below top.

Formation: Ludlow; Unit number: 010; Thickness of unit: 0.030 m (0.098 feet).
Description: Lignite, crumbly.
Palynological samples collected (field numbers): TS-88-28.

Formation: Ludlow; Unit number: 009; Thickness of unit: 2.650 m (8.694 feet).
Description: Siltstone, yellowish gray, finely interbedded with grayish brown, clayey stringers, jarositic zone 0.2 m from top. Rock color: 5Y 7/2 to 5YR 3/2.
Palynological samples collected (field numbers): TS-88-27.
Stratigraphic position of samples: -27 from base.

Formation: Ludlow; Informal unit name: beta lignite; Unit number: 008; Thickness of unit: 1.350 m (4.429 feet).
Description: Lignite. Sampled at the three localities of unit.
Palynological samples collected (field numbers): TS-88-15/26.
Stratigraphic position of samples: -15,-19,-23 from lower 0.1 m; -16,-20,-24 from 0.5 m above base; -17,-21,-25 from 1.0 m above base; -18,-22,-26 from upper 0.1 m.

Formation: Ludlow; Unit number: 007; Thickness of unit: 0.180 m (0.591 feet).
Description: Carbonaceous shale, dusky yellow brown, plant hash abundant. contacts gradational above and below. Samples collected from three localities about 5 m apart. Rock color: 10YR 2/2.
Palynological samples collected (field numbers): TS-88-06/14.
Stratigraphic position of samples: -06,-09,-12 from top 3 cm; -07,-10,-13 from 10-13 cm above base; -08,-11,-14 from 5-8 cm above base.

Formation: Ludlow; Unit number: 006; Thickness of unit: 2.300 m (7.546 feet).
Description: Sandstone, clayey, very fine-grained, moderate brown, contains abundant thin interbeds of claystone. Fragmented plant remains common. Fines upward to clayey siltstone containing abundant root traces, moderate yellow-brown. Rock color: 5YR 4/4 to 10YR 5/4.
Palynological samples collected (field numbers): TS-88-05.
Stratigraphic position of samples: -05 from uppermost 0.1 m.

Formation: Ludlow; Unit number: 005; Thickness of unit: 0.550 m (1.804 feet).
Description: Sandstone, very fine-grained, grayish yellow green, organic laminae common, bedding indistinct, five cm thick orange layer at base. Rock color: 5GY 7/2.
Palynological samples collected (field numbers): none.
Formation: Ludlow; Unit number: 004; Thickness of unit: 0.640 m (2.100 feet).
Description: Claystone, dusky yellow green, coarsens upward to clayey siltstone, dark yellowish green, uppermost 3 cm is siltstone. Rock color: 10GY 3/2 to 10GY 4/4.
Palynological samples collected (field numbers): TS-88-02/03.
Stratigraphic position of samples: -02 from near base; -03 from 0.25 m below top.

Formation: Ludlow; Unit number: 003; Thickness of unit: 0.400 m (1.312 feet).
Description: Claystone, moderate red, coarsens upward to silty claystone with a more brownish hue. Siderite concretion about 1 cm thick at top. Rock color: 5R 4/6.
Palynological samples collected (field numbers): TS-88-01.
Stratigraphic position of samples: -01 from near base.

Formation: Ludlow; Unit number: 002; Thickness of unit: 1.100 m (3.609 feet).
Description: Sandstone, very fine-grained. poorly exposed, interbedded with siltstones and mudstones, upper contact uncertain due to poor exposure.
Palynological samples collected (field numbers): none.

Formation: Ludlow; Unit number: 001; Thickness of unit: 6.850 m (22.473 feet).
Description: Covered interval.

Unit number: 000; Thickness of unit: 000.000 m (0.000 feet);
Description: Base of section at normal low water level, where vegetation begins along river bank.

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PLATE 1

Cross-Section A-A'

Hell Creek, Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation

T.J. Kroeger, 1995

Department of Geology and Geological Engineering

University of North Dakota

Prepared by BLS, 1994

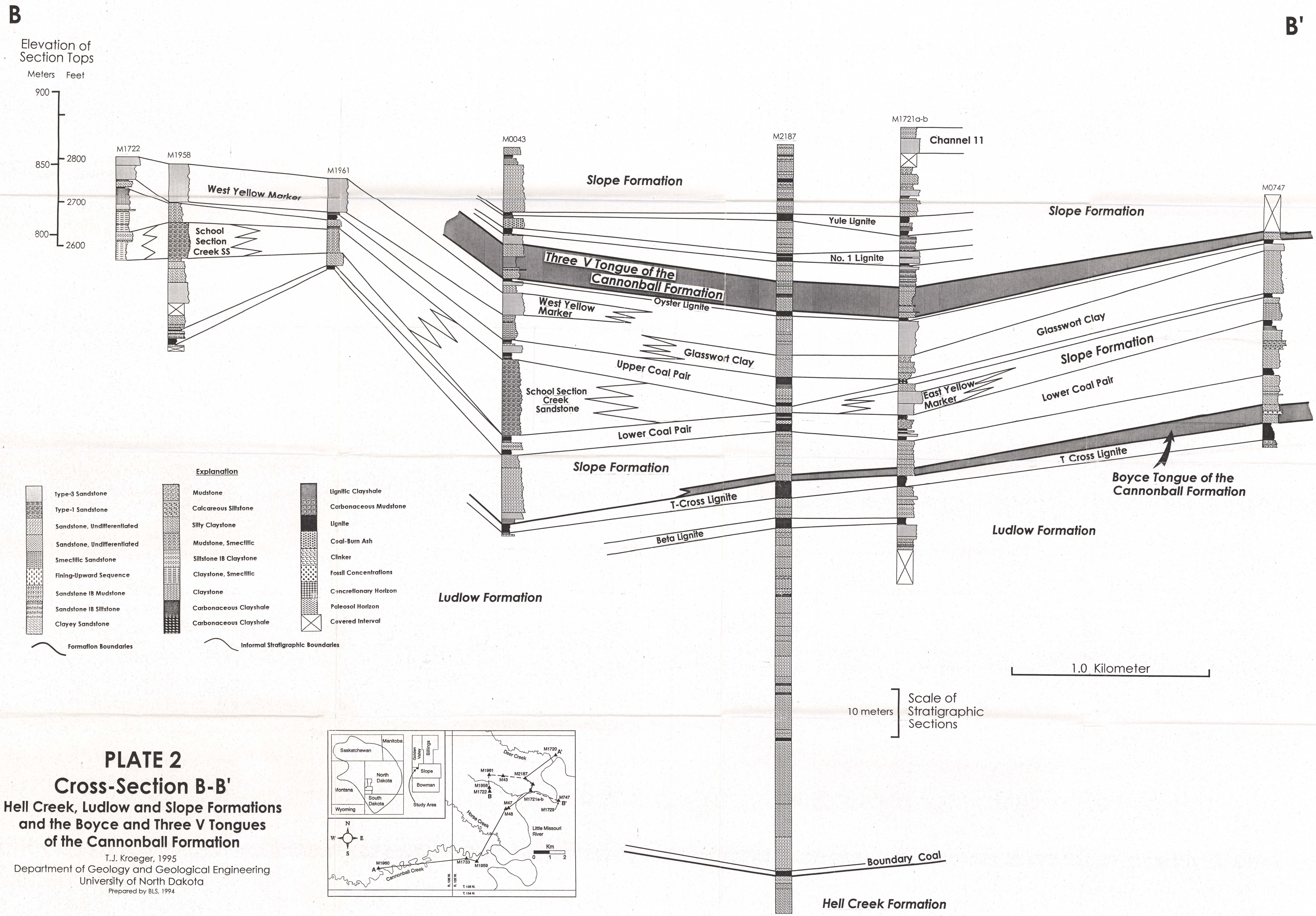

PLATE 2

Cross-Section B-B'

Hell Creek, Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation

T.J. Kroeger, 1995
Department of Geology and Geological Engineering
University of North Dakota
Prepared by BLS, 1994

PLATE 3

Diagram Illustrating the Stratigraphic Distribution of Palynomorph Taxa

Ludlow and Slope Formations and the Boyce and Three V Tongues of the Cannonball Formation Northern Slope County, North Dakota

T.J. Kroeger, 1995
Department of Geology and Geological Engineering
University of North Dakota
Prepared by BLS, 1995

PLATE 4

Diagram Illustrating the Paleoenvironmental Distribution of Palynomorph Taxa

Ludlow and Slope Formations
and the Boyce and Three V Tongues
of the Cannonball Formation
Northern Slope County, North Dakota

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Department of Geologyand Geological Engineering
University of North Dakota
Prepared by BLS, 1995