

Compliments of  
**Minnesota Geological Survey**



LOWER UPPER CRETACEOUS  
PLANT MICROFOSSILS FROM MINNESOTA



UNIVERSITY OF MINNESOTA  
MINNESOTA GEOLOGICAL SURVEY  
GEORGE M. SCHWARTZ, DIRECTOR

---

BULLETIN 42

Lower Upper Cretaceous  
Plant Microfossils from Minnesota

BY  
RICHARD L. PIERCE



MINNEAPOLIS • 1961  
THE UNIVERSITY OF MINNESOTA PRESS

---

PRINTED IN THE UNITED STATES OF AMERICA AT  
THE LUND PRESS, INC., MINNEAPOLIS



*Library of Congress Catalog Card Number: A61-9547*

PUBLISHED IN GREAT BRITAIN, INDIA, AND PAKISTAN BY THE OXFORD UNIVERSITY PRESS  
LONDON, BOMBAY, AND KARACHI, AND IN CANADA BY THOMAS ALLEN, LTD., TORONTO



## ACKNOWLEDGMENTS

This investigation could not have been completed without the aid of many people. I am particularly indebted to Jean Pierce Oswald, for her assistance in the initial preparation of the manuscript as a Ph.D. thesis, and to Dr. John W. Hall, who guided the investigation. I also wish to express my appreciation to Drs. R. E. Sloan, T. Morley, and D. Swanson, and to Agnes Hansen and Theodora G. Melone, for their generous assistance during various phases of the investigation.

Initial stages of the field work were supported by the Minnesota Geological Survey, Dr. G. M. Schwartz, Director, and the Anderson Fund of the Botany Department, University of Minnesota. The National Science Foundation, Dr. Alan T. Waterman, Director, supported the work for two years to its completion. Cost of publication has been absorbed by the Hayden Fund of the Botany Department, University of Minnesota, and the Minnesota Geological Survey.



## CONTENTS

ACKNOWLEDGMENTS .....	v
ABSTRACT .....	xi
1. INTRODUCTION .....	1
Cretaceous Deposits of Minnesota.....	1
Previous Cretaceous Palynology.....	2
Objectives .....	3
2. MATERIALS AND METHODS.....	5
Collection of Sediment Samples.....	5
Section Locations and Sample Levels.....	5
Preparation of Sediments for Analysis.....	8
Contamination.....	9
Design of the Reference Collection.....	9
The Pollen Reference Collection.....	10
Preparation of Herbarium Samples.....	10
Organization of the Reference Collection.....	11
Analysis of Sediments.....	11
3. CLASSIFICATION AND DESCRIPTION.....	12
Problems of Nomenclature and Classification.....	12
Historical Résumé of Sporomorph Nomenclature and Classification .....	13
Eclectic Aspects of Palynological Nomenclature.....	15
Sporomorph Morphology and Classification.....	17
Morphological Classification for Cretaceous Spores and Pollen of Minnesota.....	20
Descriptive Procedure .....	25

Sporomorph Descriptions . . . . .	25
Class Triletes. . . . .	25
Class Monoletes. . . . .	33
Class II. Tetradae. . . . .	34
Class IV. Vesiculatae . . . . .	34
Class V. Inaperturatae. . . . .	42
Class VI. Monoporatae. . . . .	45
Class VII. Monocolpatae. . . . .	46
Class X. Tricolpatae. . . . .	48
Class XIII. Tricolporatae . . . . .	52
 4. INTERPRETATIONS AND DISCUSSION . . . . .	 54
The Dakota Sandstone Flora. . . . .	54
Botanical Affinities of the Sporomorphs. . . . .	55
Comparison of Cretaceous Mega- and Microfossil Records. . . . .	57
Paleoecological and Paleofloristic Interpretations. . . . .	59
Cretaceous Palynology and Plant Evolution. . . . .	61
Geological Aspects of Cretaceous Palynology. . . . .	64
Sediment Analysis. . . . .	64
Stratigraphy and Paleogeography. . . . .	65
Age Relationship and Guide Fossils. . . . .	66
Correlation of Sporomorph Frequencies. . . . .	67
 5. SUMMARY AND CONCLUSIONS. . . . .	 70
 REFERENCES . . . . .	 75
 INDEX . . . . .	 82

## LIST OF ILLUSTRATIONS

Map of Minnesota showing approximate locations of sampled deposits. . .	6
Plate I. Trilete and monolete spores (figs. 1-33) . . . <i>between pages 18 and 19</i>	
Plate II. Tetrad and vesiculate pollen (figs. 34-65) <i>between pages 34 and 35</i>	
Plate III. Vesiculate pollen (continued), inaperturate sporomorphs, and monoporate, monocolpate, tricolpate, and tricolporate pollen (figs. 66-114) . . . . . <i>between pages 50 and 51</i>	

## LIST OF TABLES

1. Families and Important Genera of the Dakota Flora . . . . .	55
2. Correlation of Cretaceous Pollen with Leaf-Impression Genera . . . . .	58
3. Percentage Frequency of Distinctive or Abundant Sporomorph Types . . . . .	68



## ABSTRACT

Spores and pollen from the pre-marine Cretaceous clays and lignites of Minnesota indicate that the probable age of these deposits is Cenomanian. Forests of conifers appear to have been the main type of vegetation; however, these forests contained a diversity of species that do not occur in modern conifer forests of the State. Many of the conifer pollen species found appear to be referable to the Podocarpaceae, a family of Eastern Asiatic, Mexican, and Southern Hemispheric distribution. Dicotyledonous angiosperms were present in the flora, but their pollen is seldom abundant in the Cretaceous deposits of Minnesota. The morphological simplicity and lack of diversity of the angiosperm pollen in these rocks indicate that the angiosperms were at a lower stage of evolution than that often ascribed to them on the basis of leaf impressions from the same rocks. The physiognomy of the flora reflected by the spores, pollen, and previously described leaf impressions can be reconciled with the physiognomy of floras that occur in moist, warm-temperate areas such as Seattle, Washington. A moist, warm-temperate climate, in an area of little relief, is postulated to have prevailed in Minnesota during Cenomanian time.





LOWER UPPER CRETACEOUS  
PLANT MICROFOSSILS FROM MINNESOTA



## 1. INTRODUCTION

During the summer of 1955, on a search for Cretaceous leaf impressions, a number of well-preserved leaf cuticles were found in some clay seams of undoubted Cretaceous age at New Ulm, Minnesota. It was hoped that epidermal features on these cuticles might be compared with epidermal features on cuticles from modern genera to which leaf impressions from the Cretaceous flora of Minnesota had been assigned (Lesquereux, 1893; Berry, 1939). The probability of pollen and spores of Cretaceous plants being present was also seriously considered at this time. Samples for pollen analysis had been collected from some Cretaceous sediments in the summer of 1954, but at that time it was presumed these samples would not yield material susceptible to floristic analysis because Miner (1935) and Schemel (1950) had recovered only spores of undetermined botanical origin from sediments of comparable age. However, a brief survey of the spores and pollen in samples from the clay seam bearing the leaf cuticles indicated these clays could be a source of information that had never been tapped. Experiments on extraction and concentration of spores and pollen were performed while the cuticles were being prepared for examination. During these experiments Traverse's (1955) work on the Brandon lignites became available. A modification of the technique he used on the lignites was successful in recovering spores and pollen from the clays. Eventually the cuticle investigations were laid aside to devote full time to the pollen study.

### CRETACEOUS DEPOSITS OF MINNESOTA

Deposits of Cretaceous age are widespread through the state, but are generally covered beneath glacial drift. Reference of sediments to the Cretaceous system is generally accomplished with invertebrate marine fossils, especially ammonites (Stephenson *et al.*, 1942). It was Kloss (1872) who first recognized the Cretaceous age of invertebrate fossils contained in blue-gray clays exposed in the Sauk Valley near Richmond. In subsequent work by the Natural History and Geological Survey of Minnesota (Winchell and Upham, 1884) numerous exposures of Cretaceous clays, lignites, and sands were found in the cutbanks of streams and rivers.

In south-central Minnesota (the New Ulm area) Sardeson (1908) named the exposures of Cretaceous nonmarine or near-shore marine, deltaic, lagoonal, lacustrine, flood plain and channel deposits of sandstone, conglomerates, silts, and clays, the Big Cottonwood formation. He said of it: "A description of the Big Cottonwood formation from place to place would be very much detailed, owing to the many changes and exceptions to any rule

which might be given . . ." Similar deposits in the same area were later referred to the Dakota formation (*sensu lato*) by Stauffer and Thiel (1941).

Many of the deposits referred to the Cretaceous system in Minnesota overlie Archean granites and gneisses kaolinized to a depth of 10 to 100 feet (Grout, 1919), indicating a long pre-Cretaceous weathering interval. Much of the kaolinized material was reworked to form blue-gray Cretaceous clays. It is these blue-gray clays that contain the most excellent palynological material. Grout (1919) believed the presence of the kaolinized Archean rocks was indicative of weathering in an area of little relief, because weathering products would have been completely removed during the post-Devonian and pre-Cretaceous erosion interval in areas of high relief. The clays were thought to be of Benton age by Grout; however, Bolin (1954) referred the microfauna of the marine sediments immediately overlying the clays in Redwood and Lyon counties to a Niobrara age.

In northeastern Minnesota, Cretaceous sediments are exposed only on pit faces. In the South Judson Mine near Buhl, Minnesota, a basal conglomerate contained marine invertebrates; further east on the south face of the Enterprise Mine near Virginia, Minnesota, unfossiliferous shales not definitely known to be marine were underlain by lignites, gravels, sands, and silts deposited in fresh or brackish water. This latter site may indicate the easternmost extension in this area of the Cretaceous transgression. The marine deposits were considered to be upper Benton or Colorado equivalents on the basis of their included invertebrate fauna (Bergquist, 1938; McGill, 1955).

#### PREVIOUS CRETACEOUS PALYNOLOGY

The most extensive applications of the palynology of prehistorical materials have been to the correlation of coals, particularly those of Paleozoic and Tertiary age; to the correlation of glacial and post-glacial stages; and to the interpretation of post-glacial vegetation and climatic changes. Mesozoic palynology has been described as an almost virgin field (Just, 1951). Published palynological studies of the era have been sparse, and for the Upper Cretaceous almost nonexistent until the later 1950's. Early palynological studies of Upper Cretaceous sediments include that of Kircheimer (1932), who studied some samples obtained near Namaqualand, South Africa. Some of the specimens he found were referred to the Pinaceae and to the dicotyledonous genera *Corylus* and *Myrica*; however, he noted that exact botanical identification was impossible. Miner (1932, 1935) described spores from the Upper Cretaceous of Greenland which he assigned to form genera in the Bryophyta and Filicineae. Hoffman (1948, 1950) described a few spores and pollen from the upper Upper Cretaceous of Salzburg, Austria. She assigned some of the spores to the fern genus *Platyserium* (tropical) and some of the pollen to the Rhizophoraceae.

The major early work in Mesozoic palynology was that of Thiergart (1949). Thiergart attempted to construct a sporomorph (pollen and spores)

column from the lower Keuper (Triassic) to the Paleocene (Tertiary) of Germany and Austria; however, he was able to obtain Cretaceous sporomorphs only from the Wealden and the latest (Grenzcomplex) portion of the period. Of the remainder he said, "Proben aus der mittleren Kreide, die sicher ausserordentlich interessant gewesen wären, da sie uns den Beginn der Dikotyledonen zeigen könnten, wären leider bisher nirgends zu erhalten." Some samples from a Cenomanian coal of southern France were little better (Thiergart, 1954); a sparse florule was obtained which included a few tricolpate types referred to as *Quercoides* Typen.

Krutzsch (1957) has recently compiled the information available on the stratigraphic distribution of pollen and spores in Cretaceous and Tertiary sediments of Central Europe. Of particular interest in this compilation is the apparent paucity of angiosperm pollen in pre-Upper Cretaceous sediments.

The first publication on Cretaceous palynology in this country was on the material described by Miner (1935) from coals of the Kootenai formation (Lower Cretaceous). At that time only spores of undetermined botanical origin were recovered. Schemel (1950) later described a few spores of undetermined botanical origin from the type locality of the Dakota formation, in Iowa. Radforth and Rouse (1954) described approximately 100 sporomorphs from the Brazeau formation of western Canada. Many of these were eventually referred to modern families or genera (Rouse, 1956, 1957). Of particular interest among the specimens Rouse described were spores that could be compared to those of schizaeaceous and gleicheniaceus ferns, both taxa primarily of tropical distribution, and winged pollen comparable to pollen from podocarpaceous conifers.

Since 1950, several oil companies have collected a substantial amount of information about the spore and pollen complexes of the Mesozoic in this and other countries (Armstrong, 1953; Kuyl *et al.*, 1955). At least one person (Woods, 1955) believes this information has not been published because of a "taxonomic jungle . . . created by changing styles in nomenclature."

#### OBJECTIVES

Because it was initiated at a time when pollen and spores were not known to occur abundantly in the Cretaceous clays of Minnesota, this study should be considered preliminary. However, several avenues of approach were opened as a consequence of the find, among which the following seemed most susceptible to investigation:

1. Investigating the pollen and spore content of different sediment types of Cretaceous age.
2. Applying paleoecological methods to determine the botanical affinities of the specimens.
3. Interpreting various ecological factors, particularly climate, reflected by the flora.

4. Comparing the botanical affinities indicated by the microfossils with those deduced from the megafossils.

5. Determining what pollen and spore forms might be useful for age and correlation studies.

In addition an attempt has been made to evaluate problems of pollen and spore classification, and to outline what the writer believes to be a workable approach to classification and nomenclature.

## 2. MATERIALS AND METHODS

### COLLECTION OF SEDIMENT SAMPLES

Collections for the present study were obtained from Cretaceous exposures in various parts of the state (see the accompanying map). With the exception of the Cobb's Creek collection, most of the samples were grab samples made while investigating exposures for macrofossils. A vertical sequence of samples was collected from Cobb's Creek in June, 1956, to construct a standard section of spores and pollen against which spores and pollen from the grab samples could be compared. Unfortunately most of the samples in this sequence were sterile.

Samples from the lignites and shales of the Enterprise Mine on the Mesabi Iron Range were sealed in cans with a mixture of one part water to one part formaldehyde for preservation. All other samples were placed in 15-ml. wide-mouth specimen vials and covered with glycerine. The possibility of contamination was minimized by collecting only from freshly exposed surfaces.

### SECTION LOCATIONS AND SAMPLE LEVELS

The location of exposures and the level at which samples were taken are indicated in the following section descriptions. Where a section description is available in the literature only the relevant level has been listed. The sample identification number refers to the number engraved on the series of slides made from a sample or samples collected at that locality. These slides have been deposited in the Paleobotanical Collection of the University of Minnesota Botany Department.

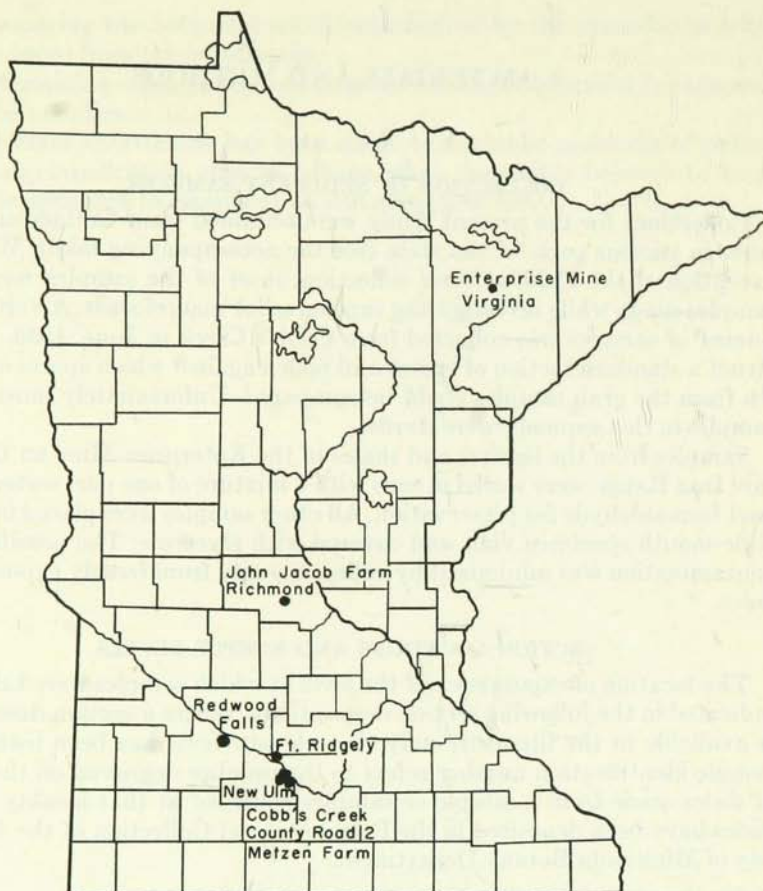
Section Description A. New Ulm, Brown County  
Metzen farm, NE $\frac{1}{4}$  Sec. 4, T. 110 N., R. 30 W.  
(Stauffer and Thiel, 1941, p. 104)

	Thickness in Feet
6. Sandstone, white to yellow; thin layers of silt interbedded with gray shales.	
Plant remains in silty layers.....	14.0

Section Description A: Several samples were collected from the sands and silts exposed at the head of a gully. Only a basal silt layer containing leaf fragments produced microfossils. Sample identification: Slide series 1 and 4.

Section Description B. New Ulm, Brown County  
Section along county road, 2 miles southwest of town  
NE $\frac{1}{4}$  Sec. 31, T. 110 N., R. 30 W.  
(Stauffer and Thiel, 1941, pp. 129-130)

	Thickness in Feet
4. Shale, gray, argillaceous, with occasional sandstone layers. Contains abundant leaf fragments. Unconformable on beds below.....	6.8



Map of Minnesota showing approximate locations of sampled deposits

Section Description B: Apparent unconformity of shales is due to recent slumping. Samples were collected from the middle of the clay shales in level 4. Sample identification: Slide series 6.

Section Description C. Redwood Falls, Redwood County  
Section at claypit of Och's Brick and Tile Company  
NW $\frac{1}{4}$  Sec. 2, T. 112 N., R. 35 W.

	Thickness in Feet
5. Till, gravelly (Wisconsin) .....	4.0
4. Clay, dark, carbonaceous .....	0.6
3. Lignite, argillaceous, more or less continuous around the south face of the pit .....	1.0
2. Clay, dark, carbonaceous .....	4.0
1. Clay, whitish, arenaceous, residual .....	4.0
Base of pit.	



Section Description C: At the time of collection, this pit was in the initial stages of excavation. The carbonaceous clays under the lignite seam represent a channel filling and are bounded laterally by gray, arenaceous clays containing occasional large, angular quartz boulders. The boulders are remnants of large dikes in the decomposed Morton gneiss. Samples were collected only from the lignite seam. Samples identification: Slide series 8 and 9.

Section Description D. Fort Ridgely, Nicollet County  
 Section along east bank of Fort Creek, on the George Floerup farm (Stauffer and Thiel, 1941, p. 179).

	Thickness in Feet
3. Shale, lignitic .....	0.6

Section Description D: Sample identification: Slide series 12.

Section Description E. New Ulm, Brown County  
 Cobb's Creek, NE $\frac{1}{4}$  Sec. 4, T. 109 N., R. 30 W.

	Thickness in Feet
8. Drift, sandy, gravelly (Wisconsin).....	30.0
7. Drift, argillaceous, bluish gray. Contains wood, invertebrate shells and dreikanter pebbles at base (Kansan) .....	10.0
6. Sandstone, whitish, cross-bedded, friable. The upper 7 feet of this layer contains several seams and lenses of clay containing leaf cuticles as well as leaf impressions .....	17.0
5. Sandstone, yellowish with darker limonitic lenses, cross-bedded, medium- to fine-grained, friable .....	9.3
4. Sandstone, grayish, cross-bedded, coarse, angular grains and occasional pebbles and with an iron cemented layer at bottom .....	2.2
3. Shale, arenaceous, friable, gray .....	5.0
2. Limestone (biogenetic?), gray on fresh surface, blocky not nodular.....	1.1
1. Shale, arenaceous, bluish gray, friable. Contains occasional limestone nodules and a basal oolitic-like layer with aggregated calcite crystals.....	4.5

Level of Cobb's Creek.

Section Description E: Cobb's Creek is referred to as Kalb Creek in Stauffer and Thiel (1941, p. 129). Samples were taken from all levels, but only samples from the upper portion of level 6 contained analyzable material. Sample identification: Slide series 24, bottom clay seam of level 6; Slide series 28 and 29, middle zone; Slide series 13, top clay seam.

Section Description F. Virginia, St. Louis County  
 Enterprise Mine (Oliver Mining Co.)

	Thickness in Feet
9. Drift .....	26.0
8. Detrital ore, reddish .....	10.4
7. Shales, argillaceous, derived from Virginia slate. In the lower 6 feet thin seams of arenaceous clay, taconite nodules and carbonaceous lenses frequently occur..	12.8
6. Shales, carbonaceous, with occasional lenses of lignite, limonitic sands, and derived paint rock .....	6.5
5. Lignite, intercalated lenses of derived paint rock frequent.....	3.9
4. Shale, limonitic, with fragmentary plant remains.....	1.0
3. Lignite .....	3.0
2. Sandstone, grayish, fine-grained, friable. Contains plant fragments, mainly wood	2.6

1. Lignite .....	3.8
Base of road on southeast side of pit.	

Section Description F: Although samples were collected from the shales of level 7 and the basal lignites of level 1, only the lignites contained pollen and spores. Sample identification: Slide series 41.

Section Description G. Sauk River, Stearns County  
 Section at West End of Highway Bridge over Sauk River, SW $\frac{1}{4}$ NE $\frac{1}{4}$  Sec. 23,  
 T. 123 N., R. 31 W.  
 (Stauffer and Thiel, 1949, p. 197.)

	Thickness in Feet
3. Shale, blue-gray, lignitic, passing into seams of lignite.....	1.2

Section Description G: A sample was collected from the stream-bank on the west side of the Sauk River on the John Jacob farm. Sample identification: Slide series 44.

#### PREPARATION OF SEDIMENTS FOR ANALYSIS

The procedure followed in this study was based on a modification of the procedure outlined by Traverse (1955) for the extraction of palynological material from organic sediments.

1. *Straining.* A sample of sediment was washed with jets of water from a wash bottle on a 2" x 2" double layer of muslin placed over the mouth of a 15-ml. test tube. Use of disposable muslin rather than a screen eliminated the necessity of flaming. With the exception of lignite samples from the Enterprise Mine, the samples processed did not need to be crushed or powdered prior to straining.

2. *Decalcification.* The sample was immediately centrifuged. The wash water was decanted and replaced with 10% HCL which was heated slightly to dissolve dolomite and to speed the reaction. Decalcification should precede desilicification because calcite is transformed to CaF<sub>2</sub> (Fluorite) during desilicification unless removed by prior treatment (Cookson and Singleton, 1954; Grayson, 1956; Sohn, 1956). The sample was then centrifuged and the water decanted.

3. *Desilicification.* (This step should be carried out under a hood if possible.) The residue from decalcification was put into suspension with a small amount of 52% HF and transferred to stoppered polyethylene vials. HF was added to half-fill the container and identification tags placed on each of the preparations. Desilicification occurred in two to seven days.

4. *Washing.* After desilicification the HF was decanted and the residue mixed with distilled water, centrifuged, and decanted; washing was repeated.

5. *Maceration.* To the residue from the last washing 10 ml. of 10% KOH were added and allowed to stand for no more than twenty-four hours. The residue from this step was washed at least three times to insure removal of KOH. It was noted that if no brown color resulted during this step, no pollen and spores were obtained from the sample.

6. *Bleaching*. The residue from step 5 was mixed with 5 ml. of commercial  $\text{NaClO}_2$  (Hi-lex, etc.), and acidified with 10% HCL. Bleaching is completed in about five minutes. Since chlorine gas is formed, the step should be performed under a hood.

7. *Dehydration*. One washing of the sediment with glacial acetic acid was used to prepare the residue from step 6 for acetolysis.

8. *Acetolysis*. About 5 ml. of a mixture of 9 parts of acetic anhydride to one part concentrated sulfuric acid were added to the dehydrated residue of step 7. This mixture was heated from room temperature to  $100^\circ \text{C}$ . in a water bath over a period of 15 minutes with frequent stirring. The residue was washed at least twice or until all brown color had disappeared.

9. *Mounting*. Glycerine jelly prepared by Agnes Hansen of the Botany Department, University of Minnesota, was heated to approximately  $50^\circ \text{C}$ . and mixed with the washed residue of step 8. Aliquots were placed on microscope slides, covered with a cover glass and cured at  $40^\circ \text{C}$ . on a warming table for two days. To prevent desiccation the slides were ringed with Turtox ringing cement after being removed from the warming table.

A more generally effective method for the processing of inorganic sediments has recently been published by Funkhouser and Evitt (1959). The application of oxidants as described by these authors can often give startling results. These oxidants can be introduced at the end of the procedure used in this study.

#### CONTAMINATION

Contamination of fossil sediments by modern sporomorphs is a hazard that must be considered when analyzing sediments. As a result of contamination of samples with Recent pollen, contamination of one sediment with another, or erroneous dating of samples, there have been a number of errors introduced into the literature (Hoffmeister and Staplin, 1955). A single control was set up in the laboratory to collect atmospheric pollen and spores during the period from June, 1956, to December, 1956. Contamination of the laboratory atmosphere was very high. *Ambrosia* spp., *Chenopodium* sp., spores and hormogonia of *Alternaria*, monolete fern spores (Polypodiaceae?), gramineaceous pollen and one grain of *Pinus strobus* L. were recognized among the atmospheric contaminants. The slides prepared from the sediments also contained contaminants. These included pollen similar to *Parthenocissus quinquefolia* (L.) Planch., *Urtica gracilis* Ait., *Tilia americana* L., *Ambrosia* sp., and grass. In the sediments investigated modern pollen contaminants were found to retain the aperture membrane; this feature was used for their identification and indicated that no control was necessary. No way was found that would enable one to distinguish microfossil contaminants accidentally introduced into an older or younger sample.

#### DESIGN OF THE REFERENCE COLLECTION

For the purposes of this investigation, a reference collection of spores and pollen of extant plants was organized in order to set up standards for deter-

mining the possible botanical affinities of the fossil sporomorphs. The design of this reference collection was based on the following working hypotheses:

1. It was assumed that some living species of genera identified from Cretaceous leaf impressions from Minnesota (Lesquereux, 1893) and the Dakota sandstone flora (Lesquereux, 1892) would have pollen morphologically comparable with pollen of Cretaceous species of these genera.

2. According to Barghoorn's (1951, p. 740) curve of modernization, about 30 per cent of the genera listed for the Dakota sandstone flora should still be present in the region. Collating this extrapolation of Barghoorn's curve with Traverse's (1955) results for the Oligocene, and Chaney's (1954) climatic interpretations, it was reasoned that other genera of the Cretaceous flora of Minnesota might still be present in the flora of southeastern United States. Selection of species from the southeastern flora was based on a species list of dominants of flood plains and uplands in the southeastern United States supplied by Dr. D. B. Lawrence of the University of Minnesota.

3. A third collection was based on the floristic relationships indicated by Li (1952) for eastern North America and eastern Asia. It was presumed that genera with closely related species in the two floras could represent long-ranging genera of a Cretaceous flora that migrated northward in the Tertiary. Species selected from the eastern North America flora were those with closely related species in eastern Asia.

*The Pollen Reference Collection.* The major portion of the material for the reference collection was obtained from herbarium specimens in the herbarium of the University of Minnesota. A brief survey of the sediments had shown that gymnosperm pollen were the most abundant, but efforts to obtain gymnosperm pollen from another herbarium were not successful. However slides of *Podocarpus* pollen were obtained from Dr. R. M. Kosanke of the Illinois Geological Survey.

To obtain spores and pollen from herbarium material several sporangia or anthers were removed from an herbarium specimen. These were placed in a small square of paper, crushed between the fingers, then stored in lip vials and covered with glacial acetic acid. All herbarium specimens from which material was removed have been annotated.

*Preparation of Herbarium Samples.* The procedure for preparation of herbarium samples stored in glacial acetic acid was essentially the same as that used for the last steps in sediment preparation.

1. Samples were transferred to 15-ml. test tubes and centrifuged. The glacial acetic acid was decanted into running water. Approximately 5 ml. of an acetylation mixture of 9 parts acetic anhydride to 1 part concentrated sulfuric acid were added to the floral sediment.

2. The mixture was heated from room temperature to 100° C. in a water bath over a period of 15 minutes with frequent stirring.

3. The acetylated residue was centrifuged; the acetylation mixture decanted, and the floral sediment washed at least twice.

4. Glycerine jelly heated to 50° C. was mixed with the floral residues; aliquots were placed on slides, covered with a cover glass and cured for at least two days on a warming table at 40° C.

*Organization of the Reference Collection.* To facilitate the reference of fossil material to the reference collection, it was necessary to construct an artificial key. The morphological sequence used in constructing the key was essentially the same sequence used in describing a specimen. The key comprised approximately 250 acetylated preparations, supplemented by non-acetylated material loaned to the writer by Agnes Hansen and Dr. R. M. Kosanke.

#### ANALYSIS OF SEDIMENTS

Several slides were made from each sediment sample and numbered serially for that sample. For each slide a separate survey sheet was kept, on which was listed the location, in latitude and longitude readings of the microscope vernier scale, of each new sporomorph found; previously noted forms with favorable orientation for study; and a brief description including class, shape, and other relevant information. A detailed survey was made of each slide using the high dry objective. After the initial survey all morphological analyses were made under oil immersion with a Bausch and Lomb dynoptic laboratory microscope.

After a specimen was keyed to a group within which it might be possible to obtain agreement, two microscopes were used for comparisons. These were placed side by side and a Zeiss split field comparison ocular used when necessary. Wodehouse (1935), Erdtman (1943, 1952), and Faegri and Iversen (1950) were used to check terminology, morphological interpretation, and to supplement the key. The terminology used in the descriptions conforms to that suggested by Faegri and Iversen (1950), with the additions and modifications suggested by Traverse (1955).

The most serious limitation felt during this portion of the study was the lack of a reference to gymnosperm pollen and a lack of these forms in the reference collection. Erdtman's (1957) illustrations have partly corrected this deficiency.

### 3. CLASSIFICATION AND DESCRIPTION

#### PROBLEMS OF NOMENCLATURE AND CLASSIFICATION

Pant (1954, p. 43) has observed that "The worker on fossil spores and pollen grains is, sooner or later, confronted with the problem of classifying and naming his tiny objects, and it is then that his interesting array of forms becomes most puzzling." The solution of this problem is the most difficult one facing palynologists today. It has been "solved" several times, but never to the satisfaction of a majority.

Under the International Rules of Botanical Nomenclature, as Faegri (1956) interprets them, there are two alternatives for the classification of sporomorphs:

1. Identification of a sporomorph to a known natural taxon — living or fossil — demands application of the name of that taxon to the sporomorph, e.g., *Alnus* for pollen grains undoubtedly derived from *Alnus* spp.

2. If a sporomorph cannot be referred to a natural taxon, it must then be referred to an existing form-taxon or a new form-taxon must be established for its inclusion.

The first alternative, identification of a sporomorph to a natural taxon, is a "consummation devoutly to be wished." Unfortunately, many such identifications are a source of misinformation, as in the case described by Erdtman (1958). And the consequences of publishing suspect or erroneous identifications are not easily corrected. For example, many Cretaceous leaf impressions have been referred to modern genera (Andrews, 1955). Often these references have been made through deference to a set of general characters (size, form, etc.), or to previous identifications in the literature. A typical leaf impression genus of this category is *Ficus*. *Ficus* is a genus of some 800 extant species (Willis, 1948) many of which have leaves indistinguishable from completely unrelated genera, e.g., *Aesclepias*. Most students of leaf impressions are, in the writer's opinion, aware of the uncertainty of many of their identifications, but these doubts have not deterred other students from accepting dubious identifications in preparing syntheses. Because such disciplines as paleoclimatology, phytogeography, phylogeny, etc., are dependent on the accuracy with which the fossil record is interpreted, there must be, as Gordon (1949) has said, "strict insistence on reliable identification or none at all." The belief that misidentification is not a serious problem because the International Code of Botanical Nomenclature has "built-in machinery" for correcting mistakes is fallacious in terms of the time and evidence required to constructively correct such mistakes.

The older a deposit, the less certain is reference of specimens from it to extant taxa. Consequently the second alternative within the code is much

more important than it appears. Within the context of this alternative, many authors (Erdtman, 1947; Potonié, 1952; Thomson and Pflug, 1953; Faegri, 1956; Van der Hammen, 1954; and others) believe it would be advantageous to have a standard procedure for the description and naming of fossil spores and pollen of pre-Quaternary deposits. In addition, these authors have suggested that it would be convenient and practicable to standardize the nomenclatural procedure by incorporating the morphology of a specimen in its assigned name. Unfortunately a standard morphological nomenclature is difficult to put into practice because of the existence of at least three different schools of descriptive terminology: the Faegri, Iversen, Troels-Smith school in Denmark; the Erdtman school in Sweden; and the Potonié *et al.* school in Germany.

A second problem attendant on the study of fossil spores and pollen is the classification of the great *number* of entities which can be obtained from a sample or a series of samples. According to Just (1957) there are 150 species of Carboniferous plants known from American coal balls. It is not impossible to obtain this number of morphologically distinct microfossils from one sample of sediment which can contain many thousands of specimens. Referring this number of specimens to existing organ-genera, form-genera, or Recent genera, and the creation of new form names for each new entity found is an almost impossible task, particularly at this stage of development of the field.

#### HISTORICAL RÉSUMÉ OF SPOROMORPH NOMENCLATURE AND CLASSIFICATION

During the initial development of Tertiary palynology Potonié (1931) found it convenient to classify all spores and pollen within the two form-genera *Sporites* and *Pollenites*. The name for species within these two genera was generally derived from some morphological characteristic of the sporomorph. Ibrahim (1933) modified Potonié's system for the classification of Paleozoic spores by combining a morphological prefix with *sporites*, e.g., *Reticulatisporites* as a genus for reticulate (*Reticulat*), trilete (*i*), spores (*sporites*). The combining letter for the other spores types was "a" for alete and "o" for monolete spores. This system gained wide use. In England, Raistrick and Simpson (1933) and Raistrick (1934, 1935, 1937) as well as Knox (1938) used seven alphabetical designates for grouping Paleozoic spores into morphological categories. These seven categories were variously subdivided with numerical subscripts. In America, Wodehouse (1933), when naming pollen obtained from the Eocene Green River shales, added "-pites," a contraction of pollenites, to the roots of family, genus, or species names of extant taxa. This approach led the Germans in the late 1930's and 1940's to modify Potonié's *Sporites* and *Pollenites* to uncontracted suffixes on the family or generic names of extant taxa, e.g., *Ericaceae-pollenites*.

In a study of Tertiary coals of Scotland, Simpson (1936) referred his material to Recent genera either directly or by preceding the generic name

with *cf.* "*Cf.*" was transformed in the German literature to Type, contraction Typ., to indicate either family or generic affinities, e.g., *Nymphaeaceen* Typ., or *Eucalyptus*-Typ. (cf. Thiergart, 1949).

Miner (1935) in an investigation of spores from Cretaceous coals of Greenland utilized morphological and shape designates to codify new forms that had unknown generic affinities; however, he contracted "spores" to "spora," e.g., *Deltoidospora*.

In 1944 Schopf, Wilson, and Bentall revised and emended the Ibrahim method for the classification of Paleozoic spores. The names they created for their new genera were usually of a commemorative nature, e.g., *Raistrickia*, thus breaking the morphological system established by Ibrahim. At a later date Potonié and Kremp (1955a) returned to morphological terms as a nomenclatural source when creating new genera for the classification of Paleozoic spores. In addition some genera, such as *Raistrickia*, within which Schopf, Wilson, and Bentall (1944) had by emendation included such previously described genera as *Setosi-sporites*, *Verrucosi-sporites*, and *Apiculati-sporites*, were re-emended by Potonié and Kremp to re-establish some of the older names; however, Wilson and Hoffmeister (1956) did not consider these re-emendations legitimate.

Erdtman (1947) published one of the first completely artificial morphological schemes for the anticipatory classification of Tertiary pollen and spores. These predefined genera were based on shape groups called "sporo-morphs." Included in the definition of "shape" were such features as aperture type and aperture position. *Tricolpites troedsonii* Erdtman 1948 and *Tricolporites protrudens* Erdtman in Ross 1949 are examples of names constructed. However, there was built-in variability in Erdtman's system in that the suffix "-ites" was used when the apertural characteristics on which the *nomen typicum abstractum*, i.e., genus, was based were apparent and "-idites" when interpretation was uncertain, e.g., *Tricolpidites*.

Cookson in Australia and Couper in New Zealand modified Erdtman's proposal, using it in part as suggested, but also using just the endings to indicate the degree of their confidence in material they referred to Recent genera or families. Interpreted literally, *Dacrydiumites* Cookson 1953a is an organ genus for pollen that was probably derived from *Dacrydium*. *Liliacidites* Couper 1953b is an organ genus for pollen that is similar to liliaceous pollen but was probably not derived from the Liliaceae. This application of Erdtman's proposal defeated the purpose of that proposal which was, in part, to keep the misinformation which can be contained in names from being introduced into the literature.

Potonié, Thomson, and Thiergart (1950) suggested revising Erdtman's proposals so that several schemes could be used concurrently:

1. The purely artificial system of indeterminate forms, but with the morphological names of Erdtman modified to permit construction of more "shape" groups, e.g., *Psilatricolpites* Van der Hammen 1956a, (writer's example).



2. The "half-natural" system within which a possible botanical affinity could be indicated, e.g., *Sequoidites*.

3. The "natural" or codified system within which material would be included if a positive identification were established.

The endings in the "half-natural" system were later modified by Potonié (1951) to "-oidae" as a suffix added to family roots, e.g., Nyssaceoidae, and to "-oisporites" and "-oipollenites" as suffixes for generic roots. The "half-natural" system, its various modifications, and the interpretive flux it created, have been responsible for most of the nomenclatural confusion now existing.

Thomson and Pflug (1953), in an attempt to reduce some of the confusion of the changing styles of nomenclature, used the morphological groupings of Ibrahim (1933) as the basis for a morphological system within which Tertiary spores could be classified, regardless of the botanical affinity of the spores. The morphological classes of Iversen and Troels-Smith (1950) were used by these authors as a basic framework for the classification of pollen regardless of affinity, e.g., *Tilia* pollen were included within the form-genus *Intratrisporipollenites* of the new class Brevaxones (oblate pollen). This classification and naming procedure for Tertiary and Cretaceous sporomorphs was followed by Weyland and Greifeld (1953), Weyland and Krieger (1953), Thiergart (1953), and Pflug (1953).

Radforth and Rouse (1954) reinstated Raistrick's system of symbol classification for Cretaceous pollen and spores from western Canada, but later Rouse (1956) used the "half-natural" system and placed "-sporites" and "-pollenites" suffixes on the names of modern genera or families to indicate affinities of Cretaceous spores and pollen to living plants.

Pant (1954) has published a detailed artificial system for the classification of pollen and spores, drawing, in large part, on systems of classification already in existence, particularly Russian procedures. The fault with Pant's system, in the writer's opinion, is its arbitrariness and lack of uniformity. However, it has not received much use.

Traverse (1955) used generic names of extant taxa for classifying Tertiary pollen and spores when he believed affinity to a modern genus was certain. Where generic relation of a sporomorph was uncertain, a new organ genus was created for inclusion in the natural system and placed in an existing family, e.g., *Siltaria*, new genus of the Fagaceae. Traverse made no attempt to refer his specimens to previously described and named sporomorphs, as he apparently believed all previous work on Tertiary palynology was invalid. This, of course, is not true and is a departure from the strict adherence to the International Botanical Code claimed by Traverse.

#### ECLECTIC ASPECTS OF PALYNOLOGICAL NOMENCLATURE

From the foregoing it is apparent that the concepts on which formalized classification of post-Paleozoic material is based can be separated into at least three different schools:

1. The German school, represented by Potonié (in part), Pflug, Thomson, and others, has promulgated the necessity for a morphological system of nomenclature. The proposals of Erdtman (1947), Norem (1954), Van der Hammen (1954), Kuyl *et al.* (1955), and Faegri (1956) can be referred to this approach. According to Thomson and Pflug (1953) such a system conforms to the rules of the Botanical Code.

2. The Couper-Cookson school (including Potonié, in part). The descriptive terminology is derived from Erdtman and nomenclatural procedures are within the rules of the Botanical Code according to Couper (1953b). New binomials are handled in a manner comparable to those usually applied to fossil leaves, i.e., affinity to a living plant is suggested in the name. The name endings are varied to indicate degree of confidence in the identification.

3. The Traverse school. Descriptive terminology is taken from Faegri, Iversen, and Troels-Smith; binomial designates and classification are handled in strict accordance with the rules of the Botanical Code according to Traverse (1955). A sporomorph apparently related to a Recent genus is so classified; specimens which cannot be referred to Recent genera are referred to new organ genera.

Several other systems of classification of plant microfossils have been reviewed by Guennel (1956) and Traverse (1956), but the conceptual basis for these systems can be found within one of the "schools."

Traverse (1955, p. 83) has taken issue with Erdtman's (1947) suggested morphological classification because "The exact relationship of this system to the ordinary biologic system is somewhat mysterious." Further, ". . . a difficult problem (if standard botanical taxonomic procedures are not followed) is created for future paleontologists." Also unacceptable to Traverse is Pflug's (1953) reference of grains that are "obviously *Tilia*" to the form-genus *Intratropopollenites*. However, the problem with which Erdtman and Pflug were concerned was to find some way in which *all* spores and pollen could be classified until such time as they could be *confidently* transferred, either singly or in groups, to extant taxa. Kuyl *et al.* (1955) believe the artificial approach is one way to reduce to some degree of order the multitude of forms encountered in ancient sediments, and the writer concurs.

The alternative is to follow either the procedure used by Couper and Cookson or the approach used by Traverse. The approach used by Couper and Cookson is essentially that used on leaf impression studies. Berry (1939) has pointed out that leaf impressions similar to leaves of *Sassafras* were referred by Lesquereux to *Araliopsis*, *Platanus*, *Cissites*, and *Sterculia*. Similar confusion has resulted from the approach of Couper and Cookson. For example, Cookson (1947, pl. 14, figs. 22-28) created the genus *Phyllocladidites* for small-winged, bivesiculate grains she called *P. mawsonii*. In 1953 she decided these grains were more closely related to *Dacrydium* and therefore changed *Phyllocladidites* to *Dacrydiumites*, designating *D. mawsonii* (Pl. 1, figs. 9-26) as the type although it was the same specimen she had

used as the type for *Phyllocladidites*. At the same time Couper (1953b) revised the generic description of *Phyllocladidites* Cookson and designated as the type Cookson's *P. mawsonii*, although Cookson had by that time designated it as the type for *Dacrydiumites*. Similarly, each of many hundreds of forms from the Tertiary of Germany has, since 1931, been revised several times by the same author, Potonié, as his ideas on classification or presumed affinity have changed. Such an approach leads only to confusion and engenders misinformation.

The ecological approach for the identification of plant microfossils used by Traverse (1955) is dependent on the accurate identification of key macrofossils of plants still present in an existing floristic association. In Traverse's study, *Cyrtilla* macrofossils suggested that the Recent plant association most like the association that occurred in the Brandon area during the Oligocene epoch was to be found in southeastern Florida. With this information to help formulate a working hypothesis, it was possible for him to design a pollen reference collection with some degree of confidence. The validity of Traverse's hypothesis was supported by the similarity of pollen he obtained from the lignite to pollen in his reference collection. However, as Erdtman (1947) has pointed out, "the older a deposit is, the greater is the danger that some (extinct) taxon possessed pollen grains similar to those of a living one." In most studies, particularly of Cretaceous and older Mesozoic deposits, it may not be possible to limit the chances of misidentification by restricting pollen comparisons to species from a predetermined plant association.

These different approaches to the classifying and naming of fossil spores and pollen and the controversy each has aroused have caused the literature to become all but inextricably confused. The problem of fossil pollen classification and nomenclature was referred to the Committee on Rules of the International Botanical Society, but the Committee rejected proposals for an artificial system during its session at Montreal in 1959. Inasmuch as morphologically similar sporomorphs have been classified in a variety of ways, rejection of a sound artificial system will continue to force eclecticism into much of pre-Quaternary microfossil nomenclature.

#### SPOROMORPH MORPHOLOGY AND CLASSIFICATION

In the writer's opinion, an artificial system within which all spores and pollen can be methodically classified regardless of their botanical affinity is an absolute necessity for the orderly development of pre-Quaternary palynology. Among the variety of such systems, the one proposed by Van der Hammen (1956a) is for several reasons the most acceptable, principally because (1) it is based on the widely accepted terminology of Iversen and Troels-Smith (1950); (2) definitive circumscription of taxonomic groupings above the level of species is an inherent characteristic of the system.

In this last respect Van der Hammen's system is far superior to such other useful proposals as that of Thomson and Pflug (1953), because cir-

cumscription of a genus is divorced from arbitrary authority. The limits imposed on the circumscription of sporomorph genera are imposed by the system automatically, as follows:

1. For nonwinged spores: exine ornamentation and tetrad marking, e.g., *Verrutritetes*.
2. For winged spores: exine ornamentation, number of wings, and tetrad marking, e.g., *Retitrites*.
3. For nonwinged pollen monads: exine ornamentation and aperture class, e.g., *Psilatricolpites*.
4. For nonwinged pollen polyads (dyads, tetrads, polyads): exine ornamentation and unit cell number, e.g., *Clavetradites*.
5. For winged pollen: exine ornamentation on the cap and wing number, e.g., *Punctabivesiculites*.

The satisfaction derived from precision in predicting the proper morphological genus into which a particular specimen will fall can be most fully appreciated when one has witnessed the embittered and confusing arguments of semantic taxonomy. As is obvious, breakdown of the genera into arbitrarily circumscribable units is accomplished at the species level.

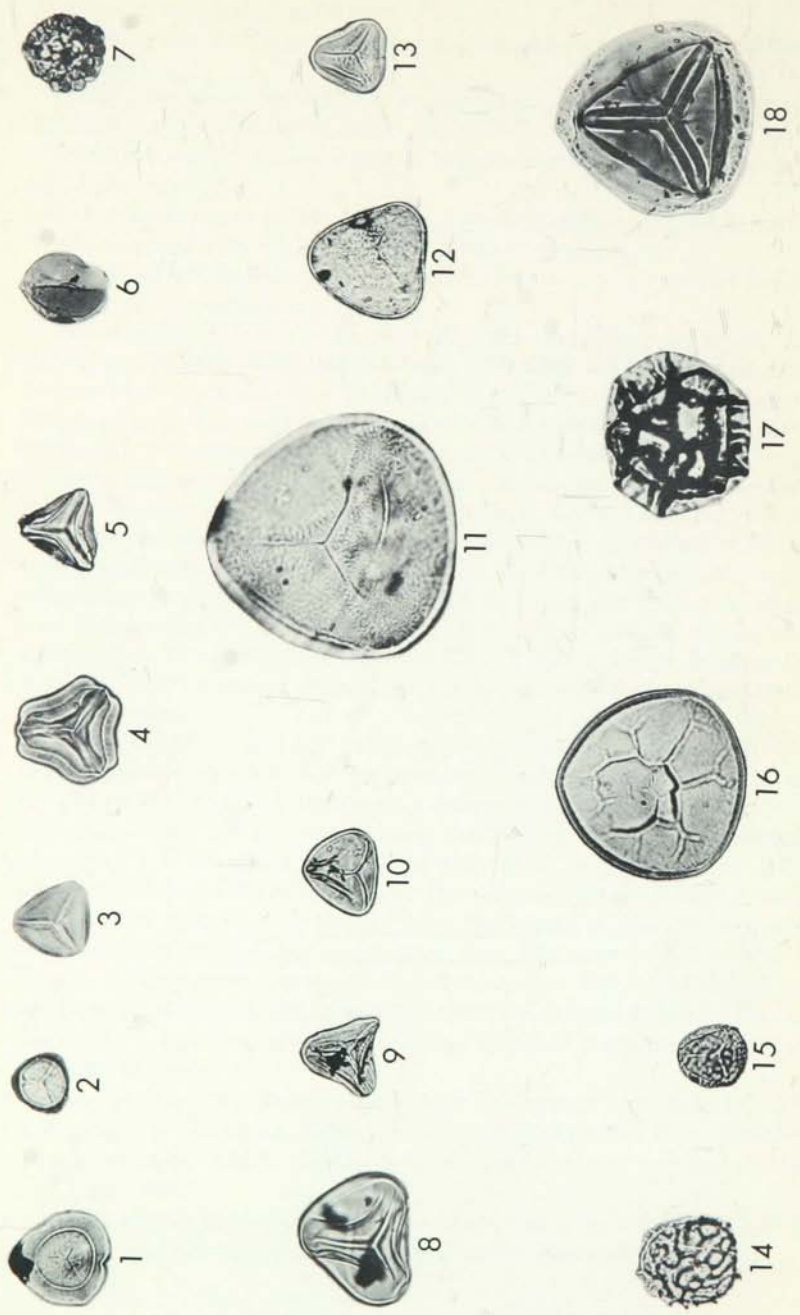
Inasmuch as this is a coding scheme, a scheme to give sporomorphs a handle for easy reference, it is not intended to delimit natural groupings. It is first and foremost an orderly, uniform method of artificial classification based on the morphology of a specimen. It is meant to discourage the use of numbers, e.g., BT-77; the use of arbitrary form-genera, e.g., *Endosporites* and *Raistrickia*; or the use of genera that imply a natural relationship e.g., *Liliacidites*. It is meant to be, as are BT-77, *Endosporites*, *Raistrickia*, *Liliacidites*, etc., an initial depository for sporomorphs whose natural origins are not known.

Only when the origin of certain groupings becomes known, and only then, is it proper to transfer such groupings to their natural taxa. For example, let us say that through thorough monographing of a sporomorph we shall call *Rugubivesiculites convolutus* it can be proved that the natural genus of origin is *Dacrydium*; then, and only then, is it proper to codify this grouping of dispersed pollen within the natural system. There is nothing to prevent one from saying that, within the limits of one's experience, *Rugubivesiculites convolutus* looks more like *Dacrydium* pollen than pollen from any other genera with which one is familiar. But, as most palynologists are becoming increasingly aware, alternative natural affinities for the most distinctive of pollen have a distressing habit of popping up after a paper has gone to press.

Because Van der Hammen's system has been thoroughly explained by him (Van der Hammen, 1956a), it will not be repeated here. However, the principles upon which this system is based deserve particular attention (*op. cit.*, p. 70):

1. The names of the artificial genera are based on morphological characters only, and constructed according to one uniform scheme.

*PLATE I. TRILETE AND MONOLETE SPORES*



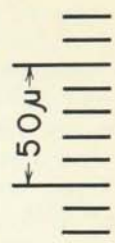
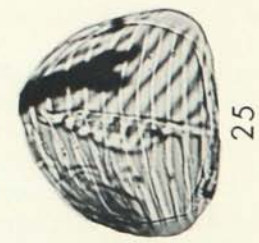


PLATE I. 1. *Cingutriletes congruens* (p. 25); 2. *C. densocingulatus* (p. 26); 3. *C. parvicingulus* (p. 26); 4. *C. trijugatus* (p. 26); 5. *C. interruptus* (p. 26); 6. *Foveotriletes triplanus* (p. 27); 7. *Gemmatriletes morulus* (p. 27); 8. *Psilatriletes excelsus* (p. 27); 9. *P. vulgaris* (p. 27); 10. *P. vitreus* (p. 28); 11. *Punctatriletes magnimundus* (p. 28); 12. *P. punctus* (p. 28); 13. *P. parvimundus* (p. 28); 14. *Retitriletes globosus* (p. 29); 15. *R. varius* (p. 29); 16. *R. pluricellulus* (p. 29); 17. *R. anulatus* (p. 29); 18. *R. triradius* (p. 30); 19. *Rugutriletes regularis* (p. 30); 20. *R. obscurans* (p. 30); 21. *R. quintus* (p. 30); 22. *R. toratus* (p. 30); 23. *R. rugosus* (p. 31); 24, 25. *Striutriletes striatus* (p. 31); 26. *S. bifurcus* (p. 31); 27. *S. coronarius* (p. 32); 28. *S. tetrajugatus* (p. 32); 29. *S. nodosus* (p. 32); 30. *Verrutriletes verus* (p. 32); 31. *Gemmamonoletes gemmatus* (p. 33); 32. *Retimonoletes foveolatus* (p. 33); 33. *Verrumonoletes morulus* (p. 33).



2. The morphological terms used in the construction of the generic names are the well-defined terms of Iversen and Troels-Smith (1950).

3. Possible or supposed natural relationship is never used for the construction of generic nor subgeneric names.

Van der Hammen used trinomials in his scheme rather than binomials; however, he recognized (1956a, p. 73) that this practice was eclectic. The writer prefers to consider the combination of an aperture type with a sculptural prefix a genus rather than a subgenus. In addition, *punctate* is here substituted for *scabrata*, for which it is a partial synonym. Also, the terms *alete* and *inaperturate* have been combined to form the single class *Inaperturateae*, because it is difficult or impossible to distinguish between fossil *alete* spores and fossil *inaperturate* pollen grains.

The use of Van der Hammen's system is dependent on an understanding of pollen morphology. Inasmuch as such understanding is requisite to description, this requirement is not a limitation. It is true that descriptive terminology for the ektexine varies slightly with different authors, but such variation is a defect of all nonmathematical description. In practice the essential elements of description are quite uniform. The writer has used, without change, the aperture classes for pollen outlined by Iversen and Troels-Smith (1950) as given in Faegri and Iversen (1950). Use of descriptive morphology for the ektexine varies only slightly from the definitions given in Faegri and Iversen, but for the sake of clarity can be outlined as follows:

- I. Ektexine Construction (Structure)
  - A. *Tectate*: ektexine separated by columellae into two more or less continuous layers.
  - B. *Intectate*: ektexine not separated into two discernible layers.
- II. Subtectum Columellae Patterns (Structure)
  - A. *Infragranulate*: columellae  $\geq 1\mu$  in diameter, not forming a geometric design.
  - B. *Infrapunctate*: columellae  $< 1\mu$  in diameter, not forming a geometric design.
  - C. *Infrareticulate*: columellae arranged in a network.
  - D. *Infrarugulate*: columellae aligned in angular or irregular folds.
  - E. *Infrastriate*: columellae aligned in straight or whorled parallel lines.
- III. Surface Ornamentation (Sculpture)
  - A. *Foveolate*: pitted, diameter of pits  $\geq 1\mu$ .
  - B. *Granulate*: coarse-textured aspect, imparted by positive sculptural elements, grana,  $\geq 1\mu$  in some diameter.
    1. *Baculate*: grana rod-shaped (baculae).
    2. *Clavate*: grana club-shaped (clavae).
    3. *Echinate*: grana broad-based, sharp-pointed (echinae).
    4. *Gemmate*: grana globular with constricted bases (gemmae).
    5. *Spinate*: grana narrow-based, sharp-pointed (spinae).
    6. *Verrucate*: grana broad-based, dome-shaped (verrucae).

- C. *Psilate*: ornamentation absent, surface smooth.
- D. *Punctate*: fine-textured aspect, imparted by *pits or projections*  $< 1\mu$  in diameter.
- E. *Reticulate*: network design formed by interconnected ridges (muri) enclosing polyhedral spaces (lumina).
- F. *Rugulate*: ornamentation of more or less irregularly arranged, sinuous or convolute ridges or grooves.
- G. *Striate*: ornamentation of parallel ridges and/or grooves.

In the writer's outline of ektexine morphology above, granulate is used as an inclusive textural term for most of the sculptural types. Granulate should be used as a morphological prefix only when there is a question about the shape of the sculptural element. In practice such questions arise more often than one would like. It is also possible that the shape of sculptural elements less than one micron in diameter may, in some cases, be easily discerned. When such is the case, the more definitive sculptural prefix (spinate, gemmate, etc.) should be used in place of punctate for the sake of clarity. The design of the positive sculptural elements (striate, reticulate, etc.) should always take precedence as a morphological prefix. However, in psilate specimens with a conspicuous infra-design (see section II above) it is advantageous to give the negative design precedence over psilate even though it is not a positive feature, because it is this design that strikes the observer's eye.

#### MORPHOLOGICAL CLASSIFICATION FOR CRETACEOUS SPORES AND POLLEN OF MINNESOTA (A PARTIAL OUTLINE)

##### I. Division SPORITES H. Potonié 1893

DIAGNOSIS: Spores with trilete or monolete sutures on proximal surface.

A. Class TRILETES (Reinsch) Ibrahim 1933. DIAGNOSIS: Triradiate tetrad scar present.

1. Form-genus *Cingutritetes* new genus. DIAGNOSIS: Cingulate, trilete spores in which the cingulum, or equatorial flange, is the most conspicuous sculptural element, i.e., exine is psilate, punctate, or granulate. TYPE SPECIES (here designated): *Cingutritetes congruens*, Pl. I, fig. 1.
2. Form-genus *Foveotritetes* new genus. DIAGNOSIS: Foveolate, trilete spores. TYPE SPECIES (here designated): *Foveotritetes triplanus*, Pl. I, fig. 6.
3. Form-genus *Gemmatritetes* new genus. DIAGNOSIS: Gemmate, trilete spores. TYPE SPECIES (here designated): *Gemmatritetes morulus*, Pl. I, fig. 7.
4. Form-genus *Psilatritetes* V. d. Ham. 1956a. DIAGNOSIS: Psilate, trilete spores. TYPE SPECIES: *Psilatritetes guadensis* V. d. Ham. 1956b, Pl. II, fig. 4.
5. Form-genus *Punctatritetes* new genus. DIAGNOSIS: Punctate, trilete

spores. TYPE SPECIES (here designated): *Punctatriletes magnimundus*, Pl. I, fig. 11.

6. Form-genus *Retitriletes* new genus. DIAGNOSIS: Reticulate, trilete spores. TYPE SPECIES (here designated): *Retitriletes globosus*, Pl. I, fig. 14.
7. Form-genus *Rugutriletes* new genus. DIAGNOSIS: Rugulate, trilete spores. TYPE SPECIES (here designated): *Rugutriletes regularis*, Pl. I, fig. 19.
8. Form-genus *Striutriletes* V. d. Ham. 1956a. DIAGNOSIS: Striate, trilete spores. TYPE SPECIES: *Striutriletes susannae* V. d. Ham. 1956b. Pl. II, fig. 5.
9. Form-genus *Verrutriletes* new genus. DIAGNOSIS: Verrucate, trilete spores. TYPE SPECIES (here designated): *Verrutriletes verus*, Pl. I, fig. 30.

B. Class MONOLETES Ibrahim 1933. DIAGNOSIS: Spores with a single line of dehiscence on the more or less concave to level proximal surface. (Occasionally the proximal surface of the spore will be less conspicuously sculptured than its distal surface. This feature, when observable, may be of aid in separating spores from monocolpate pollen grains).

1. Form-genus *Gemmamonoletes* new genus. DIAGNOSIS: Gemmate, monolete spores. TYPE SPECIES (here designated): *Gemmamonoletes gemmatus*, Pl. I, fig. 31.
2. Form-genus *Retimonoletes* new genus. DIAGNOSIS: Reticulate, monolete spores. TYPE SPECIES (here designated): *Retimonoletes foveolatus*, Pl. I, fig. 32.
3. Form-genus *Verrumonoletes* V. d. Ham. 1956a. DIAGNOSIS: Verrucate, monolete spores. TYPE SPECIES: *Verrumonoletes usmensis* V. d. Ham. 1956b, Pl. II, fig. 7.

## II. Division POLLENITES R. Potonié 1931

DIAGNOSIS: None to many furrows or pores present, single furrow of monocolpate forms located on the distal surface of the grain. (Note: The separation of monocolpate pollen from monolete spores may prove impossible in many instances; however, monocolpate forms always lack a perispore, the germinal aperture is usually less slit-like in appearance than in spores, i.e., is broader, often more vague in actual outline, and the structural and sculptural features are more "pollen-like." Thomson and Pflug (1953) separated the two groups by defining monolete spores as possessing two planes of symmetry and monocolpate pollen only one. This is not a true statement *per se* but does serve as a guide for initial evaluations.)

A. Class II. TETRADAE Iversen and Troels-Smith 1950. DIAGNOSIS: Sporomorphs adherent in groups of fours.

Form-genus *Retitetradites* new genus. DIAGNOSIS: Reticulate pollen ad-

herent in groups of four. TYPE SPECIES (here designated): *Retitetradites monocarpatus*, Pl. II, fig. 34.

- B. Class IV. VESICULATAE Iversen and Troels-Smith 1950. DIAGNOSIS: Forms with one, two, or more wing-like or saccate projections (vesiculae) formed by separation of ectexine from endexine.
1. Form-genus *Bacubivesiculites* new genus. DIAGNOSIS: Two-winged pollen with baculate sculptural elements on cap. TYPE SPECIES (here designated): *Bacubivesiculites inchoatus*, Pl. II, fig. 35.
  2. Form-genus *Clavabivesiculites* new genus. DIAGNOSIS: Two-winged pollen with clavate sculptural elements on cap. TYPE SPECIES (here designated): *Clavabivesiculites inchoatus*, Pl. II, fig. 36.
  3. Form-genus *Granabivesiculites* new genus. DIAGNOSIS: Two-winged pollen with granulate cap. The sculptural elements, though  $\geq 1\mu$ , do not have a definable morphology. TYPE SPECIES (here designated): *Granabivesiculites inchoatus*, Pl. II, fig. 38.
  4. Form-genus *Punctabivesiculites* new genus. DIAGNOSIS: Two-winged pollen with punctate cap. TYPE SPECIES (here designated): *Punctabivesiculites constrictus*, Pl. II, fig. 44.
  5. Form-genus *Retibivesiculites* new genus. DIAGNOSIS: Two-winged pollen with reticulate design on cap. TYPE SPECIES (here designated): *Retibivesiculites parvus*, Pl. II, fig. 51.
  6. Form-genus *Rugubivesiculites* new genus. DIAGNOSIS: Two-winged pollen with rugulate design on cap. TYPE SPECIES (here designated): *Rugubivesiculites convolutus*, Pl. II, fig. 57.
  7. Form-genus *Granatrivesiculites* new genus. DIAGNOSIS: Three-winged pollen with granulate cap. The sculptural elements, though  $\geq 1\mu$ , do not have a definable morphology. TYPE SPECIES (here designated): *Granatrivesiculites dubius*, Pl. III, fig. 66.
  8. Form-genus *Granamultivesiculites* new genus. DIAGNOSIS: Pollen with more than four wings and with granulate cap. The sculptural elements, though  $\geq 1\mu$ , do not have a definable morphology. TYPE SPECIES (here designated): *Granamultivesiculites inchoatus*, Pl. III, fig. 67.
- C. Class V. INAPERTURATAE Iversen and Troels-Smith 1950. DIAGNOSIS: Sporomorphs without apertures; symmetry usually radial or spherical; shape spherical to lenticular; variously ornamented but never with wing-like bladders (vesiculae).
1. Form-genus *Bacuinaperturites* new genus. DIAGNOSIS: Baculate, inaperturate sporomorphs. TYPE SPECIES (here designated): *Bacuinaperturites setosus*, Pl. III, fig. 70.
  2. Form-genus *Foveoinaperturites* new genus. DIAGNOSIS: Foveolate, inaperturate sporomorphs. TYPE SPECIES (here designated): *Foveoinaperturites forameniferus*, Pl. III, fig. 71.
  3. Form-genus *Gemmainaperturites* new genus. DIAGNOSIS: Gemmate,

inaperturate sporomorphs. TYPE SPECIES (here designated): *Gemmainaperturites gemmatus*, Pl. III, fig. 74.

4. Form-genus *Psilainaperturites* new genus. DIAGNOSIS: Psilate, inaperturate sporomorphs. TYPE SPECIES (here designated): *Psilainaperturites psilatus*, Pl. III, fig. 76.
  5. Form-genus *Punctainaperturites* new genus. DIAGNOSIS: Punctate, inaperturate sporomorphs. TYPE SPECIES (here designated): *Punctainaperturites scaber*, Pl. III, fig. 77.
  6. Form-genus *Ruginaperturites* new genus. DIAGNOSIS: Rugulate, inaperturate sporomorphs. TYPE SPECIES (here designated): *Ruginaperturites sphaeroides*, Pl. III, fig. 78.
  7. Form-genus *Spinainaperturites* new genus. DIAGNOSIS: Spinulate, inaperturate sporomorphs. TYPE SPECIES (here designated): *Spinainaperturites recurvatus*, Pl. III, fig. 79.
  8. Form-genus *Striainaperturites* new genus. DIAGNOSIS: Striate, inaperturate sporomorphs. TYPE SPECIES (here designated): *Striainaperturites ovatus*, Pl. III, fig. 80.
  9. Form-genus *Verruinaperturites* new genus. DIAGNOSIS: Verrucate inaperturate sporomorphs. TYPE SPECIES (here designated): *Verruinaperturites depressus*, Pl. III, fig. 81.
- D. Class VI. MONOPORATAE Iversen and Troels-Smith 1950. DIAGNOSIS: Sporomorphs with a single distinctive pore, or with an iso-diametric area texturally differentiated from remainder of surface.
1. Form-genus *Bacumonoporites* new genus. DIAGNOSIS: Baculate, monoporate pollen. TYPE SPECIES (here designated): *Bacumonoporites baculatus*, Pl. III, fig. 82.
  2. Form-genus *Rugumonoporites* new genus. DIAGNOSIS: Rugulate, monoporate pollen. TYPE SPECIES (here designated): *Rugumonoporites convolutus*, Pl. III, fig. 83.
  3. Form-genus *Verrumonoporites* new genus. DIAGNOSIS: Verrucate, monoporate pollen. TYPE SPECIES (here designated): *Verrumonoporites verrucatus*, Pl. III, fig. 84.
- E. Class VII. MONOCOLPATAE Iversen and Troels-Smith 1950. DIAGNOSIS: Sporomorphs with a single furrow on assumed distal surface; one plane of symmetry may or may not be present through the equator. Exine variously ornamented but never with bladders (vesiculae).
1. Form-genus *Granamonocolpites* new genus. DIAGNOSIS: Granulate, monocolpate pollen. The sculptural elements, though  $\geq 1\mu$ , do not have a definable morphology. TYPE SPECIES (here designated): *Granamonocolpites asymmetricus*, Pl. III, fig. 85.
  2. Form-genus *Punctamonocolpites* new genus. DIAGNOSIS: Punctate, monocolpate pollen. TYPE SPECIES (here designated): *Punctamonocolpites scaphoformis*, Pl. III, fig. 86.
  3. Form-genus *Retimonocolpites* new genus. DIAGNOSIS: Reticulate,

- monocolpate pollen. TYPE SPECIES (here designated): *Retimonocolpites dividuus*, Pl. III, fig. 87.
4. Form-genus *Verrumonocolpites* new genus. DIAGNOSIS: Verrucate, monocolpate pollen. TYPE SPECIES (here designated): *Verrumonocolpites conspicuus*, Pl. III, fig. 89.
- F. Class X. TRICOLPATAE Iversen and Troels-Smith 1950. DIAGNOSIS: Forms with three equally spaced longitudinally elongate furrows; three planes of symmetry are usually present through the poles and one through the equator.
1. Form-genus *Bacutricolpites* V. d. Ham. 1956a. DIAGNOSIS: Baculate, tricolpate pollen. TYPE SPECIES: *Bacutricolpites magnus*, Pl. 8, fig. 25, V. d. Ham. 1956a.
  2. Form-genus *Clavatricolpites* new genus. DIAGNOSIS: Clavate, tricolpate pollen. TYPE SPECIES (here designated): *Clavatricolpites prolatus*, Pl. III, fig. 93.
  3. Form-genus *Foveotricolpites* new genus. DIAGNOSIS: Foveolate, tricolpate pollen. TYPE SPECIES (here designated): *Foveotricolpites sphaeroides*, Pl. III, fig. 95.
  4. Form-genus *Gemmatricolpites* new genus. DIAGNOSIS: Gemmate, tricolpate pollen. TYPE SPECIES (here designated): *Gemmatricolpites prolatus*, Pl. III, fig. 96.
  5. Form-genus *Psilatricolpites* V. d. Ham. 1956a. DIAGNOSIS: Psilate, tricolpate pollen. TYPE SPECIES: *Psilatricolpites incomptus*, Pl. 7, fig. 22, V. d. Ham. 1956a.
  6. Form-genus *Punctatricolpites* new genus. DIAGNOSIS: Punctate, tricolpate pollen. TYPE SPECIES (here designated): *Punctatricolpites brevis*, Pl. III, fig. 100.
  7. Form-genus *Retitricolpites* V. d. Ham. 1956a. DIAGNOSIS: Reticulate, tricolpate pollen. TYPE SPECIES (here designated): *Retitricolpites ornatus*, Pl. 9, fig. 26, V. d. Ham. 1956a.
  8. Form-genus *Verrutricolpites* new genus. DIAGNOSIS: Verrucate, tricolpate pollen. TYPE SPECIES (here designated): *Verrutricolpites sphaeroides*, Pl. III, fig. 112.
- G. Class XIII. TRICOLPORATAE Iversen and Troels-Smith 1950. DIAGNOSIS: Radially symmetrical grains with three planes of symmetry through the poles and one through the equator; characterized by three longitudinal furrows with definite evidence of equatorial pores in or having been in the furrows.
1. Form-genus *Foveotricolporites* new genus. DIAGNOSIS: Foveolate, tricolporate pollen. TYPE SPECIES (here designated): *Foveotricolporites rhombohedralis*, Pl. III, fig. 113.
  2. Form-genus *Psilatricolporites* V. d. Ham. 1956a. DIAGNOSIS: Psilate, tricolporate pollen. TYPE SPECIES: *Psilatricolporites inornatus*, Pl. 9, fig. 28, V. d. Ham. 1956a.

## DESCRIPTIVE PROCEDURE

The systematic descriptions of the sporomorphs include a slide number which refers to the sample location. A hyphenated suffix indicates the number of the slide in the series of slides made from the sample. The location of the specimen on the slide is described in latitude and longitude readings of a vernier scale; a reference number is given in latitude and longitude for a conspicuous cross marked on the right-hand side of each slide for the calibration of vernier scales on other microscopes (Pierce, 1959). The description of a sporomorph includes the following items, in the order of occurrence: orientation in the microscope field, haptotypic features, symmetry, shape or form, size, exine thickness and morphology, botanical affinity, similar forms noted in the literature, and frequency. The term frequency as used in this study refers only to the number of times a sporomorph was noted. *Low* indicates it was noted five or fewer times, *medium* six to ten times, *high* more than ten times. Frequency was less important in this study than constancy, i.e., recurrence in different samples, because there was no attempt to do stratigraphic zonation. Constancy and sample frequency of the more abundant or distinctive forms are given in Table 3.

For a taxon indicated as new, the slide and location listed are for the type. When more than one specimen of a new taxon is illustrated a holotype has been specified. The slides from which these specimens have been described are deposited in the Paleobotanical Collection of the University of Minnesota Botany Department.

## SPOROMORPH DESCRIPTIONS (Plates I, II, and III)

## Class TRILETES (Reinsch) Ibrahim 1933

DIAGNOSIS: Spores with triradiate tetrad scar on proximal surface.

## CINGUTRILETES new genus

DIAGNOSIS: Trilete spores with equatorial flange or cingulum as most conspicuous sculptural or design feature.

*Plate I between pp. 18 and 19*

## CINGUTRILETES CONGRUENS new species

Pl. I, fig. 1. Type for genus and species. Slide 41L-1. Location: 16.6 x 132.7 (Reference: 54.0 x 126.9). DESCRIPTION: Proximal view, mid-focus. Trilete, laesurae extend halfway to equator; triradially symmetrical; subtriangular; maximum size excluding flange 26 $\mu$ . Exine punctate on distal surface, psilate on proximal surface, ca. 1.5 $\mu$  thick. Equatorial region encircled by a flange 6 $\mu$  broad. BOTANICAL AFFINITY: Selaginellaceae(?). SIMILAR FORMS: *Pero trilites granulatus* Rouse not Couper in Radforth and Rouse 1956 Pl. 1, fig. 37, Cretaceous, Canada. REMARKS: *Anulatisporites* is a morphological form genus constructed by Potonié and Kremp (1955a) for cingulate Carboniferous forms similar to the present specimen; cf. also, *Pero trilites* Couper 1953b. Frequency medium.

**CINGUTRILETES DENSOCINGULATUS** new species

Pl. I, fig. 2. Type for species. Slide 8H-1. Location: 41.1 x 132.1 (Reference: 59.5 x 128.2). DESCRIPTION: Distal view (proximal surface also apparent), mid-focus. Trilete, laesurae extend to equator, commissures closed and unbordered; triradially symmetrical; body spherical, ca. 20 $\mu$  in diameter excluding equatorial flange, including equatorial flange subtriangular; maximum diameter ca. 24.5 $\mu$ . Exine psilate, thin; equatorial flange ca. 3 $\mu$  wide at laesural apices, 1.5 $\mu$  wide (variable) in interlaesural region. BOTANICAL AFFINITY: Bryophyta(?). SIMILAR FORMS: *Sphagnites australis* f. *crassa* Cookson 1953b, Pl. 1, figs. 2-4, Tertiary, Australia. REMARKS: Frequency low.

**CINGUTRILETES PARVICINGULUS** new species

Pl. I, fig. 3. Type for species. Slide 8H-1. Location: 30.8 x 132.1 (Reference: 59.5 x 128.2). DESCRIPTION: Proximal view, mid-focus. Trilete, laesurae extend to equator, commissures usually gaping and weakly bordered; triradially symmetrical; triangular; maximum diameter 31 $\mu$ . Exine psilate, ca. 2 $\mu$  thick (variable) with a narrow flange in the interlaesural zone of the equator. BOTANICAL AFFINITY: Filicineae(?). REMARKS: Frequency low.

**CINGUTRILETES TRIJUGATUS** new species

Pl. I, fig. 4. Type for species. Slide 41-2. Location: 37.2 x 136.0 (Reference: 60.5 x 129.8). DESCRIPTION: Distal view, mid-focus. Trilete, laesurae extend to periphery, commissures straight, unbordered; triradially symmetrical; triangular; maximum diameter ca. 43 $\mu$ . Exine ca. 1.5 $\mu$  thick at apices, 6 $\mu$  thick through equatorial ridges; triradiate ridge ca. 7 $\mu$  wide present on distal surface in planes of symmetry; distal and peripheral ridges sparsely pitted. BOTANICAL AFFINITY: Filicineae(?). REMARKS: Frequency low.

**CINGUTRILETES INTERRUPTUS** new species

Pl. I, fig. 5. Slide 4L-1. Location: 25.2 x 128.6 (Reference: 59.0 x 128.4). DESCRIPTION: Proximal view, mid-focus. Trilete, laesurae extend to periphery; triradially symmetrical; triangular, contact faces of proximal surface collapsed; maximum diameter including flange 33 $\mu$ . Exine psilate except for three interlaesural equatorial ridges forming a peripheral flange; exine ca. 1 $\mu$  thick, peripheral flange 3.5 $\mu$  wide. BOTANICAL AFFINITY: Gleicheniaceae(?). SIMILAR FORMS: *Camarozonotriletes* form, Naumova 1937, Pl. 2, Cretaceous, Russia. Cyatheaceae, Firtion 1952, Pl. 10, fig. 5, Upper Cretaceous, France. *Gleichenia circinidites* Cookson 1953b, Pl. 1, figs. 5-6, Tertiary, Australia. REMARKS: Frequency high.

**FOVEOTRILETES** new genus

DIAGNOSIS: Trilete spores on which foveolae are the most conspicuous sculptural feature.



## FOVEOTRILETES TRIPLANUS new species

Pl. I, fig. 6. Type for genus and species. Slide 8H-2. Location: 37.2 x 134.5 (Reference: 57.0 x 127.9). DESCRIPTION: Mid-focus. Trilete; triradially symmetrical; maximum diameters 30.5 x 36.5 $\mu$  with polar axis longest. Exine ca. 1 $\mu$  thick, sparsely pitted. BOTANICAL AFFINITY: Unknown. SIMILAR FORMS: Class Triplanes, Thomson and Pflug 1953. REMARKS: Very common in European Tertiary material. Similar forms were classified by Thomson and Pflug in a category of trilete spores characterized by a longer polar than equatorial axis. Kuyl, *et al.* (1955) believe these forms may be either trilete or inaperturate sporomorphs that have collapsed. Frequency medium.

## GEMMATRILETES new genus

DIAGNOSIS: Gemmate trilete spores.

## GEMMATRILETES MORULUS new species

Pl. I, fig. 7. Type for genus and species. Slide 41L-1. Location: 23.1 x 121.4 (Reference: 54.0 x 126.9). DESCRIPTION: Proximal view, mid-focus. Trilete, laesurae indistinct; triradially symmetrical; spherical; ca. 35 $\mu$  in diameter including sculpture. Exine thickness variable, ca. 4-7 $\mu$ ; sculpturing of closely spaced gemmae up to 6 $\mu$  in diameter. BOTANICAL AFFINITY: Polyodiaceae(?). REMARKS: Frequency high.

## PSILATRILETES V. d. Ham. 1956a

DIAGNOSIS: Psilate trilete spores. TYPE FOR GENUS: *Psilatrilletes quadensis* V. d. Ham. 1956b, Pl. 11, fig. 4.

## PSILATRILETES EXCELSUS new species

Pl. I, fig. 8. Type for species. Slide 41-2. Location: 21.7 x 122.3 (Reference: 60.5 x 129.8). DESCRIPTION: Proximal view, high mid-focus. Trilete, laesurae extend to periphery, commissure straight, not bordered but appearing elevated; three planes of symmetry through poles; triangular; maximum diameter ca. 55 $\mu$ . Exine ca. 1.5-2 $\mu$  thick; psilate; proximal contact faces usually concave. BOTANICAL AFFINITY: Gleicheniaceae(?). SIMILAR FORMS: *Laevigatisporites neddeni* spp. *torus* Pf. in Thomson and Pflug 1953, p. 54, Pl. 2, fig. 8-16, Tertiary, Germany. REMARKS: Frequency high.

## PSILATRILETES VULGARIS new species

Pl. I, fig. 9. Type for species. Slide 1H-2. Location: 19.3 x 128.3 (Reference 55.0 x 127.7). DESCRIPTION: Proximal view, mid-focus. Trilete, laesurae extend to equator, commissure borders slightly invaginated; triradially symmetrical; triangular; maximum diameter ca. 30 $\mu$ . Exine psilate, ca. 1 $\mu$  thick; proximal contact faces and interapical (interlaesural) equatorial rim usually invaginated. BOTANICAL AFFINITY: Gleicheniaceae(?). SIMILAR FORMS: *Gleichenia linearis* (Burm.) Cl. in Selling 1946, Pl. 3, figs. 50-51, Recent,

Hawaii. "Fernspore" Reissinger 1950, Pl. 12, fig. 9, Jurassic (Lias), Germany. REMARKS: A common form in most samples. Frequency high.

*PSILATRILETES VITREUS* new species

Pl. I, fig. 10. Type for species. Slide 41L-1. Location: 10.3 x 131.1 (Reference: 54.0 x 126.9). DESCRIPTION: Oblique proximal view, mid-focus. Trilete, laesurae extend nearly to periphery; triradially symmetrical; subtriangular; maximum diameter 37.5 $\mu$ . Exine psilate, ca. 1.5 $\mu$  thick. BOTANICAL AFFINITY: Filicineae. SIMILAR FORMS: *Deltoidospora cascadiensis* Miner 1935, Pl. 24, fig. 9, Lower Cretaceous (Aptian), Montana. *Sporites adriennis* Potonié *mesozoicus* Thiergart 1949, Pl. 5, fig. 50, Upper Cretaceous (Grenzcomplex), Germany. *Laevigatisporites neddeni* subsp. *irregularis* Pflug in Thomson and Pflug 1953, p. 54, Pl. 2, fig. 3, Tertiary, Germany. *Laevigatisporites neddeni* Thomson and Pflug in Thiergart 1954, Pl. 3, fig. 23, Upper Cretaceous (Cenomanian) France. REMARKS: Frequency high.

*PUNCTATRILETES* new genus

DIAGNOSIS: Punctate (scabrate), trilete spores.

*PUNCTATRILETES MAGNIMUNDUS* new species

Pl. I, fig. 11. Type for genus and species. Slide 13M-2. Location: 46.7 x 131.3 (Reference: 62.3 x 127.1). DESCRIPTION: Proximal view, high mid-focus. Trilete, laesurae extend three-fourths of the distance to the equator, lips of commissures slightly thickened; triradially symmetrical; subtriangular; maximum diameter 106 $\mu$ . Exine 4.5 $\mu$  thick, punctate on all surfaces. BOTANICAL AFFINITY: Filicineae(?). SIMILAR FORMS: *Punctatisporites mundus* Kosanke 1950, Pl. 2, fig. 8, Pennsylvanian, United States. REMARKS: Frequency low.

*PUNCTATRILETES PUNCTUS* new species

Pl. I, fig. 12. Type for species. Slide 28L-2. Location: 28.6 x 127.8 (Reference: 56.4 x 127.6). DESCRIPTION: Distal view (proximal surface apparent), mid-focus. Trilete, laesurae extend three-fourths the distance to the equator, commissures closed and unbordered; triradially symmetrical; triangular; maximum diameter 50 $\mu$ . Exine 1.5–2 $\mu$  thick, punctate on all surfaces. BOTANICAL AFFINITY: Filicineae(?). SIMILAR FORMS: *Punctatisporites punctus* Pflug in Thomson and Pflug 1953, p. 57, Pl. 2, figs. 63–70, Paleocene to Eocene, Germany. REMARKS: Frequency medium.

*PUNCTATRILETES PARVIMUNDUS* new species

Pl. I, fig. 13. Type for species. Slide 41-2. Location: 30.3 x 35.9 (Reference: 60.5 x 129.8). DESCRIPTION: Proximal view, mid-focus. Trilete, laesurae extend to equator, commissures straight, unbordered; triradially symmetrical; triangular; maximum diameter ca. 31 $\mu$ . Exine punctate, 1.5 $\mu$  thick. BOTANICAL AFFINITY: Filicineae(?). REMARKS: Frequency high.

**RETITRILETES** new genus

DIAGNOSIS: Reticulate, trilete spores.

**RETITRILETES GLOBOSUS** new species

Pl. I, fig. 14. Type for genus and species. Slide 41-2. Location: 42.8 x 132.1 (Reference: 60.5 x 129.8). DESCRIPTION: Oblique distal view, mid-focus. Trilete, laesurae probably extend to equator, commissures without thickened border; triradially symmetrical; spherical; maximum diameter ca. 39 $\mu$  excluding sculpture. Exine, excluding sculpture, ca. 1 $\mu$  thick, coarsely reticulate. BOTANICAL AFFINITY: Lycopodiaceae cf. *Lycopodium annotinum* L. SIMILAR FORMS: *Reticulatisporites potoniei* Pflug and Thomson, in Weyland and Greifeld 1953, p. 41, Pl. 10, figs. 38, 39, 43, 44, Upper Cretaceous (Senonian), Germany. *Reticulatisporites reticulocingulum* Loose in Potonié and Kremp 1955b, Pl. 16, figs. 306-308, Carboniferous, Germany. REMARKS: Frequency high.

**RETITRILETES VARIUS** new species

Pl. I, fig. 15. Type for species. Slide 41L-1. Location: 17.0 x 130.8 (Reference 54.0 x 126.9). DESCRIPTION: Proximal view, mid-focus. Trilete, laesurae extend three-fourths the distance to the equator; triradially symmetrical; subtriangular; maximum diameter including sculpture ca. 30 $\mu$ . Exine thickness variable, 1.5-3 $\mu$ , thickest in interlaesural area of equator; ruguloreticulate sculpturing distinct on distal surface, faint on proximal surface, height of muri unequal. BOTANICAL AFFINITY: Lycopodiaceae(?). REMARKS: Frequency low.

**RETITRILETES PLURICELLULUS** new species

Pl. I, fig. 16. Type for species. Slide 13M-1. Location: 45.9 x 130.5 (Reference: 57.5 x 128.4). DESCRIPTION: Polar view, mid-focus. Trilete, laesurae short, indistinct, possibly absent; triradially symmetrical; subtriangular; maximum diameter ca. 82 $\mu$ . Exine ca. 3 $\mu$  thick, psilate or faintly punctate but with conspicuous reticulate design from what may be remnants of cell walls. BOTANICAL AFFINITY: Unknown. REMARKS: Internal markings appear to be cell wall remnants—not cracks. Pluricellular spores characterized the pteridosperms and Bennettitales; however, no Bennettitalean furrow is present. Frequency low, noted 4 times.

**RETITRILETES ANULATUS** new species

Pl. I, fig. 17. Type for species. Slide 8H-1. Location: 18.2 x 131.5 (Reference: 59.5 x 128.2). DESCRIPTION: Distal view, mid-focus. Trilete; triradially symmetrical; triangular; maximum diameter 52 $\mu$  excluding sculpture. Exine coarsely reticulate on distal surface, psilate on proximal surface; equatorial flange present which ranges up to 13 $\mu$  wide. BOTANICAL AFFINITY: Lycopodiaceae(?). REMARKS: Frequency very high.

**RETITRILETES TRIRADIUS** new species

Pl. I, fig. 18. Type for species. Slide 12H-2. Location: 20.0 x 135.9 (Reference: 57.9 x 127.7). DESCRIPTION: Proximal view, mid-focus. Trilete, laesurae extend to periphery, commissures conspicuously bordered by ridges; triradially symmetrical, triangular, 62 $\mu$  in longest diameter excluding sculpture. Exine psilate on proximal surface, coarsely reticulate on distal surface, muri intersect once at distal pole and intersect at equator with equatorial flange; membranous equatorial flange ca. 8 $\mu$  wide. BOTANICAL AFFINITY: Lycopodiaceae(?). REMARKS: Frequency low.

**RUGUTRILETES** new genus

DIAGNOSIS: Rugulate, trilete spores.

**RUGUTRILETES REGULARIS** new species

Pl. I, fig. 19. Type for genus and species. Slide 41-2. Location: 20.3 x 133.0 (Reference: 60.5 x 129.8). DESCRIPTION: Slightly oblique distal view, high mid-focus. Trilete, laesurae extend three-quarters of distance to equator, commissures unbordered; subtriangular, appearing spherical as a result of sculpturing; maximum diameter including sculpture 32 $\mu$ . Exine 1.5–3 $\mu$  thick, coarsely rugulate, rugulae higher in inter-laesural region of equator than at apices. BOTANICAL AFFINITY: Lycopodiaceae, cf. *Lycopodium inundatum* L. REMARKS: Frequency high.

**RUGUTRILETES OBSCURANS** new species

Pl. I, fig. 20. Type for species. Slide 8H-1. Location: 26.1 x 136.7 (Reference: 59.5 x 128.2). DESCRIPTION: Polar view, mid-focus. Trilete, laesurae very short, indistinct; triradially symmetrical; spherical; ca. 36.5 $\mu$  in diameter. Exine ca. 1.5 $\mu$  thick; sculpturing rugulate. BOTANICAL AFFINITY: Osmundaceae(?). SIMILAR FORMS: *Osmunda regalis* L. REMARKS: Frequency low.

**RUGUTRILETES QUINTUS** new species

Pl. I, fig. 21. Type for species. Slide 28H-31. Location: 28.9 x 122.4 (Reference: 57.8 x 127.8). DESCRIPTION: Oblique proximal view, mid-focus. Trilete, laesurae extend to equator, commissures not bordered; triradially symmetrical; spherical; maximum diameter 41 $\mu$ . Exine 3 $\mu$  thick, sculpturing rugulate with clavoid aspect in optical section. BOTANICAL AFFINITY: Filicinaeae(?). SIMILAR FORMS: *Rugulatisporites quintus* Pflug and Thomson in Thomson and Pflug 1953, p. 56, Pl. 2, fig. 45, Tertiary, Germany. REMARKS: Frequency low.

**RUGUTRILETES TORATUS** new species

Pl. I, fig. 22. Type for species. Slide 41-2. Location: 48.4 x 133.5 (Reference: 60.5 x 129.8). DESCRIPTION: Proximal view, mid-focus. Trilete, laesurae extend to equator, commissures straight, not bordered; triradially symmetrical; triangular; maximum diameter ca. 64 $\mu$ . Exine thickness extremely var-

iable, 2–9 $\mu$ ; distal surface with coarse rugulo-striate sculpturing, proximal surface coarsely rugulate. BOTANICAL AFFINITY: Filicineae(?). SIMILAR FORMS: *Corrugatisporites toratus* Weyland and Greifeld 1953, p. 42, Pl. 11, figs. 56–59, Upper Cretaceous (Senonian), Germany. REMARKS: Frequency low.

#### RUGUTRILETES RUGOSUS new species

Pl. I, fig. 23. Type for species. Slide 8H-1. Location: 42.4 x 133.4 (Reference: 59.5 x 128.2). DESCRIPTION: Distal view, mid-focus. Trilete but tetrad scar nearly indiscernible; triradially symmetrical; body triangular but over-all form appears spherical due to width variation in encircling equatorial flange; maximum diameter including flange ca. 44 $\mu$ . Exine exclusive of sculpture ca. 1.5 $\mu$  thick; sculpturing of partially anastomosing, pitted rugulae. BOTANICAL AFFINITY: Lycopodiaceae(?). REMARKS: Frequency low.

#### *Striatriletes* V. d. Ham. 1956b

DIAGNOSIS: Striate, trilete spores. TYPE FOR GENUS: *Striatriletes susannae* V. d. Ham. 1956b, Pl. II, fig. 5.

#### STRIATRILETES STRIATUS new species

Pl. I, figs. 24 and 25. Type for species, fig. 24. Slide 13M-2. Location: 20.9 x 131.0 (Reference: 62.3 x 127.1). DESCRIPTION: Proximal view, mid-focus. Trilete, laesurae extend to equator, commissures bordered by ridges except at proximal pole; form triradially symmetrical but bilaterally symmetrical with respect to sculpture; triangular; maximum diameter 97 $\mu$ . Exine about 4 $\mu$  thick; striate sculpturing present on all surfaces; ridges pitted, occasionally dichotomizing on distal surface mid-way between distal pole and equator. Fig. 25, Slide 13M-2. Location: 45.5 x 123.6. Oblique lateral view mid-focus. 97 x 82 $\mu$ . BOTANICAL AFFINITY: Schizaeaceae. SIMILAR FORMS: *Mohria* Typ. Thiergart 1949, Pl. 4, fig. 8, Lower Cretaceous (Wealden) Germany. *Mohriospores dorogensis* R. Potonié and Gelletich 1932, in R. Potonié 1951, Pl. 20, fig. 14, Paleocene-Oligocene, Germany. *Appendicisporites triceps* Weyland and Krieger 1953, p. 12, Pl. 3, fig. 15, Upper Cretaceous (Senonian), Germany. *Mohriospores australiensis* Cookson 1953b, Pl. 2, fig. 32, Tertiary, Australia. REMARKS: Sittler (1954a) states that spores of the "dorigensis" type are not found in the geological record in France until the beginning (Wealden) of the Cretaceous. Boodle (1895, fig. 1) found similar spores embedded in the aerial roots of *Tempskya* and said they were most comparable to *Anemia (Trochopteris) elegans*. Frequency medium.

#### STRIATRILETES BIFURCUS new species

Pl. I, fig. 26. Type for species. Slide 29H-3. Location: 13.4 x 130.0 (Reference: 53.8 x 127.6). DESCRIPTION: Distal view, high mid-focus. Trilete, laesurae extend to equator, commissures bordered by ridges except at proximal pole; form triradially symmetrical but bilaterally symmetrical with respect

to sculpture; triangular; maximum diameter including sculpture 70 $\mu$ . Exine ca. 3 $\mu$  thick including sculpture; striate sculpturing present on all surfaces, ridges distinctly punctate usually dichotomizing at or immediately adjacent to the equatorial region. BOTANICAL AFFINITY: Schizaeaceae. SIMILAR FORMS: *Cicatricosisporites pseudorogensis* (R. Pot.) Pf. and Th. in Weyland and Greifeld 1953, Pl. 11, fig. 52, Upper Cretaceous, Germany. REMARKS: Frequency low.

*STRIATRILETES CORONARIUS* new species

Pl. I, fig. 27. Type for species. Slide 41-2. Location: 47.5 x 130.3 (Reference: 60.5 x 129.8). DESCRIPTION: Oblique distal view, high mid-focus. Trilete, laesurae extend to equator, commissures with slightly thickened borders; triradially symmetrical; triangular; maximum diameter including sculpture 57 $\mu$ . Exine including sculpture 6 $\mu$  thick; sculpturing striate; distal surface surmounted by a more or less circular crown with an inside diameter of 20 $\mu$  from the margin of which radiate closely appressed ridges that terminate in an equatorial flange. BOTANICAL AFFINITY: Lycopodiaceae(?). REMARKS: Frequency low, noted once.

*STRIATRILETES TETRAJUGATUS* new species

Pl. I, fig. 28. Type for species. Slide 1L-3. Location: 49.0 x 133.8 (Reference: 59.2 x 128.4). DESCRIPTION: Distal view, mid-focus. Trilete with laesurae extending to equator; triradially symmetrical; subtriangular to oval; maximum diameter 59 $\mu$ . Exine ca. 2.5 $\mu$  thick, variable; sculpturing striate of concentric ridges with minute, scattered pits; ridge encircling equator slightly thickened at laesurae apices. BOTANICAL AFFINITY: Filicineae(?). REMARKS: Frequency low, noted once.

*STRIATRILETES NODOSUS* new species

Pl. I, fig. 29. Slide 41-2. Location: 31.0 x 120.9 (Reference: 60.5 x 129.8). DESCRIPTION: Oblique distal view, mid-focus. Trilete, laesurae extend to equator, commissures not bordered; form triradially symmetrical but bilaterally symmetrical with respect to sculpture; triangular; maximum diameter including sculpture ca. 72 $\mu$ . Exine thickness variable, ca. 3.5 $\mu$  in interlaesural region of equator; sculpturing striate of one distal but grooved ridge which bisects spore; apices with swollen, knob-like thickenings. BOTANICAL AFFINITY: Filicineae (?). REMARKS: Frequency low.

*VERRUTRILETES* new genus

DIAGNOSIS: Verrucate, trilete spores.

*VERRUTRILETES VERUS* new species

Pl. I, fig. 30. Type for genus and species. Slide 28H-2. Location: 34.4 x 136.9 (Reference: 57.8 x 129.0). DESCRIPTION: Proximal view, mid-focus. Trilete, laesurae extend to equator, rim of commissures slightly thickened; triradi-

ally symmetrical; triangular; maximum diameter including sculpture  $68.5\mu$ . Exine about  $2\mu$  thick; irregular verrucate sculpturing present on all three apices; proximal surface psilate, distal surface slightly punctate. BOTANICAL AFFINITY: Filicineae(?). SIMILAR FORMS: *Triquitrites rotalis* Weyland and Krieger 1953 p. 11, Pl. 1, fig. 2, Upper Cretaceous (Senonian), Germany. *Triquitrites arcuatus* Wilson and Coe 1940, p. 185, Pl. 8, figs. 1-8, Pennsylvanian, United States. *Triquitrites crassus* Kosanke 1950, p. 38, Pl. 8, fig. 6, Pennsylvanian, United States. REMARKS: Schopf, Wilson, and Bentall (1944, p. 46) indicate that morphologically similar Paleozoic forms may be filicinean. Frequency low.

#### Class MONOLETES Ibrahim 1933

GEMMAMONOLETES new genus

DIAGNOSIS: Gemmate, monolete spores.

GEMMAMONOLETES GEMMATUS new species

Pl. I, fig. 31. Type for genus and species. Slide 4L-3. Location:  $47.6 \times 130.0$  (Reference:  $57.2 \times 127.5$ ). DESCRIPTION: Lateral view, mid-focus. Monolete; bilaterally symmetrical, kidney-shaped,  $15 \times 23\mu$ . Exine ca.  $1.3\mu$  thick excluding sculpture; sculpturing of scattered gemmate projections occasionally fused and appearing wart-like in surface view. BOTANICAL AFFINITY: Polypodiaceae. SIMILAR FORMS: *Dryopteris goggilodus* (Schk.) O. Kze. emend. Fosberg in Selling 1946, Pl. 7, fig. 143, Hawaii, Recent. REMARKS: Frequency low.

RETIMONOLETES new genus

DIAGNOSIS: Reticulate, monolete spores.

RETIMONOLETES FOVEOLATUS new species

Pl. I, fig. 32. Type for genus and species. Slide 4I-2. Location:  $30.3 \times 135.2$  (Reference:  $60.5 \times 129.8$ ). DESCRIPTION: Lateral view, mid-focus. Monolete; bilaterally symmetrical; maximum diameter  $89\mu$ . Exine ca.  $4-5\mu$  thick; structure of thick-trunked columellae fused apically; sculpture reticulo-foveoloid, lumina angular, usually 4-6 sided, often reduced to pits. BOTANICAL AFFINITY: Schizaeaceae. SIMILAR FORMS: *Schizaea Skottsbergii* Selling 1946, Pl. 2, figs. 41-44, xerothermic maximum, Hawaii (not present on islands at present time). *Schizaea pusilla* Pursh. REMARKS: Similarity to *S. pusilla* remarkable. Frequency low, noted twice.

*Verrumonoletes* V. d. Ham. 1956a

DIAGNOSIS: Verrucate, monolete spores. TYPE FOR GENUS: *Verrumonoletes usmensis* V. d. Ham. 1956b, Pl. II, fig. 7.

VERRUMONOLETES MORULUS new species

Pl. I, fig. 33. Type for species. Slide 29H-4. Location:  $13.4 \times 130.0$  (Reference:  $53.0 \times 128.0$ ). DESCRIPTION: Oblique lateral(?) view, mid-focus. Pre-

sumed monolete, haptotypic features indiscernible; symmetry presumed bilateral; maximum diameter  $53\mu$ . Exine ca.  $1.2\mu$  thick excluding sculpture; verrucate sculptural elements ca.  $4\mu$  in diameter are closely spaced over entire surface. BOTANICAL AFFINITY: Polypodiaceae(?). SIMILAR FORMS: *Polypodiites senonicus* Ross 1949, p. 33, Pl. 1, figs. 8-9, Upper Cretaceous (Senonian), Sweden. REMARKS: The verrucate sculpturing of this specimen is suggestive of *Sciadopitys* as figured in Erdtman 1943, p. 127, fig. 387; however, *Sciadopitys* usually has the distal surface invaginated and is radially symmetrical. The form figured here is presumed bilateral and monolete. Frequency low, noted only once.

#### Class (II) TETRADAE Iversen and Troels-Smith 1950

##### RETITETRADITES new genus

DIAGNOSIS: Pollen tetrads with reticulate sculpturing.

*Plate II between pp. 34 and 35*

##### RETITETRADITES MONOCOLPATUS new species

Pl. II, fig. 34. Type for genus and species. Slide 41-2. Location:  $33.3 \times 137.1$  (Reference:  $60.5 \times 129.8$ ). DESCRIPTION: Mid-focus. Tetrad, four grains arranged in a tetrahedron (base uppermost in illustration); individual grains monocolpate, aperture located on proximal surface; spherical, ca.  $13\mu$  in diameter. Exine intectate, reticulate, ca.  $1\mu$  thick. Over-all diameter of tetrad about  $20\mu$ . BOTANICAL AFFINITY: Dicotyledoneae. REMARKS: Frequency high.

#### Class (IV) VESICULATAE Iversen and Troels-Smith 1950

##### BACUBIVESICULITES new genus

DIAGNOSIS: Baculate, two winged pollen.

##### BACUBIVESICULITES INCHOATUS new species

Pl. II, fig. 35. Type for genus and species. Slide 12L-1. Location:  $22.4 \times 130.8$  (Reference:  $57.5 \times 129.4$ ). DESCRIPTION: Distal view, mid-focus. Vesiculate, wings rudimentary, represented by two elongate, cavate projections bordering the germinal furrow; bilaterally symmetrical; spherical; diameter ca.  $61\mu$ . Exine ca.  $3\mu$  thick; closely spaced baculate projections give surface a densely granular aspect. BOTANICAL AFFINITY: Coniferae. REMARKS: Frequency high.

##### CLAVABIVESICULITES new genus

DIAGNOSIS: Clavate, two-winged pollen.

##### CLAVABIVESICULITES INCHOATUS new species

Pl. II, fig. 36. Type for genus and species. Slide 12L-1. Location:  $38.4 \times 123.0$  (Reference:  $57.7 \times 129.4$ ). DESCRIPTION: Distal view, high mid-focus. Vesiculate, wings rudimentary, represented by two saccate projections parallel to



*PLATE II. TETRAD AND VESICULATE POLLEN*



34



35



36



37



38



39



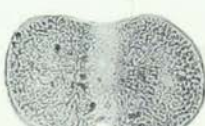
40



41



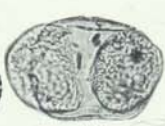
42



43



44



45



46



47



48



49



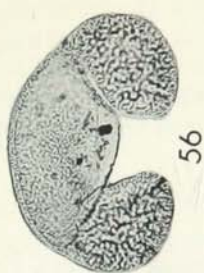
50



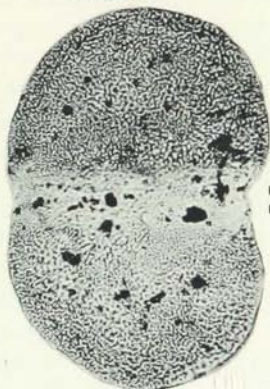
51



52



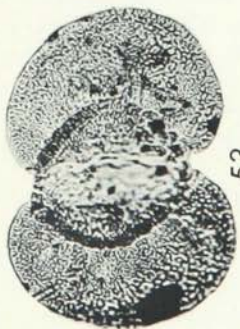
56



55



54



53



61



60



59



58



57



65



64



63



62

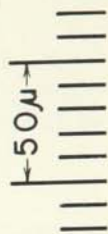


PLATE II. 34. *Retitetradites monocolpatus* (p. 34); 35. *Bacubivesiculites inchoatus* (p. 34); 36. *Clavabivesiculites inchoatus* (p. 34); 37. *C. pannosus* (p. 35); 38. *Granabivesiculites inchoatus* (p. 35); 39. *G. tuberosus* (p. 35); 40. *G. cingularis* (p. 35); 41. *G. constrictus* (p. 36); 42, 43. *G. latus* (p. 36); 44, 45. *Punctabivesiculites constrictus* (p. 37); 46. *P. radiatus* (p. 37); 47. *P. crassus* (p. 37); 48. *P. parvus* (p. 37); 49. *P. inchoatus* (p. 37); 50. *P. tenuis* (p. 38); 51, 52. *Retibivesiculites parvus* (p. 38); 53. *R. fatulus* (p. 38); 54. *R. oppositus* (p. 39); 55. *R. planus* (p. 39); 56. *R. concors* (p. 39); 57. *Rugubivesiculites convolutus* (p. 39); 58. *R. multiplex* (p. 40); 59, 60. *R. rugosus* (p. 40); 61, 62. *R. fluens* (p. 40); 63. *R. floridus* (p. 40); 64, 65. *R. reductus* (p. 41).

but not bordering germinal furrow; bilaterally symmetrical; oval; maximum diameter ca.  $53\mu$ . Exine ca.  $2\mu$  thick; closely spaced clavate projections give grain a coarse, dense, granular texture. BOTANICAL AFFINITY: Coniferae. REMARKS: Luber (1939) described forms he called *Subsacculifer* from Permian coals of Russia, which in part appear to be descriptively similar to rudimentary winged forms from the Cretaceous of Minnesota. Frequency high.

CLAVABIVESICULITES PANNOSUS new species

Pl. II, fig. 37. Type for species. Slide 12H-2. Location:  $19.8 \times 130.3$  (Reference:  $57.9 \times 127.7$ ). DESCRIPTION: Distal view, mid-focus. Vesiculate, wings rudimentary, represented by two serpentine, cavate projections bordering the narrow germinal furrow; bilaterally symmetrical; spherical; diameter ca.  $49\mu$ . Exine  $1.5\mu$  thick; sculpturing clavate, clavae may fuse apically; surface texture granular. BOTANICAL AFFINITY: Coniferae. REMARKS: Frequency high.

GRANABIVESICULITES new genus

DIAGNOSIS: Two-winged pollen with sculptural elements on cap  $\geq 1\mu$  giving the cap a granular texture but with the individual grana too nondescript to describe more precisely.

GRANABIVESICULITES INCHOATUS new species

Pl. II, fig. 38. Type for genus and species. Slide 8H-1. Location:  $43.0 \times 130.6$  (Reference:  $59.5 \times 128.2$ ). DESCRIPTION: Distal view, mid-focus. Vesiculate, wings rudimentary, represented by two rectangular, internally granulate out-pocketings; bilaterally symmetrical; oval; ca.  $37 \times 46\mu$ . Exine ca.  $2\mu$  thick; coarsely granulate and occasionally sparsely pitted. BOTANICAL AFFINITY: Coniferae, *Phyllocladus*(?). SIMILAR FORMS: *Disaccites* (*Phyllocladidites*) *Ruei* Cookson 1947, Pl. 14, fig. 34, Tertiary, Kerguelen Archipelago. REMARKS: Frequency high.

GRANABIVESICULITES TUBEROSUS new species

Pl. II, fig. 39. Type for species. Slide 24L-3. Location:  $32.5 \times 128.8$  (Reference:  $57.7 \times 127.6$ ). DESCRIPTION: Lateral view, mid-focus. Vesiculate, wings appearing balloon-like in specimen illustrated, well-developed coarse-meshed internal reticulum present; body laterally constricted; maximum diameter ca.  $30.5\mu$ , including wings ca.  $63.5\mu$ . Exine  $3\mu$  thick at proximal pole, thickening to  $4\mu$  at proximal roots of wings; coarsely granulate texture. BOTANICAL AFFINITY: cf. *Pinus* spp. REMARKS: Frequency low.

GRANABIVESICULITES CINGULARIS new species

Pl. II, fig. 40. Type for species. Slide 24H-1. Location:  $32.5 \times 135.8$  (Reference:  $57.0 \times 128.7$ ). DESCRIPTION: Distal view, mid-focus. Vesiculate, wings broadly attached to body, appearing to encircle it, internally reticulate; bilaterally symmetrical; ellipsoidal; maximum diameter excluding wings ca.

44 $\mu$ . Exine ca. 2 $\mu$  thick, granulate, no marginal crest. BOTANICAL AFFINITY: Coniferae. REMARKS: Frequency high.

*GRANABIVESICULITES CONSTRICTUS* new species

Pl. II, fig. 41. Type for species. Slide 24L-3. Location: 18.9 x 119.2 (Reference: 57.7 x 127.6). DESCRIPTION: Lateral view, low mid-focus. Vesiculate, wings constricted at base, coarse-meshed internal reticulations; body diameter ca. 58.5 $\mu$  including wings ca. 84.5 $\mu$ . Exine ca. 2.5 $\mu$  thick, coarsely granular. BOTANICAL AFFINITY: cf. *Pinus resinosa* Ait. SIMILAR FORMS: *Pinus silvestris* Typ. Reissinger 1950, Pl. 17, fig. 1, Jurassic (Lias), Germany. *Pityosporites labdacus* R. Potonié in Thomson and Pflug 1953, Pl. 5, figs. 60-62, Tertiary, Germany. REMARKS: This specimen has also been made the type of *Pinus resinosipites* Pierce 1957. Proof of the relationship of these pollen to pollen of *Pinus resinosa* Ait. is, however, indirect. Needles and cones comparable to those of *Pinus resinosa* have been found in Cretaceous sediments from Minnesota (Chaney, 1954), and some of the pollen from these same sediments are morphologically identical to pollen of *Pinus resinosa*. However, many of the specimens included within *Granabivesiculites constrictus* are, with respect to the natural system, quite probably specifically and even generically different from any one isolate. Consequently, reference of isolates to the natural system does not automatically refer all specimens included within a morphological category to the natural taxon to which the isolate has been referred. Particularly in samples from deposits of different age, the probability is that morphologically similar forms are, in terms of origin, derived from species that differ at the species, generic, or even family level.

Pollen morphologically similar to *Granabivesiculites constrictus* range from the Liassic to the Recent. Frequency high.

*GRANABIVESICULITES LATUS* new species

Pl. II, figs. 42 and 43. Type for species fig. 42. Fig. 42. Slide 12L-1. Location: 38.0 x 121.4 (Reference: 57.5 x 129.4). DESCRIPTION: Lateral view, mid-focus. Vesiculate, wings confluent with proximal surface, broadly attached to body, internally reticulate, reticulum well developed; bilaterally symmetrical, body diameter 47 $\mu$ , including wings 73 $\mu$ . Exine ca. 2 $\mu$  thick, 3 $\mu$  at proximal roots of wings; coarse, granular surface texture. Fig. 43, Slide 12L-2. Location: 42.8 x 121.0 (Reference: 58.4 x 127.6). DESCRIPTION: Distal view, high mid-focus. Diameter ca. 50 $\mu$ , including wings ca. 83 $\mu$ . BOTANICAL AFFINITY: *Podocarpus* (?). SIMILAR FORMS: *Disaccites (Podocarpidites) elliptica* Cookson 1947, Pl. 13, fig. 6, Tertiary, Kerguelen Archipelago. *Podocarpaceen* Typ. Reissinger 1950, Pl. 15, fig. 11, Jurassic (Lias), Germany. *Podocarpaceen* Typ. Reissinger 1950, Pl. 15, fig. 12, Jurassic (Lias), Germany. *Podocarpus spicatus* R. Br. REMARKS: Common from Liassic through Tertiary of Europe. Frequency high.

## PUNCTABIVESICULITES new genus

DIAGNOSIS: Two-winged pollen with punctate (scabrate) sculpture and texture on grain cap.

## PUNCTABIVESICULITES CONSTRICTUS new species

Pl. II, figs. 44 and 45. Type for genus and species, fig. 44. Fig. 44, Slide 13M-1. Location: 40.2 x 136.9 (Reference 57.5 x 128.4). DESCRIPTION: Lateral view, mid-focus. Vesiculate, wings constricted basally, internal reticulum well developed; bilaterally symmetrical; diameter ca. 48.5 $\mu$ , including wings ca. 74 $\mu$ . Exine ca. 1.5 $\mu$  thick, punctate, marginal crest weakly developed. Fig. 45, Slide 13M-1. Location: 43.1 x 127.3. DESCRIPTION: Distal view, mid-focus. Diameter 56 $\mu$ , including wings 66.5 $\mu$ . BOTANICAL AFFINITY: *Pinus*(?). SIMILAR FORMS: *Pinus silvestris* Typ. Reissinger 1950, Pl. 17, fig. 1, Jurassic (Lias), Germany. REMARKS: Frequency high.

## PUNCTABIVESICULITES RADIATUS new species

Pl. II, fig. 46. Type for species. Slide 12H-3. Location: 32.3 x 123.3 (Reference: 58.1 x 128.5). DESCRIPTION: Distal view, mid-focus. Vesiculate, wings broader than and attached full length of body, internally reticulate, reticulum fine-meshed and appearing to radiate from grain center; bilaterally symmetrical; body ellipsoidal, width ca. 36 $\mu$ , including wings ca. 61 $\mu$ . Exine thin, thickness not determinable, marginal crest present at proximal roots of wings, body punctate. BOTANICAL AFFINITY: *Podocarpoideae*(?). REMARKS: Frequency high.

## PUNCTABIVESICULITES CRASSUS new species

Pl. II, fig. 47. Type for species. Slide 13M-1. Location: 26.1 x 127.7 (Reference: 57.5 x 128.4). DESCRIPTION: Distal view, high focus. Vesiculate, wings basally broad, coarse-meshed internal reticulum well developed; bilaterally symmetrical; lateral diameter ca. 47 $\mu$ , including wings ca. 115 $\mu$ . Exine punctate, marginal crest present. BOTANICAL AFFINITY: cf. *Pinus*. SIMILAR FORMS: *Pityospor. microalatus* R. Pot. in Thomson and Pflug 1953, Pl. 5, fig. 1, Tertiary, Germany. REMARKS: Frequency high.

## PUNCTABIVESICULITES PARVUS new species

Pl. II, fig. 48. Type for species. Slide 13M-1. Location: 31.5 x 121.3 (Reference 57.5 x 128.4). DESCRIPTION: Lateral view, mid-focus. Vesiculate, wings appear rudimentary in lateral view; bilaterally symmetrical; maximum diameter ca. 79 $\mu$ . Exine ca. 3 $\mu$  thick, punctate. BOTANICAL AFFINITY: *Picea*(?). SIMILAR FORMS: (?) *Picea* A. Dietr. in Rogalska, 1954, Pl. 9, fig. 1, Jurassic (Lias), Poland. REMARKS: Frequency high.

## PUNCTABIVESICULITES INCHOATUS new species

Pl. II, fig. 49. Type for species. Slide 6H-3. Location: 33.7 x 133.2 (Reference: 50.3 x 128.0). DESCRIPTION: Oblique distal view, mid-focus. Vesiculate,

wings rudimentary, represented by two lateral out-pocketings; bilaterally symmetrical; oval; maximum diameter ca.  $27\mu$ , including wings ca.  $35\mu$ . Exine ca.  $1.5\mu$  thick, punctate. BOTANICAL AFFINITY: Coniferae, *Phyllocladus*(?), *Dacrydium*(?). SIMILAR FORMS: *Disaccites* (*Phyllocladidites*) *Mawsoni* Cookson 1947, Pl. 14, fig. 27, Tertiary, Kerguelen Archipelago. REMARKS: Frequency low.

#### PUNCTABIVESICULITES TENUIS new species

Pl. II, fig. 50. Type for species. Slide 4L-4. Location:  $29.5 \times 121.4$  (Reference:  $57.4 \times 126.6$ ). DESCRIPTION: Proximal view, mid-focus. Vesiculate, wings represented by two broad but inconspicuous projections parallel to but not bordering the germinal furrow; bilaterally symmetrical; spherical; diameter ca.  $55\mu$ . Exine thickness variable, ca.  $1-3\mu$ ; punctate. BOTANICAL AFFINITY: Coniferae. REMARKS: Frequency low.

#### RETIBIVESICULITES new genus

DIAGNOSIS: Two-winged pollen with sculptural elements forming a reticulate design on the cap.

#### RETIBIVESICULITES PARVUS new species

Pl. II, figs. 51 and 52. Type for species and genus fig. 51. Fig. 51, Slide 29H-3. Location:  $21.2 \times 131.5$  (Reference:  $53.8 \times 127.6$ ). DESCRIPTION: Lateral view mid-focus. Vesiculate, wings broadly attached to body but of minor lateral extent, lumina of internal reticulum radially elongate; body width  $64\mu$ , including wings  $72\mu$ . Exine ca.  $2\mu$  thick; finely but distinctly reticulate. Fig. 52, Slide 13M-3. Location:  $32.9 \times 122.9$  (Reference:  $60.0 \times 126.6$ ). Proximal view, low mid-focus. Body ovate; lateral diameter ca.  $64\mu$ , including wings ca.  $80.5\mu$ . BOTANICAL AFFINITY: Coniferae. SIMILAR FORMS: (?). *Picea* A. Dietr. in Rogalska 1954, Pl. 9, fig. 1, Jurassic (Lias), Poland. *Pinus haploxylon*-Form Rudolph in Kremp 1949, Pl. 4, fig. 21, Miocene, Germany. REMARKS: Frequency high.

#### RETIBIVESICULITES FATULUS new species

Pl. II, fig. 53. Type for species. Slide 28L-3. Location:  $25.4 \times 125.8$  (Reference:  $56.4 \times 127.6$ ). DESCRIPTION: Proximal view, mid-focus. Vesiculate, wings conspicuously overdeveloped, flaccid, with fine meshed, uniform, internal reticulations; equatorial contour circular; body diameter, including marginal crest, ca.  $65\mu$ , including wings ca.  $128\mu$ . Exine thickness not determinable, texture granular with definite reticulate arrangement apparent; marginal crest developed completely around equator. BOTANICAL AFFINITY: Podocarpoideae(?). SIMILAR FORMS: cf. *Podocarpus* Thiergart 1949, Pl. 5, fig. 40, Upper Cretaceous, Paleocene, Germany. *Podocarpidites biformis* Rouse in Radforth and Rouse 1956, Pl. 1, fig. 5, Lower Cretaceous, Canada. REMARKS: Similar forms common in Liassic sediments of Europe. Frequency high.



**RETIBIVESICULITES OPPOSITUS** new species

Pl. II, fig. 54. Type for species. Slide 24L-3. Location: 25.4 x 136.9 (Reference: 57.7 x 127.6). DESCRIPTION: Proximal view (appears distal in illustration), mid-focus. Vesiculate, wings small in comparison to body, coarse-meshed internal reticulum present; body elliptical, maximum diameter ca. 64 $\mu$ , including wings ca. 121.5 $\mu$ . Exine ca. 2 $\mu$  thick, the reticulation of the wings grade into a finely reticulo-granulate exine sculpturing. BOTANICAL AFFINITY: Pinaceae. REMARKS: Frequency low.

**RETIBIVESICULITES PLANUS** new species

Pl. II, fig. 55. Type for species. Slide 28H-3. Location: 13.2 x 119.7 (Reference: 57.8 x 127.8). DESCRIPTION: Distal view, mid-focus. Vesiculate, wings large and broadly attached to body, fine-meshed internal reticulum; body outline circular; diameter ca. 75 $\mu$ , including wings 166.5 $\mu$ . Exine thickness not determined, finely reticulo-granulate. BOTANICAL AFFINITY: Abietoideae(?). SIMILAR FORMS: *Leptostrobus longus* Harris in Rogalska 1954, Pl. 7, fig. 7, Jurassic (Lias), Poland. REMARKS: *Leptostrobus longus* is the name created by Harris (1935) for detached male cones of uncertain affinity from the Jurassic of Greenland. Two types of pollen were isolated by Harris from this material, but neither was described. One of the forms (Pl. 7, fig. 10) does appear to be illustratively comparable to the present specimen, but Harris indicated doubt that either of the pollen types isolated belonged to *Leptostrobus*. Frequency high.

**RETIBIVESICULITES CONCORS** new species

Pl. II, fig. 56. Type for species. Slide 13M-1. Location: 22.7 x 130.2 (Reference: 57.5 x 128.4). DESCRIPTION: Lateral view, mid-focus. Vesiculate, proximal contour of wings smoothly confluent with equatorial curve, internal reticulum well developed; bilaterally symmetrical; diameter ca. 88 $\mu$ , including wings ca. 109 $\mu$ . Exine ca. 3 $\mu$  thick; sculpture reticuloid. BOTANICAL AFFINITY: Abietoideae, cf. *Picea*. REMARKS: Frequency high.

**RUGUBIVESICULITES** new genus

DIAGNOSIS: Two-winged pollen with rugulate design on cap.

**RUGUBIVESICULITES CONVOLUTUS** new species

Pl. II, fig. 57. Type for genus and species. Slide 24L-3. Location: 41.3 x 137.4 (Reference: 57.7 x 127.6). DESCRIPTION: Proximal view, high focus. Vesiculate, wings flaccid, broadly attached to body, internally granulate; bilaterally symmetrical; body spherical; maximum diameter, excluding frill, 48.5 $\mu$ , including wings ca. 94 $\mu$ . Exine apparently ca. 1–1.5 $\mu$  thick and psilate between ridges; wings merge proximally with a conspicuous marginal saccate frill and distinctive, convoluted or rugulate, cavate ridges which extend more or less uniformly over the proximal surface of the grain. BOTANICAL AFFINITY: Podocarpaceae, cf. *Dacrydium* spp. REMARKS: *Dacrydium* pollen

(Cranwell, 1940; Cookson and Pike, 1953) may have a rugulate proximal surface and a saccate frill around the germinal furrow. Although these features are more extensively developed in *Rugubivesiculites* than in *Dacrydium*, their presence in *Dacrydium* would suggest that *Rugubivesiculites* forms are more closely allied to the Podocarpaceae than to the Pinaceae. Frequency very high.

*RUGUBIVESICULITES MULTIPLEX* new species

Pl. II, fig. 58. Type for species. Slide 12L-1. Location: 41.1 x 125.3 (Reference: 57.5 x 129.4). DESCRIPTION: Proximal view, high focus. Vesiculate, wings broad but flaccid, internal thickenings granulate; diameter, exclusive of sculpture, ca. 61 $\mu$ , including wings ca. 116 $\mu$ . Exine psilate in inter-ridge area, ca. 1 $\mu$  thick; proximal surface completely covered by tortuously rugulate, cavate ridges. BOTANICAL AFFINITY: Podocarpaceae; cf. *Dacrydium* spp. REMARKS: Frequency high.

*RUGUBIVESICULITES RUGOSUS* new species

Pl. II, figs. 59 and 60. Type for species fig. 59. Fig. 59, Slide 12M-1. Location: 41.2 x 124.8 (Reference: 57.5 x 128.4). DESCRIPTION: Proximal view, mid-focus. Vesiculate, wings broadly attached to body and internally granulate; diameter ca. 49 $\mu$ , including wings ca. 76 $\mu$ . Exine thickness not determinable; proximal surface densely covered by somewhat angular rugulate, cavate ridges. Fig. 60, Slide 12L-3. Location: 39.0 x 138.5 (Reference: 57.8 x 128.9). Side view at high mid-focus of similar specimen. BOTANICAL AFFINITY: Podocarpaceae; cf. *Dacrydium* spp. REMARKS: Frequency high.

*RUGUBIVESICULITES FLUENS* new species

Pl. II, figs. 61 and 62. Type for species fig. 61. Fig. 61, Slide 24L-2. Location: 33.7 x 130.3 (Reference: 56.2 x 128.2). DESCRIPTION: Distal view, low mid-focus. Vesiculate, wings broadly attached to body, internal structuring of short rods arranged in a broken, reticuloid pattern; bilaterally symmetrical; body elliptical; maximum diameter ca. 47 $\mu$ , including wings ca. 70 $\mu$ . Exine about 1 $\mu$  thick; rugulate, cavate ridges flow smoothly over the proximal surface and a saccate equatorial frill appears well developed around the equator of the grain. Fig. 62, Slide 13M-1. Location: 38.9 x 122.6 (Reference: 57.5 x 128.4). Oblique lateral view, high mid-focus. The continuity of the wings with the marginal frill and ridges is not as apparent in the photograph as in the actual specimen. BOTANICAL AFFINITY: Podocarpaceae, cf. *Dacrydium* spp. REMARKS: Frequency high.

*RUGUBIVESICULITES FLORIDUS* new species

Pl. II, fig. 63. Type for species. Slide 12L-3. Location: 45.0 x 128.2 (Reference: 57.8 x 128.9). DESCRIPTION: Proximal view, high mid-focus. Vesiculate, wings flaccid, internally granulate, broadly attached to body; bilaterally symmetrical; body diameter, excluding cavate ca. 30 $\mu$ , including wings ca.

58 $\mu$ . Exine thickness indeterminable, proximal surface covered by appressed ruguloid, saccate projections. BOTANICAL AFFINITY: Podocarpaceae(?). REMARKS: Frequency low.

*RUGUBIVESICULITES REDUCTUS* new species

Pl. II, figs. 64 and 65. Type for species fig. 64. Fig. 64, Slide 12L-1. Location: 18.2 x 125.7 (Reference: 57.5 x 129.4). DESCRIPTION: Oblique lateral view, mid-focus. Vesiculate, wings flaccid, internally reticulate, reticulum elements well developed; bilaterally symmetrical; body diameter ca. 58 $\mu$ , including wings ca. 87 $\mu$ . Exine ca. 2 $\mu$  thick; saccate marginal frill best developed at proximal roots of wings, proximal surface granular, rugulate ridges sparse and weakly developed. Fig. 65. Slide 12L-3. Location: 42.5 x 122.3 (Reference: 57.8 x 128.9). DESCRIPTION: Proximal view, high mid-focus. Wings slightly constricted basally, internal reticulum well developed; diameter 33 $\mu$ , including wings 67 $\mu$ . Exine thickness indeterminable; saccate marginal frill well developed, rugulate ridges weakly developed. BOTANICAL AFFINITY: Podocarpaceae. REMARKS: Frequency high.

Form-genus *GRANATRIVESICULITES* new genus

DIAGNOSIS: Three-winged pollen with granular texture on cap but sculptural elements, though  $\geq 1\mu$ , not accurately definable.

*Plate III between pp. 50 and 51*

*GRANATRIVESICULITES DUBIUS* new species

Pl. III, fig. 66. Type for genus and species. Slide 13M-2. Location: 40.7 x 131.5 (Reference: 62.3 x 127.1). DESCRIPTION: Distal view, mid-focus. Vesiculate, three-winged, two wings symmetrically opposed, well developed, internally reticulate; third wing smaller, obviously aberrant, developed on cap margin between normal wings; body circular; maximum diameter ca. 41 $\mu$ , including wings 76 $\mu$ . Exine thickness ca. 2 $\mu$ ; granular texture; marginal crest present at proximal roots of normal wings. BOTANICAL AFFINITY: cf. *Pinus*. REMARKS: Lakhanpal and Nair (1956) and Wilson and Webster (1944) have indicated that extra wings in normally two-winged forms are not unusual.

Form-genus *GRANAMULTIVESICULITES* new genus

DIAGNOSIS: Winged pollen with more than four wings. Granular texture on cap from sculptural elements  $\geq 1\mu$  but these elements without accurately definable morphology.

*GRANAMULTIVESICULITES INCHOATUS* new species

Pl. III, fig. 67. Type for genus and species. Slide 8H-2. Location: 22.6 x 129.4 (Reference: 57.0 x 127.9). DESCRIPTION: Oblique side view, high-focus. Vesiculate, wings rudimentary, represented by 6 saccate projections ca. 6 $\mu$  high; bilaterally symmetrical, plano-convex; maximum diameter ca. 47 $\mu$ . Exine

ca.  $2.5\mu$  thick; coarsely granulate with occasional echinoid elements protruding beyond surface; design suggestively areolate. BOTANICAL AFFINITY: Coniferae. REMARKS: These forms may have a natural affinity with the nonvesiculate forms illustrated in figs. 89 and 90 (*Verrumonocolpites conspicuus*). Frequency high.

Form-genus PUNCTAMULTIVESICULITES new genus

DIAGNOSIS: Winged pollen with more than four wings; cap of grain punctate.

PUNCTAMULTIVESICULITES INCHOATUS new species

Pl. III, fig. 68. Type for genus and species. Slide 41-2. Location:  $40.3 \times 127.6$  (Reference:  $60.5 \times 129.8$ ). DESCRIPTION: Distal view, high mid-focus. Multivesiculate, ca. ten "wings"—all reduced to saccate pouches—are present on the distal surface either on margin of germinal furrow, or halfway between furrow margin and equator. Two small vesicles are developed almost on the equator. All "wings" have verrucoid internal thickenings. Body elliptical, major axis parallels germinal furrow; maximum diameters  $62\mu \times 68\mu$ . Exine ca.  $2\mu$  thick, uniformly punctate. BOTANICAL AFFINITY: Coniferae. REMARKS: Frequency high.

PUNCTAMULTIVESICULITES FIMBRIATUS new species

Pl. III, fig. 69. Type for species. Slide 29H-4. Location:  $38.2 \times 123.7$  (Reference:  $53.0 \times 128.0$ ). DESCRIPTION: Proximal but appears distal, mid-focus. Multivesiculate; two elongate pouches are symmetrically located on either side of a poorly defined germinal furrow, three saccate pouches are located subequatorially at one end of the germinal furrow; bilaterally symmetrical; body elliptical, ca.  $20 \times 36\mu$  in diameter. Exine ca.  $3\mu$  thick; punctate. BOTANICAL AFFINITY: Phyllocladoideae(?). REMARKS: Frequency low.

#### Class (V) INAPERTURATAE Iversen and Troels-Smith 1950

Form-genus BACUINAPERTURITES new genus

DIAGNOSIS: Baculate, inaperturate sporomorphs.

BACUINAPERTURITES SETOSUS new species

Pl. III, fig. 70. Type for genus and species. Slide 4L-1. Location:  $25.8 \times 132.4$  (Reference:  $59.0 \times 128.4$ ). DESCRIPTION: Mid-focus. Inaperturate; radially symmetrical, oval (probably a collapsed sphere), axial lengths ca.  $24 \times 32\mu$ . Exine less than  $1\mu$  thick; sparse, baculate sculpturing, individual baculae up to  $4.5\mu$  in length. BOTANICAL AFFINITY: Unknown; definitely *not* a hys-trichosphaerid. REMARKS: Except for lack of trilete mark this specimen could be compared to Penn. spores described within the genus *Raistrickia* (Schopf *et al.*, 1944). Frequency low.

Form-genus FOVEOINAPERTURITES new genus

DIAGNOSIS: Foveolate, inaperturate sporomorphs.

## FOVEOINAPERTURITES FORAMENIFERUS new species

Pl. III, fig. 71. Type for genus and species. Slide 8H-1. Location: 15.6 x 127.8 (Reference: 59.5 x 128.2). DESCRIPTION: High mid-focus. Inaperturate; spherical, may appear to have a dehiscence suture and ellipsoidal form; maximum diameters 35 x 46 $\mu$ . Exine ca. 1.5 $\mu$  thick, foveolate, pits round to oval, ca. 4 $\mu$  in diameter. BOTANICAL AFFINITY: Filicineae(?). SIMILAR FORMS: *Punctati-sporites quaesitus* Kosanke 1950, Pl. 2, fig. 2, Pennsylvanian, United States. REMARKS: There is no discernible difference between this specimen and the one described by Kosanke. He placed his form in *Punctati-sporites*, though he was unable to discern a trilete marking. Frequency high.

## FOVEOINAPERTURITES PAUCIPUNCTATUS new species

Pl. III, fig. 72. Type for species. Slide 44-1. Location: 52.4 x 124.6 (Reference: 64.5 x 128.2). DESCRIPTION: Mid-focus. Inaperturate; radially symmetrical; oval to subspherical; maximum diameters ca. 67 x 79 $\mu$ . Exine ca. 4 $\mu$  thick, clearly resolvable into a structured ectexine layer ca. 3 $\mu$  thick and an underlying thinner layer of endexine; infrapunctate, sparsely foveolate, ca. 50 pits on a hemisphere. BOTANICAL AFFINITY: Gymnospermae(?). Definitely *not* tasmanaceous. REMARKS: Frequency low.

## FOVEOINAPERTURITES SCAPHOFORMIS new species

Pl. III, fig. 73. Type for species. Slide 12H-2. Location: 35.0 x 136.7 (Reference: 57.9 x 127.7). DESCRIPTION: Mid-focus. Inaperturate; bilaterally symmetrical, ellipsoidal, ca. 25 x 38 $\mu$ . Exine ca. 1 $\mu$  thick; about 25 more or less evenly distributed pits occur on an observable hemisphere. BOTANICAL AFFINITY: Gymnospermae(?). REMARKS: These forms are probably ovate and radially symmetrical; however, they are always seen with an invagination. For purpose of identification in sediments the description of the specimens as bilaterally symmetrical is more applicable than the presumption of radial symmetry. Frequency high.

## Form-genus GEMMAINAPERTURITES new genus

DIAGNOSIS: Gemmate, inaperturate sporomorphs.

## GEMMAINAPERTURITES GEMMATUS new species

Pl. III, fig. 74. Type for genus and species. Slide 6H-3. Location: 24.3 x 134.5 (Reference: 50.3 x 128.0). DESCRIPTION: Mid-focus. Inaperturate; radially symmetrical, oval, maximum diameter 29 x 23 $\mu$ . Exine less than 1 $\mu$  thick excluding sculpturing; sculpture of uniformly arranged evenly spaced gemmate elements slightly under 1 $\mu$  in height. BOTANICAL AFFINITY: Gymnospermae(?). REMARKS: Frequency low.

## GEMMAINAPERTURITES RUGOSUS new species

Pl. III, fig. 75. Type for species. Slide 12H-3. Location: 45.5 x 127.4 (Reference: 58.1 x 128.5). DESCRIPTION: Mid-focus. Inaperturate; spherical; diame-

ter ca. 33 $\mu$ . Exine under 1 $\mu$  thick, flecked with gemmate granules. BOTANICAL AFFINITY: Thujoideae, cf. *Libocedrus*, *Thuja*, *Thujopsis*, etc. REMARKS: Compares quite well with *Thuja*. Frequency high.

Form-genus PSILAINAPERTURITES new genus

DIAGNOSIS: Psilate, inaperturate sporomorph.

PSILAINAPERTURITES PSILATUS new species

Pl. III, fig. 76. Type for genus and species. Slide 12H-1. Location: 49.9 x 133.3 (Reference: 56.3 x 128.4). DESCRIPTION: Mid-focus. Inaperturate; radially symmetrical, appearing oval but may be spherical, maximum diameter 52 $\mu$ . Exine ca. 1 $\mu$  thick, psilate. BOTANICAL AFFINITY: Pinaceae(?), cf. *Pseudotsuga*; Equisetaceae(?). SIMILAR FORMS: *Laricoipollenites magnus* R. Pot. in R. Potonié 1951, Pl. 20, fig. 26, Eocene-Miocene, Germany. *Inaperturopoll. magnus* R. Pot. in Thomson and Pflug 1953, Pl. 4, fig. 86-88, Tertiary, Germany. REMARKS: Frequency medium.

Form-genus PUNCTAINAPERTURITES new genus

DIAGNOSIS: Punctate, inaperturate sporomorphs.

PUNCTAINAPERTURITES SCABER new species

Pl. III, fig. 77. Type for genus and species. Slide 1H-3. Location: 46.8 x 137.6 (Reference: 54.1 x 126.9). DESCRIPTION: Mid-focus. Inaperturate; spherical; maximum diameter ca. 55 $\mu$ . Exine ca. 1.5 $\mu$  thick, punctate. BOTANICAL AFFINITY: Gymnospermae(?). SIMILAR FORMS: *Inaperturo-pollenites globulus* Weyland and Greifeld 1953, p. 44, Pl. 13, figs. 83-84, Upper Cretaceous (Senonian), Germany. REMARKS: Frequency low.

Form-genus RUGUINAPERTURITES new genus

DIAGNOSIS: Rugulate, inaperturate sporomorphs.

RUGUINAPERTURITES SPHAEROIDES new species

Pl. III, fig. 78. Type for genus and species. Slide 13M-1. Location: 48.6 x 124.0 (Reference: 57.5 x 128.4). DESCRIPTION: Mid-focus. Inaperturate; spherical; maximum diameter ca. 70 $\mu$ . Exine thin, ca. 1 $\mu$ , with faint but distinct rugulate design. BOTANICAL AFFINITY: Gymnospermae(?). SIMILAR FORMS: *Inaperturo-pollenites globulus* Weyland and Greifeld 1953, p. 44; Pl. 13, figs. 83-84, Upper Cretaceous (Senonian), Germany. REMARKS: Frequency medium.

Form-genus SPINAINAPERTURITES new genus

DIAGNOSIS: Spinulate, inaperturate sporomorphs.

SPINAINAPERTURITES RECURVATUS new species

Pl. III, fig. 79. Type for genus and species. Slide 1L-1. Location: 18.5 x 132.3 (Reference: 57.6 x 127.1). DESCRIPTION: Lateral view, high mid-focus. Inap-

erturate; radially symmetrical, subspherical, ca.  $21 \times 26\mu$  excluding sculpture. Exine ca.  $1\mu$  thick; sculpturing of moderately abundant recurved spines ca.  $3\mu$  long. BOTANICAL AFFINITY: Unknown; definitely *not* a hystrichosphaerid. REMARKS: Frequency low.

Form-genus STRIAINAPERTURITES new genus

DIAGNOSIS: Striate, inaperturate sporomorphs.

STRIAINAPERTURITES OVATUS new species

Pl. III, fig. 80. Type for genus and species. Slide 29H-4. Location:  $33.9 \times 123.7$  (Reference:  $53.0 \times 128.0$ ). DESCRIPTION: Lateral view, mid-focus. Inaperturate; radially symmetrical about major axis, oval,  $23 \times 47\mu$ . Exine thickness variable, up to ca.  $3\mu$ ; sculpturing of 8-9 parallel, longitudinal, unstructured ridges up to  $6\mu$  wide. BOTANICAL AFFINITY: Gnetales cf. *Ephedra*. SIMILAR FORMS: Cf. *Ephedra*, Thiergart 1949, Pl. 5, fig. 39, Upper Cretaceous (Grenzcomplex), Germany. *Ephedra strobilacea* type, Kuyl *et al.* 1955, Pl. 1, fig. 5, Upper Cretaceous, Venezuela. *Ephedra* type, Cookson 1956, p. 47, fig. 4, Paleocene-Eocene, New Zealand. REMARKS: Lack of structure in ridges is characteristic of gnetalean exine. Kuyl *et al.* (1955) have observed that gnetalean type pollen is characteristic of younger Mesozoic sediments of tropical areas. It may be that occasional gnetalean grains were transported from the lower latitudes to the higher latitudes or some species of this group may have been a minor element in the Cretaceous flora of Minnesota. Frequency low, noted twice.

Form-genus VERRUINAPERTURITES new genus

DIAGNOSIS: Verrucate, inaperturate sporomorphs.

VERRUINAPERTURITES DEPRESSUS new species

Pl. III, fig. 81. Type for genus and species. Slide 4L-2. Location:  $22.4 \times 127.8$  (Reference:  $57.2 \times 129.1$ ). DESCRIPTION: Mid-focus. Inaperturate, always invaginated; asymmetrically ovate; maximum diameter ca.  $48\mu$ . Exine ca.  $1\mu$  thick, intectate, punctate from small verrucae. BOTANICAL AFFINITY: Dicotyledoneae(?). REMARKS: Grains may be compared to invaginated forms of *Populus* but lack the irregular verrucate sculpturing of *Populus* pollen. Frequency high.

#### Class (VI) MONOPORATAE Iversen and Troels-Smith 1950

Form-genus BACUMONOPORITES new genus

DIAGNOSIS: Baculate, monoporate sporomorphs.

BACUMONOPORITES BACULATUS new species

Pl. III, fig. 82. Type for genus and species. Slide 12H-3. Location:  $23.6 \times 133.7$  (Reference:  $58.1 \times 128.5$ ). DESCRIPTION: Oblique side view, mid-focus. Monoporate, apertural area represented by a circular zone ca.  $20\mu$  in diam-

eter ornamented with scattered baculate projections; radially symmetrical; oval; ca. 30 x 35 $\mu$ . Exine ca. 3 $\mu$  thick, coarsely granulate, sculptural elements basically baculate. BOTANICAL AFFINITY: Gymnospermae(?). Possibly nymphaeaceous(?). REMARKS: Frequency low.

Form-genus **RUGUMONOPORITES** new genus

DIAGNOSIS: Rugulate, monoporate sporomorphs.

**RUGUMONOPORITES CONVOLUTUS** new species

Pl. III, fig. 83. Type for genus and species. Slide 41L-3. Location: 24.3 x 127.9 (Reference: 51.7 x 126.0). DESCRIPTION: Distal view, mid-focus. Monoporate, pore represented by a vague, circular area ca. 20 $\mu$  in diameter that is texturally different from rest of surface; spherical; maximum diameter ca. 59 $\mu$ . Exine thickness indeterminate, sculpturing of convoluted cavate ridges that give a rugulate design to the surface and coarsely structured verrucoid elements that impart a "cauliflower" aspect not apparent in illustration. BOTANICAL AFFINITY: Coniferae(?). SIMILAR FORMS: Vermutlich cf. *Tsuga*. Reissinger 1950, Pl. 17, fig. 34, Jurassic (Lias), Germany. REMARKS: Frequency low.

Form-genus **VERRUMONOPORITES** new genus

DIAGNOSIS: Verrucate, monoporate sporomorphs.

**VERRUMONOPORITES VERRUCATUS** new species

Pl. III, fig. 84. Type for genus and species. Slide 6H-3. Location: 40.3 x 129.3 (Reference: 50.3 x 128.0). DESCRIPTION: Distal view, mid-focus. Monoporate, pore represented by an unsculptured circular area ca. 15 $\mu$  in diameter; radially symmetrical; spherical; ca. 45 $\mu$  in diameter. Exine ca. 4 $\mu$  thick; sculpturing of concentrically arranged verrucae, verrucae occasionally fused and exhibiting some structuring. BOTANICAL AFFINITY: Coniferae(?). SIMILAR FORMS: *Tsuga* or *Sciadopitys*-Typus Reissinger 1950, p. 113, Pl. 17, fig. 34, Jurassic (Lias), Germany. REMARKS: The general sculpturing of the grain does not appear comparable to *Sciadopitys* pollen or to *Tsuga* pollen. Frequency medium.

#### Class (VII) MONOCOLPATAE Iversen and Troels-Smith 1950

Form-genus **GRANAMONOCOLPITES** new genus

DIAGNOSIS: Granulate, monocolpate pollen; although the sculptural elements are  $\geq 1\mu$  their morphology is not definable.

**GRANAMONOCOLPITES ASYMMETRICUS** new species

Pl. III, fig. 85. Type for genus and species. Slide 13M-2. Location: 22.7 x 122.5 (Reference: 62.3 x 127.1). DESCRIPTION: Distal view, high mid-focus. Monocolpate, furrow bordered by irregular ridges when grain not expanded; asymmetrically ovate, 52 x 65 $\mu$ . Exine ca. 2.5 $\mu$  thick; coarsely



granulate, intectate. BOTANICAL AFFINITY: Magnoliaceae, cf. *Magnolia*. SIMILAR FORMS: *Magnolia virginiana* L. REMARKS: The ectexine is thicker in *Granamonomolpites asymmetricus* than in *Magnolia* pollen; however, the slight differences are obscured by the over-all comparability of the two. Frequency low.

Form-genus PUNCTAMONOLPITES new genus

DIAGNOSIS: Punctate, monocolpate pollen.

PUNCTAMONOLPITES SCAPHOFORMIS new species

Pl. III, fig. 86. Type for genus and species. Slide 28H-3. Location: 38.6 x 122.2 (Reference: 57.8 x 127.8). DESCRIPTION: Mid-focus. Monocolpate, furrow margins always invaginated; bilaterally symmetrical; boat-shaped, ca. 25 x 55 $\mu$ . Exine ca. 1 $\mu$  thick; punctate. BOTANICAL AFFINITY: Gymnospermae(?). SIMILAR FORMS: Vermutlich Cycadeen-oder Ginkgoaceenpollen, Reissinger 1950, Pl. 13, fig. 21, Jurassic (Lias), Germany. Cycadineae, Rogalska 1954, Pl. 6, figs. 1-5, Jurassic (Lias), Poland. REMARKS: Luber (1939) assigned to his genus *Libumella* some forms from the Permian of Russia which are of doubtful similarity. Frequency medium.

Form-genus RETIMONOLPITES new genus

DIAGNOSIS: Reticulate, monocolpate pollen.

RETIMONOLPITES DIVIDUUS new species

Pl. III, fig. 87. Type for genus and species. Slide 12H-1. Location: 38.4 x 128.9 (Reference: 56.3 x 128.4). DESCRIPTION: Lateral view, mid-focus. Monocolpate, aperture almost encircles grain dividing it into two hemispheres; one polar and one equatorial plane of symmetry; ellipsoidal to spherical; maximum diameters ca. 27.5 x 34 $\mu$ . Exine ca. 1.5 $\mu$  thick; finely reticulate, muri of distinct columellae fused apically, reticulum occasionally separated from endexine. BOTANICAL AFFINITY: Monocotyledoneae(?). SIMILAR FORMS: *Liliacidites* Couper 1953b, p. 56, Upper Cretaceous-Lower Tertiary forms, New Zealand. REMARKS: Frequency high.

RETIMONOLPITES FRAGILIS new species

Pl. III, fig. 88. Type for species. Slide 29H-4. Location: 34.4 x 137.6 (Reference: 53.0 x 128.0). DESCRIPTION: Distal view, mid-focus. Monocolpate; bilaterally symmetrical, ellipsoidal, 20 x 27 $\mu$ . Exine ca. 1 $\mu$  thick; sculpturing reticulate, weakly developed, exine of invaginated surface longitudinally wrinkled. BOTANICAL AFFINITY: Cycadaceae(?). SIMILAR FORMS: "Cycad or Ginkgo" Reissinger 1950, Pl. 13, fig. 23. Jurassic (Lias), Germany. REMARKS: If the invaginated surface is a germinal furrow, this form would compare with Wodehouse's (1935) description of the *Dioon-Microcycas* section of the Cycadaceae. Frequency low, noted once.

Form-genus *VERRUMONOCOLPITES* new genus

DIAGNOSIS: Verrucate, monocolpate pollen.

*VERRUMONOCOLPITES* *CONSPICUUS* new species

Pl. III, figs. 89 and 90. Type for genus and species fig. 89. Fig. 89, Slide 8H-2. Location: 29.2 x 128.8 (Reference: 57.0 x 127.9). DESCRIPTION: Distal view, mid-focus. Monocolpate, germinal furrow with thickened lateral margins; bilaterally symmetrical; maximum diameter ca. 45.5 $\mu$ . Exine ca. 3 $\mu$  thick; sculpturing of structured verrucate and gemmoid elements which occasionally fuse; sculptural elements sometimes suggestively arranged in an areolate design. Fig. 90, Slide 8H-3. Location: 38.1 x 122.1 (Reference: 54.7 x 128.7). Distal view, mid-focus. Furrow closed. BOTANICAL AFFINITY: Gymnospermae(?). REMARKS: The thickened margins on many of the specimens have the appearance of rudimentary wings. Frequency high.

#### Class (X) TRICOLPATAE Iversen and Troels-Smith 1950

Form-genus *Bacutricolpites* V. d. Ham. 1956a

DIAGNOSIS: Baculate, tricolpate pollen. TYPE FOR GENUS: *Bacutricolpites magnus* V. d. Ham. 1956a, Pl. VIII, fig. 25.

*BACUTRICOLPITES* *CONSTRICUS* new species

Pl. III, figs. 91 and 92. Type for species fig. 91. Fig. 91, Slide 12L-3. Location: 44.5 x 125.1 (Reference: 57.8 x 128.19). DESCRIPTION: Equatorial view, mid-focus. Tricolpate, colpi elongate, constricted equatorially, furrow margins thickened; prolate; oval; 30.5 x 41 $\mu$ , with three polar and one equatorial planes of symmetry. Exine ca. 2 $\mu$  thick, intectate; sculpture of small, close-spaced baculae. Fig. 92, Slide 6H-3. Location: 20.0 x 127.4 (Reference: 50.3 x 128.0). Equatorial view, mid-focus; 24 x 41 $\mu$  in diameter, grain collapsed. BOTANICAL AFFINITY: Dicotyledoneae. REMARKS: Frequency high.

Form-genus *CLAVATRICOLPITES* new genus

DIAGNOSIS: Clavate, tricolpate pollen.

*CLAVATRICOLPITES* *PROLATUS* new species

Pl. III, fig. 93. Type for genus and species. Slide 8H-3. Location: 16.1 x 123.5 (Reference: 54.7 x 128.7). DESCRIPTION: Equatorial view, mid-focus. Tricolpate, colpi elongate, margins smooth; prolate; oval; 16 x 20 $\mu$  with three polar and one equatorial planes of symmetry. Exine less than 1.5 $\mu$  thick, intectate; sculpturing of small, closely-spaced clavae, clavae with slightly longer columns, or trunks, in the equatorial region than in the polar areas. BOTANICAL AFFINITY: Dicotyledoneae. REMARKS: Frequency low.

*CLAVATRICOLPITES* *FIRMUS* new species

Pl. III, fig. 94. Type for species. Slide 12H-3. Location: 42.1 x 135.3 (Reference: 58.1 x 128.5). DESCRIPTION: Equatorial view, mid-focus. Tricolpate,

colpi elongate, margins slightly thickened, smooth; prolate; oval;  $14 \times 17\mu$ ; three polar and one equatorial planes of symmetry. Exine ca.  $1.5\mu$  thick, intectate; sculpture of minute clavae. BOTANICAL AFFINITY: Dicotyledoneae. REMARKS: Frequency low.

Form-genus *FOVEOTRICOLPITES* new genus

DIAGNOSIS: Foveolate, tricolpate pollen.

*FOVEOTRICOLPITES SPHAEROIDES* new species

Pl. III, fig. 95. Type for genus and species. Slide 12H-1. Location:  $42.1 \times 133.1$  (Reference:  $56.3 \times 128.4$ ). DESCRIPTION: Equatorial view, mid-focus. Tricolpate, colpi elongate with conspicuously thickened aperture margins; sub-prolate,  $18 \times 21.5\mu$ , three polar and one equatorial planes of symmetry. Exine ca.  $1.5\mu$  thick, tectate; foveolate, foveolae small, closely spaced. BOTANICAL AFFINITY: Dicotyledoneae. REMARKS: Frequency low.

Form-genus *GEMMATRICOLPITES* new genus

DIAGNOSIS: Gemmate, tricolpate pollen.

*GEMMATRICOLPITES GEMMATUS* new species

Pl. III, figs. 96 and 97. Type for genus and species fig. 96. Fig. 96, Slide 41L-2. Location:  $23.9 \times 137.4$  (Reference:  $55.6 \times 128.7$ ). DESCRIPTION: Equatorial view, mid-focus. Tricolpate, colpi elongate, margins smooth; prolate (spherical when expanded);  $15 \times 18.5\mu$ ; three polar and one equatorial planes of symmetry. Exine ca.  $1.5\mu$  thick, intectate; sculpturing of sparse, uniformly distributed gemmate elements. Fig. 97, Slide 41L-1. Location:  $31.5 \times 124.4$  (Reference:  $55.6 \times 128.7$ ). Oblique polar view, mid-focus.  $18\mu$ . BOTANICAL AFFINITY: Dicotyledoneae. REMARKS: Frequency high.

Form-genus *PSILATRICOLPITES* V. d. Ham. 1956a

DIAGNOSIS: Psilate, tricolpate pollen. TYPE FOR GENUS: *Psilatricolpites incomptus* V. d. Ham. 1956a, Pl. VII, fig. 22.

*PSILATRICOLPITES PSILATUS* new species

Pl. III, figs. 98 and 99. Type for species fig. 98. Fig. 98, Slide 1L-2. Location:  $14.9 \times 120.5$  (Reference:  $58.5 \times 127.3$ ). DESCRIPTION: Equatorial view, mid-focus. Tricolpate, colpi elongate, furrow margins ragged; prolate; a truncated (depressed) oval;  $21 \times 29\mu$ , with three polar and one equatorial planes of symmetry. Exine ca.  $1.5\mu$  thick, intectate; psilate. Fig. 99, Slide 8H-1. Location:  $30.2 \times 121.5$  (Reference:  $59.5 \times 128.2$ ). Oblique polar view, mid-focus. Maximum diameter ca.  $22\mu$ . BOTANICAL AFFINITY: Fagaceae(?) cf. *Quercus ilex* L. SIMILAR FORMS: Quercoide Typen, Thiergart 1954, Pl. 4, figs. 47-53, Upper Cretaceous (Cenomanian), France. REMARKS: Frequency medium.

Form-genus *PUNCTATRICOLPITES* new genus

DIAGNOSIS: Punctate, tricolpate pollen.

*PUNCTATRICOLPITES BREVIS* new species

Pl. III, fig. 100. Type for genus and species. Slide 4L-3. Location: 47.3 x 130.6 (Reference: 57.2 x 127.5). DESCRIPTION: Polar view, mid-focus. Tricolpate, colpi short, smooth, angulaperturate; presumed spherical in equatorial view, subtriangular in polar view; maximum diameter ca. 29 $\mu$ . Exine ca. 1.5 $\mu$  thick, tectate; punctate. BOTANICAL AFFINITY: Fagaceae(?) Symplocaceae(?). SIMILAR FORMS: *Tricolpites subobblatus* Ross 1949, Pl. 2, fig. 31, Cretaceous (Senonian), Sweden. *Tripoporollenites robustus* Pflug in Thomson and Pflug 1953, Pl. 8, fig. 136, Tertiary, Germany. *Fagus parvifossilis* Traverse 1955, Pl. 10, fig. 37, Oligocene, Vermont. *Symplocos novae-angliae* Traverse 1955, Pl. 13, fig. 132, Oligocene, Vermont. *Quercus laurifolia* Michx. REMARKS: Except for aperture morphology, this grain appears almost identical to comparably oriented grains of *Quercus laurifolia*. Frequency low.

Form-genus *Retitricolpites* V. d. Ham. 1956a

DIAGNOSIS: Reticulate, tricolpate pollen. TYPE FOR GENUS: *Retitricolpites ornatus* V. d. Ham. 1956a, Pl. IX, fig. 26.

*RETITRICOLPITES VULGARIS* new species

Pl. III, figs. 101 and 102. Type for species fig. 101. Fig. 101, Slide 1H-2. Location: 14.4 x 128.3 (Reference: 55.0 x 127.7). DESCRIPTION: Equatorial view, mid-focus. Tricolpate, colpi elongate (appearing foreshortened in illustrated specimen); spherical; three polar and one equatorial planes of symmetry; 21 x 21.5 $\mu$ . Exine ca. 1.5 $\mu$  thick, intectate; finely reticulate. Fig. 102, Slide 1L-1. Location: 25.8 x 133.8 (Reference: 57.6 x 127.1). Polar view, mid-focus. 26 $\mu$  in diameter. BOTANICAL AFFINITY: Hamamelidaceae cf. *Hamamelis* spp. SIMILAR FORMS: *Corylopsis* sp. Simpson 1936, Pl. 3, figs. 9, 10, Tertiary, Scotland. *Hamamelis vernalis* Sarg. REMARKS: These pollen compare almost perfectly with *Hamamelis vernalis*. Frequency very high; most common dicotyledonous pollen in samples.

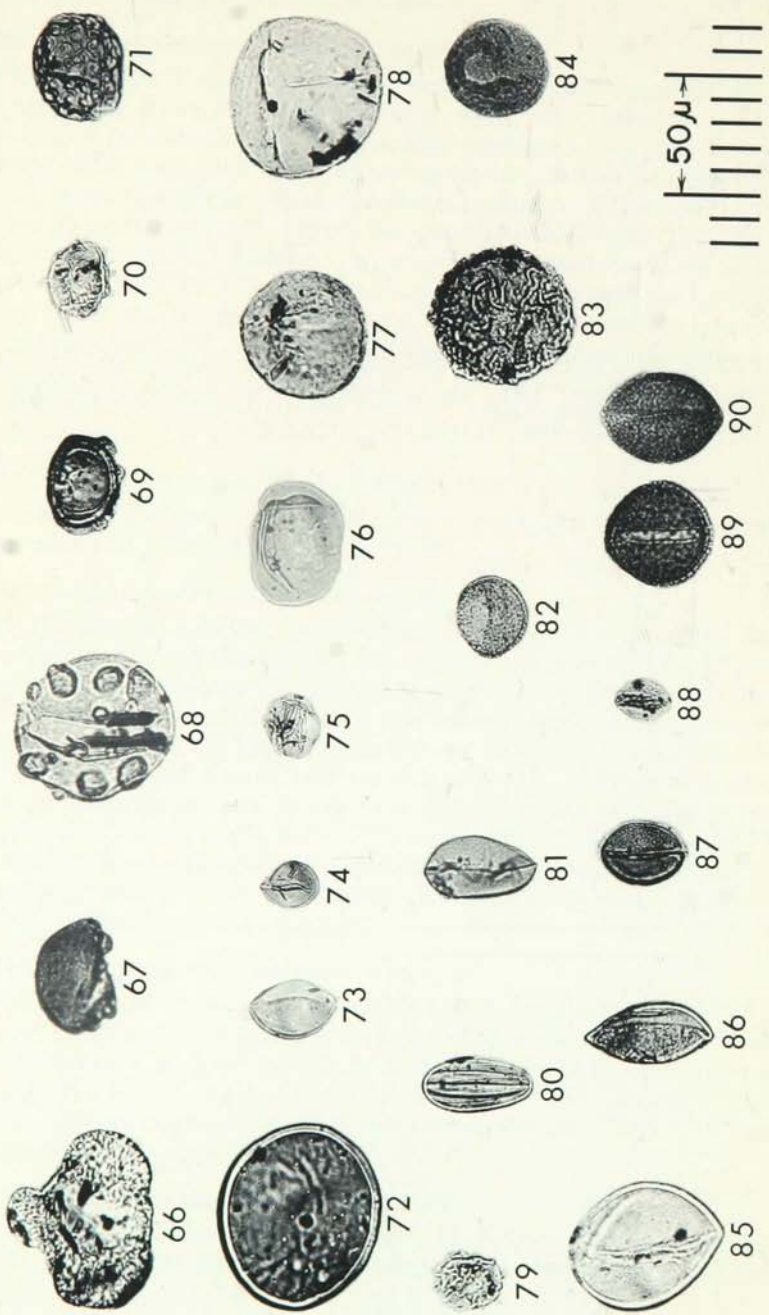
*RETITRICOLPITES SPHAEROIDES* new species

Pl. III, fig. 103. Type for species. Slide 12H-3. Location: 31.3 x 129.5 (Reference: 58.1 x 128.5). DESCRIPTION: Equatorial view, mid-focus. Tricolpate, colpi elongate, margins smooth; spheroidal; 17.5 x 18.5 $\mu$ ; three polar and one equatorial planes of symmetry. Exine ca. 1.5 $\mu$  thick, intectate; reticulate, muri with columellate structure. BOTANICAL AFFINITY: Dicotyledoneae. REMARKS: Frequency medium.

*RETITRICOLPITES OBLATOIDES* new species

Pl. III, fig. 104. Type for species. Slide 1L-1. Location: 22.4 x 136.4 (Reference: 57.6 x 127.1). DESCRIPTION: Oblique polar view, mid-focus. Tricolpate,

*PLATE III. VESICULATE POLLEN (continued), INAPERTURATE  
SPOROMORPHS, AND MONOPORATE, MONOCOLPATE, TRI-  
COLPATE, AND TRICOLPORATE POLLEN*



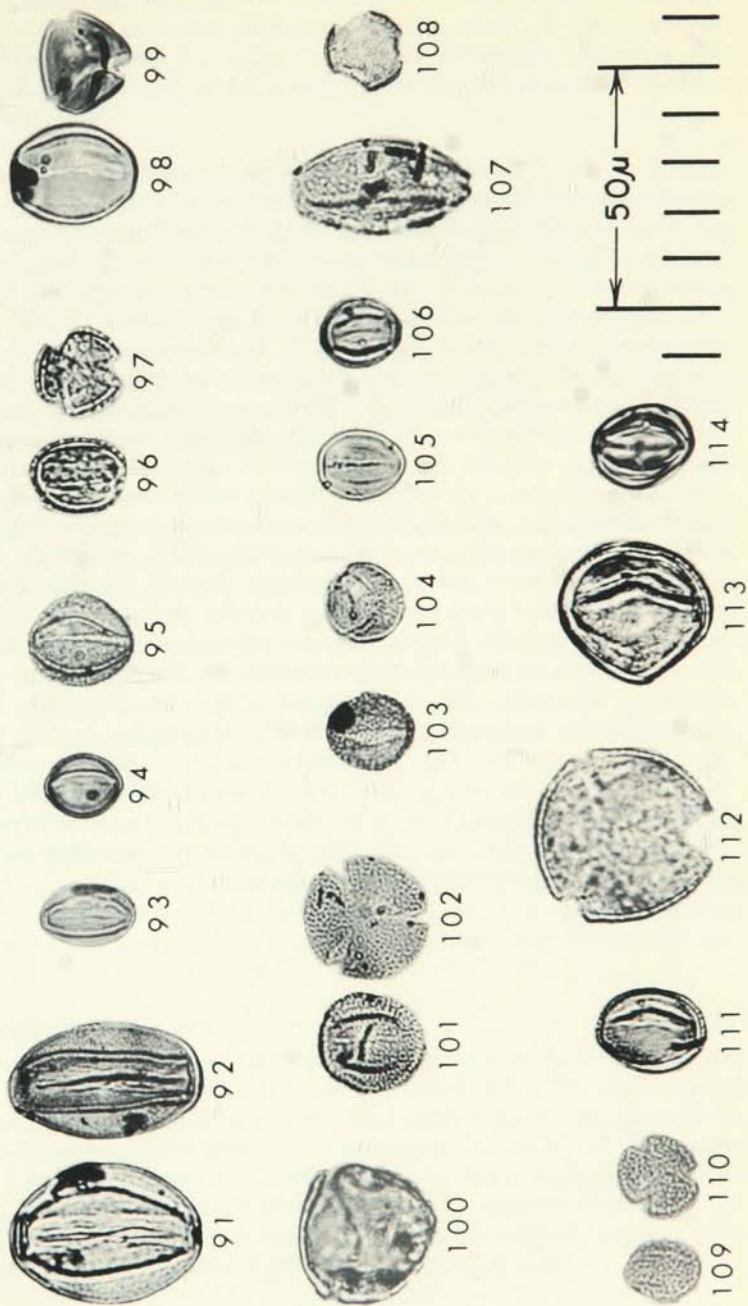


PLATE III. 66. *Granatrivesiculites dubius* (p. 41); 67. *Granamultivesiculites inchoatus* (p. 41); 68. *Punctamultivesiculites inchoatus* (p. 42); 69. *P. fimbriatus* (p. 42); 70. *Bacuinaperturites setosus* (p. 42); 71. *Foveoinaperturites forameniferus* (p. 43); 72. *F. paucipunctatus* (p. 43); 73. *F. scaphoformis* (p. 43); 74. *Gemmainaperturites gemmatus* (p. 43); 75. *G. rugosus* (p. 43); 76. *Psilainaperturites psilatus* (p. 44); 77. *Punctainaperturites scaber* (p. 44); 78. *Ruginaperturites sphaeroides* (p. 44); 79. *Spinainaperturites recurvatus* (p. 44); 80. *Striainaperturites ovatus* (p. 45); 81. *Verruinaperturites depressus* (p. 45); 82. *Bacumonoporites baculatus* (p. 45); 83. *Rugumonoporites convolutus* (p. 46); 84. *Verrumonoporites verrucatus* (p. 46); 85. *Granamonocolpites asymmetricus* (p. 46); 86. *Punctamonocolpites scaphoformis* (p. 47); 87. *Retimonocolpites dividius* (p. 47); 88. *R. fragilis* (p. 47); 89, 90. *Verrumonocolpites conspicuus* (p. 48); 91, 92. *Bacutricolpites constrictus* (p. 48); 93. *Clavatricolpites prolatus* (p. 48); 94. *C. firmus* (p. 48); 95. *Foveotricolpites sphaeroides* (p. 49); 96, 97. *Gemmatricolpites gemmatus* (p. 49); 98, 99. *Psilatricolpites psilatus* (p. 49); 100. *Punctatricolpites brevis* (p. 50); 101, 102. *Retitricolpites vulgaris* (p. 50); 103. *R. sphaeroides* (p. 50); 104. *R. oblatoides* (p. 50); 105. *R. pannosus* (p. 51); 106. *R. prolatus* (p. 51); 107. *R. truncus* (p. 51); 108. *R. patens* (p. 51); 109, 110. *R. minutus* (p. 52); 111. *R. foveoloides* (p. 52); 112. *Verrutricolpites sphaeroides* (p. 52); 113. *Foveotricolporites rhombohedralis* (p. 52); 114. *Psilatricolporites prolatus* (p. 53).



colpi elongate, margins smooth; spherical;  $17\mu$  in diameter with three polar and one equatorial planes of symmetry. Exine ca.  $1.5\mu$  thick, intectate; reticulate. BOTANICAL AFFINITY: Hamamelidaceae. SIMILAR FORMS: *Bucklandia* sp. Simpson 1936, Pl. 3, fig. 7, Tertiary, Scotland. REMARKS: The muri of the illustrated specimen are slightly thicker than the muri of *Hamamelis vernalis* Sarg.

#### RETITRICOLPITES PANNOSUS new species

Pl. III, fig. 105. Type for species. Slide 1H-1. Location:  $37.2 \times 128.2$  (Reference:  $55.4 \times 127.5$ ). DESCRIPTION: Equatorial view, mid-focus. Tricolpate, colpi elongate, constricted at equator, margins slightly ragged; prolate; oval;  $15 \times 18.5\mu$ . Exine less than  $1.5\mu$  thick, intectate, very faintly reticulate. BOTANICAL AFFINITY: Dicotyledoneae. REMARKS: The sculpturing, form and symmetry of *Guaicum sanctum* L. and *Sambucus canadensis* L. are comparable to similar characters of the fossil specimen; however, the aperture morphology of pollen from these species is not comparable to the aperture morphology of the fossil grains. Frequency low.

#### RETITRICOLPITES PROLATUS new species

Pl. III, fig. 106. Type for species. Slide 12L-1. Location:  $36.9 \times 124.8$  (Reference:  $57.5 \times 129.4$ ). DESCRIPTION: Equatorial view, mid-focus. Tricolpate, colpi elongate; prolate; oval;  $15 \times 18\mu$ ; three polar and one equatorial planes of symmetry. Exine ca.  $1.5\mu$  thick, intectate; very finely reticulate, muri indistinctly structured. BOTANICAL AFFINITY: Menispermaceae, cf. *Menispermum* spp. SIMILAR FORMS: *Menispermum canadense* L. REMARKS: Except for slight difference in size, there is no observable difference in form or sculpture between this grain and *Menispermum canadense*. Frequency low.

#### RETITRICOLPITES TRUNCUS new species

Pl. III, fig. 107. Type for species. Slide 4L-1. Location:  $39.0 \times 131.4$  (Reference:  $59.0 \times 128.4$ ). DESCRIPTION: Equatorial view, mid-focus. Tricolpate, colpi elongate; prolate; truncate oval;  $20 \times 36\mu$ ; apparently heteropolar with three planes of symmetry through poles. Exine ca.  $1.5\mu$  thick, intectate; reticulate. BOTANICAL AFFINITY: Dicotyledoneae. REMARKS: Frequency low, noted once.

#### RETITRICOLPITES PATENS new species

Pl. III, fig. 108. Type for species. Slide 13M-1. Location:  $45.6 \times 133.3$  (Reference:  $57.5 \times 128.4$ ). DESCRIPTION: Polar view, mid-focus. Tricolpate, colpi short with more or less rounded apices and slightly ragged margins; spherical;  $18\mu$  in diameter; three polar and one equatorial planes of symmetry. Exine ca.  $1.5\mu$  thick, intectate; finely reticulate, muri indistinctly structured. BOTANICAL AFFINITY: Platanaceae. SIMILAR FORMS: *Platanus occidentalis* L. REMARKS: Although the fossil grains are slightly smaller they compare very well with pollen of *Platanus*. Frequency high.

**RETITRICOLPITES MINUTUS** new species

Pl. III, figs. 109 and 110. Type for species fig. 109. Fig. 109, Slide 6H-1. Location: 30.6 x 137.3 (Reference: 56.4 x 127.1). DESCRIPTION: Equatorial view, mid-focus. Tricolpate, colpi elongate, margins smooth and slightly thickened; prolate; oval; 12.5 x 14 $\mu$ ; three polar and one equatorial planes of symmetry. Exine ca. 2 $\mu$  thick, intectate; reticulate. Fig. 110, Slide 6H-3. Location: 15.9 x 132.3 (Reference: 50.3 x 128.0). DESCRIPTION: Polar view, mid-focus. Diameter 15 $\mu$ . BOTANICAL AFFINITY: Dicotyledoneae. REMARKS: Frequency high.

**RETITRICOLPITES FOVEOLOIDES** new species

Pl. III, fig. 111. Type for species. Slide 44L-1. Location: 29.5 x 137.2 (Reference: 53.8 x 128.2). DESCRIPTION: Equatorial view, mid-focus. Tricolpate (suggestively tricolporoidate), colpi elongate, protruding at the equator; prolate; oval; 18 x 23 $\mu$ ; three polar and one equatorial planes of symmetry. Exine ca. 1.5 $\mu$  thick, intectate; reticulate on polar and inter-apertural areas, lumina grade into foveolae at the colpi margins. BOTANICAL AFFINITY: Celastraceae(?). REMARKS: Although comparable to *Celastrus* and *Euonymus*, the fossil grains lack the thickened colpi margins characteristic on pollen of these genera. Frequency low.

Form-genus **VERRUTRICOLPITES** new genus

DIAGNOSIS: Verrucate tricolpate pollen.

**VERRUTRICOLPITES SPHAEROIDES** new species

Pl. III, fig. 112. Type for genus and species. Slide 13M-2. Location: 52.3 x 126.9 (Reference: 62.3 x 127.1). DESCRIPTION: Polar view, mid-focus. Tricolpate (may be tricolporoidate), colpi margins thickened, ragged, and with acuminate apex (similar to *Fagus*); equatorial outline circular, grain spherical; diameter 38 $\mu$ , three polar and one equatorial planes of symmetry. Exine ca. 2 $\mu$  thick, tectate; sculpturing verrucate becoming punctate towards colpi; structure infrapunctate. BOTANICAL AFFINITY: Fagaceae(?). SIMILAR FORMS: *Quercus laurifolia* Michx. REMARKS: The general morphology of these specimens is comparable to *Quercus* but the sculpturing is not. Frequency high.

Class (XIII) **TRICOLPORATAE** Iversen and Troels-Smith 1950Form-genus **FOVEOTRICOLPORITES** new genus

DIAGNOSIS: Foveolate, tricolporate pollen.

**FOVEOTRICOLPORITES RHOMBOHEDRALIS** new species

Pl. III, fig. 113. Type for genus and species. Slide 30H-2. Location: 50.3 x 121.1 (Reference: 57.4 x 127.0). DESCRIPTION: Equatorial view, mid-focus. Tricolporate, colpi elongate, margin smooth; prolate; rhomboidal; 30.5 x

33.5 $\mu$  in diameter; three polar and one equatorial planes of symmetry. Exine ca. 2 $\mu$  thick, tectate; foveolate. BOTANICAL AFFINITY: Dicotyledoneae. REMARKS: Frequency low.

Form-genus *Psilatricolporites* V. d. Ham. 1956a

DIAGNOSIS: Psilate, tricolporate pollen. TYPE FOR GENUS: *Psilatricolporites inornatus* V. d. Ham. 1956a, Pl. IX, fig. 28.

PSILATRICOLPORITES PROLATUS new species

Pl. III, fig. 114. Type for species. Slide 41L-1. Location: 39.3 x 124.9 (Reference: 54.0 x 126.9). DESCRIPTION: Equatorial view, mid-focus. Tricolporate, colpi elongate, furrow margins smooth, pores transversely elongate; prolate; oval; 18 x 23 $\mu$ . Exine less than 1.5 $\mu$  thick, tectate; psilate, faintly infra-punctate. BOTANICAL AFFINITY: Castanoideae cf. *Lithocarpus*. SIMILAR FORMS: *Tricolporopollenites cingulum* spp. *pusillus* Pflug in Thomson and Pflug 1953, Pl. 12, fig. 40, Tertiary, Germany. *Castaneoipoll. exactus* R. Potonié 1951, Pl. 20, fig. 77, Tertiary, Germany. *Castanea insleyana* Traverse 1955, Pl. 10, fig. 39, Oligocene, Vermont. *Lithocarpus densiflora* Rehd. REMARKS: Except for larger size these grains compare well with *Lithocarpus densiflora*. Frequency low.

## 4. INTERPRETATIONS AND DISCUSSION

### THE DAKOTA SANDSTONE FLORA

The Dakota sandstone flora, flora of the Dakota group, or Dakota flora, is a collection of plant impressions, primarily leaves, figured and described from sandstones of the Great Plains—in particular those of Kansas and Nebraska.

The original discovery of dicotyledonous leaf impressions in Kansas and Nebraska was made during explorations of the region by F. B. Meek and F. V. Hayden in the early 1850's. In a description of formations on the upper Missouri River, Meek and Hayden (1856) assigned the leaf-bearing clays and sandstones to their formation No. 1 as "Sandstones and clays not positively known to belong to the Cretaceous system . . . 90 feet." Hawn (1858) assigned lithologically similar deposits in central Kansas to the Triassic, a conclusion based on invertebrate fossils which Swallow and Hawn (1858) considered closely related to fossils from the Permian of Kansas. Newberry in a personal communication to Meek and Hayden (1858) assigned the leaf impressions a Cretaceous age; however, Heer (1859) believed the impressions indicated the deposits were of early Miocene age. This interpretation was refuted by Newberry (1860), who had based his determination of the age of the beds on the position of marine strata containing Cretaceous invertebrates. These strata were conformably superposed on the leaf-bearing beds.

A Cretaceous age for the sandstones from which the leaf impressions were obtained and subsequently figured (Lesquereux, 1868, 1874, 1892) was consequently accepted, but the stage to which deposits assigned to the Dakota group belong is still a matter of dispute. Tester (1931) considered the Dakota stage of Meek and Hayden's type locality to be at least as old as the Mentor formation of Kansas (mid-Albian); however, the term Dakota has been applied to deposits as old as middle Early Cretaceous (earliest Aptian) to early Late Cretaceous (middle Cenomanian) by Cobban and Reeside (1952).

Berry (1922, 1929) has pointed out that many of the leaf impressions referred to the Dakota flora have not been stratigraphically verified. Also, he (Berry, 1922) would restrict the term Dakota flora to those impressions obtained from deposits contemporaneous with the transgressing Benton sea.

Most of the leaf impressions described by Lesquereux were obtained from eastern Kansas and Nebraska and little has been added since his final report (1892). The species for the Dakota sandstone flora listed in that report indicated a predominantly dicotyledonous flora composed of 6 ferns, 12 cycads, 15 conifers, 8 monocotyledons, and 429 dicotyledons. A more

TABLE 1. FAMILIES AND IMPORTANT GENERA OF THE DAKOTA FLORA

PTERIDOPHYTES	DICOTYLEDONS	DICOTYLEDONS
Polypodiaceae	Aristolochiaceae	Menispermaceae
<i>Asplenium</i>	Betulaceae	<i>Menispermites</i>
	<i>Betulites</i>	Monimiaceae
GYMNOSPERMS	<i>Alnites</i>	Moraceae
Cycadaceae	Balanphoraceae	<i>Ficus</i>
<i>Podozamites</i>	Caprifoliaceae	Myricaceae
Pinaceae	<i>Viburnum</i>	<i>Myrica</i>
<i>Sequoia</i>	Celastraceae	Myrsinaceae
Podocarpaceae	<i>Celastrophyllum</i>	Myrtaceae
<i>Protophyllocladus</i>	Cornaceae	<i>Eucalyptus</i>
	<i>Cornus</i>	Platanaceae
MONOCOTYLEDONS	Dioscoreaceae	<i>Platanus</i>
Alismataceae	Ebenaceae	Proteaceae
Araceae	<i>Diospyros</i>	Rhamnaceae
Bromeliaceae	Ericaceae	<i>Rhamnus</i>
<i>Bromelia</i>	<i>Andromeda</i>	Rosaceae
Gramineae	Fagaceae	<i>Crataegus</i>
Liliaceae	<i>Quercus</i>	Salicaceae
<i>Smilax</i>	Hamamelidaceae	<i>Populus</i>
Palmae	<i>Hamamelites</i>	<i>Salix</i>
	Juglandaceae	Sapindaceae
DICOTYLEDONS	<i>Juglans</i>	<i>Sapindus</i>
Aceraceae	Lauraceae	Sapotaceae
<i>Acerites</i>	<i>Laurus</i>	<i>Sapotacites</i>
Anacardiaceae	<i>Sassafras</i>	Sterculiaceae
Anonaceae	<i>Cinnamomum</i>	<i>Sterculia</i>
<i>Anona</i>	Leguminosae	Tiliaceae
Aquifoliaceae	<i>Leguminosites</i>	<i>Grewiopsis</i>
<i>Ilex</i>	Magnoliaceae	Ulmaceae
Araliaceae	<i>Magnolia</i>	Vitaceae
<i>Aralia</i>	<i>Liriodendron</i>	<i>Cissites</i>

complete species list was compiled by Berry (1916), to which some minor additions and annotations have been made by Berry (1939) and Baxter (1954). Table 1 reviews the families and genera of common occurrence in this fossil flora. Although *Protophyllocladus* is found through the Cretaceous and Tertiary (Andrews, 1955), it is the most important diagnostic plant fossil of the Dakota group (Berry, 1903, 1939).

The small flora described by Lesquereux (1893) from Minnesota, mainly New Ulm, was referred by him to the Dakota flora. Nine of the species were considered new, but no new genera were listed. The total flora consisted of 28 species — 2 conifers and 26 dicotyledons — which were referred to 18 genera. Berry (1939) listed 4 new species, including one new form-genus which he substituted for a previous form-genus of Lesquereux's. Stauffer and Thiel (1941) list a total of 40 species. Additions in these publications were from identifications of specimens collected in the New Ulm area.

#### BOTANICAL AFFINITIES OF THE SPOROMORPHS

Although the Cretaceous spores and pollen from Minnesota have been classified within an artificial system, an attempt has been made to deter-

mine their botanical affinity. These determinations were made in order to compare them with identifications made from the Cretaceous leaf impression record, and in order to evaluate the phytogeographic and paleoecologic potentiality of Cretaceous spore and pollen investigations. The reference of a sporomorph to a modern taxon is based on a comparison of its morphological similarity to material in the reference collection and/or on a subjective comparison of material described in the literature.

The 114 specimens described have been placed into 103 species within 48 morphological form-genera. Tentative botanical identifications made within these categories include: Bryophyta 1, Lycopsidea 7, Filicineae 22, Cycadaceae 1, Coniferae 36, Ephedraceae 1, Monocotyledoneae 1, and Dicotyledoneae 23. Of the 11 forms to which no botanical affinity was assigned, 7 may be gymnospermous and 4 may be pteridophyte spores. More restrictive identification, more tentative than the foregoing, has included reference of some sporomorphs to *Lycopodium*, *Selaginella*, *Osmunda*, *Gleichenia*, *Dioon* or *Microcycas*, *Phyllocladus*, *Dacrydium*, *Picea*, *Thuja*, and the Liliaceae. In addition, some of the sporomorphs compared almost perfectly with material from the reference collection of modern pollen. These included sporomorphs similar to or identical with spores or pollen of *Schizaea*, *Podocarpus*, *Pinus*, *Magnolia*, *Platanus*, *Hamamelis*, *Menispermum*, *Quercus*, and *Lithocarpus*.

The present distribution of these taxa suggests affinity of the Cretaceous flora of Minnesota with Northern Hemisphere temperate plants rather than Southern Hemisphere temperate or tropical plants. Although the Podocarpaceae is considered a family of the Southern Hemisphere (Buchholz, 1948; Li, 1953), the genus *Podocarpus* is present in the flora of eastern Asia. Only *Dacrydium* and *Phyllocladus* are absent from the Northern Hemisphere. The present distribution of these genera and the other taxa is indicated in the following list. These data are taken from Willis (1948), Lawrence (1951), Croizat (1952), Good (1953), and Li (1953):

Bryophyta: ubiquitous.

Lycopodiaceae, *Lycopodium*: abundant in tropics, extends to arctic, world wide.

Selaginellaceae, *Selaginella*: abundant in tropics, extends throughout tropic zone, world wide.

Osmundaceae, *Osmunda*: mainly tropical, extends into subarctic of Western Hemisphere.

Schizaeaceae, *Schizaea*: abundant tropical and subtropical, extends to Nova Scotia, world wide.

Gleicheniaceae, *Gleichenia*: mainly tropical, extends into warm temperate regions of Southern and Northern Hemispheres.

Cycadaceae (*Dioon-Microcycas*): mainly tropical to subtropical.

Podocarpaceae, *Phyllocladus*: six spp. restricted to New Zealand, Tasmania, and New Guinea to Malaysia; *Dacrydium* has a similar distribution but also occurs in Chile. *Podocarpus*: mainly temperate regions of South-

- ern Hemisphere, north to Cuba and Mexico in Western Hemisphere, widely distributed in Central China and Southern Japan.
- Pinaceae, *Pinus*: mainly temperate regions of Northern Hemisphere, extends from subarctic to subtropic. *Picea*: mainly cool temperate regions of Northern Hemisphere, extends from subarctic to temperate regions.
- Cupressaceae, *Thuja*: mainly temperate regions of Northern Hemisphere, extends to warm temperate regions of North America and Eastern Asia.
- Ephedraceae: mainly tropical to subtropical.
- Liliaceae: cosmopolitan.
- Magnoliaceae, *Magnolia*: mainly warm temperate regions of Northern Hemisphere, extends from temperate to tropical regions of North America and Eastern Asia.
- Hamamelidaceae, *Hamamelidoideae*: mainly Northern Hemisphere, Asiatic to Eastern North America, extends from tropics to temperate regions.
- Menispermaceae, *Menispermum*: mainly warm temperate to temperate regions of Eastern North America, extends from tropics to temperate regions.
- Fagaceae, *Quercus*: mainly temperate regions of Northern Hemisphere. *Lithocarpus*: mainly temperate regions of Asia, one species in Western North America.
- Platanaceae, *Platanus*: mainly temperate regions of North America and Europe, one species in Eastern Asia.

Pollen assigned to the Ephedraceae, and Cycadaceae were not abundant enough in the tabulations to be considered as indisputably derived from elements of the regional flora. Pollen production of the Ephedraceae and the Cycadaceae is high (Andrews, 1947) and susceptible to long-distance transport.

Among the pollen in the sediments the greatest number of direct comparisons with modern pollen could be made with dicotyledonous pollen. However, dicotyledonous pollen are not as abundant as conifer pollen (Table 3), and there are more different conifer types than there are dicotyledonous types. Conifer pollen, particularly vesiculate forms, because of their variety and abundance, may prove to be of greater phytogeographic and floristic significance in the interpretation of the Cretaceous flora of Minnesota than angiosperm pollen. It is not improbable that a detailed study of Southern Hemisphere conifer pollen, particularly *Dacrydium*, would reveal that many are present in the Cretaceous sediments of Minnesota. However, most pollen that could be evaluated were from taxa with, at present, a Northern Hemisphere distribution.

#### COMPARISON OF CRETACEOUS MEGA- AND MICROFOSSIL RECORDS

Many of the leaf impressions from the Cretaceous flora of Minnesota have been assigned to modern genera, or have names which suggest modern genera. By taking pollen from species of these genera and comparing them with pollen from the Cretaceous sediments, it should be possible to deter-

TABLE 2. CORRELATION OF CRETACEOUS POLLEN WITH  
LEAF-IMPRESSION GENERA

Genus	Morphologically Comparable Pollen	
	Present	Absent
<i>Acer</i> .....		X?
<i>Alnites</i> .....		X
<i>Andromeda</i> .....		X
<i>Aralia</i> .....		X
<i>Bumelia</i> .....		X
<i>Cinnamomum</i> .....		X
<i>Cissus</i> .....		X
<i>Crateagus</i> .....		X
<i>Diospyros</i> .....		X
<i>Ficus</i> .....		X
<i>Juglans</i> .....		X
<i>Laurus</i> .....		X
<i>Liriodendron</i> .....		X
<i>Magnolia</i> .....	X	
<i>Pinus</i> .....	X	
<i>Platanus</i> .....	X	
<i>Populus</i> .....		X
<i>Protophyllocladus</i> .....	X?	
<i>Salix</i> .....		X?
<i>Sapindus</i> .....		X
<i>Sassafras</i> .....		X
<i>Sequoia</i> .....		X

mine if these genera are also represented in the palynological record. The generic list of Table 2 has been taken from the list compiled by Stauffer and Thiel (1941) of genera represented by leaf impressions in the Cretaceous flora of the state. Of the 22 genera represented by leaf impressions only four could be considered as represented in the pollen record, i.e., the agreement between leaf impressions and pollen was less than 20 per cent. Such genera as *Acer*, *Salix*, etc., do have pollen types which can be referred to pollen types present in the sediments, but there was not sufficient morphological agreement between the reference pollen and the fossils to suggest affinity.

A more extensive reference collection might indicate that some of the genera represented as absent — which produce inaperturate, monocolpate, tricolpate, and tricolporate pollen — are present in the palynological record. For this reason, the indicated absence of pollen comparable to those from such genera as *Laurus*, etc., is not proof that these genera were absent from the flora. Their status is, however, open to question. The complete absence of pollen even remotely similar to pollen from extant species of *Sequoia*, *Juglans*, *Alnus*, *Sapindus*, and *Bumelia*, suggests that impressions referred to these genera have been misidentified. An alternative possibility is that the pollen morphology of these genera was greatly different during the Cretaceous, and that the leaf-impression record is a more reliable record of the presence of these genera than the pollen record. In the writer's opinion, this is not an acceptable explanation for the absence of such genera as *Sequoia* from the pollen record of the early Late Cretaceous.



Of the 40 species listed in Stauffer and Thiel (1941), 3 are conifers and 37 are dicotyledons. By comparison, the pollen list contains species of 36 conifers, 23 dicotyledons, and 1 monocotyledon. The floristic predominance of dicotyledonous species indicated by the leaf impression record is not substantiated by the pollen record.

#### PALEOECOLOGICAL AND PALEOFLORESTIC INTERPRETATIONS

Often the regional aspect of the fossil vegetation of an area can be visualized by quantitative studies of the fossil remains of the various taxa represented (Cain, 1944). Such studies as Chaney's (1924, 1925) reconstruction of the Miocene Bridge Creek flora are not available for the Dakota flora; however, the list of important genera of the Dakota flora (Table 1) is closely comparable to generic lists in Braun (1950) of plant communities in the Ohio River drainage basin and the Ridge and Valley Province of eastern Tennessee. On the other hand, Chaney (1954) concluded that the camptodrome venation pattern, which predominates in the leaf impressions, was evidence that the Dakota flora was more closely related to modern tropical forests than to temperate vegetation. Chaney's interpretation, within which he included the Cretaceous flora of Minnesota, does not agree with the palynological record. Instead, the pollen record suggests a flora that can be visualized (physiognomically, not taxonomically) as a warm temperate coniferous rain forest similar to that of the Pacific Northwest or the coastal areas of eastern Asia. It is of interest to note that in Rubel's (1936) physiognomic classification of vegetation, a conifer forest comparable to that of the Pacific Northwest would be placed in the Laurisilvae or laurel-leaved forests. The laurel-like leaf impression is common in our Cretaceous record. The conifer forests of the Laurisilvae are climatically characterized by mild winters and cool summers, with little difference between the means of the coldest and warmest month (for Seattle 13.4° C.). Precipitation is high and regular, fog abundant, and the climatic pattern moist, warm-temperate.

Because of Chaney's belief that the leaf impressions indicated the Dakota flora was related to tropical or subtropical vegetation, conifer fossils that could be compared to *Pinus resinosa*, red pine, led both Chaney (1954) and the writer (Pierce, 1957) to conclude that relief in the New Ulm area during the Cretaceous was of sufficient magnitude to climatically segregate the flora into vegetation zones. The zones implied would have extended, climatically, from at least warm temperate or subtropical angiospermous vegetation in the lowlands to cool temperate conifer forests in the uplands. Easily deducible conclusions from adiabatic lapse rate calculations show that Chaney and the writer could only be erroneous in envisioning relief of this magnitude, as shown below.

By utilizing adiabatic lapse rates, and the average January temperature of a warm temperate and a cool temperate environment, it is possible to calculate the minimum altitude necessary to separate the two climatic environments. During the transgression of the Benton and Niobrara seas the

atmosphere of Minnesota was probably more moist than at present, but as the adiabatic lapse rate of dry air (5.4° F. per thousand feet) is greater than the adiabatic lapse rate of moist air (approximately 1.8° F. per thousand feet) the dry air lapse rate can be used to obtain a minimum figure for the requisite altitude of the topographic highs. If the leaf-impression flora is assumed to indicate a moderately warm temperate — rather than a subtropical — environment, an average January temperature such as occurs at the latitude of southern Tennessee, 40° F., is reasonable to assume. For a moderately cool temperate environment the average January temperature of northern Illinois, 20° F., is reasonable. Converting these data to altitude:

$$\frac{40^{\circ} \text{ F.} - 20^{\circ} \text{ F.}}{5.4^{\circ} \text{ F.}} \times 1000 \text{ feet} = 3700^+ \text{ feet.}$$

In other words, altitudinal differences of at least 3700 feet would have had to have been present to segregate the vegetation into warm temperate and cool temperate associations.

It should be noted that the data used give only a minimum altitude figure for the separation of the two environments. More realistic figures, e.g. 2° F. for the adiabatic lapse rate of moist air, would give a figure of 10,000 feet. Dr. R. E. Sloan (personal communication) has assured the writer that gravity meter data indicate it is unlikely that altitudinal differences of over 500 feet were present.

If these calculations can be assumed to fairly represent the relief necessary to separate a warm temperate from a cool temperate environment, then it seems unlikely that the red pines of the Cretaceous grew in a climatic belt similar to that of the modern red pine. Cain (1944, p. 37) has clearly outlined the problems of paleoecological interpretation, especially paleoclimatology, by emphasizing that “the possibility of a changed physiology (ecology) without a detectable morphological change should be kept in mind when conclusions are being made with respect to the significance of an element in a fossil flora.”

Concerning the paleoclimatology of the Dakota formation as indicated by its flora Lesquereux (1874, p. 39) has said, “Considered as a whole, most of the types of the Dakota group, related to those of our present flora, represent a moderate climate, like the one prevailing now between the 30° and 45° of latitude north. The vegetable types more distinctly characterized by their leaves, and which are recognized by all the paleontologists, *Salix*, *Fagus*, *Platanus*, *Sassafras*, *Aralia*, *Magnolia*, *Liriodendron*, *Menispermum*, *Paliurus*, *Rhus*, etc., are all co-ordinate to identical climatic circumstances, or to the same average temperature which governs at our time the vegetation of the latitude indicated above.” Although the pollen flora does not necessarily agree with the vegetational aspect of the Dakota flora as interpreted from leaf impressions, the climatic zone in which this flora occurred, as interpreted from the pollen record, closely parallels Lesquereux’s interpretation of the climatic zone.

It may be possible to explain the disagreement between the physiognomy of the Cretaceous flora as deduced from its sporomorphs (coniferous), and as deduced from its leaf impressions (angiospermous), in terms of plant communities. Lateral variation in the plant population does not appear to have been influenced to any great extent by relief. Climatic factors, such as light, atmospheric moisture, temperature, etc., though not uniform, were probably not variable enough regionally to cause lateral zonation of the vegetation within the area studied. More probable is that the disagreement in the interpretations from the megafossil and microfossil records is caused by there having been regional dissection of the plant formation into plant communities in various stages of succession. The marginal areas of the basins of deposition, the river banks, stream banks, deltaic areas, swamps and lakes, were areas of primary plant communities. It was, in general, the foliage of these primary communities which entered into the megafossil record. The microfossils, on the other hand, were probably derived from numerous plant communities, in particular the climax communities of the region.

Because of such factors as alteration of plant associations and evolution of organisms over a long period of geological time, it seems doubtful that the Cretaceous flora of Minnesota, as interpreted from its spore and pollen record, can be compared with any existing plant association except by physiognomic analogy. The vegetational aspect suggested by the pollen record through analogy — warm temperate, coniferous rain forests — is in striking contrast to the subtropical, evergreen angiosperm forests suggested by Chaney (1954) from his study of the leaf-impression record of the Dakota flora.

#### CRETACEOUS PALYNOLOGY AND PLANT EVOLUTION

Although the earliest definitive appearance of undoubted dicotyledonous pollen in the fossil record has not yet been established, no great diversity of angiosperm microfossils appears in the Northern Hemisphere until the Turonian. Not until the Eocene do all pollen classes begin to appear in the fossil record (Kuyl *et al.*, 1955; Pflug, 1953). Thiergart (1949) and Pflug (1953) have pointed out that the undoubted appearance of dicotyledonous pollen in the fossil record of Europe is a post-Wealden, pre-Senonian event. According to Pflug (1953) such groups as the Urticales, Juglandales, Myricales, and Betulaceae go back to the same palynological "roots" in the Senonian of Europe, i.e., these taxa cannot be identified in the pollen record until the middle of the Late Cretaceous.

Axelrod (1952), Arnold (1947), Camp (1952), and others have postulated a long pre-Cretaceous evolutionary period for the angiosperms and explain the absence of angiosperms in the fossil record as due to "their predominantly upland habits." If this were true the pollen of these upland plants should occur as at least occasional elements in sedimentary deposits, particularly near shore marine deposits. Muller (1959) has found *Alnus* pollen in

Recent sediments of the Orinoco delta. The nearest source for these pollen is at an altitude of 2000 meters in the Andes, 500 miles from the Orinoco delta. Therefore "predominant upland habits" is not an explanation for the lack of angiosperm pollen in pre-Cretaceous sediments.

Most reports of the pre-Cretaceous occurrence of angiosperm pollen have been seriously questioned. Tricolpate nymphaeaceous microfossils of the Devonian of Canada (Radforth and McGregor, 1954) were sample contaminants according to Hoffmeister and Staplin (1955); the Jurassic tricolpate eucommiaceous forms described by Erdtman (1948), Thiergart's (1949) *Pollenites reclusus*, and the *Tetradopollenites* forms of Klaus (1953), also described from the Jurassic, are probably of gymnospermous origin (Kuyl *et al.*, 1955, Couper, 1956). Scott, *et al.* (1960) have reviewed the microfossil and megafossil record of the angiosperms and have concluded that there is no unequivocal evidence of angiosperms in pre-Cretaceous rocks.

If the angiosperms had a long pre-Cretaceous evolutionary history and were fairly well advanced by the beginning of the Aptian, their negligible appearance in the fossil record of the Northern Hemisphere could be construed as presumptive evidence for a Southern Hemisphere origin. Croizat (1952), Camp (1952), and Good (1953), among others, have argued that the distributional patterns of many of the angiosperm families point to origins in the Southern Hemisphere.

Couper (1953b) separated the Cretaceous from the Jurassic in New Zealand on the basis of first appearance of angiosperm pollen, but the Paparoa beds in which angiosperm pollen first appear had been classed as Upper Cretaceous-Eocene (Morgan, 1922) prior to Suggate's and Couper's (1952) assignment of the beds to the Lower Cretaceous. Later McQueen (1954, 1956) examined the plant macrofossils of the Paparoa beds and concluded these indicated the beds were at least as young as Senonian. Inasmuch as there is considerable disagreement about the age of these beds, it cannot be concluded that undoubted angiosperm pollen appear in abundance earlier in the fossil record of the Southern Hemisphere than in that of the Northern Hemisphere.

The only work familiar to the writer which departs from the general picture of sparse representation of angiosperm pollen, mainly tricolpate forms, in the Lower Cretaceous is from Central Russia, the study by Bolkhovitina (1953). She has described relatively advanced tricolporate, triporate, tetraporate, and syncolpate dicotyledonous pollen from deposits assigned by Russian stratigraphers to the Lower Cretaceous.

Perhaps one of the more significant pieces of information obtainable from the present study is the observation that angiosperm pollen in the Cretaceous flora of Minnesota are restricted to inaperturate, monocolpate, tricolpate, prolate tricolporate, and tetrad forms. This observation is in accord with previous observations of the paucity of angiosperm pollen classes in pre-Senonian sediments (Kruttsch, 1957). A reference to hexaporate forms assigned to *Pterocarya* from the lowermost Cretaceous of Canada (Rad-

forth and Rouse, 1956) has not been verified. Even if verified, it would not invalidate the conclusion that the pollen record of the angiosperms in the middle Cretaceous deposits of the Northern Hemisphere is lacking many of the pollen classes or forms which should be present if the angiosperms had differentiated into the numerous families and genera listed (Berry, 1916) for the lower Upper Cretaceous leaf-impression floras. That this paucity of pollen classes could be accounted for by postulating obligate entomophily is doubtful.

Baxter (1954) has said of the Dakota flora that the diversity and number of modern genera present in it (identified from leaf impressions) is "*positive proof*" of a long period of evolution of the angiosperms prior to their appearance in this flora. Even though Brown (1956) has described palm-like leaves from the Triassic of Colorado, the palynological record does not support the thesis that the angiosperms, particularly the dicotyledons, had a long pre-Cretaceous history (Kuyl *et al.*, 1955), or that there was the diversity of modern angiosperm genera present in the Dakota flora that Baxter believes the leaf impressions indicate.

It has been pointed out by many authors (Anderson, 1948, 1949; Heiser, 1949; Anderson and Stebbins, 1954) that the most rapid evolution of species at present is in disturbed areas. During the Dakota stage of the Cretaceous in Minnesota, disturbed areas undoubtedly occurred as a result of the physiographic and climatic changes brought about by the transgressing Cretaceous seas. In these areas the angiosperms may have been undergoing rapid adaptive and quantum evolution (Simpson, 1944, 1953). During this same stage the palynological record indicates that conifers were the dominant elements of the climax communities with pteridophytes, mosses, etc., in the understory. It has already been indicated (p. 59) that this association was probably not too dissimilar physiognomically from some conifer associations of the Pacific Northwest. The angiosperms in this dominantly conifer flora were probably not differentiated into the numerous modern genera and families deduced from the leaf impressions. Opinions that they were, are based on the assumption of fixity and generic continuity of leaf form, clearly stated by Berry (1916, p. 73): "There may . . . be considerable variation in the leaves of a single species, but foliar characters in general are more fixed than those of almost any other organs of plants. They are subject to less complex environmental factors and always have been." However, Rubel (1936), among others, has pointed out that physiognomic classification of vegetation is possible because foliar characters *are* modified by the environment.

According to Ross (Fries and Ross, 1950) the Upper Cretaceous (Senonian) pollen flora of Europe is characterized by tricolporate and tricolpate sporomorphs with distinctive protruding (lobate) germinal apertures similar morphologically to *Eucalyptus* pollen grains. One of the more common types, *Tricolporites protrudens* (Erdtman *in* Ross, 1949) has been compared by Erdtman (1952) to the pollen of *Faramea cuspidata* (Rubiaceae)

from Colombia. Thiergart (1940) also found this type in the Paleocene and Eocene, after which it disappeared.

The protruding or lobate aperture eucalyptoid type, together with pollen referable to *Sciadopitys*, *Podocarpus*, *Pinus*, and spores of schizaeaceous ferns, tend to give the pollen assemblages from the Upper Cretaceous of Europe a distinctive Australasian aspect according to Fries and Ross (1950). However, after extensive study of the Australian eucalypts, Blake (1953) concluded that none of the leaf impressions from the Northern Hemisphere referred to *Eucalyptus* could be *Eucalyptus* and further doubted that *Eucalyptus* was ever present in the Northern Hemisphere. The *Tricolporites protrudens* type, so characteristic of the Senonian and younger Cretaceous deposits of Europe, was not found in the writer's material; however, similar forms have been found in the Senonian of the western United States by Sarmiento (1957). In the Upper Cretaceous of New Zealand *Nothofagus* and proteaceous pollen types are the more characteristic (Couper, 1953b).

Another interesting problem of concern to plant evolution is the antiquity of the Gnetales. The leaf impressions referred to dicotyledons in the Lower Cretaceous Pautuxent formation (Fontaine, 1889) had been questioned by Berry (1918, 1945), who referred the leaf impressions *Rogersia*, *Ficophyllum*, and *Proteaphyllum* to the Gnetales. However, the supposed absence of the Gnetales from the fossil record prior to the Tertiary (Lawrence, 1951), with the possible exception of Triassic petrified wood (Daugherty, 1941), weighed against Berry's identifications. Palynological studies of Cretaceous deposits of the present day tropics have shown that gnetalean pollen is abundant in these deposits (Kuyll *et al.*, 1955). Steeves (1959) has also shown that gnetalean pollen (*Ephedra*) is present in the Raritan formation of Long Island. Although proof of the pre-Tertiary existence of gnetalean gymnosperms is not proof that they were the ancestors of the angiosperms, there is now no reason to exclude them from such consideration simply because of the lack of gnetalean megafossils in pre-Tertiary rocks.

#### GEOLOGICAL ASPECTS OF CRETACEOUS PALYNOLOGY

*Sediment Analysis.* One of the aims of the present investigation was to determine the susceptibility of various Cretaceous sediments of Minnesota to spore and pollen analysis. Previous analyses of Cretaceous sediments had been confined to coals and lignites (Miner, 1932, 1935; Schemel, 1950; Thiergart, 1949, 1954; Weyland and Krieger, 1953; Weyland and Greifeld, 1953; Couper, 1953a, 1953b; Radforth and Rouse, 1954; Rouse, 1956, and others). For these sediments the maceration technique for Paleozoic coals, often in combination with desilicification techniques involving differential flotation or hydrofluoric acid, has been used. In the present investigation, modifications of Traverse's (1955) technique were found the most applicable to noncoalified sediments of Cretaceous age. In contrast to the results

of Traverse, the sediments containing the best-preserved material were found to include clays as well as lignites. Some clay samples which did not contain spores and pollen may have been leached and oxidized. As indicated by Zetsche and Kalin (1931) the chemical constituents (sporopollenine) of the spore and pollen wall auto-oxidize after reaching a certain oxygen uptake level. The blue-gray clays, e.g., the Fort Ridgely samples, contained exceptionally well-preserved material indicative of little or no leaching and oxidation of the clays. Some samples of clays, silts, and lignite did not contain plant microfossils, but sandstone was the only sediment in which microfossils were never found. It is concluded that with the application of proper techniques of extraction and concentration, most Cretaceous deposits of Minnesota will have included plant microfossils unless oxidized or initially formed in highly aerobic environments. What concentration of pollen and spores per gram of sample for the noncoalified continental deposits is to be expected, has not been established. In all probability this quantity is an extreme variable; however, Wilson (1946) believes the concentration is sufficient in most continental deposits for correlation purposes.

*Stratigraphy and Paleogeography.* Although pre-Quaternary palynology is a comparatively new discipline, it has the potential to significantly contribute to problems concerned with the age relationship of sedimentary deposits. With respect to nonmarine deposits, in which animal fossils are only rarely encountered, palynology could become the primary stratigraphic arbiter.

One such problem in which palynology is being actively applied is the age relationship of the Raritan and Potomac group formations in Maryland and Delaware and the Raritan formation in New Jersey. Spangler and Peterson (1950) considered the Raritan of New Jersey to be in part correlative with formations of the Potomac group in Maryland and Delaware. In their opinion, based mainly on lithology, the Raritan of New Jersey is early Late Cretaceous (Cenomanian) and Early Cretaceous in age. The Arundel and Patapsco formations, as well as the upper portion of the Patuxent formation, are also considered by them to be Cenomanian equivalents. Dorf (1952) has refuted this interpretation on paleobotanical grounds. According to Dorf the Raritan formation in Maryland, Delaware, and New Jersey is of early Late Cretaceous age and the Potomac group distinctly Early Cretaceous without equivalents in New Jersey. Inasmuch as the Arundel and Patapsco formations are considered the oldest formations in which dicotyledons appear in abundance (Seward, 1931; Arnold, 1947; Andrews, 1947), their age is important to paleobotanists. Geologically the problem is of interest because of the stratigraphic problems involved and as a test of the efficacy of palynology in resolving stratigraphic problems.

Steeves (1959), in a palynological study of samples obtained from a core taken at Brookhaven, Long Island, concluded that pollen and spore assemblages from that portion of the core labeled "lower Raritan formation" were

indicative of an Early Cretaceous age and supported the Spangler and Peterson hypothesis. Dorf (personal communication) has pointed out that the relationship of Steeves' "lower Raritan formation" samples to the Raritan formation of New Jersey has not been established well enough to support Steeves' conclusion. Penny and Groot (1959, abstract only) examined samples from the Raritan and Potomac group but enigmatically conclude that "The conventional formation assignments of the Potomac group have shown no logical correlation with the age of the sediments indicated by . . . pollen studies."

Although the age and relationship of the formations have not been resolved, the above studies clearly indicate the presence of pollen and spores in the formations involved in the controversy. In the writer's opinion, all that is needed to resolve the problem is a well-planned program of sampling and analysis.

In marine deposits palynology is applicable to paleogeographic studies on the position of ancient shorelines. It is this aspect of palynology that the Carter Oil Company patented (Hoffmeister, 1954; White, 1955). Woods (1955) has shown that the concentration of spores and pollen in marine deposits varies from 25,000/gm. of sediment in the littoral area to 2000/gm. 80 miles off shore. Compositional frequencies are, in general, independent of facies produced by oscillation in environments of deposition (Kuyf *et al.*, 1955).

In general, marine deposits and nonmarine deposits can be easily distinguished. Almost invariably marine and brackish water deposits will be found to contain hystrichosphaerids (Wetzel, 1933), microforaminifera (Wilson and Hoffmeister, 1952), and dinoflagellates. The ratio of the quantity of these marine and/or brackish water organisms to the quantity of pollen and spores in a particular sample may be a better index to distance of the sample location from an ancient shoreline than is straight computation of pollen and spore concentration (cf. Sarmiento, 1957).

In addition, Foreman (1955) has also pointed out that the geological applicability of spores and pollen is not limited to problems of correlation. In deep cores from a Mexican lake he was able to determine from a study of plant microfossils the points at which variations in sedimentation rates were due to climatic change and the points at which the variations were due to tectonic influences.

When the problems of processing and nomenclature are resolved, it is obvious that Cretaceous palynology can be as much of an aid to some aspects of pre-Quaternary geology as Recent palynology has been to Quaternary geology (Just, 1951; Sittler, 1954b).

*Age Relationship and Guide Fossils.* The samples collected for the present investigation have been obtained from pre-marine deposits all of which have been classified within the Cenomanian stage (Cobban and Reeside, 1952); however, the greatest transgression of the Cretaceous seas was during Niobrara time. Therefore, the deposits from which the samples were



collected may be Cenomanian or may be as young as Coniacian (lower Senonian), depending on the relation of erosion and deposition of the non-marine deposits to the transgressions. Because deposition predominates during transgression, an age only slightly older (Turonian) than the Niobrara deposits of the state might be anticipated for the nonmarine deposits. However, a comparison of the specimens and their frequency of occurrence with European sporomorph distributions (Kruttsch, 1957) favors a Cenomanian age assignment to the sections studied.

By referring forms from a sample to the illustrations and descriptions of this study, a particular deposit can be definitively included or excluded from the stratigraphic range of deposits from which the present material was obtained. The similarity of forms (Table 3) from areas in Minnesota as widely separated as Virginia and New Ulm indicates that any extensive deviation in the spore and pollen assemblage of a sample of a presumed pre-marine, Cretaceous deposit is not to be expected.

Guide fossils for the pre-marine Cretaceous deposits of Minnesota are *Rugubivesiculites*, *Granamultivesiculites*, *Punctamultivesiculites*, and *Verrumonocolpites conspicuus*. These are listed as guide forms since they are fairly abundant, widespread, readily recognized and have not been described from stages older or younger than the deposits investigated. This assessment of vertical range is based mainly on European material.

Schizaeaceous fern spores of the "dorogensis" type characterize all Cretaceous deposits of Europe (Thiergart, 1949; Weyland and Krieger, 1953; Weyland and Greifeld, 1953). They are not found below the Wealden (Sittler, 1954a) and disappear in the Oligocene (Potonié, 1951). According to Radforth and Rouse (1956) the "dorogensis" type is present in Canadian coals from early Late Cretaceous through early Tertiary. Schizaeaceous fern spores (*Striatriletes*, Table 3) are infrequent in the Cretaceous sediments of Minnesota but are quickly noted when present.

*Correlation of Sporomorph Frequencies.* The data in Table 3 present the frequency of some of the more distinctive or abundant sporomorphs. These data have been interpreted as follows:

1. The sporomorph types from samples from the Ochs Brick and Tile Company, Redwood Falls pit, depart radically from the composition exhibited by the remainder of the samples. The most frequently occurring form in these samples was *Retitriletes anulatus* (fig. 17) which constituted an estimated 30 per cent of the total sample. However, the compositional difference of this sample is probably caused by an ecological rather than by a time segregate. The lignite from which the samples were taken is interpreted as autochthonous, since traces of root channels were present in the underlying residual and nonresidual clays. Samples from areas of swamp and bog vegetation often over-represent localized conditions (Faegri and Iversen, 1950). It is of interest to note the predominance of *Punctamultivesiculites*, *Granamultivesiculites*, and *Verrumonocolpites conspicuus*. If representative of a localized pollen flora, then it is probable these pollen forms

TABLE 3. PERCENTAGE FREQUENCY OF DISTINCTIVE OR ABUNDANT SPOROMORPH TYPES

Type	Location *									
	1	2	3	4	5	6	7	8	9	10
<i>Rugubivesiculites</i> spp. . . . .	0.0	2.7	10.7	12.3	2.3	3.1	11.8	20.0	16.5	8.4
Multivesiculate forms . . . . .	9.3	0.0	0.0	0.6	5.1	6.6	0.0	0.0	0.5	0.8
<i>Verrumonocolpites conspic-</i> <i>uus</i> . . . . .	20.0	0.0	1.3	4.9	12.5	1.6	6.5	15.6	9.8	0.8
<i>Bacutricolpites constrictus</i> . . . . .	0.0	1.4	5.3	0.3	1.7	0.2	0.0	0.5	0.5	0.8
<i>Retitricolpites vulgaris</i> . . . . .	0.0	25.7	4.0	1.2	0.6	0.2	0.5	0.0	2.1	4.6
<i>Verrutricolpites sphaeroides</i> . . . . .	0.0	0.0	4.0	0.0	1.1	0.0	0.5	0.0	0.5	0.0
<i>Psilatriteles</i> spp. . . . .	7.0	4.0	5.3	31.5	15.3	19.7	0.0	6.8	4.1	0.0
<i>Striatriteles</i> spp. . . . .	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
Undiff. gymnosperms, mainly bivesiculates . . . . .	6.3	10.8	48.0	23.9	26.8	21.5	74.2	50.8	40.2	37.2
Undiff. angiosperm pollen . . . . .	4.0	51.4	14.7	9.6	5.1	6.2	6.5	3.4	16.5	32.1
Undiff. spores . . . . .	53.4	4.0	6.7	15.7	29.5	40.9	0.0	2.9	9.3	14.5
Total Count = 100% . . . . .	301	74	75	324	176	482	170	205	194	131

\* Location (see also section descriptions in Chapter 2): 1—Ochs Brick and Tile Co. clay pit, Redwood Falls; 2—Nicholas Metzen farm, New Ulm; 3—Exposure, NE $\frac{1}{4}$  Sec. 31, T. 110 N., R. 30 W., New Ulm; 4—Exposure, George Floerup farm, Ft. Ridgely; 5—Exposure, John Jacob farm, Richmond; 6—Enterprise Mine, Virginia; 7—Cobb's Creek, New Ulm, lowest clay seam; 8—Cobb's Creek, New Ulm, middle zone of clay seams; 9—Cobb's Creek, New Ulm, middle zone 3" above previous sample; 10—Cobb's Creek, New Ulm, topmost clay seam.

were derived from those plants that grew in the swamp and could be used as indicators of swamp vegetation.

2. The samples from the Metzen farm exposure contained a pollen flora that deviated from the general trend. Four samples were treated, but only two samples from the same silt layer contained plant microfossils. The multivesiculate and *Verrumonocolpites conspicuus* types, dominant elements in the Redwood Falls samples, are absent. Angiosperms predominate, particularly tricolpate dicotyledonous pollen. Considering the genetic and lithologic continuity of the Metzen farm exposure with the Cobb's Creek exposure and the occurrence of the multivesiculate and *Verrumonocolpites conspicuus* types in the Cobb's Creek samples, the differences noted in the Metzen farm samples may be without significance. However, the dominance of angiosperm pollen may indicate another ecological segregate, a delta flood plain community. The surrounding area may have been well drained and may have lacked those environmental conditions in which the species producing the multivesiculate and *Verrumonocolpites conspicuus* pollen types were present, i.e., stagnant swamps.

The predominance of angiosperm pollen in these samples may have another significance if they are representative of a deltaic or flood plain community. In the study as a whole, gymnosperms, particularly conifers, are represented by a greater variety of pollen forms than are the angiosperms, an observation not in accord with the leaf-impression record. If the angiosperms were closer to the basins of depositions, and if these included alluvial basins, then during this portion of their geological history the an-

giosperms may have been mainly members of primary plant communities for which disturbed habitats of water courses were both migratory and evolutionary pathways (Anderson and Stebbins, 1954).

If the interpretation that Cretaceous angiosperms of the state were mainly members of primary plant communities is correct, then the frequency of angiosperm pollen in a sample may be useful in interpreting the habitat of a deposit. The disturbed habitats of large deltas and large river flood plains would be further removed from the regional climax vegetation of gymnosperms and pteridophytes than the disturbed habitats of streams and lakes. The greater the extent of the disturbed area, the higher might be the frequency of angiosperm pollen. However, such interpretations could be complicated by seasonal variation in pollen production.

3. *Rugubivesiculites* is a constant, distinctive, and occasionally abundant element in the pollen flora of most samples. Inasmuch as it probably contains more separable forms than were defined during this study, it may prove to be a valuable zoning fossil for the Cretaceous deposits of the state.

4. On the basis of morphological groupings the pollen flora of all samples is resolvable into a distinct and characteristic pattern indicating a general contemporaneity of the deposits from which the samples were taken. It is concluded that all deposits, including those at the Metzen farm exposure and the Ochs Company clay pit at Redwood Falls, were deposited during the same flora-time interval.

## 5. SUMMARY AND CONCLUSIONS

The Cretaceous deposits of Minnesota, though widespread in the state, are generally covered with glacial drift; where exposed in stream banks, open pits, etc., they have been recognized through their fragmented plant remains, thin seams of lignites, and marine fossils. Impressions of leaves, mostly dicotyledons, have been found in siltstones and fine-grained sandstones, particularly in Brown County along the Big Cottonwood River. The study of these leaves led Lesquereux (1893) to conclude that the Cretaceous sediments in southern Minnesota were coeval with the Dakota group of Kansas and Nebraska.

While searching for leaf impressions on Cobb's Creek (Brown County) during the summer of 1955, the writer found an extensive exposure of cross-bedded sandstone with seams of shaly clays in which leaf cuticles as well as leaf impressions occurred. The presence of preserved cuticular material indicated that spores and pollen should also be present. Numerous spores and pollen were obtained with the extraction technique used by Traverse (1955) on the Brandon lignites. Of the entities found, 114 specimens have been described and illustrated. These have been classified within 48 morphological form-genera and referred to 103 species. Most of the species described are considered to be new; however, similar forms previously described by others have been indicated in the sporomorph descriptions. The indicated natural affinities of these species are Bryophyta 1, Lycopsida 7, Filicineae 22, Cycadaceae 1, Coniferae 36, Ephedraceae 1, Monocotyledoneae 1, and Dicotyledoneae 23. Seven of the indeterminate forms are possibly gymnospermous and four are spores.

The generic categories within which the sporomorphs are classified are essentially those outlined by Van der Hammen (1956a). Most of these categories were not formalized by Van der Hammen; consequently they have been formalized in this publication. The advantage of Van der Hammen's system is that it permits the ready classification of a large number of specimens, which is the *sine qua non* for palynological work at this stage of the discipline's development. In addition, as do other morphological systems, Van der Hammen's eliminates the practice of codifying a reference to Recent genera or families in the name of a sporomorph.

The following conclusions were reached as a result of this investigation:

1. The angiosperm pollen types present in the Cretaceous sediments of Minnesota are not as complex or diversified as the angiosperm pollen of the Recent flora or the Senonian and younger pollen floras of Europe. Angiosperm pollen classes in the Minnesota sediments are limited to inaperturate, monocolpate, tricolpate, tricolporate, and tetrad forms. The paucity of an-

giosperm pollen classes during the early part of the Late Cretaceous and the profusion of classes during the latter part of the epoch may indicate that, among the angiosperms, rapid evolution as well as possible migration from some source area was occurring in this taxon during the early part of the Late Cretaceous.

2. The most common type of angiosperm pollen in the sediments consists of tricolpate, reticulate forms of hamamelidaceous aspect.

3. The most common pollen in the sediments are of conifer origin. These are not only the most abundant but are also the most diverse morphologically.

4. The transgressing Benton and Niobrara seas probably initiated a cycle of events, including increased deposition of sediments, that permitted a rapid expansion of the angiosperms into changing ecological niches. Differentiation of the angiosperms, particularly the dicotyledons, into definitely modern genera and modern floristic associations probably did not occur until post-Eocene climatic deterioration started a southward shifting of the Holarctic floras in the Northern Hemisphere. If this is true, the floristic elements found in pre-Eocene sediments represent components of plant associations too different from present-day associations to be described in terms of Recent plant associations, and the ecological approach utilized by Traverse (1955) in the analysis of the Brandon lignites is limited to those stages, probably post-Eocene, in which floras become referable to extant plant associations.

5. The flora of the Cretaceous of Minnesota as interpreted from its pollen record has been compared by *physiognomic analogy* to warm temperate, coniferous rain forests of the Pacific Northwest or the east coast of Asia. This interpretation is in disagreement with Chaney's (1954) interpretation that the leaf-impression record indicates the Dakota flora was closely related to extant subtropical, evergreen, angiosperm forests.

6. Of the 23 genera present in the leaf-impression record of the Cretaceous flora of Minnesota, only 4, by implication, are represented by morphologically comparable pollen in the sediments. These are *Pinus*, *Protophyllacladus*, *Magnolia*, and *Platanus*. Other taxa having pollen or spores morphologically comparable to pollen and spores found in the Minnesota sediments are the Bryophyta, Lycopodiaceae, Sellaginellaceae, Schizaeaceae, Cycadaceae, Podocarpaceae, Pinaceae, Ephedraceae, Monocotyledoneae, Hamamelidaceae, Magnoliaceae, Platanaceae, Menispermaceae, and Fagaceae. Most of these taxa are primarily distributed, or represented by genera, in the Northern Hemisphere. In addition, almost perfect morphological agreement could be obtained in comparisons of modern spores or pollen from *Schizaea*, *Podocarpus*, *Pinus*, *Magnolia*, *Platanus*, *Hamamelis*, *Menispermum*, *Quercus*, and *Lithocarpus* with some of the Cretaceous sporomorphs.

7. It has been pointed out in the literature (Chaney, 1954; Pierce, 1957) that cones and pollen similar to those of *Pinus resinosa* suggest there may

have been extensive relief differences in Minnesota during the Cretaceous. However, the relief necessary for the separation of warm temperate and cool temperate environments, as calculated from the dry adiabatic lapse rate, suggests it is highly improbable that Cretaceous pines with the ecological requirements of *Pinus resinosa* could have occurred in the same geographical area as a warm temperate flora. The climatic regime indicated by the pollen is interpreted as moist warm temperate, with no extensive differences in relief.

8. It appears possible to correlate the Cretaceous deposits of Minnesota by analyzing the plant microfossils of these deposits. Guide fossils for these correlations are *Rugubivesiculites*, *Verrumonocolpites conspicuus*, and multivesiculate pollen. All Cretaceous sediments of the state, with the possible exception of the sandstones and oxidized deposits, are susceptible to spore and pollen analysis. The blue-gray clays were found to be a particularly rich source of palynological material. Analyses of sediments from various locations in the state show that these sediments were deposited during the same flora-time interval. Deviation in spore and pollen content of samples from Redwood Falls and one location in New Ulm, the Metzen farm, are interpreted as caused by ecological factors. In samples from these two areas at least one of the indicated pollen guide fossils was present. A comparison of the plant microfossils from the Cretaceous of Minnesota with plant microfossils from the Cretaceous of Europe indicates that the pre-marine Cretaceous deposits of the state are Cenomanian equivalents.

## REFERENCES AND INDEX





## REFERENCES

- Anderson, E. 1948. Hybridization of the habitat. *Evolution*. 2: 1-9.
- . 1949. Introgressive hybridization. John Wiley and Sons, New York. 109pp.
- , and G. L. Stebbins, Jr. 1954. Hybridization as an evolutionary stimulus. *Evolution*. 8: 378-388.
- Andrews, H. N., Jr. 1947. Ancient plants and the world they lived in. Comstock Publishing Co., Inc., Ithaca. 279pp.
- . 1955. Index of generic names of fossil plants, 1820-1950. U.S. Geol. Surv. Bull. 1013. 262pp.
- Arnold, C. A. 1947. An introduction to paleobotany. McGraw-Hill Book Co., Inc., New York. 433pp.
- Armstrong, T. A. 1953. New exploration tool. *Oil and Gas Jour.* 51: 64-65.
- Axelrod, D. E. 1952. A theory of angiosperm evolution. *Evolution*. 6: 29-60.
- Barghoorn, E. S. 1951. Age and environment: a survey of North American Tertiary floras in relation to paleoecology. *Jour. Paleont.* 25: 736-744.
- Baxter, R. W. 1954. The University of Kansas collection of fossil plants. I. The Dakota sandstone flora. *Trans. Kansas Acad. Sci.* 57: 41-47.
- Bergquist, H. R. 1938. The Cretaceous of the Mesabi Range. Unpub. Ph.D. thesis, Geol. Dept., Univ. of Minn. 96pp.
- Berry, E. W. 1903. The American species referred to *Thinnfeldia*. *Bull. Torrey Bot. Club.* 30: 438-445.
- . 1916. The Upper Cretaceous floras of the world. *Md. Geol. Surv., Upper Cretaceous*: 183-313.
- . 1918. Paleogeographic significance of the Cenozoic floras of equatorial America and the adjacent regions. *Bull. Geol. Soc. Amer.* 29: 631-636.
- . 1922. The flora of the Woodbine sand at Arthur's Bluff, Texas. U.S. Geol. Surv. Prof. Paper 129: 153-180.
- . 1929. A revision of the flora of the Latah formation. U.S. Geol. Surv. Prof. Paper 154: 225-265.
- . 1939. Fossil plants from the Cretaceous of Minnesota. *Jour. Wash. Acad. Sci.* 29: 331-336.
- . 1945. The origin of land plants, and four other papers. Johns Hopkins Univ. Studies in Geol. 14. 194pp.
- Blake, S. T. 1953. Botanical contributions of the northern Australia regional survey. I. Studies on northern Australian species of *Eucalyptus*. *Aust. Jour. Bot.* 1: 185-352.
- Bolin, E. J. 1954. Some Foraminifera, Radiolaria and Ostracoda from the Cretaceous of Minnesota. *Jour. Paleont.* 28: 512.
- Bolkhovitina, N. A. 1953. Caractères sporo-polliniques du Crétacé de la partie centrale de l'U.S.S.R. *Trudy Inst. Geol. Nauk. AN. SSSR.* 145 (Geol. Ser. 61). 184pp. (In Russian.)
- Boodle, L. A. 1895. Spores in a specimen of *Tempskya* (*Endogenites*). *Annals Bot.* 9: 137-141.
- Boureau, E. 1956. Paleobotanistes du monde. *Taxon.* 5(7): 168-170.
- Brown, R. W. 1950. Cretaceous plants from Western Colorado. U.S. Geol. Surv. Prof. Paper 221-D: 45-66.
- . 1956. Palm-like plants from the Dolores formation (Triassic), Southwestern Colorado. U.S. Geol. Surv. Prof. Paper 274-H: 205-209.
- Braun, E. Lucy. 1950. Deciduous forests of Eastern North America. The Blakiston Company, Philadelphia. 596pp.
- Buchholz, J. T. 1948. Generic and sub-generic distribution of the Coniferales. *Bot. Gaz.* 110: 80-91.
- Camp, W. H. 1952. Phytophyletic patterns on lands bordering the southern Atlantic basin. *Bull. Amer. Mus. Nat. Hist.* 99: 205-212.
- Cain, S. A. 1944. Foundations of plant geography. Harper and Bros., New York. 556 pp.

- Chaney, R. W. 1924. Quantitative studies of the Bridge Creek Flora. *Am. Jour. Sci.* 8:127-144.
- . 1925. Comparative study of the Bridge Creek Flora and the Modern redwood forest. *Carn. Inst. Wash. Pub.* 349. 22 pp.
- . 1954. A new pine from the Cretaceous of Minnesota and its paleoecological significance. *Ecology*. 35: 145-151.
- Cobban, W. A. and J. B. Reeside, Jr. 1952. Correlation of the Cretaceous formations of the Western Interior of the United States. *Bull. Geol. Soc. Amer.* 63: 1011-1044.
- Cookson, Isabel C. 1947. Plant microfossils from the lignites of the Kerguelen Archipelago, B.A.N.Z. Antarct. Res. Expd. (1929-1931) Rept. 2(8): 129-142.
- . 1950. Fossil pollen grains of the proteaceous type from Tertiary deposits in Australia. *Aust. Jour. Sci. Res. B.* 3:166-177.
- . 1953a. The identification of the sporomorph *Phyllocladidites* with *Dacrydium* and its distribution in southern Tertiary deposits. *Aust. Jour. Bot.* 1: 64-70.
- . 1953b. Difference in microspore composition of some samples from a bore at Coamum, South Australia. *Aust. Jour. Bot.* 1:462-473.
- . 1954. A palynological examination of No. 1 Bore, Birregurra, Victoria. *Proc. Roy. Soc. Victoria*. 66:119-128.
- . 1956. Pollen grains of the *Ephedra* type in Australian Tertiary deposits. *Nature*. 177: 47-48.
- , and Kathleen M. Pike. 1953. The Tertiary occurrence and distribution of *Podocarpus* (section *Dacrycarpus*) in Australia and Tasmania. *Aust. Jour. Bot.* 1: 71-82.
- , and O. P. Singleton. 1954. The preparation of translucent fossils by treatment with hydrofluoric acid. *Geol. Soc. Australia News Bull.* 2:1-2.
- Couper, R. A. 1953a. Distributions of Proteaceae, Fagaceae and Podocarpaceae in the Southern Hemisphere Cretaceous and Tertiary beds. *New Zealand Jour. Sci. Tech. Ser. B.* 34: 247-250.
- . 1953b. Upper Mesozoic and Cainozoic spores and pollen grains from New Zealand. *New Zealand Geol. Surv. Paleont. Bull.* 22. 77pp.
- . 1956. Evidence of a possible gymnospermous affinity for *Tricolpites troedsonii* Erdtman. *New Phytologist*. 55: 280-285.
- Cranwell, Lucy M. 1940. Pollen grains of the New Zealand conifers. *New Zealand Jour. Sci. Tech. Ser. B.* 22: 1-17.
- Croizat, L. 1952. *Manual of phytogeography*. N. V. Drukkerij. Hooiberg, Epe., Netherlands. 587pp.
- Daugherty, L. H. 1941. The Upper Triassic flora of Arizona. *Carn. Inst. Wash. Pub.* 526. 108pp.
- Dorf, E. 1952. Critical analysis of Cretaceous stratigraphy and paleobotany of the Atlantic Coastal Plain. *Bull. Amer. Assoc. Petrol. Geol.* 36: 2161-2184.
- Erdtman, G. 1943. An introduction to pollen analysis. *Chronica Botanica Company*, Waltham. 2nd ed., 239pp.
- . 1947. Suggestions for the classification of fossil and recent pollen grains and spores. *Svensk. Bot. Tidskr.* 41: 104-114.
- . 1948. Did dicotyledonous plants exist in early Jurassic times? *Geol. Foren. Forh.* 70: 265-271.
- . 1952. Pollen morphology and plant taxonomy-angiosperms. (An introduction to palynology I.) Almquist and Wiksell, Stockholm. 539pp.
- . 1957. Pollen and spore morphology — Gymnospermae, Pteridophyta, Bryophyta. (An introduction to palynology, II.) The Ronald Press, New York. 151pp.
- . 1958. On the risks of overstressing the denominations of fossil spores as illustrated by a paper on the former distribution of *Lophosoria* ("*Cyathea annulata*"). *Svensk. Bot. Tidskr.* 51: 611-613.
- Faegri, K. 1956. Recent trends in palynology. *Bot. Rev.* 22: 639-664.
- , and J. Iversen. 1950. Text-book of modern pollen analysis, Ejnar Munksgaard. Copenhagen. 168pp.
- Fernald, M. L. 1950. *Gray's manual of botany*. American Book Company, New York. 8th ed., 1, 632pp.
- Firtion, F. 1952. Le Cenomanian inférieur du Nouvion-en-Thierache; examen micro-paléontologique. *Ann. Soc. Geol. Nord. Lille.* 72: 150-164.
- Florin, R. 1936. On the structure of the pollen grains in the Cordaitales. *Svensk. Bot. Tidskr.* 30: 624-651.

- Fontaine, W. M. 1889. The Potomac or younger Mesozoic flora of Virginia. U.S. Geol. Surv. Mono. 15. 377pp.
- Foreman, F. 1955. Palynology in Southern North America. Part II: Study of two cores from lake sediments of the Mexico City Basin. Bull. Geol. Soc. Amer. 66: 475-510.
- Fritzsche, C. J. 1837. Ueber den Pollen. Mem. Sav. Etrang. Acad. St. Petersburg. 3: 649-672.
- Fries, M. 1953. Notiser: A pre-Quaternary pollen found in post-glacial clay mud at Varnhem in Vastergotland. Sweden. Geol. Foren. Forh. 75: 106-108.
- , and N. E. Ross. 1950. Pre-Quaternary pollen grains and spores found in late-glacial and post-glacial clays in Bohuslan, southwestern Sweden. Ark. Min. Geol. 1: 199-210.
- Funkhouser, J. W., and W. R. Evitt. 1959. Preparation techniques for acid insoluble microfossils. Micropaleontology. 5(3): 369-375.
- Good, R. 1953. The geography of the flowering plants. Longmans, Green and Company, New York. 2nd ed., 452pp.
- Gordon, H. D., 1949. The problem of sub-Antarctic plant distribution. Report Aust. and New Zealand Assoc. Adv. Sci. (Hobart meeting): 142-149.
- Grayson, J. F. 1956. The conversion of calcite to fluorite. Micropaleontology. 2: 71-78.
- Grout, F. F. 1919. Clays and shales of Minnesota. U.S. Geol. Surv. Bull. 678. 259pp.
- Guennel, G. K. 1956. Systematic methods for Paleozoic plant microfossils. Micropaleontology. 2: 393-395.
- Harris, T. M. 1935. The fossil flora of Scoresby Sound, East Greenland. Part 4: Ginkgoales, Coniferales, Lycopodiales and isolated fructifications. Medd. Om Grøn. 112: 1-176.
- Hawn, F. 1858. The Trias of Kansas. Trans. St. Louis Acad. Sci. 1: 171-172.
- Heer, O. 1859. Descriptions of fossil plants from No. 1 of the Nebraska section. Phil. Acad. Nat. Sci. Proc. 10: 265-266.
- Heiser, C. B., Jr. 1949. Natural hybridization with particular reference to introgression. Bot. Rev. 15: 645-687.
- Hoffman, Elise. 1948. Das Flyschproblem im Lichte der Pollenanalyse. Phytion. 1: 80-101.
- . 1950. Pollenkorner im Oberkreideflysch von Muntigl bei Salzburg, in Pre-Quaternary pollen grains and spores. Proc. 7th International Botan. Cong. Stockholm: 886-887.
- Hoffmeister, Wm. S. 1954. Microfossil prospecting for petroleum. U.S. Patent No. 2,686,108. 4pp.
- , and F. L. Staplin. 1955. Additions and corrections to "Geologic range of Paleozoic plant spores in North America." Micropaleontology. 1: 381-382.
- Howell, R. H., Jr. 1954. Pollen and spore floras from the Laramie formation, Jefferson County, Colorado Abstract. Bull. Geol. Soc. Amer. 65: 1378.
- Ibrahim, Ahemdjan. 1933. Sporenformen des Aegirhorizonts des Ruhr-Reviers. Dissertation, Technischen Hochschule zu Berlin. Privately pub. by Konrad Triltsch, Würzburg. 48pp.
- International Code of Botanical Nomenclature. 1956. J. Lanjouw, editorial chairman. Eighth International Botanical Congress, Paris, July, 1954.
- Iversen, J., and J. Troels-Smith. 1950. Pollenmorphologiske definitioner og typer. Danmarks Geol. Unders. IV. Raekke. 3: 1-54.
- Just, T. 1951. Mesozoic plant microfossils and their geologic significance. Jour. Paleont. 25: 729-735.
- . 1957. Fifty years of paleobotany. Am. Jour. Bot. 44: 93-99.
- Kirchheimer, F. 1932. On pollen from the Upper Cretaceous Dysodil of Banke, Namaqualand (South Africa). Trans. Roy. Soc. South Africa. 21: 171-191.
- Klaus, W. 1953. Palynology of coal, salt and oil in Austria. The Micropaleontologist. 7: 28-30.
- Kloss, J. H. 1872. A Cretaceous basin in the Sauk Valley, Minnesota. Amer. Jour. Sci., 3rd ser. 3: 17-26.
- Knox, Elizabeth M. 1938. The spores of Pteridophyta, with observations on microspores in coals of Carboniferous age. Trans. and Proc. Botan. Soc. Edinburgh. 32: 438-466.
- . 1951. Spore morphology in British ferns. Trans. and Proc. Botan. Soc. Edinburgh. 35: 437-449.
- Kosanke, R. M. 1947. Plant microfossils in the correlation of coal beds. Jour. Geol. 55: 280-284.
- . 1950. Pennsylvanian spores of Illinois and their use in correlation. Ill. State Geol. Surv. Bull. 74. 128pp.
- Kremp, G. 1949. Pollenanalytische Untersuchung des miozänen Braunkohlenlagers von Konin an der Warthe. Palaeontographica. 90(B): 53-93.

- Krutzsch, W. 1957. Sporen- und pollengruppen aus der Ober-Kreide und dem Tertiär Mitteleuropas und ihre stratigraphische verteilung. *Zeit. Angewandte Geologie*. 3: 509-548.
- Kuyl, O. S., J. Muller, and H. T. Waterbolk. 1955. The application of palynology to oil geology with reference to western Venezuela. *Geologie en Mijnbouw* nr. 3., N.S. 17: 49-76.
- Lakhanpal, R. N., and P. K. K. Nair. 1956. Some abnormal pollen grains of *Picea smithiana* Boiss. *Jour. Indian Botan. Soc.* 35: 426-429.
- Lawrence, G. H. M. 1951. *Taxonomy of vascular plants*. The Macmillan Company, New York. 823pp.
- Lesquereux, L. 1868. On some Cretaceous fossil plants from Nebraska. *Amer. Jour. Sci. and Arts.* 46: 91-104.
- . 1874. Contributions to the fossil flora of the Western Territories. Part I. The Cretaceous flora. *U.S. Geol. Surv. of the Territories*. 6: 1-136.
- . 1892. The flora of the Dakota group. *U.S. Geol. Surv. Mono.* 17: 1-400.
- . 1893. Cretaceous fossil plants from Minnesota. *Geol. and Nat. Hist. Surv. of Minnesota*. 3: 1-22.
- Li, H. 1952. Floristic relationships between Eastern Asia and Eastern North America. *Trans. Amer. Phil. Soc.*, N.S. 42: 371-429.
- . 1953. Present distribution and habitats of the conifers and taxads. *Evolution*. 7: 245-261.
- Luber, A. A. 1939. The correlation by means of spores of coal-bearing Upper Paleozoic deposits of the Kusnetsk and Minussinsk Basins. *Bulletin de l'Academie des Sciences de L'URSS. Serie Géologique* No. 6: 88-104. (In Russian with a two-page English summary.)
- McGill, G. E. 1955. The geology of the Elbern and Judson open pit mines, with special reference to the Cretaceous. Unpub. M.S. thesis, Geol. Dept., Univ. Minn. 73pp.
- McQueen, D. R. 1954. Revision of supposed Jurassic angiosperms from New Zealand. *Nature*. 175: 177-178.
- . 1956. Leaves of middle and Upper Cretaceous pteridophytes and cycads from New Zealand. *Trans. Roy. Soc. New Zealand*. 84: 673-685.
- Meek, F. B., and F. V. Hayden. 1856. Descriptions of new species of Gastropods from the Cretaceous formations of Nebraska Territory. *Phil. Acad. Nat. Sci.* 8: 63-69.
- . 1858. Remarks on the Lower Cretaceous of Kansas and Nebraska, together with descriptions of some new species of Carboniferous fossils from the valley of Kansas River. *Phil. Acad. of Nat. Sci. Proc.* 10: 256-260.
- Miner, E. L. 1932. Megaspores ascribed to *Selaginellites*, from the Upper Cretaceous coals of Western Greenland. *Jour. Wash. Acad. Sci.* 22: 497-506.
- . 1935. Paleobotanical examinations of Cretaceous and Tertiary coals. Part I. Cretaceous coals from Greenland. Part II. Tertiary coals from Montana. *Amer. Midl. Nat.* 16: 585-625.
- Morgan, P. G. 1922. Notes on the geology of New Zealand. *New Zealand Jour. Sci. Tech.* 5: 46-57.
- Muller, J. 1959. Palynology of Recent Orinoco Delta and Shelf sediments. *Micropaleontology*. 5: 1-32.
- Naumova, S. N. 1937. Spores and pollen of the coals of the U.S.S.R. (English trans. by A. S. Brashina.) 17th Int. Geol. Cong., Moscow. 1: 354-364.
- Newberry, J. S. 1860. Notes on the ancient vegetation of North America. *Am. Jour. Sci.* ser. 2. 29: 208-219.
- Norem, W. L. 1954. Classification of spores and pollen for paleontologic classification. *Jour. Sed. Petrol.* 24: 143-144.
- Pant, D. D. 1954. Suggestions for the classification and nomenclature of fossil spores and pollen grains. *Bot. Rev.* 20: 33-60.
- Penny, J. S., and J. J. Groot. 1959. Plant microfossils and age of nonmarine Cretaceous sediments of Maryland and Delaware (abstract). *Bull. Geol. Soc. Amer.* 70 (12-2): 1655.
- Pflug, H. D. 1953. Zur Entstehung und Entwicklung des angiospermiden Pollens in der Erdgeschichte. *Palaeontographica*. 95(B): 60-171.
- Pierce, R. L. 1957. Minnesota Cretaceous pine pollen. *Science*. 125: 26.
- . 1959. Converting coordinates for microscope-stage scales. *Micropaleontology*. 5: 377-378.
- Potonié, R. 1931. Pollenformen aus Tertiären Braunkohlen. *Jahr. Preuss. Geol. Landesanstalt*. 52: 1-7.
- . 1934. Sur Mikrobotanik des eozänen Humodils des Geiseltales. *Arb. Inst. Paläob. u. Petr. Brennsteine* 4, Preuss. Geol. L.A.: 26-125.

- . 1951. Revision stratigraphisch wichtiger sporomorphen des mitteleuropäischen Tertiärs. *Palaeontographica*. 91(B):131-151.
- . 1952. Zur Systematik isolierter Sporen fossiler Pflanzen. Bemerkung zu den Besprechungen auf der tagung der paläontologischen Gesellschaft in Grier 1951, in *Palynology. Aspects and prospects*. III. *Svensk. Bot. Tidskr.* 46:158-173.
- , and J. Gelletich. 1932. Über Pteridophytensporen einer eocänen Braunkohle aus Dorog, Ungarn. *Sitz-Berlin Ges. Naturf. Freunde*: 517-528.
- , and G. Kremp. 1955a. Die Gattungen des paläozoischen Sporae dispersae und ihre Stratigraphie. *Geol. Jahrb.* 69:111-194.
- , and G. Kremp. 1955b. Die Sporae dispersae des Ruhrkarbons, ihre Morphographie und Stratigraphie mit Ausblicken auf Arten anderer gebiete und zeitschnitte. Teil I. *Palaeontographica*. 98(B):1-136.
- , P. W. Thomson, and F. Thiergart. 1950. Zur Nomenklatur and Klassifikation der neogenen Sporomorphae (Pollen and Sporen). *Geol. Jahrb.* 65:35-69.
- Radforth, N. W., and D. C. McGregor. 1954. Some plant microfossils important to pre-Carboniferous stratigraphy and contributing to our knowledge of the early floras. *Can. Jour. Bot.* 32:601-621.
- , and G. E. Rouse. 1954. The classification of recently discovered Cretaceous plant microfossils of potential importance to the stratigraphy of Western Canada coals. *Can. Jour. Bot.* 32:187-201.
- , and G. E. Rouse. 1956. Floral transgressions of major geological time zones. *Trans. Roy. Soc. Can. (ser. 3, sec. V)*. 1:17-26.
- Raistrick, A. 1934. The correlation of coal seams by microspore content. Part I—the seams of Northumberland. *Inst. Min. Eng. Trans. London*. 88:142-153.
- . 1935. The microspore analysis of coal. *Naturalist*. 1935:145-510.
- . 1937. The microspores of coal and their use in correlation. *Congrès pour l'avancement des études de stratigraphie carbonifère, Heerlen, 1935*. 2:909-917.
- , and J. Simpson. 1933. The microspores of some Northumberland coals, and their use in the correlation of coal seams. *Inst. Min. Eng. Trans. London*. 85:225-235.
- Reissinger, A. 1950. Die "Pollenanalyse" ausgedehnt auf alle Sedimentgesteine der geologischen Vergangenheit II. *Palaeontographica*. 90(B):99-126.
- Rogalska, Maria. 1954. Analiza sporowo-pylkowa Liasowego weyla Blanorwiewickiego Z gornego Slaska. *Instytut Geologiczny Biuletyn*. 89:1-46. (In Polish with an English summary.)
- Ross, N. E. 1949. On a Cretaceous pollen and spore bearing clay of Scania. *Bull. Geol. Instn. Univ. Upsala*. 34:25-43.
- Rouse, G. E. 1956. The disclosure and paleobotanical evaluation of plant microfossils from selected Cretaceous coal-bearing strata of Canada. Unpub. Ph.D. thesis, McMaster University, Hamilton, Ontario, Canada. 304pp.
- . 1957. The application of a new nomenclatural approach to Upper Cretaceous plant microfossils from Western Canada. *Can. Jour. Bot.* 35:349-375.
- Rubel, E. 1936. Plant communities of the world, in *Essays in geobotany*, T. H. Goodspeed, ed., Univ. Calif. Press, Berkeley:263-290.
- Rudolf, K. 1935. Mikrofloristische Untersuchung tertiärer Ablagerungen im nördlichen Böhmen. *Beihefte zum Botanischen Centralblatt*. 54(B):244-328.
- Sardeson, F. W. 1908. Geological history of the Redstone Quartzite. *Bull. Geol. Soc. Amer.* 19:221-242.
- Sarmiento, R. 1957. Microfossil zonation of Mancos group. *Bull. Amer. Assoc. Petrol. Geol.* 41:1683-1693.
- Schemel, M. P. 1950. Cretaceous plant microfossils from Iowa. *Amer. Jour. Bot.* 37:750-754.
- Schopf, J. M., L. R. Wilson, and R. Bentall. 1944. An annotated synopsis of Paleozoic fossil spores and the definition of generic groups. *Ill. Geol. Surv. Rept. Inv.* 91. 72pp.
- Scott, R. A., E. S. Barghoorn, and Estella B. Leopold. 1960. How old are the angiosperms? *Am. Jour. Sci., Bradley Volume*. 258-A:284-289.
- Selling, O. H. 1946. Studies in Hawaiian pollen statistics. Part I. The spores of the Hawaiian Pteridophytes. *Bernice P. Bishop Museum Special Pub.* 37, Honolulu. 87pp.
- Seward, A. C. 1914. Antarctic fossil plants. *British Antarctic (Terra Nova) expedition, 1910. Geology* 1:1-49.
- . 1931. *Plant life through the ages*. The Macmillan Company, New York. 601pp.
- Simpson, G. G. 1944. *Tempo and mode in evolution*. Columbia University Press, New York. 237pp.

- . 1953. The major features of evolution. Columbia University Press, New York. 434pp.
- Simpson, J. B. 1936. Fossil pollen in Scottish Tertiary coals. *Proc. Roy. Soc. Edinburgh.* 56: 90-108.
- Sittler, C. 1954a. Présence de formes polliniques dans quelques sédiments du Kimmeridgien en France. *C. R. Somm. Soc. Geol. France.* 13: 338-341.
- . 1954b. Palynologie et stratigraphie. Principe et application de l'analyse des pollens aux études de recherches du pétrole. *Rev. Inst. François Pétrol.* 9: 367-375.
- Sohn, I. G. 1956. The transformation of opaque calcium carbonate to translucent calcium fluoride in fossil ostracoda. *Jour. Paleont.* 30: 113-114.
- Spangler, W. B., and J. J. Peterson. 1950. Geology of the Atlantic Coastal Plain in New Jersey, Delaware, Maryland and Virginia. *Bull. Amer. Assoc. Petrol. Geol.* 34: 1-99.
- Stauffer, C. R., and G. A. Thiel. 1941. Paleozoic and related rocks of southeastern Minnesota. *Minn. Geol. Surv. Bull.* 29. 261pp.
- Steeves, Margaret Wolfe. 1959. The pollen and spores of the Raritan and Magothy formations (Cretaceous) of Long Island. Unpubl. Ph.D. Thesis, Radcliffe College, Depart. Biol., Cambridge, Mass.
- Stephenson, L. W., P. B. King, W. H. Monroe, and R. W. Imlay. 1942. Correlation of the out-cropping Cretaceous formations of the Atlantic and Gulf Coastal plains and Trans-Pecos Texas. *Bull. Geol. Soc. Amer.* 53: 435-448.
- Suggate, R. P., and R. A. Couper. 1952. The stratigraphic relations and plant microfossils of New Zealand coal measures. *New Zealand Jour. Sci. Tech. Ser. B.* 29: 32-35.
- Swallow, G. C., and F. Hawn. 1858. The rocks of Kansas. *Trans. St. Louis Acad. Sci.* 1: 173-197.
- Tester, A. C. 1931. The Dakota stage of the type locality. *Iowa Geol. Surv. Ann. Rept.* 35: 200-332.
- Thiergart, F. 1940. Die Mikropalaontologie als Pollenanalyse im Dienst der Braunkohlenforschung. *Schr. aus dem Gebiet der Brennstoff-Geologie* 13. 48pp.
- . 1949. Der Stratigraphische wert mesozoischer Pollen and Spores. *Palaeontographica.* 89(B): 1-33.
- . 1953. Über einige Sporen und Pollen der Perutzer Schichten (Bohem.). *Palaeontographica.* 95(B): 53-59.
- . 1954. Einige Sporen and Pollen aus einer Cenomankohle Südfrankreichs und Vergleiche mit gleichhaltigen Ablagerungen. *Geologie.* 3(H5): 548-559.
- Thomson, P. W., and H. Pflug. 1953. Pollen und Sporen des mitteleuropäischen Tertiärs. *Palaeontographica.* 94(B): 1-138.
- Traverse, A. 1955. Pollen analysis of the Brandon lignite of Vermont. *U.S. Bureau of Mines, Report Invest.* 5151. 107pp.
- . 1956. Systematic methods for Mesozoic and Cenozoic plant microfossils. *Micro-paleontology.* 2: 396-398.
- Van der Hammen, Th. 1954. Principios para la nomenclatura palinologica sistematica. *Boletin Geologico, Colombia.* 2: 3-24.
- . 1956a. A palynological systematic nomenclature. *Boletin Geologico, Colombia.* 4: 63-101.
- . 1956b. Description of some genera and species of fossil pollen and spores. *Boletin Geologico, Colombia.* 4: 111-117.
- Vokes, H. E. 1948. The stratigraphy, paleontology and sedimentology of three deep test wells on the eastern Shore of Maryland; in *Cretaceous and Tertiary subsurface geology.* J. L. Anderson, ed. Maryland Dept. Geol., Mines and Resources Bull. 2: 126-151.
- Wetzel, O. 1933. Die in organischer substans erhaltenen mikrofossilien des baltischen Kreide-feuersteins. *Palaeontographica.* 77: 147-186; 78: 1-110.
- Weyland, H., and G. Greifeld. 1953. Über strukturbietende Blätter und pflanzliche Mikrofossilien aus den Untersenonen Tonen der gegend von Quedlinburg. *Palaeontographica.* 95(B): 30-52.
- , and W. Krieger. 1953. Die Sporen und Pollen der Aachener Kreide und ihre Bedeutung für die Charakterisierung des mittleren Senon. *Palaeontographica.* 95(B): 30-52.
- White, A. 1955. Carter makes available patent on microfossils. *The Tulsa Tribune.* Tues., Aug. 16, 1955. p. 27.
- Willis, J. C. 1948. Dictionary of flowering plants and ferns. Cambridge University Press, Cambridge. 6th ed. 804pp.
- Wilmarth, M. Grace. 1938. Lexicon of geological names of the United States. *U.S. Geol. Surv. Bull.* 896. 2,396pp.

- Winchell, N. H., and W. Upham. 1884. The geology of Minnesota. Geol. and Nat. Hist. Surv. Minn. Final Rept. I. 697pp.
- Wilson, L. R. 1946. The correlation of sedimentary rocks by fossil spores and pollens. Jour. Sed. Petrol. 16: 110-120.
- , and E. A. Coe. 1940. Descriptions of some unassigned plant microfossils from the Des Moines series of Iowa. Amer. Midl. Nat. 23: 182-186.
- , and Ruth M. Webster. 1944. Microfossil studies of three north-central Wisconsin bogs. Trans. Wis. Acad. Sci. Arts and Letters. 34: 177-193.
- , and W. S. Hoffmeister. 1952. Small foraminifera. The Micropaleontologist. 6: 26-28.
- , and W. S. Hoffmeister. 1956. Plant microfossils of the Croweburg Coal. Oklahoma Geol. Surv. Circ. 32. 57pp.
- Wodehouse, R. P. 1933. Oil shales of the Green River formation. Bull. Torrey Bot. Club. 60: 479-524.
- . 1935. Pollen grains. McGraw-Hill Book Co., Inc., New York. 574pp.
- . 1936. Evolution of pollen grains. Bot. Review. 2: 67-84.
- Woods, R. D. 1955. Spores and pollen — a new stratigraphic tool for the oil industry. Micropaleontology. 1: 368-375.
- Zetzsche, F. and O. Kälín. 1931. Untersuchungen über die Membran der Sporen und Pollen V. 4. Zur Autooxydation der Sporopollenine. Helv. Chim. Acta. 14: 517-519.

## INDEX

- Abietoideae, 39  
*Acer*, 58  
 Adiabatic lapse rate: relief calculated from, 59-60, 72  
*Aesclepias*: leaves of, 12  
*Alnus*, 58; pollen from Andes, 61-62  
*Alternaria*: contamination, 9  
*Ambrosia*: contamination, 9  
 Ammonites: recognition of Cretaceous by, 1  
 Andes: *Alnus* pollen from, 62  
*Anemia elegans*, 31  
 Angiosperm evolution, 61-64  
 Angiosperms: pre-Upper Cretaceous pollen of, 3; palynological record of, 61-63, 70; overrepresentation of pollen, 68; in evolution of floras, 71  
*Anulatisporites*, 25  
*Apiculatisporites*, 14  
*Appendicisporites triceps*, 31  
*Aralia*, 60  
*Araliopsis*: similarity to *Sassafras*, 16  
 Archean rocks: kaolinization of, 2  
 Arundel formation, 65  
  
*Bacubivesiculites*: described, 22, 34; *inchoatus*, type for genus, 22, 34  
*Bacuinaperturites*: described, 22, 42; *setosus*, type for genus, 22, 42  
*Bacumonoporites*: described, 23, 45; *baculatus*, type for genus, 23, 45  
*Bacutricolpites*: described, 24, 48; *constrictus*, 48; *magnus*, type for genus, 24, 48  
 Barghoorn's curve, 10  
 Bennettitales, 29  
 Benton sea: and Dakota sandstone flora, 54; 59, 71  
 Betulaceae, 61  
 Big Cottonwood formation, 1  
 Brandon flora: working hypothesis for, 17  
 Brandon lignite, 1, 17, 70, 71  
 Brazeau formation: sporomorphs in, 3  
 Brevaxones: oblate pollen class, 15  
 Bridge Creek flora, 59  
 Brown County: section descriptions, 5, 7; 70  
 Bryophyta: sporomorphs from Greenland, 2; 26, 56, 70, 71  
*Bucklandia*, 51  
 Buhl, Minnesota: Cretaceous exposed at, 2  
*Bumelia*, 58  
  
*Camarozonotriletes*, 26  
  
*Castanea insleyana*, 53  
 Castanoideae, 53  
 Celastraceae, 52  
*Celastrus*, 52  
*Chenopodium*: contamination, 9  
*Cicatricosisporites pseudorogensis*, 32  
*Cingutriletes*: described, 20, 25; *congruens*, type for genus, 20, 25; *densocingulatus*, 26; *interruptus*, 26; *parvicingulus*, 26, *trijugatus*, 26  
*Cissites*: similarity to *Sassafras*, 16  
*Clavabivesiculites*: described, 22, 34; *inchoatus*, type for genus, 22, 34; *pannosus*, 35  
*Clavatetradites*, 18  
*Clavatricolpites*: described, 24, 48; *firmus*, 48; *prolatus*, type for genus, 24, 48  
 Climate, 59, 72  
 Coal balls: number of species from, 13  
 Cobb's Creek: samples from, 5; section description, 7; 68, 70  
 Coniferae, 34, 35, 36, 38, 42, 46, 56, 70  
 Conifers: importance in Cretaceous, 58-59  
*Corrugatisporites toratus*, 31  
*Corylopsis*, 50  
*Corylus*, 2  
 Couper-Cookson school: nomenclatural procedure, 16  
 Cupressaceae, 57  
 Cyathaceae, 26  
 Cycadaceae, 47, 56, 57, 70, 71  
 Cycadineae, 47  
*Cyrilla*, 17  
  
*Dacrydium*, 16, 18, 38, 39, 40, 56, 57  
*Dacrydiomites*, 14; and *Phyllocladidites*, 16  
 Dakota formation: Big Cottonwood formation equivalent to, 2; sporomorphs at type locality, 3; disputed age of, 54; leaf impressions in, 54  
 Dakota group, 70  
 Dakota sandstone flora: described, 54; climatic interpretations from, 59-61; floristic comparisons made from, 59-61; and angiosperm evolution, 63  
*Deltoideospora*, 14; *cascadensis*, 28  
 Dicotyledoneae, 34, 45, 48, 49, 50, 51, 52, 53, 56, 70  
 Dinoflagellates, 66  
*Dioon*, 47, 56  
*Disaccites*: *elliptica*, 36; *Mawsoni*, 38; *Ruei*, 35  
*Dryopteris goggilodus*, 33



- Ektexine: morphology of, 19-20  
 Enterprise Mine: Cretaceous exposed at, 2;  
   samples from, 5; section description, 7  
*Endosporites*, 18  
*Ephedra*, 45, 64; *strobilacea*, 45  
 Ephedraceae, 56, 57, 70, 71  
 Equisetaceae, 44  
 Erdtman's classification system, 14  
*Ericaceae-pollenites*, 13  
*Eucalyptus*, 63, 64  
*Eucalyptus* Typ., 14  
*Euonymous*, 52  
 Evolution, of angiosperms, 61-64, 71
- Fagaceae, 15, 49, 50, 52, 57, 71  
*Farama cuspidata*, 63  
*Ficophyllum*, 64  
*Ficus*: and leaf impressions, 12  
 Filicineae: sporomorphs in Greenland, 2; 26,  
   28, 31, 32, 33, 43, 56, 70  
 Floerup farm: section description, 7  
 Flora, of Cretaceous: predominance of coni-  
   fers in, 58-59  
 Flora, of Northern Hemisphere: affinity of  
   Cretaceous flora to, 56  
 Fluorite: calcite transformation to, 8  
 Fort Creek: section description, 7  
 Fort Ridgely: section description, 7; 65  
*Foveinaperturites*: described, 22, 42; *fora-*  
*meniferus*, type for genus, 22, 43; *pauci-*  
*punctatus*, 43; *scaphoformis*, 43  
*Foveotricolpites*: described, 24, 49; *sphae-*  
*roides*, type for genus, 24, 49  
*Foveotricolporites*: described, 24, 52; *rhom-*  
*bohedralis*, type for genus, 24, 52  
*Foveotriletes*: described, 20, 26; *triplanus*,  
   type for genus, 20, 27
- Gemmainaperturites*: described, 22, 43; *gem-*  
*matus*, type for genus, 23, 43; *rugosus*, 43  
*Gemmamonoletes*: described, 21, 33; *gem-*  
*matus*, type for genus, 21, 33  
*Gemmatricolpites*: described, 24, 49; *pro-*  
*latus*, type for genus, 24, 49  
*Gemmatriletes*: described, 20, 27; *morulus*,  
   type for genus, 20, 27  
 German school: nomenclatural procedure, 16  
*Gleichenia*, 56; *circinidites*, 26; *linearis*, 27  
 Gleicheniaceae, 26, 27, 56  
 Gnetales, 45, 64  
*Granabivesiculites*: described, 22, 35; *cingu-*  
*laris*, 35; *constrictus*, 36; *inchoatus*, type  
   for genus, 22, 35; *latus*, 36; *tuberosus*, 35  
*Granamonocolpites*: described, 23, 46; *asym-*  
*metricus*, type for genus, 23, 46, 47  
*Granamultivesiculites*: described, 22, 41; as  
   guide fossil, 67; *inchoatus*, type for genus,  
   22, 41  
*Granatrivesiculites*: described, 22, 41; *du-*  
*bius*, type for genus, 22, 41  
 Great Plains: leaf impressions from, 54
- Green River shales, 13  
*Guaiacum sanctum*, 15  
 Gymnospermae, 43, 44, 46, 47, 48
- Hansen, Agnes, 9, 11  
 Hamamelidaceae, 50, 51, 57, 71  
 Hamamelidoideae, 57  
*Hamamelis*, 50, 56, 71; *vernalis*, 50, 51  
 Hystrichosphaerids, 66
- Inaperturatae, 19, 22, 42-45  
*Inaperturo-pollenites: globulus*, 44; *magnus*,  
   44  
*Intratrirporopollenites*, 15, 16
- Jacob farm: section description, 8  
 Juglandales, 61  
*Juglans*, 58
- Kalb Creek. See Cobb's Creek  
 Kootenai formation: sporomorphs in, 3  
 Kosanke, R. M., 10, 11
- Laevigatisporites neddeni*, 28; ssp. *irregularis*,  
   28; ssp. *torus*, 27  
*Laricopollenites magnus*, 44  
 Laurisilvae: conifer rain forest classified in,  
   59  
*Laurus*, 58  
 Lawrence, D. B., 10  
 Leaf form: stability of, 63  
 Leaf impressions: in Dakota sandstone, 54;  
   from New Ulm, 55; climate deduced  
   from, 59; and palynological record, 61  
*Leptostrobus longus*, 39  
*Libocedrus*, 44  
*Libumella*, 47  
 Liliaceae, 56, 57  
*Liliacidites*, 14, 18, 47  
*Liriodendron*, 60  
*Lithocarpus*, 53, 56, 57, 71; *densiflora*, 53  
 Lycopodiaceae, 29, 30, 31, 32, 56, 71  
*Lycopodium*, 56; *annotinum*, 29; *inundatum*,  
   30  
 Lycopsidea, 56, 70  
 Lyon County, 2
- Magnolia*, 47, 56, 57, 60, 71; *virginiana*, 47  
 Magnoliaceae, 47, 57, 71  
 Marine sediments: palynological identifica-  
   tion of, 66  
 Menispermaceae, 51, 57, 71  
*Menispermum*, 51, 56, 60, 71; *canadense*, 51  
 Mentor formation, 54  
 Mesabi Iron Range: samples from, 5  
 Metzen farm: section description, 5; sam-  
   ples from, 68; 69, 72  
*Microcycas*, 47, 56  
 Microfauna: Niobrara age of, 2  
 Microforaminifera, 66  
*Mohria*, 31

- Mohriospirites*: *australiensis*, 31; *dorogensis*, 31
- Monocolpatae, 23, 46-48
- Monocotyledoneae, 47, 56, 70, 71
- Monoletes, 21, 33-34
- Monoporatae, 23, 45-46
- Morton gneiss: decomposed dikes of, 7
- Myrica*, 2
- Myricales, 61
- New Ulm, Minnesota: clay seams, 1; section descriptions, 5, 7; leaf impressions from, 55; 67, 72
- Nicollet County: section description, 7
- Niobrara deposits: microfauna in, 2; age relationship, 67
- Niobrara sea, 59, 71
- Niobrara time: transgressions during, 66
- Nomenclature: morphology in, 13
- Nomenclatural systems: development of, 13; artificial, 14, 16, 17; of Erdtman, 14; half-natural, 15; German school, 16; Couper-Cookson school, 16; Traverse school, 16; of Van der Hammen, 17, 19
- Nothofagus*, 64
- Nymphaeaceen* Typ., 14
- Nyssaceoidae*, 15
- Ochs Brick and Tile Company, 6, 67, 69
- Oliver Mining Company: Enterprise Mine of, 7
- Orinoco delta: *Alnus* pollen in, 62
- Osmunda*, 56; *regalis*, 30
- Osmundaceae, 30, 56
- Paleoclimatology, of Dakota stage, 60
- Paliurus*, 60
- Palynological record: and leaf impression record, 61, 71; angiosperms in, 61-63
- Paparoa beds, 62
- Parthenocissus quinquefolia*: contamination, 7
- Patapsco formation, 65
- Patuxent formation, 64, 65
- Perotrites*, 25; *granulatus*, 25
- Phyllocladidites*, 16, 17; *Mawsoni* (or *mawsonii*), 16, 17, 38; *Ruei*, 35
- Phyllocladoideae, 42
- Phyllocladus*, 35, 38, 56
- Phytogeography, 56-57
- Picea*, 37, 38, 39, 56, 57
- Pinaceae, 2, 39, 40, 44, 57, 71
- Pinus*, 35, 37, 41, 56, 57, 64, 71; *haploxyylon*, 38; *resinosa*, 36, 59, 71, 72; *resinosipites*, 36; *silvestris*, 36, 37; *strobilus*, 9
- Pityosporites*: *labdacus*, 36; *microalatus*, 37
- Platanaceae, 51, 57, 71
- Platanus*: similarity to *Sassafras*, 16; *occidentalis*, 51; 51, 56, 57, 60, 71
- Platycerium*, 2
- Podocarpaceae, 39, 40, 41, 56, 71
- Podocarpaceen*, 36
- Podocarpidites*: *biformis*, 38; *elliptica*, 36
- Podocarpoideae, 37, 38
- Podocarpus*, 10, 36, 38, 56, 64, 71; *spicatus*, 36
- Pollen. See Sporomorphs
- Pollenites, 13, 21-24, 34-53; *reclusus*, 62
- Polypodiaceae: contamination, 9; 27, 33, 34
- Polypodiites senonicus*, 34
- Populus*, 45
- Potomac group, 65, 66
- Proteaephyllum*, 64
- Protophyllocladus*, 55, 71
- Pseudotsuga*, 44
- Psilainaperturites*: described, 23, 44; *psilatus*, type for genus, 23, 44
- Psilatricolpites*: described, 24, 49; *incompitus*, type for genus, 24, 49; *psilatus*, 49; 14, 18
- Psilatricolporites*: described, 24, 53; *inornatus*, type for genus, 24, 53; *prolatus*, 53
- Psilatriteles*: described, 20, 27; *excelsus*, 27; *guadensis*, type for genus, 20, 27; *vitreus*, 28; *vulgaris*, 27
- Pteridosperms, 29
- Pterocarya*, 62
- Punctabivesiculites*: described, 22, 37; *contractus*, type for genus, 22, 37; *crassus*, 37; *inchoatus*, 37; *parvus*, 37; *radiatus*, 37; *tenuis*, 38; 18
- Punctainaperturites*: described, 23, 44; *scaber*, type for genus, 23, 44
- Punctatisporites*, 43; *mundus*, 28; *punctus*, 28; *quaesitus*, 43
- Punctanonocolpites*: described, 23, 47; *sca-phoformis*, type for genus, 23, 47
- Punctamultivesiculites*: described, 42; as guide fossil, 67; *fimbriatus*, type for genus, 42; *inchoatus*, 42
- Punctatricolpites*: described, 24, 50; *brevis*, type for genus, 24, 50
- Punctatriteles*: described, 20, 28; *magnimundus*, type for genus, 21, 28; *parvimumundus*, 28
- Queroide*, 3
- Quercus*, 52, 56, 57, 71; *ilex*, 49; *laurifolia*, 50, 52
- Raistrickia*: 14, 18
- Raritan formation, 64, 65, 66
- Redwood County, 2
- Redwood Falls, Minnesota: section description, 6; 67, 68, 69, 72
- Retibivesiculites*: described, 22, 38; *concors*, 39; *fatulus*, 38; *oppositus*, 39; *parvus*, type for genus, 22, 38; *planus*, 39
- Reticulatisporites*, 13; *potonieii*, 39; *reticulocingulum*, 29
- Retimonocolpites*: described, 23-24, 47; *dividius*, type for genus, 24, 47; *fragilis*, 47

- Retimonoletes*: described, 21, 33; *foveolatus*, type for genus, 21, 33
- Retitetradites*: described, 21–22, 34; *monocolpatus*, type for genus, 22, 34
- Retitricolpites*: described, 24, 50; *foveoloides*, 52; *minutus*, 51; *oblatoides*, 50; *ornatus*, type for genus, 24, 50; *pannosus*, 51; *patens*, 51; *prolatus*, 51; *sphaeroides*, 50; *truncus*, 51; *vulgaris*, 50
- Retitriteles*: described, 21, 29; *anulatus*, 29, 67; *globosus*, type for genus, 21, 29; *pluricellulus*, 29; *triradius*, 30; *varius*, 29
- Retitrivesitriteles*, 18
- Rhizophoraceae, 2
- Rhus*, 60
- Richmond, Minnesota, 1
- Rogersia*, 64
- Rubiaceae, 63
- Rugubivesiculites*: described, 22, 39–40; as guide fossil, 67, 69, 72; *convolutus*, type for genus, 18, 22, 39; *floridus*, 40; *fluens*, 40; *multiplex*, 40; *reductus*, 41; *rugosus*, 40
- Ruguinaperturites*: described, 23, 44; *sphaeroides*, type for genus, 23, 44
- Rugulatisporites quintus*, 30
- Rugumonoporites*: described, 23, 46; *convolutus*, type for genus, 23, 46
- Ruguritriteles*: described, 21, 30; *obscurans*, 30; *quintus*, 30; *regularis*, type for genus, 21, 30; *rugosus*, 31; *toratus*, 30
- St. Louis County: section description, 7
- Salix*, 58, 60
- Sambucus canadensis*, 51
- Sapindus*, 58
- Sassafras*: leaf genera similar to, 16; 60
- Sauk River: section description, 8
- Sauk Valley: Cretaceous invertebrates at, 1
- Schizaea*, 56, 71; *pusilla*, 33; *Skottsbergii*, 33
- Schizaeaceae, 31, 32, 33, 56, 71
- Sciadopitys*, 34, 46, 64
- Selaginella*, 56
- Selaginellaceae, 25, 56, 71
- Sequoia*, 58
- Sequoidites*, 15
- Setosi-sporites*, 14
- Shorelines: palynological determination of, 66
- Siltaria*, 15
- South Judson Mine: Cretaceous exposed at, 2
- Sphagnites australis* f. *crassa*, 26
- Spinainaperturites*: described, 23, 44; *recurvatus*, type for genus, 23, 44
- Spores. See Sporomorphs
- Sporites, 13; 20–21, 25–34; *adriennis* ssp. *mesozoicus*, 28
- Sporomorph terminology, schools of, 13
- Sporomorphs: defined, 2; and nomenclatural rules, 12; morphology in name, 13; shape group definition of, 14; morphology of, 19–20; and phylogeographic implications, 56–57; and leaf-impression record, 58; coniferous species predominant, 58–59; climatic and floristic interpretations from, 59–61; concentration in continental and marine sediments, 65–66; localized overrepresentation of, 67
- Stearns County: section description, 8
- Sterculia*: similarity to *Sassafras*, 16
- Striainaperturites*: described, 23, 45; *ovatus*, type for genus, 23, 45
- Striatriteles*: described, 21, 31; *bifurcus*, 31; *coronarius*, 32; *nodosus*, 32; *striatus*, 31; *susannae*, type for genus, 21, 31; *tetrajugatus*, 32
- Subsacculifer*, 35
- Symplocaceae, 50
- Symplocos novae-angliae*, 50
- Tempskya*, 31
- Tetradaceae, 21, 31
- Thuja*, 44, 56, 57
- Thujoideae, 44
- Thujopsis*, 44
- Tetradopollenites*, 62
- Tilia*, 15, 16; *americana*, 9
- Topography: deduced from megafossils, 59; deduced from adiabatic lapse rate, 59–60
- Transgression: of Cretaceous seas, 2, 66
- Traverse, A., Brandon flora, 17
- Traverse school: nomenclatural procedure, 16
- Tricolpatae, 24, 48–52
- Tricolpidites*, 14; *suboblatatus*, 50; *troedsonii*, 14
- Tricolporatae, 24, 52–53
- Tricolporites protrudens*, 14, 63, 64
- Tricolporopollenites cingulum* ssp. *pusillus*, 53
- Triletes, 20–21, 25–33
- Triplanes, 27
- Tripoporollenites robustus*, 50
- Triquitrites*: *arculatus*, 33; *crassus*, 33; *rotalis*, 33
- Tsuga*, 46
- Urtica gracilis*: contamination, 9
- Urticales, 61
- Van der Hammen, Th.: system proposed by, 17–19
- Vegetation: zonation and adiabatic lapse rate, 59–60; physiognomic classification of, 59, 63
- Verrucosi-sporites*, 14
- Verruinaperturites*: described, 23, 45; *depressus*, type for genus, 23, 45

- Verrumonocolpites*: described, 24, 48; *conspicuus*, type for genus, 24, 48; as guide fossil, 67, 72; 68
- Verrumonoletes*: described, 21, 33; *morulus*, 33; *usmensis*, type for genus, 21, 33
- Verrumonoporites*: described, 23, 46; *verrucatus*, type for genus, 23, 46
- Verrutricolpites*: described, 24, 52; *sphaeroides*, type for genus, 24, 52
- Verrutritetes*: described, 21, 32; *verus*, type for genus, 21, 32; 18
- Vesiculatae. 22, 34-42
- Virginia, Minnesota: Cretaceous exposed at, 2; section description, 7; 67







