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Key to the Quaternary Pollen and Spores of the Great Lakes Region

John H. McAndrews, Albert A. Berti
and Geoffrey Norris

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JOHN H. McANDREWS,
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Key to the Quaternary Pollen and Spores of the Great Lakes Region

Introduction

In recent years the method of fossil pollen and spore analysis (Faegri and Iversen, 1964) has become important in both paleoecological reconstructions of vegetation and climate and in biostratigraphic correlation of sediments. Effective reconstructions and correlations depend upon accurate fossil identifications.

Scattered information is available on pollen and spore morphology, but relatively little has been organized in a form that can be used for fossil identification in the Great Lakes region. These aids include Sears (1930), "Common fossil pollen of the Erie Basin," which contains a key to only 33 taxa, illustrated by drawings. Presently, pollen analysts commonly use the unillustrated key to the northwest European pollen types (Faegri and Iversen, 1964), but it is not wholly applicable to our region nor does it include spores. Likewise, the key of Kapp (1969), "How to know pollen and spores," covers only the United States, is illustrated by drawings and does not focus on fossil identification. Another geographically limited but useful aid is Richard's (1970) "Atlas pollinique des arbres et de quelques arbustes indigènes du Québec," which contains excellent photographs and descriptions but omits herb pollen and lacks a general key. The recent atlas of tree pollen by Adams and Morton (1972) has similar limitations, but its scanning electron micrographs are excellent for sculptural detail.

Fossil pollen assemblages are composed primarily of pollen of wind-pollinated species, especially trees, and to a lesser extent shrubs and herbs. Except for aquatic plants, pollen of insect-pollinated species are rare. Our photo-illustrated key is designed for the identification of fossil pollen and spores (microspores and homospores of pteridophytes and *Sphagnum*) commonly found in Quaternary deposits of the states and the province surrounding the Great Lakes. The key is most applicable in the middle Great Lakes region, especially southern Ontario and Michigan, but is also useful in such peripheral areas as the Atlantic Coast, and the subarctic and prairie regions as shown in Fig. 1.

Materials and Methods

The 144 entries in the key were selected from our analyses of sediments of late Pleistocene (Sangamonian, Wisconsinan) and Holocene age and on fossils reported by others. The majority of taxa (76) are rare, that is, they usually represent less than 1% of a total fossil spectrum. Aquatic taxa are also rare, but some may be locally abundant. Only 46 taxa are common enough to occur consistently with values greater than 1%. Not all grow in the Great Lakes region today, but most grew in this region sometime in the

Fig. 1—Zonal vegetation map of the Great Lakes region (modified from Braun, 1950, and Rowe, 1959). The key is most applicable in the conifer-hardwood forest zone.

Quaternary. Fossil *Ephedra* and *Sarcobatus* are exceptions, in that they appear to have been blown in from beyond our region (Maher, 1964).

The key is in two parts, one for the sixteen classes of pollen and the second for the three classes of spores. In our fossil flora, spores (Figs. 16–21) tend to be morphologically simpler than pollen (Figs. 2–15). Spores have a slit-shaped aperture (laesura) that lacks a membrane. They may have a single laesura (monolete, Fig. 16c) or three triradiate laesurae (trilete, Fig. 18c). The only exception treated here is the alele *Equisetum* (Fig. 16A).

In pollen grains apertures may be absent (Fig. 5E), simple (elongate colpi, Fig. 10K, or circular pores, Fig. 5M), or compound (colpi with pores, Fig. 13N). Usually multiple apertures are present, and in fossils the apertures often retain a membrane (Figs. 9c,s; 10L). Spores commonly have a relatively thick, structureless wall, and many taxa possess a loose-fitting sac or perine that is often lost from fossil spores. Pollen have walls of varying thickness and complexity and may have easily distinguished columellae and a tectum (Fig. 13E); pollen never have a perine. The size of spores and pollen is generally similar except that the minimum size of pteridophyte spores is about 25 μm , whereas many pollen are smaller. Fungal spores (not considered in the key) can be confused with pollen and spores of vascular plants but are distinguishable by their small size (5–20 μm), general lack of apertures, and simple wall structure.

We attempted to keep terminology to a minimum and have defined terms in the glossary (p. 15). Spore terminology follows Harris (1955), and pollen terminology is based on Faegri and Iversen (1964). More exhaustive and detailed treatments of pollen and spore morphology are found in texts such as Erdtman (1957, 1965, 1966), Erdtman and Sorsa (1971), Kremp (1965), and Tschudy and Scott (1969).

The key is illustrated with reference pollen and spores collected from herbarium sheets or living plants, treated according to the method of Faegri and Iversen (1964) with KOH and acetolysis solution, and mounted in silicone oil. Due to the inflated and uncompressed nature of the pollen and the

shallow depth of focus of high magnification microscope objectives, it was not possible to illustrate all morphologic features in one photograph. In general, spores and pollen are best illustrated either in "optical section" to show features of the internal wall structure (Fig. 6F) or in surface view to show details of the external sculpture pattern (Fig. 6A). Occasionally, both the optical section and the surface pattern of the exine are illustrated in the same photograph (Fig. 6E). Only the most useful diagnostic features are illustrated in this work allowing the user to "key-out" an unknown grain with the aid of a light microscope.

Both polar and equatorial views have been used to illustrate the various morphologic features in this key; these views are indicated in the Figure captions by the abbreviations "pv" and "ev" respectively. Photograph magnifications are at X1000 except for the vesiculate genera *Pinus*, *Picea*, and *Abies* (Fig. 2) which are at X500.

Pollen and spore measurements in the Figure captions were made with an ocular micrometer on 10 undistorted grains from a single slide. Measurements are of the greatest dimension excluding sculptural projections and the perine. Measurements of vesiculate grains are of the body in equatorial view. The average size is given in μm with the range in parentheses.

In addition to reference slides, the most effective use of the key requires a high quality microscope, and good fossil preparations. Fossil pollen are often folded, broken or shrunk, and size measurements of reference pollen must be used with caution. Apertures are often obscured, and we recommend the use of a liquid mounting medium (silicone oil or glycerine) so that grains can be rolled to reveal key features.

In some cases the pollen or spore class to which a grain belongs (e.g. *Equisetum*, *Ambrosia*, *Tilia* or *Cyperaceae*) is either uncertain or difficult to determine. This problem has been overcome by entering the pollen or spore in more than one class. In addition, because the key is basically for identification rather than taxonomy, *Equisetum* and *Selaginella selaginoides* are entered in both the pollen and the spore classes.

Using the Key

Use of the key involves several steps. First the unknown is classified as a pollen grain or spore. Then it must be keyed to class with either the "Key to pollen classes" or the "Key to spore classes." The third step is to identify the unknown within the proper class in the "Key to pollen grains" or "Key to spores." Finally, the unknown specimen should be compared with the photographs and with reference material, to confirm or reject the identification.

Nomenclature follows the 8th edition of Gray's Manual of Botany (Fernald, 1950). Species names and authors that do not appear in that manual are *Sarcobatus vermiculatus* (Hook.) Torr., *Iva axillaris* Pursh, *Ephedra aspera* Engelm., *E. coryi* Reed, *E. nevadensis* Wats., *E. torreyana* Wats., *E. trifurca* Torr., and *E. viridis* Coville.

Key to Pollen Classes

A. Grains in groups of 4	1 Tetrad	p. 5
AA. Grain single (monads)		
B. Apertures absent (or indistinct)		
C. With two bladders	2 Vesiculate	p. 5
CC. Without bladders		
D. With ridges separated by folds	3 PolyPLICATE	p. 5
DD. Without ridges and folds	4 Inaperturate	p. 5
BB. Apertures present		
E. Apertures simple, i.e. either pores or colpi		
F. With pores		
1 pore	5 Monoporate	p. 6
2 pores	6 Diporate	p. 6
3 pores	7 Triporate	p. 6
More than 3 pores equatorially arranged		
	8 Stephanoporate	p. 7
More than 3 pores, some or all not equatorial		
	9 Periporate	p. 7
FF. With colpi		
1 colpus	10 Monocolpate	p. 8
2 colpi	11 Dicolpate	p. 8
3 meridional colpi	12 Tricolpate	p. 8
More than 3 meridional colpi	13 Stephanocolpate	p. 10
More than 3 colpi, some or all not meridional		
	14 Pericolpate	p. 10
EE. Apertures compound, i.e. pores in colpi		
3 colpi meridionally arranged	15 Tricolporate	p. 10
More than 3 colpi meridionally arranged		
	16 Stephanocolporate	p. 12

Key to Spore Classes

A. Spore without aperture	1 Alete	p. 13
AA. Spore with slit-shaped aperture (laesura)		
B. Spore with single laesura	2 Monolete	p. 13
BB. Spore with triradiate laesurae	3 Trilete	p. 13

Key to Pollen Grains

1. Tetrads

- A. Reticulate, tetrads usually rhombohedral, each grain monoporate.
Typhaceae *Typha latifolia* 2A, B
- AA. Not reticulate, tetrahedral tetrads
 - B. Echinate
 - C. Spines 5–8 μm long and spaced 5–10 μm apart. Rare to locally abundant. Selaginellaceae ... *Selaginella selaginoides* 2C; 19E
 - CC. Spines 2–3 μm long and more closely spaced. Rare. Droseraceae *Drosera* 2D
 - BB. Psilate or scabrate, each grain tricolpate or tricolporate Ericaceae 2E-J

2. Vesiculate Bladders with internal reticulum. Pinaceae

- A. Bladders hemispherical (not constricted at attachment with body of grain), cap of body (proximal surface) of even thickness, body 50–80 μm broad. Reticulum of bladder finer than in *Pinus* (Fig. 3D) or *Abies* (Fig. 3F) *Picea* 3A-D
- AA. Bladders more than hemispherical (constricted at attachment to body), cap of uneven thickness
 - B. Body of grain 60–90 μm broad, bladder 45–70 μm broad, cap thick (5 μm) but often appearing thinnest in centre *Abies* 3E, F
 - B.B. Body 40–55 μm broad, bladder 24–40 μm broad, cap thinner (2 μm) and of even thickness except along margin. *Pinus*. Species separation by size statistics is not reliable (Whitehead, 1964).
 - C. Distal verrucae present and about 1 μm broad. (Smaller and more scattered verrucae occur on *Picea*). Section Haploxylon *Pinus strobus* 3K
 - CC. Distal verrucae absent. Section Diploxylon (*P. banksiana*, *P. resinosa* and *P. rigida*) *Pinus banksiana* type 3G-J

3. Polyplicate (with meridional folds), prolate, grain $c. 25 \times 45\text{--}65 \mu\text{m}$. Ephedraceae

- A. Grain with $c. 15$ straight folds. Includes among others *E. aspera* and *E. trifurca*. Rare *Ephedra torreyana* type 4A
- AA. Grain with $c. 6$ branched folds. Includes among others *E. coryi* and *E. viridis*. Rare *Ephedra nevadensis* type 4B

4. Inaperturate

- A. Grain banana-shaped, with an imperfect reticulum, grain $c. 35 \times 70 \mu\text{m}$. Rare. Zosteraceae *Ruppia* 4C
- AA. Grain spheroidal (or pear-shaped in Cyperaceae) but often distorted by splits and folds
 - B. Grain 55–85 μm . Pinaceae
 - C. Psilate *Larix* 4D
 - CC. With irregular, hollow verrucae *Tsuga* 4E
 - BB. Grain 20–45 μm except some Cyperaceae as large as 60 μm

- D. Gemmate with gemmae distinct but scattered, fossil grains often angularly broken. Cupressineae *Thuja* or *Juniperus* 5A-C
- DD. Psilate, scabrate or reticulate
 - E. Psilate or scabrate-verrucate
 - F. Psilate, often with a wrinkled perine. Rare to locally abundant. Equisetaceae *Equisetum* 5D; 16A
 - FF. Scabrate-verrucate
 - G. Spheroidal, no poroids and often folded or flattened. Rare to locally abundant. Salicaceae *Populus* 5E
 - GG. Pear-shaped with 3 lateral poroids and 1 poroid on broad end. Most fossil grains are probably aquatic species of *Carex*, *Scirpus*, *Eleocharis* or *Cyperus*. See Faegri and Iverson (1964) for more detailed identification Cyperaceae 5F, G; 7L, M
 - EE. Reticulate
 - H. Reticulum broken (muri incomplete). Includes the other members of the subgenus *Coleogeton*, i.e. *P. filiformis* and *P. vaginatus*. Zosteraceae *Potamogeton pectinatus* type 5H
 - HH. Reticulum unbroken. Zosteraceae or Juncaginaceae *Potamogeton natans* type (subgenus *Eupotamogeton*) or *Triglochin* 5I, J
- 5. **Monoporate**
 - A. Pore with distinct annulus, psilate or scabrate, grain c. 20–50 μm (larger in cereals, e.g. *Zea* Fig. 5M) Gramineae 5K-M
 - AA. Pore without annulus, grain 18–30 μm
 - B. Reticulate. Sparganiaceae or Typhaceae *Sparganium* or *Typha angustifolia* 6A, B
 - BB. Echinulate. Rare. Lemnaceae *Lemna* 6C
- 6. **Diporate**
 - A. Psilate, pore circular and annulate, exine thin, grain spheroidal, 18–20 μm . Rare. Moraceae *Morus* 6D; 7D
 - AA. Psilate, but with protruding pores, exine thicker rare grains of Corylaceae
- 7. **Triporate** Grains of *Ostrya* and *Carpinus* occasionally have 4 pores.
 - A. Pores distinctly protruding, psilate
 - B. Grain 45–80 μm . Rare. Onagraceae *Epilobium* 6E
 - BB. Grain 16–35 μm
 - C. Inner surface of pore margin rough. Myricaceae *Comptonia* or *Myrica* 6F
 - CC. Inner surface of pore margin smooth. Corylaceae
 - D. With separation of endexine at base of pore, exine thick *Betula* 6G-I
 - DD. Without separation of endexine, exine thinner *Ostrya* or *Carpinus* 6J-K
 - AA. Pores scarcely protruding

- E. Reticulate, endexine conspicuously thickened around pore, oblate.
 Tiliaceae *Tilia* 6L; 14M
- EE. Psilate-scabrate
- F. Annulate, spheroidal
- G. Pore sunken, i.e. tectum swells outward at pore and bends inward at inner margin, psilate. Rare. Cannabinaceae
 Humulus 6M
- GG. Pore not sunken, scabrate. Rare. Ulmaceae *Celtis* 6N, O
- FF. Not annulate, suboblate-oblate
- H. Grain 40–55 μm , slightly heteropolar. Juglandaceae
 Carya 7A
- HH. Grain < 40 μm
- I. Grain 20–30 μm , pores equatorial and slightly protruding, exine thick. Corylaceae *Corylus* 7B
- II. Grain 12–20 μm , psilate, pores not protruding, exine thin (0.5 μm). (Exceptional triporate *Morus*, Fig. 7D, will key out here.) Rare. Urticaceae *Urtica* 7C
8. **Stephanoporate**
- A. Arci (internal thickenings) connecting the 4 or 5 (rarely 3 or 6) protruding pores. Corylaceae *Alnus* 7E-G
- AA. Without arc
- B. Rugulate-reticulate, 4–6 non-protruding and non-annulate pores, oblate. Ulmaceae *Ulmus* 7H, I
- BB. Psilate-scabrate, 4 (3–6) non-protruding but strongly annulate pores. (*Ostrya* and *Carpinus* occasionally have 4 protruding pores). Haloragaceae
- C. Annulus 2–3 μm high, pores asymmetrically situated. Rare
 Myriophyllum alterniflorum 7J
- CC. Annulus 1–2 μm high, pores symmetrically situated. Includes among others *M. farwellii*, *M. spicatum*, *M. verticillatum*
 Myriophyllum exalbescens type 7K
9. **Periporate**
- A. Heteropolar (pores mostly concentrated on one hemisphere)
- B. Pear-shaped, scabrate, with 3 (4–6) lateral poroids (thin areas) and 1 poroid on broad end Cyperaceae 5F, G; 7L, M
- BB. Oblate, psilate, 7–18 annulate pores. Juglandaceae
- C. 7–11 pores *Juglans cinerea* 7N, O
- CC. 12–18 pores *Juglans nigra* 7P
- AA. Not heteropolar, spheroidal
- D. Echinulate with spines 2 μm long and regularly spaced, pores indistinct. Alismataceae *Sagittaria* 7Q
- DD. Not echinate
- E. Reticulate, grain 30–50 μm
- F. Reticulum coarse (lumina 5–10 μm), pores at bottom of lumina. Includes among others *P. hydropiper*, *P. hydropiperoides*, *P. pensylvanicum*, *P. punctatum* and *P. sagittatum*. Rare. Polygonaceae *Polygonum lapathifolium* type 8A

- FF. Reticulum finer (lumina $1\ \mu\text{m}$). Hamamelidaceae *Liquidambar* 8B
- EE. Psilate-scabrate or verrucate
- G. Distinctly annulate, grain $15\text{--}30\ \mu\text{m}$
- H. More than 16 pores, exine thick. Rare Caryophyllaceae 8C
- HH. Fewer than 16 pores
- I. About 14 pores, psilate. Rare. Chenopodiaceae *Sarcobatus* 8D
- II. $8\text{--}14$ pores, scabrate. Mostly restricted to sediments of the past century. Plantaginaceae *Plantago lanceolata* 8E
- GG. Not distinctly annulate
- J. More than 30 pores. Includes Amaranthaceae and Chenopodiaceae except *Sarcobatus*. For method of distinguishing species by pore number see McAndrews and Swanson (1967) Chenopodiaceae p.p. 8F, G
- JJ. Fewer than 30 pores
- K. Pore margin distinct, exine very thick, grain $> 30\ \mu\text{m}$. Rare Caryophyllaceae
- KK. Pore margin indistinct, grain $15\text{--}30\ \mu\text{m}$
- L. Psilate, $6\text{--}12$ pores. Rare. Ranunculaceae *Thalictrum* 8H
- LL. Verrucate, $4\text{--}11$ pores. Mostly restricted to sediments of this century. Includes among others *P. virginica* and *P. pusilla*. See also Bassett and Crompton (1968). Rare *Plantago major* type 8I
10. **Monocolpate** Nymphaeaceae
- A. Colpus circular, baculate *Nymphaea* 8J, K
- AA. Colpus linear
- B. Echinate, spines $5\text{--}6\ \mu\text{m}$ long *Nuphar* 8L
- BB. Psilate-scabrate. Rare *Brasenia* 8M
11. **Dicolpate**, scabrate-verrucate, $50\text{--}72\ \mu\text{m}$. Rare. Pontederiaceae *Heteranthera* 8N
12. **Tricolpate**
- A. Sculpturing elements elongated parallel to surface
- B. Striate or rugulate
- C. Striate
- D. Colpus without membrane, $> 30\ \mu\text{m}$. For detailed treatment of *Acer* pollen see Helmich (1963). Aceraceae *Acer rubrum* 9A, B
- DD. Colpus with verrucate membrane, $< 30\ \mu\text{m}$. Rare. Saxifragaceae *Saxifraga oppositifolia* 9C, D
- CC. Rugulate
- E. Grain $> 30\ \mu\text{m}$, delicately rugulate-reticulate, with colpus membrane. Aceraceae *Acer saccharinum* 9E, F
- EE. Grain $< 30\ \mu\text{m}$

- F. With colpus membrane, endexine thin. Rare. Rosaceae
Dryas 9G-I
- FF. Colpus membrane absent, endexine thick. Rare. Aceraceae
Acer negundo 9J-L
- BB. Reticulate
- G. Colpus with psilate-scabrate margin, polar area small
- H. Subprolate-prolate, without operculum. Salicaceae
- I. Reticulum unbroken (muri complete) *Salix* p.p. 9M-P
- II. Reticulum broken. Rare *Salix herbacea* 9Q, R
- HH. Prolate-perprolate, grain c. $25 \times 45 \mu\text{m}$, with operculum, reticulum fine, Rare. Leguminosae
Petalostemum purpureum 9S
- GG. Margin absent, i.e. reticulum of exine extends to edge of colpus
- J. Tectate, polar area small
- K. Exine thick ($2.2 \mu\text{m}$), lumina $1.5 \mu\text{m}$, colpus membrane absent. Aceraceae
Acer saccharum 9T, U
- KK. Exine thinner, lumina smaller. Includes among others *Stachys* and *Scutellaria*. Rare Labiatae p.p. 10A, B
- JJ. Intectate
- L. Polar area small, exine thick ($2.5 \mu\text{m}$), lumina $1.5 \mu\text{m}$, Rare
 Cruciferae 10C, D
- LL. Polar area medium to large, exine thinner ($< 1.5 \mu\text{m}$), lumina smaller ($< 1.5 \mu\text{m}$)
- M. Colpus membrane absent, $20\text{--}25 \mu\text{m}$. Oleaceae
Fraxinus nigra or *F. quadrangulata* 10E-G
- MM. Colpus with scabrate membrane, spherical, grain $16\text{--}20 \mu\text{m}$. Platanaceae
Platanus 10H
- AA. Sculpturing elements absent or isodiametric, or elongated perpendicular to surface (not striate, rugulate or reticulate)
- N. Scabrate, spheroidal-subprolate
- O. Irregularly scabrate, no colpus membrane, large polar area, grain $20\text{--}35 \mu\text{m}$. Fagaceae
Quercus 10I-K
- OO. Very regularly scabrate, colpus membrane scabrate, small polar area, grain $22\text{--}26 \mu\text{m}$. Rare. Ranunculaceae
Caltha 10L
- NN. Not scabrate
- P. Echinulate, spines short (c. $1 \mu\text{m}$), polar area large, spherical, grain $18\text{--}23 \mu\text{m}$. Compositae
Ambrosia 10M; 12M, N
- PP. Verrucate or clavate
- Q. Verrucate, grain $26\text{--}32 \mu\text{m}$. Rare. Includes species of the section *Batrachium*. Ranunculaceae
Ranunculus flabellaris type 10N
- QQ. Clavate
- R. Colpus with margin of smaller clavae, prolate, grain $22\text{--}32 \mu\text{m}$. Rare. Aquifoliaceae
Ilex or *Nemopanthus* 10O, P
- RR. Colpus without special margin, clavae-verrucae of various sizes, subprolate, grain $30\text{--}36 \mu\text{m}$. Rare. Rosaceae
Rubus chamaemorus 10Q, R

13. **Stephanocolpate**

A. Psilate-scabrate

B. Small polar area, 6–10 colpi. Rare. Rubiaceae → *Galium* 10S-U

BB. Large polar area, 4 (5–6) colpi each with a broad membrane.
Rare. Hippuridaceae *Hippuris* 11A

AA. Reticulate or echinate

C. Reticulate

D. 6 colpi, small polar area. Rare. Includes among others *Lycopus*,
Mentha, *Monarda*, and *Prunella* Labiatae p.p. 11B, C

DD. 4 colpi, large polar area

E. Subprolate, reticulum fine, grain 20–24 μm . Oleaceae
..... *Fraxinus pennsylvanica* or *F. americana* 11D-F

EE. Grain with shape of rectangular prism, reticulum medium-
coarse, 4 short colpi, grain c. 32 μm . Rare. Balsaminaceae
..... *Impatiens* 11G, H

CC. Echinate, 3 long and 3 short colpi. Rare. Loranthaceae
..... *Arceuthobium* 11I, J

14. **Pericolpate**

A. Reticulate, with clavae at bottom of lumina. Rare. Polygonaceae
..... *Polygonum amphibium* or *P. coccineum* 11K, L

AA. Echinate. Rare. Portulacaceae *Portulaca oleracea* 11M

15. **Tricolporate** This is the largest class and somewhat difficult because pores are often obscure. Reference slides are especially important.

A. Echinate. Compositae

B. Exine structure consisting of lacunae separated by echinate ridges
arranged in a geometrical pattern. Rare
..... subfamily Liguliflorae 12A-C

BB. Exine without lacunae or ridges. Subfamily Tubuliflorae

C. Spines > 1.5 μm polar area small. Includes all genera except the
Ambrosia group and *Artemisia* Tubuliflorae p.p. 12D-G

CC. Spines short (< 1.5 μm), pores indistinct, grains 14–26 μm .
Ambrosia group

D. Columellae of tectum distinct, colpi indistinct, polar area large

E. Exine thick, spines c. 1 μm long. Rare to locally abundant
..... *Iva ciliata* 12H, I

EE. Exine thinner, spines shorter. Rare *Xanthium* 12J

DD. Columellae indistinct

F. Colpi long and distinct, small polar area. Rare to locally
abundant *Iva xanthifolia* 12K, L

FF. Colpi short and indistinct, large polar area. The pre-
dominantly western *Iva axilaris* is identical
..... *Ambrosia* 10M; 12M, N

AA. Not echinate

G. Psilate-scabrate

H. Grain < 16 μm , prolate, pores equatorially elongated. Fagaceae
..... *Castanea* 12O, P

- HH. Grain $> 18 \mu\text{m}$
- I. Oblate, triangular in polar view, pores protruding. Elaeagnaceae
- J. Colpi short (c. $8 \mu\text{m}$). Rare *Elaeagnus* 13A
- JJ. Colpi long (c. $20 \mu\text{m}$). Rare. *Shepherdia argentea* 13B
- II. Spheroidal to prolate or perprolate
- K. Spheroidal to prolate
- L. Equatorial thickening of endexine. Includes among others *P. cristatum* and *P. achoreum*. Rare. Polygonaceae
..... *Polygonum aviculare* type 13C, D
- LL. No equatorial thickening
- M. Grains spheroidal
- N. Exine thick ($3\text{--}4 \mu\text{m}$) but thinning toward colpus, columellae distinct, micro-echinate, grain $20\text{--}30 \mu\text{m}$. Compositae *Artemisia* 13E, F
- NN. Exine thinner and of uniform thickness
- O. Pore protruding slightly, circular and annulate, grain $30\text{--}34 \mu\text{m}$. Rare. Nyssaceae
..... *Nyssa* 13G-I
- OO. Pore not protruding
- P. Grain $35\text{--}43 \mu\text{m}$, scabrate, pore often elongated along meridian and often not very distinct. Fagaceae *Fagus* 13J, K
- PP. Grain $25\text{--}30 \mu\text{m}$, pore circular and distinct. Rare to locally abundant. Polygonaceae
..... *Rumex* 13L, M
- MM. Grains prolate
- Q. Pore circular and slightly annulate, grain $24 \times 35 \mu\text{m}$. Rare to locally abundant. Elaeagnaceae
..... *Shepherdia canadensis* 13N, O
- QQ. Pore not circular
- R. Pore not elongated but characterized by a constriction of the colpus. Cornaceae
- S. Grain $< 25 \mu\text{m}$, psilate. Rare
..... *Cornus canadensis* 13P, Q
- SS. Grain $> 35 \mu\text{m}$. Rare. Includes among others *C. racemosa*, *C. alternifolia* and *C. rugosa*
..... *Cornus stolonifera* type 14A-C
- RR. Pore elongated equatorially, exine thicker at poles than at equator, grain c. $35 \times 50 \mu\text{m}$. Rare. Polygonaceae
..... *Polygonum viviparum* 14D, E
- KK. Perprolate, exine of varying thickness, pore elongated equatorially. Rare. Umbelliferae 14F-H
- GG. Striate or reticulate
- T. Striate

- U. Striae very pronounced and parallel with meridional orientation, transverse colpus absent. Rare. Gentianaceae *Menyanthes* 14I, J
- UU. Striae finer, pore indistinct, transverse colpus present or absent. Includes among others *Potentilla* and *Prunus* Rosaceae p.p. 14K, L
- TT. Reticulate
 - V. Oblate, endexine conspicuously thickened around pore, colpi short and indistinct, ca. 36 μ m. Tiliaceae . . . *Tilia* 6L; 14M
 - VV. Spherical to prolate, endexine not conspicuously thickened around pore, colpi longer and distinct
 - W. Pore large (about $\frac{1}{2}$ diameter of spheroidal grain), colpus with an operculum, grain 20–22 μ m. Rare. Leguminosae *Amorpha* 14N, O
 - WW. Pore smaller
 - X. Colpus margin psilate, reticulum fine, prolate, pore not pronounced. Salicaceae *Salix* p.p. 14P, Q
 - XX. No distinct colpus margin
 - Y. Pore an equatorial constriction of the colpus, grain 15–20 μ m. Rare. Caprifoliaceae *Sambucus* 15A
 - YY. Pore circular and annulate
 - Z. Pore wider than colpus, micro-reticulate. Rare. Vitaceae *Vitis* 15B, C
 - ZZ. Pore not as wide as colpus, reticulum coarser. Rare to locally abundant. Rubiaceae *Cephalanthus* 15D, E
- 16. **Stephanocolporate**
 - A. With c. 15 colpi, pores fused together around the equator. Rare. Lentibulariaceae *Utricularia* 15F, G
 - AA. With 6 colpi that form 3 pairs, each pair of colpi within an equatorially elongated pore. Rare. Rosaceae *Sanguisorba canadensis* 15H, I

Key to Spores

1. **Alete** Perine wrinkled and grain often broken. Rare to locally abundant.
 Equisetaceae *Equisetum* 5D; 16A
2. **Monolete**
 - A. Perine absent. Polypodiaceae
 - B. Psilate. Includes among others *Asplenium trichomanes*, *Cystopteris fragilis*, *Dryopteris spinulosa* and *Onoclea sensibilis* Polypodiaceae p.p. 16B, C
 - BB. Verrucate
 - C. Grain $< 42\ \mu\text{m}$, verrucae small and scattered. Rare *Athyrium filix-femina* 16D
 - CC. Grain $> 44\ \mu\text{m}$, verrucae larger and dense. Rare *Polypodium virginianum* 16E
 - AA. Perine present
 - D. Perine psilate-scabrate
 - E. Perine ragged in the region of the laesura. Rare to locally abundant. Isoetaceae *Isoetes* 16F
 - EE. Not ragged in the region of the laesura. Rare. Polypodiaceae *Pteritis pensylvanica* 16G
 - DD. Perine variously sculptured, not psilate-scabrate
 - F. Perine not echinate
 - G. Perine reticulate and loose fitting. Rare. Polypodiaceae *Woodsia ilvensis* 16H
 - GG. Perine variously ridged and folded. Includes among others *Athyrium thelypteroides*, *Dryopteris thelypteris* and *D. goldiana* Polypodiaceae p.p. 16I, J
 - FF. Perine echinate. Polypodiaceae
 - H. Echinae projecting from a tight-fitting perine
 - I. Echinae sharp and up to $6\ \mu\text{m}$ long. Rare *Cystopteris fragilis* 16L
 - II. Echinae blunt and $2\text{--}4\ \mu\text{m}$ long. Rare *Cystopteris bulbifera* 16K
 - HH. Perine loose-fitting, echinae on ridges
 - J. Echinae c. $1\ \mu\text{m}$ long. Rare *Dryopteris spinulosa* 17A
 - JJ. Echinae $2\text{--}4\ \mu\text{m}$ long and very irregular. Rare *Camptosorus* or *Polystichum lonchitis* 17B, C
 3. **Trilete**
 - A. With perine
 - B. Perine $70\text{--}85\ \mu\text{m}$ with folds and thickenings forming an imperfect reticulum. Rare. Polypodiaceae *Cheilanthes* 17D, H
 - BB. Perine $30\text{--}55\ \mu\text{m}$
 - C. Perine large ($40\text{--}55\ \mu\text{m}$) loose-fitting and densely verrucate. Rare to locally abundant. Selaginellaceae *Selaginella rupestris* 17E

- CC. Perine smaller (30–55 μm) tight-fitting and densely verrucate.
Polypodiaceae *Pteridium aquilinum* 17F, G
- AA. Without perine
- D. With negative sculptural elements or only psilate-scabrate
- E. Psilate or scabrate. Polypodiaceae
- F. Spore > 45 μm , psilate. Rare *Cheilanthes* 17D, H
- FF. Spore < 45 μm , scabrate
- G. Laesurae with lips, exine > 1.5 μm thick. Rare
..... *Adiantum* or *Dennstaedtia* 18A, B
- GG. Laesurae simple, exine < 1.5 μm thick
..... *Pteridium aquilinum* 18C, D
- EE. Foveolate or fossulate
- H. Foveolate. Lycopodiaceae
- I. Spore < 25 μm , sides of spore concave in polar view. Rare
..... *Lycopodium lucidulum* 18E, F
- II. Spore > 30 μm and nearly triangular in polar view. Rare
..... *Lycopodium selago* 18G, H
- HH. Fossulate. Rare. Ophioglossaceae
..... *Botrychium multifidum* or *B. dissectum* 18I, J-L
- DD. With positive sculptural elements, not scabrate
- J. Sculptural elements radially elongated (baculate or echinate)
- K. Baculae of varying size, spore spheroidal. Osmundaceae
- L. Baculae about twice as long as broad and not fused. Rare
..... *Osmunda cinnamomea* 19A
- LL. Baculae broader and some fused to form short ridges.
Rare *Osmunda regalis* or *O. claytoniana* 19B-D
- KK. Echinate with spines pointed or truncate and 5–8 μm long,
spores often in tetrads. Rare to locally abundant. Selaginellaceae
..... *Selaginella selaginoides* 2C, 19E
- JJ. Sculptural elements elongated parallel to surface
- M. Rugulate or reticulate
- N. Rugulate, distal face with zig-zag ridges and proximal face
verrucate. Rare. Lycopodiaceae
..... *Lycopodium inundatum* 19F, G
- NN. Reticulate (at least on distal surface)
- O. Muri with a broad base (tapering in cross-section). Rare.
Ophioglossaceae *Ophioglossum* 20A, B
- OO. Muri with vertical walls. Lycopodiaceae
- P. Reticulum extending well onto proximal surface
- Q. Nodes at angles of muri. Rare
..... *Lycopodium clavatum* 20C, D
- QQ. Without nodes. Rare
..... *Lycopodium
complanatum* or *L. tristachyum* 20E-H
- PP. Reticulum not extending well onto proximal surface
- R. Laesurae about two-thirds spore radius, lumina
small (up to 7 μm). Rare
..... *Lycopodium obscurum* 20I, J

- RR. Laesurae reaching equator, lumina larger (up to 10 μm). Rare *Lycopodium annotinum* 21A, B
- MM. Verrucate
- S. Laesurae without lips, verrucae up to 6 μm broad, spore 30–36 μm . Rare. Ophioglossaceae *Botrychium virginianum* 21c, d
- SS. Laesurae with lips
- T. Spore < 35 μm . Sphagnaceae *Sphagnum* 21E, F
- TT. Spore > 35 μm . Rare. Includes among others *Botrychium lunaria* and *B. lanceolatum*. Ophioglossaceae *Botrychium simplex* type 21G–K

Glossary of Morphological Terms

Terms are mostly defined in their singular noun form; adjectival forms are indicated with the suffix “ate”.

AMB: outline of a pollen grain or spore in polar view (*Betula* Fig. 6G-I; *Adiantum* Fig. 18A).

ANNULUS: area surrounding a pore characterized by a thickening of the pollen wall (Caryophyllaceae Fig. 8c, d; Gramineae Fig. 5K-M).

APERTURE: a thinning or break in the pollen or spore wall that functions as a site for the emergence of the pollen tube or gametophyte.

ARCUS: elongate, narrow, curved thickening (arc) of the exine not parallel to the edges of the apertures (*Alnus* Fig. 7E, F).

BACULUM: sculptural element with radial projection isodiametric, at least one dimension $> 1 \mu\text{m}$, height $>$ width, sides parallel and top not pointed (*Nymphaea* Fig. 8J, K).

CAP: the thickened proximal surface of the body of vesiculate grains (*Picea* Fig. 3A, C).

CLAVA: sculptural element with radial projection isodiametric, at least one dimension $> 1 \mu\text{m}$, height $>$ width, base constricted and top rounded (*Nemopanthus* Fig. 10P).

COLPUS: an aperture, arbitrarily defined as one with a length-breadth ratio ≥ 2.0 , the ends more or less acute (*Quercus* Fig. 10K).

COLUMELLA: radial rod of the exine separating a basal layer from the outer tectum (*Artemisia* Fig. 13E).

DISTAL: that part of a pollen or spore which faces outward in its tetrad, representing for example, in monoporate and monocolpate pollen, the area around the aperture.

ECHINUS: sculptural element with radial projection isodiametric, at least one dimension $> 1 \mu\text{m}$, height $>$ width, and pointed (*Agoseris* Fig. 12A-C; *Helianthus* Fig. 12D).

EKTEXINE: the outer part of the exine, consisting of a basal layer, radial columellae and an outer tectum.

- ENDEXINE: the innermost part of the exine, a relatively homogeneous zone below the ectexine.
- EQUATOR: the imaginary line midway between the two poles that divides the grain into two polar hemispheres.
- EXINE: the highly resistant wall surrounding the cytoplasm of pollen and spores, divisible into two main layers, the inner endexine and the outer ectexine.
- FOSSULATE: sculptural type with surface of exine grooved (*Botrychium multifidum* Fig. 18I, J).
- FOVEOLATE: sculptural type with surface of exine pitted $> 1 \mu\text{m}$ diameter (*Lycopodium lucidulum* Fig. 18E).
- GEMMA: sculptural element with radial projection isodiametric, at least one dimension $> 1 \mu\text{m}$, height $\leq$ width, base constricted and top rounded (*Juni-perus* Fig. 5B).
- HETEROPOLAR: apertures not distributed with equal density over the distal and proximal hemispheres (*Juglans* Fig. 7N-P).
- INTECTATE: pollen in which the ectexine elements, if present, are free and isolated (*Ilex* Fig. 10o), or form an open pattern (*Fraxinus nigra* Fig. 10E, F).
- LACUNA: depressed area in the ectexine, few in number and regularly spaced in relation to the symmetry of the pollen grain (*Agoseris* Fig. 12A-C); c.f. lumen.
- LAESURA: aperture of spores functioning as a dehiscence fissure.
- LIP: a swelling or thickening along the margin of a laesura (*Adiantum* Fig. 18A); c.f. annulus.
- LUMEN: the space bounded by the muri (walls) of a reticulum, not regularly spaced (*Impatiens* Fig. 11G, H); c.f. lacuna.
- MEMBRANE: exine that forms the floor of an aperture (*Saxifraga oppositifolia* Fig. 9c, d).
- MURUS: wall of the network that together with the lumina forms a reticulum (*Impatiens* Fig. 11G, H).
- OBLATE: shape class with ratio between the polar and equatorial axes less than 0.75 (*Ulmus* Fig. 7H).
- OPERCULUM: an isolated part of the ectexine that is contained within a colpus or pore (*Amorpha canescens* Fig. 14N, o).
- PERINE: loose-fitting sac enclosing certain spore taxa (*Pteretis pensylvanica* Fig. 16g).
- PERPROLATE: shape class with ratio between polar and equatorial axes ≥ 2.0 (*Umbelliferae* Fig. 14F-H).
- POLAR AREA INDEX: greatest distance between the ends of two colpi expressed as a ratio of the greatest breadth of the grain.
- POLE: that part of a pollen grain or spore turned either inward or outward in its tetrad, characterized for example in the tricolpate class by the area between the ends of the colpi.
- PORE: an aperture, arbitrarily defined as one with a length breadth ratio < 2.0 (*Juglans* Fig. 7N-P).
- POROID: pore-like, a poorly-defined pore (Cyperaceae Fig. 7L, M).
- p.p.: *pro parte*, in part.
- PROLATE: shape class with ratio between polar and equatorial axes 1.33 – 2.0 (*Shepherdia canadensis* Fig. 13N, o).
- PROXIMAL: that part of a pollen grain or spore which faces inward in its tetrad, representing for example in trilete spores the area around the triradial laesurae.

- PSILATE:** sculptural type with elements absent, exine smooth (*Larix* Fig. 4b).
- RETICULUM:** net-like sculpturing with diameter of lumina $>$ breadth of muri (*Lycopodium obscurum* Fig. 20j).
- RHOMBOHEDRAL:** shape of a tetrad that approximates a rhombus (*Typha latifolia* Fig. 2A).
- RUGULA:** sculptural element tangentially elongated and with an irregular distribution (*Lycopodium inundatum* (Fig. 19F, G).
- SCABRA:** sculptural element with radial projection isodiametric and no dimension $\geq 1 \mu\text{m}$ (Cyperaceae Fig. 7L, M).
- STRIA:** sculptural element tangentially elongated and more or less parallel to another stria (*Acer rubrum* Fig. 9A, B).
- SUBOBLATE:** shape class with ratio between polar and equatorial axes 0.88 – 0.75.
- SUBPROLATE:** shape class with ratio between polar and equatorial axes 1.33 – 1.14 (*Salix herbacea* Fig. 9o, R).
- TECTATE:** exine structure where tectum covers most of the surface of the grain.
- TECTUM:** outer layer (roof) of the exine that is most easily observed when separated from the endexine by a cavity (*Artemisia* Fig. 13E, F).
- TETRAD:** the four pollen grains or spores that are the product of a mother cell; although pollen or spores of most species separate and are dispersed as monads, some disperse as tetrads in a tetrahedral arrangement (Ericaceae Fig. 2E, J; *Selaginella selaginoides* Fig. 2c), or a rhombohedral arrangement (*Typha latifolia* Fig. 2A).
- VERRUCA:** sculptural element with radial projection more or less isodiametric, at least one dimension $> 1 \mu\text{m}$, height $\leq$ width, base not constricted, and top not pointed (*Plantago major* Fig. 8i).

FIGURES

Fig. 2—Class 1, Tetrads, X1000 (p. 5)

A. <i>Typha latifolia</i> , rhombohedral tetrad	39.6(38–42) μm
B. <i>T. latifolia</i> , irregular tetrad	
C. <i>Selaginella selaginoides</i>	49.8(46–54) μm
D. <i>Drosera rotundifolia</i>	46.6(42–52) μm
E. <i>Kalmia polifolia</i>	29.2(28–30) μm
F. <i>K. polifolia</i>	
G. <i>Chamaedaphne calyculata</i>	28.1(26–30) μm
H. <i>Arctostaphylos uva-ursi</i>	45.2(44–50) μm
I. <i>Andromeda glaucophylla</i>	40.3(38–47) μm
J. <i>Vaccinium uliginosum</i>	38.2(34–40) μm

FIGURE 2

Fig. 3—Class 2, Vesiculate, X500 (p. 5)

A. <i>Picea glauca</i> , ev	68.8(62–74) μm
B. <i>P. glauca</i> , pv, distal	
C. <i>P. mariana</i> , ev	56.0(50–60) μm
D. <i>P. mariana</i> , pv, distal	
E. <i>Abies balsamea</i> , ev	69.0(60–80) μm
F. <i>A. balsamea</i> , pv, distal	
G. <i>Pinus banksiana</i> , ev	36.4(34–40) μm
H. <i>P. banksiana</i> , pv, distal	
I. <i>P. resinosa</i> , ev	53.0(48–54) μm
J. <i>P. resinosa</i> , ev	
K. <i>P. strobus</i> , pv, distal	48.6(44–50) μm

FIGURE 3

Fig. 4—Class 3, Polyplicate, X1000 (p. 5)

A. *Ephedra torreyana*, ev

45.0(42–50) μm

B. *E. nevadensis*, ev

67.4(62–70) μm

Class 4, Inaperturate, X1000 (p. 5)

C. *Ruppia occidentalis*

71.0(60–78) μm

D. *Larix laricina*

66.8(58–80) μm

E. *Tsuga canadensis*

76.0(70–80) μm

FIGURE 4

Fig. 5—Class 4, Inaperturate cont'd., X1000 (p. 5)

A. <i>Thuja occidentalis</i>	23.0(22–26) μm
B. <i>Juniperus communis</i>	26.0(24–28) μm
C. <i>J. communis</i>	
D. <i>Equisetum arvense</i>	40.8(36–44) μm
E. <i>Populus tremuloides</i>	28.8(24–32) μm
F. <i>Carex pensylvanica</i>	42.0(40–48) μm
G. <i>Cyperus inflexus</i>	22.0(20–24) μm
H. <i>Potamogeton pectinatus</i>	36.5(32–42) μm
I. <i>P. natans</i>	21.0(20–22) μm
J. <i>Triglochin maritima</i>	22.4(20–24) μm

Class 5, Monoporate, X1000 (p. 6)

K. <i>Zizania aquatica</i> , cv	34.2(32–36) μm
L. <i>Andropogon gerardi</i>	39.2(34–44) μm
M. <i>Zea mays</i> pv, distal	82.6(76–88) μm

FIGURE 5

Fig. 6—Class 5, Monoporate cont'd., X1000 (p. 6)

A. <i>Sparganium eurycarpum</i> , pv, distal	26.4(24–30) μm
B. <i>Typha angustifolia</i> , pv, distal	21.4(18–22) μm
C. <i>Lemna trisulca</i> , ev	21.5(19–23) μm

Class 6, Diporate, X1000 (p. 6)

D. <i>Morus rubra</i> , ev	19.0(18–20) μm
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Class 7, Triporate, X1000 (p. 6)

E. <i>Epilobium latifolium</i> , pv	79.0(62–86) μm
F. <i>Myrica gale</i> , pv	27.8(26–30) μm
G. <i>Betula papyrifera</i> , pv	29.6(28–34) μm
H. <i>B. glandulosa</i> , pv	21.2(18–24) μm
I. <i>B. populifolia</i> , pv	24.0(20–26) μm
J. <i>Ostrya virginiana</i> , pv	28.0(26–30) μm
K. <i>Carpinus caroliniana</i> , pv	31.0(28–32) μm
L. <i>Tilia americana</i> , pv	36.2(34–38) μm
M. <i>Hunulus lupulus</i> , pv	23.0(20–26) μm
N. <i>Celtis occidentalis</i> , pv	29.6(28–32) μm
O. <i>C. occidentalis</i> , ev	

FIGURE 6

Fig. 7—Class 7, Triporate cont'd., X1000 (p. 7)

A. <i>Carya cordiformis</i> , pv	44.4(42–46) μm
B. <i>Corylus cornuta</i> , pv	22.4(22–24) μm
C. <i>Urtica procera</i> , pv	15.6(14–18) μm
D. <i>Morus rubra</i> , pv	19.0(18–20) μm

Class 8, Stephanoporate, X1000 (p. 7)

E. <i>Alnus rugosa</i> , pv	22.0(20–24) μm
F. <i>A. rugosa</i> , pv	
G. <i>A. crispa</i> , pv	18.4(18–20) μm
H. <i>Ulmus thomasi</i> , ev	35.0(32–38) μm
I. <i>U. thomasi</i> , pv	
J. <i>Myriophyllum alterniflorum</i> , pv	19.8(18–22) μm
K. <i>M. exalbescens</i> , pv	30.2(30–32) μm

Class 9, Periporate, X1000 (p. 7)

L. <i>Eriophorum angustifolium</i>	38.8(36–40) μm
M. <i>Carex lacustris</i>	45.8(42–50) μm
N. <i>Juglans cinerea</i> , pv	38.2(36–40) μm
O. <i>J. cinerea</i> , pv	
P. <i>J. nigra</i> , pv	37.4(34–40) μm
Q. <i>Sagittaria latifolia</i>	24.0(22–26) μm

FIGURE 7

Fig. 8—Class 9, Periporate cont'd., X1000 (p. 7)

A. <i>Polygonum lapathifolium</i>	34.8(32–38) μm
B. <i>Liquidambar styraciflua</i>	34.4(32–36) μm
C. <i>Stellaria crassifolia</i>	28.0(24–32) μm
D. <i>Sarcobatus vermiculatus</i>	25.6(24–28) μm
E. <i>Plantago lanceolata</i>	24.8(22–26) μm
F. <i>Suaeda depressa</i>	24.6(22–28) μm
G. <i>Salsola pestifer</i>	26.8(24–30) μm
H. <i>Thalictrum dasycarpum</i>	22.8(20–26) μm
I. <i>Plantago major</i>	21.8(20–24) μm

Class 10, Monocolpate, X1000 (p. 8)

J. <i>Nymphaea</i> sp., ev	25.8(24–28) μm
K. <i>Nymphaea</i> sp., pv	
L. <i>Nuphar variegatum</i> , pv	48.6(46–50) μm
M. <i>Brasenia schreberi</i> , ev	52.0(48–56) μm

Class 11, Dicolpate, X1000 (p. 8)

N. <i>Heteranthera dubia</i>	63.0(50–72) μm
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FIGURE 8

Fig. 9—Class 12, Tricolpate, X1000 (p. 8)

A. <i>Acer rubrum</i> , ev	34.4(32–38) μm
B. <i>A. rubrum</i> , pv	
C. <i>Saxifraga oppositifolia</i> , ev	29.8(28–32) μm
D. <i>S. oppositifolia</i> , pv	
E. <i>A. saccharinum</i> , ev	37.4(32–42) μm
F. <i>A. saccharinum</i> , ev	
G. <i>Dryas integrifolia</i> , ev	23.6(20–28) μm
H. <i>D. integrifolia</i>	
I. <i>D. integrifolia</i> , pv	
J. <i>Acer negundo</i> , ev	23.4(22–26) μm
K. <i>A. negundo</i> , ev	
L. <i>A. negundo</i> , pv	
M. <i>Salix discolor</i> , pv	26.8(24–28) μm
N. <i>S. discolor</i> , ev	
O. <i>S. candida</i> , ev	20.8(18–24) μm
P. <i>S. interior</i> , ev	15.4(14–18) μm
Q. <i>S. herbacea</i> , ev	19.0(18–20) μm
R. <i>S. herbacea</i> , ev	
S. <i>Petalostemum purpureum</i> , ev	43.6(40–50) μm
T. <i>Acer saccharum</i> , ev	32.0(28–34) μm
U. <i>A. saccharum</i> , pv	

FIGURE 9

Fig. 10—Class 12, Tricolpate cont'd., X1000 (p. 9)

A. <i>Stachys palustris</i> , pv	25.4(24–28) μm
B. <i>S. palustris</i> , pv	
C. <i>Rorippa islandica</i> , ev	19.6(18–22) μm
D. <i>Brassica kaber</i> , pv	27.2(24–32) μm
E. <i>Fraxinus nigra</i> , ev	23.0(22–24) μm
F. <i>F. nigra</i> , pv	
G. <i>F. quadrangulata</i> , pv	22.0(20–24) μm
H. <i>Platanus occidentalis</i> , pv	18.0(16–20) μm
I. <i>Quercus rubra</i> , pv	24.8(24–28) μm
J. <i>Q. rubra</i> , ev	
K. <i>Q. macrocarpa</i> , ev	28.2(26–30) μm
L. <i>Caltha palustris</i> , ev	24.2(22–26) μm
M. <i>Ambrosia psilostachya</i> , pv	23.4(22–24) μm
N. <i>Ranunculus flabellaris</i> , ev	37.0(30–40) μm
O. <i>Ilex verticillata</i> , pv	28.8(24–32) μm
P. <i>Nemopanthus mucronata</i> , ev	24.2(22–26) μm
Q. <i>Rubus chamaemorus</i> , pv	33.8(30–36) μm
R. <i>R. chamaemorus</i> , ev	
Class 13, Stephanocolpate, X1000 (p. 10)	
S. <i>Galium boreale</i> , ev	23.8(22–26) μm
T. <i>G. asprellum</i> , pv	18.4(16–20) μm
U. <i>G. asprellum</i> , pv	

FIGURE 10

Fig. 11—Class 13, Stephanocolpate cont'd., X1000 (p. 10)

A. <i>Hippuris vulgaris</i> , pv	30.2(26–32) μm
B. <i>Lycopus virginicus</i> , pv	28.6(26–32) μm
C. <i>Mentha arvensis</i> , ev	32.8(30–36) μm
D. <i>Fraxinus pennsylvanica</i> , pv	22.2(20–24) μm
E. <i>F. pennsylvanica</i> , ev	
F. <i>F. americana</i> , pv	26.2(24–30) μm
G. <i>Impatiens capensis</i> , pv	32.4(30–36) μm
H. <i>I. capensis</i> , pv	
I. <i>Arceuthobium pusillum</i> , pv	24.0(22–26) μm
J. <i>A. pusillum</i> , pv	
Class 14, Pericolpate, X1000 (p. 10)	
K. <i>Polygonum amphibium</i>	50.2(46–54) μm
L. <i>P. coccinium</i>	59.8(52–66) μm
M. <i>Portulaca oleracea</i>	56.8(54–64) μm

FIGURE 11

Fig. 12—Class 15, Tricolporate, X1000 (p. 10)

A. <i>Agoseris glauca</i> , ev	42.4(38–50) μm
B. <i>A. glauca</i> , pv	
C. <i>A. glauca</i> , pv	
D. <i>Helianthus laetiflorus</i> , ev	33.0(30–36) μm
E. <i>H. laetiflorus</i> , pv	
F. <i>Eupatorium perfoliatum</i> , ev	18.0(16–20) μm
G. <i>E. perfoliatum</i> , pv	
H. <i>Iva ciliata</i> , pv	20.8(20–22) μm
I. <i>I. ciliata</i> , pv	
J. <i>Xanthium pensylvanicum</i> , pv	25.0(24–26) μm
K. <i>Iva xanthifolia</i> , ev	15.8(14–16) μm
L. <i>I. xanthifolia</i> , pv	
M. <i>Ambrosia artemisiifolia</i> , ev	18.0(16–20) μm
N. <i>A. artemisiifolia</i> , pv	
O. <i>Castanea dentata</i> , ev	13.0(12–14) μm
P. <i>C. dentata</i> , ev

Fig. 13—Class 15, Tricolporate cont'd., X1000 (p. 11)

A. <i>Elaeagnus commutata</i> , pv	35.8(30–40) μm
B. <i>Shepherdia argentea</i> , pv	34.8(30–40) μm
C. <i>Polygonum aviculare</i> , ev	28.8(26–32) μm
D. <i>P. cristatum</i> , ev	26.6(26–28) μm
E. <i>Artemisia ludoviciana</i> , pv	23.0(22–26) μm
F. <i>A. ludoviciana</i> , ev	
G. <i>Nyssa sylvatica</i> , ev	31.6(30–34) μm
H. <i>N. sylvatica</i> , ev	
I. <i>N. sylvatica</i> , ev	
J. <i>Fagus grandifolia</i> , ev	41.2(40–44) μm
K. <i>F. grandifolia</i> , pv	
L. <i>Rumex mexicanus</i> , ev	25.4(24–30) μm
M. <i>R. mexicanus</i> , pv	
N. <i>Shepherdia canadensis</i> , ev	35.8(34–38) μm
O. <i>S. canadensis</i> , ev	
P. <i>Cornus canadensis</i> , ev	23.4(22–26) μm
Q. <i>C. canadensis</i> , ev	

FIGURE 13

Fig. 14—Class 15, Tricolporate cont'd., X1000 (p. 11)

A. <i>Cornus stolonifera</i> , ev	58.2(54–64) μm
B. <i>C. stolonifera</i> , ev	
C. <i>C. racemosa</i> , ev	38.5(37–40) μm
D. <i>Polygonum viviparum</i> , ev	47.0(42–54) μm
E. <i>P. viviparum</i> , ev	
F. <i>Sium suave</i> , ev	27.6(26–30) μm
G. <i>S. suave</i> , ev	
H. <i>Cicuta bulbifera</i> , ev	26.6(24–28) μm
I. <i>Menyanthes trifoliata</i> , ev	30.8(28–34) μm
J. <i>M. trifoliata</i> , pv	
K. <i>Prunus pensylvanica</i> , ev	29.4(26–32) μm
L. <i>Potentilla palustris</i> , ev	20.0(18–22) μm
M. <i>Tilia americana</i> , ev	36.2(34–38) μm
N. <i>Amorpha canescens</i> , ev	20.8(20–22) μm
O. <i>A. canescens</i> , ev	
P. <i>Salix amygdaloides</i> , ev	20.4(20–22) μm
Q. <i>S. amygdaloides</i> , ev	

FIGURE 14

Fig. 15—Class 15, Tricolporate cont'd., X1000 (p. 12)

A. <i>Sambucus pubens</i> , ev	18.6(18–20) μm
B. <i>Vitis riparia</i> , ev	20.6(20–22) μm
C. <i>V. riparia</i> , pv	
D. <i>Cephalanthus occidentalis</i> , ev	17.4(16–20) μm
E. <i>C. occidentalis</i> , ev	

Class 16, Stephanocolporate, X1000 (p. 12)

F. <i>Utricularia vulgaris</i> , pv	36.4(32–40) μm
G. <i>U. vulgaris</i> , ev	
H. <i>Sanguisorba canadensis</i> , pv	24.2(22–26) μm
I. <i>S. canadensis</i> , ev

Fig. 16—Spore class 1, Alele, X1000 (p. 13)

A. <i>Equisetum arvense</i>	40.8(36–44) μm
Spore class 2. Monolete, X1000 (p. 13)	
B. <i>Dryopteris spinulosa</i> , ev	45.6(40–52) μm
C. <i>Cystopteris fragilis</i> , pv, proximal	38.2(34–44) μm
D. <i>Athyrium filix-femina</i> , ev	36.8(34–40) μm
E. <i>Polypodium virginianum</i> , ev	67.2(56–76) μm
F. <i>Isoetes macrospora</i> , ev	51.4(46–56) μm
G. <i>Pteris pensylvanica</i> , ev	45.6(38–50) μm
H. <i>Woodsia ilvensis</i> , ev	47.8(44–56) μm
I. <i>Dryopteris thelypteris</i> , ev	44.8(42–48) μm
J. <i>D. goldiana</i> , ev	31.6(28–34) μm
K. <i>Cystopteris bulbifera</i> , pv, distal	33.2(30–36) μm
L. <i>C. fragilis</i> , ev	41.4(38–44) μm

FIGURE 16

Fig. 17—Spore class 2, Monolete cont'd., X1000 (p. 13)

A. <i>Dryopteris spinulosa</i> , ev	45.6(40–52) μm
B. <i>Camptosaurus rhizophyllus</i> , pv, proximal	27.0(24–32) μm
C. <i>Polystichum lonchitis</i> , pv, distal	35.9(32–38) μm

Spore class 3, Trilete, X1000 (p. 13)

D. <i>Cheilanthes feei</i> , pv, proximal	76.8(74–80) μm
E. <i>Selaginella rupestris</i> , pv, proximal	44.4(38–52) μm
F. <i>Pteridium aquilinum</i> , pv, proximal	31.2(30–36) μm
G. <i>P. aquilinum</i> , pv, distal	
H. <i>Cheilanthes feei</i> , pv, proximal	59.0(52–64) μm

FIGURE 17

Fig. 18—Spore class 3, Trilete cont'd., X1000 (p. 14)

A. <i>Adiantum pedatum</i> , pv, proximal	37.0(36–40) μm
B. <i>Dennstaedtia punctiloba</i> , pv, proximal	31.6(30–34) μm
C. <i>Pteridium aquilinum</i> , pv, proximal	31.2(30–36) μm
D. <i>P. aquilinum</i> , pv, proximal	
E. <i>Lycopodium lucidulum</i> , pv, distal	32.0(30–36) μm
F. <i>L. lucidulum</i> , pv, proximal	
G. <i>L. selago</i> , pv, distal	38.4(34–42) μm
H. <i>L. selago</i> , pv, proximal	
I. <i>Botrychium multifidum</i> , pv, distal	35.8(34–40) μm
J. <i>B. multifidum</i> , pv, proximal	
K. <i>B. dissectum</i> , pv, distal	37.2(34–42) μm
L. <i>B. dissectum</i> , pv, proximal

A

B

C

D

E

F

G

H

I

J

K

L

Fig. 19—Spore class 3, Trilete cont'd., X1000 (p. 14)

A. <i>Osmunda cinnamomea</i> , pv, distal	41.2(38–44) μm
B. <i>O. regalis</i> , pv, proximal	51.2(48–54) μm
C. <i>O. regalis</i> , pv, distal	
D. <i>O. claytoniana</i> , pv, proximal	42.2(40–46) μm
E. <i>Selaginella selaginoides</i> , pv, proximal	32.8(30–36) μm
F. <i>Lycopodium inundatum</i> , pv, proximal	48.0(46–50) μm
G. <i>L. inundatum</i> , pv, distal

Fig. 20—Spore class 3, Trilete cont'd., X1000 (p. 14)

A. <i>Ophioglossum vulgatum</i> , pv, proximal	44.4(40–50) μm
B. <i>O. vulgatum</i> , pv, distal	
C. <i>Lycopodium clavatum</i> , pv, proximal	37.6(36–40) μm
D. <i>L. clavatum</i> , pv, distal	
E. <i>L. complanatum</i> , pv, proximal	34.6(32–36) μm
F. <i>L. complanatum</i> , pv, distal	
G. <i>L. tristachyum</i> , pv, proximal	32.0(30–36) μm
H. <i>L. tristachyum</i> , pv, distal	
I. <i>L. obscurum</i> , pv, proximal	37.0(34–40) μm
J. <i>L. obscurum</i> , pv, distal

A

B

C

D

E

G

H

F

I

J

Fig. 21—Spore class 3, Trilete cont'd., X1000 (p. 15)

A. <i>Lycopodium annotinum</i> , pv, proximal	37.8(34–40) μm
B. <i>L. annotinum</i> , pv, distal	
C. <i>Botrychium virginianum</i> , pv, proximal	34.0(30–36) μm
D. <i>B. virginianum</i> , pv, distal	
E. <i>Sphagnum</i> sp., pv, distal	32.0(26–34) μm
F. <i>Sphagnum</i> sp., pv, proximal	
G. <i>Botrychium simplex</i> , pv, proximal	51.2(46–56) μm
H. <i>B. lunaria</i> , pv, proximal	39.2(38–44) μm
I. <i>B. lunaria</i> , pv, distal	
J. <i>B. lanceolatum</i> , pv, proximal	37.4(34–40) μm
K. <i>B. lanceolatum</i> , pv, distal

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