Appendix

Palynological Laboratory Techniques

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1 General Introduction

This appendix provides simple directions for processing various sorts of samples for palynomorph study, along with comments about some techniques used elsewhere, and some related matters. The emphasis is on techniques that can be adapted easily to basic laboratory facilities even of small institutions. Since publication of the first edition of this book, a number of elegant “system” techniques have been described, using various very sophisticated pieces of equipment such as special microwave heating devices to facilitate the precise processing of large numbers of samples or smaller suites of samples in a highly controlled environment. These systems do not address the purposes of most people who will use this book, and they are not essential for the production of very good preparations of fossil palynomorphs. They mostly were introduced because of situations in certain installations and localities requiring very precise control of the processing chemicals and by-products of the procedures.

Simes and Wrenn (1998), for example, describe a microwave digestion system, combined with gravity-separations and sieving techniques, designed for the stringent requirements of processing in a facility in Antarctica. Poulsen et al. (1990) describe a “maceration tank” procedure and apparatus involving the use of polypropylene tanks for HF processing, with the acid and water and other washing solutions transported by plastic pipes from tank to tank and to drainage sinks. It was inevitable that microwave heating would be applied to palynological processing, as it is a marvelously effective way of getting fast heating that penetrates to all part of the contents of a vessel being so heated. Jones (1994, 1998) describes an outfit for the purpose based on focused microwave digestion in a commercially available digestion system. Samples are processed quickly and relatively safely because of the sealed vessel basis of the digestion. A somewhat different microwave heating for HF digestion of palynological rock samples is described by Ellin and McLean (1994).

Turning to methods of more practical use for most readers of this book, I would recommend Doher’s (1980) 30-page publication about palynomorph processing, which contains directions for various preparation techniques. Another valuable publication on techniques is Phipps & Playford (1984). Kummel and Raup’s (1965) Handbook of Paleontological Techniques contains a number of chapters about palynology. The chapter by Gray summarizes the then current maceration methods, most of which are still in use. Well-described techniques in Evitt (1984), intended for preparation of dinoflagellate cysts, are also applicable to spores/pollen. Bryant and Wrenn (1998) present some processing techniques that students may find instructive for unusual situations. Jones and Rowe (1999) have many chapters on palynological techniques, with potential help for a variety of laboratory problems encountered.

It should also be stressed that all of the lab techniques described herein fall into the category of “kitchen chemistry,” and hardly any two laboratories perform the
various operations in exactly the same way. I noticed over the decades that my graduate students all developed their own “wrinkles” to the procedures I taught them—at least some of these were improvements. Always use common sense. For example, do not use a bleaching technique merely for cosmetic purposes; if the study involves close examination of exine sculpture, it is not sensible to risk ruining it by bleaching procedures. For studies in which estimation of thermal alteration is to be made (cf. Fig. [19.2]), bleaching may affect the validity of your observations. Readers will find it useful to consider the studies by Colbath (1985) about the negative effects our processing techniques can have on the makeup of the palynofloras we obtain. His results do not mean that we need to abandon any of the methods he studied, but rather that we should be careful about too much dependence on statistical measurements of the exact proportions of fossils in a palynoflora, remaining mindful of the possible influence of the lab procedures on the data.

In recent years a number of commercial laboratories have appeared that will process rock samples for palynomorph study, or do other sorts of palynological laboratory work on a per-sample fee basis. This outsourcing is practical for a person who is able to establish a microscopic laboratory facility but for whom the establishment of a wet lab would be financially or practically impossible. However, the outsourcing approach is clearly not as good for the palynologist’s understanding of the samples at hand as is processing in her/his own lab, because close observation of the effects of the various processes can be very instructive; furthermore, procedures can be adjusted to advantage in response to such observation. Users of this book may get information on outsource labs from the author or from other paleopalynologists. Officers of the American Association of Stratigraphic Palynologists (http://www.palynology.org) would be a good place to start in inquiring about this matter. The information changes too often for it to make sense to give individual addresses here.

2 Extant Spores/ Pollen

2.1 Introduction

People who work with fossil spores/pollen should study extant forms, at least to get ideas on morphology and structure potentially important for identification. When studying post-Cretaceous materials, awareness of modern forms is obviously important for suggesting possible botanical relationships. By late Neogene time practically all of the forms encountered are from extant genera, and collections of modern spores/pollen provide the basic material for all identification efforts.

It is possible to study “raw” pollen, and indeed aerobiologists routinely do this: atmospheric pollen is trapped, often directly on a slide to which Vaseline (petrolatum), glycerin or some other translucent sticky mountant has been applied, and
the spores/pollen are studied without treatment. It is possible to recognize pollen so prepared, especially as the aerobiologist has to recognize only a relatively few taxa that occur over and over. However, to determine the exine features with any degree of satisfaction, this is not a good approach, as untreated exines contain oil droplets and other intercalary inclusions, or there are external coatings that cover significant features. Furthermore, the protoplast and the intine of the spores/pollen make microscopic study of the exine very difficult, because the transmitted light of a conventional, biological type microscope must go through those structures before hitting the upper layer of exine. The adherent oils and included lipids and the whole protoplasm and intine need to be removed if the exine is to be properly studied. Also, since the exine alone is what a paleopalynologist studies, the reference materials need to be, as it were, artificially fossilized. One way this can be done is to boil anthers, sporangia, or even small flowers in 10% KOH. The cellulose is hydrolyzed and protoplasts lysed. The resulting exines are, however, practically colorless and must be stained for proper light microscopy (safranin-O, basic fuchsin or other red stains are good, because optical systems are usually corrected for green light). G. Erdtman (with help from his chemist-brother) long ago introduced the practice of acetolyzing sporulating/flowering material in a mixture of nine parts acetic anhydride, and one part concentrated sulfuric acid. The procedure has been retained by palynologists since, with little change (Traverse 1955). The reaction is as follows:

\[
(C_6H_{10}O_5) + 3(CH_3CO)_2O \overset{H_2SO_4 as catalyst}{\longrightarrow} (C_6H_7O_5)(CH_3CO)_3 + 3CH_3COOH
\]

(For structure of cellulose, see Chapter 3. Cellulose is really a long chain compound, with thousands of repeating units.) The sulfuric acid is a catalyst and also a desiccating agent. Sporopollenin of most pollen comes through relatively unscathed, at least at the level of magnification usually used, but the color is altered from almost colorless to a yellow, amber or orange color depending on length of treatment and thickness and structure of the exine. Some modern pollen grains, e.g., Malvaceae, are characteristically thick-walled. It is impossible to prolong acetolysis long enough to remove the cellulose of anthers and other flower parts of these plants without getting the exines very dark brown, sometimes almost black. These grains should therefore be bleached carefully with sodium hypochlorite (use laundry bleach) after acetolysis. Some grains are very pale even after acetolysis. These can be stained. In practice, staining and bleaching are seldom necessary. If acetolysis is done carefully, 95% of the forms processed will come out an acceptable yellow to orange color. Apparently, exines of at least some sorts of pollen are considerably modified in microstructure by acetolysis when it is combined with other treatments, as demonstrated by
Aubran (1977) for the use of acetolysis, plus potassium permanganate fixation (of cycadeaceous pollen), and by Hafsten (1959) for acetolysis combined with HF and bleaching (oxidation). In my experience, this is not a serious problem for practical palynology, where one seldom uses these combinations of methods. For very thin-walled or otherwise delicate pollen and spore exines, it is possible to use enzymes such as cellulase and pectinase for digestion of the non-sporopollenin parts of the grains (Schols et al., 2004). For applied paleopalynology this has little significance because such easily destroyed exines are unlikely to occur as fossils, but the method could be important for basic research studies of pollen morphology. The Schols method also employs a critical-point dryer, such as a Balzers CPD, an elegant way to dry plant material without application of either strong chemicals or microwave heating, when, for whatever reason, complete dryness is demanded quickly.

It is very important to understand that reference spores/pollen should not ordinarily be prepared from flowers, anthers or pollen collected by palynologists from the field into envelopes or vials, although it is possible to do this, and there are sometimes adequate reasons.

2.2 Preparation of Spores/Pollen for Microscopic Study

2.2.1 Drying Techniques

This assumes pressed, dried plants. Fresh flowers, etc., must be first dried. Both glacial acetic acid and acetone are readily available, good drying agents for this purpose, because one can go directly from a thorough soak in tightly covered containers (overnight is best) to acetolysis mixture after centrifuging off the drying liquid. Heating the glacial acetic acid and sample will expedite the reaction. If acetone is used, do not heat, because acetone is too volatile and flammable. Care should be taken not to breathe the fumes of either liquid. Freeze drying is another possibility, and it is also possible to dry plant material very quickly by a very brief (2-3 min) treatment in a microwave oven (Hall, 1981; Bacci and Palandri, 1985). Investigations in our laboratory showed that microwave drying damages varying percentages of pollen because of explosive production of internal steam inside some of the grains, but leaves ample undamaged pollen for adequate study. Incidentally, microwave treatment used for insect control on previously dried herbarium specimens does not harm pollen exines at all, although undried, fresh pollen is more or less damaged by the steam generated (see Arens and Traverse, 1989).

By far the best procedure (see Traverse, 1965) is to take the trouble to make pressed, dried plant specimens using conventional botanical techniques. These specimens will match up with field notes and numbers, and they can be used to prepare standard herbarium sheets. These are then “voucher sheets,” and the identity of the plants producing the spores/pollen can be checked, even decades
later, by a plant taxonomist. Study of the pollen morphology has shown me that specimens of *Nyssa sylvatica* were marked “*Maclura pomifera*” in several prominent herbaria in various parts of the USA. This dramatizes the point: if university herbarium curators make mistakes in identification of material, the average palynologist should not depend exclusively on her/his own field identifications.

2.2.2 *Outside the “Wet Laboratory”*

(a) Isolate sporiferous/polleniferous material as much as possible, dissecting off leaves, stems, peduncles, sepals, petals, etc. Ideally, just sporangia/anthers are best (easy with *Magnolia, Lilium*, and some ferns), but for plants with tiny flowers, such as Apiaceae, or ferns with well protected sporangia, whole flowers or pieces of a frond with many sori/sporangia must be used, although one should take care to remove as much extraneous tissue as possible. Work on a piece of white paper, using needles, scalpel, and fine scissors. A dissecting microscope (or at least a hand lens) is very useful. The best material is several florets that, when collected, were just on the point of opening but not yet open. Younger florets will often contain immature, atypical pollen, while older, open florets may have shed much or all of the pollen. Where large flowers such as *Camellia* are the subject, one collects just anthers, and should avoid opening a flower that was still closed when collected, and thus damaging the specimen too much, if it is part of a specimen of potential systematic significance, for example in an institutional herbarium. In such cases, and with fern sori and gymnosperm male cones, always carefully study the anthers, sporangia or pollen sacs with a dissecting microscope or hand lens, to be sure that abundant spores/pollen are present. Spore/pollen-bearing material removed from the specimen which is difficult to pick up can be easily poured from the sheet of white paper mentioned above into a collecting envelope. For cleaner slides, use as little material as possible to get a good preparation. If the material is from a working herbarium, the curator will welcome palynological predation more cheerfully if one is very conservative: anthers only where possible, as few florets as possible, etc.

(b) Record data immediately on the collecting envelope; one can get too little information but never too much. Get the original collector’s name and field number, locality information, and the herbarium where the voucher sheet resides. If it is one’s own specimen, or if the herbarium curator permits it, annotate the sheet from which material is taken. Remember that all of this preliminary work should be done outside the processing laboratory because contamination, though seldom a serious problem, can become so if spores/pollen are willy-nilly introduced to the dust load of the “wet” laboratory. A data file should be created for each maceration that preserves all information from the collecting envelope. If the preparation is productive, assign a serial spore/pollen collection number to it. File the completed slides by family, then by genus and species. File the data by serial number, with cross-references to genus + species and family.
2.2.3 Inside the “Wet Laboratory”: Acetolysis

(c) Working in a fume hood, prepare the acetolysis mixture of nine parts acetic anhydride and one part concentrated sulfuric acid. Each preparation will take about 12 ml of mixture. It is best to calculate how much will be needed for the number of samples you intend to process, and to make approximately that much, discarding the excess in a hooded sink with plenty of running water, or into a “decant bottle” of water which is periodically dumped in an approved place and manner (check with safety officers of your institution). The mixing-reaction is exothermic. Therefore add the acid to the anhydride a little at a time (acetic anhydride is very hydrophilic, and fumes will go for the moisture in your mucous membranes with uncomfortable results if you do not work in a hood!). Do not stopper or tightly cover the mixture until it has “settled down.” (Be sure to wear lab goggles if you don’t wear regular eyeglasses, in case there is spattering. Indeed, in my lab nobody was allowed in the door without eye protection.) Be certain that all utensils used in preparing the mixture are absolutely dry, as even a little moisture inadvertently introduced will turn the mixture immediately dark brown and render it useless. The correct color for the completed mixture is pale yellow. Acetolysis mixture can be stored in a refrigerator in a stoppered bottle for later (but not too much later) use. It will change with time from the original pale yellow through orange and eventually to brown, decreasing in effectiveness as it darkens. It is better not to store the stuff beyond the time required for one session of pollen preparation, but on occasion I have left it in a refrigerator for a week and found it still yellowish and usable. On other occasions even one day was too long.

(d) For each envelope of sporiferous/polleniferous material to be processed, prepare a 15 ml high quality, high temperature resistant glass centrifuge tube, to which a laboratory number has been affixed (I prefer the special laboratory tape for this purpose). This number should be recorded in a working laboratory book, along with the species name and more information, if more than one preparation of a species is to be made. Stand the tube in a tube rack and put a small glass funnel in the tube. On the top of the funnel put a slightly cupped square of 40 × 40-mesh (0.420 mm) brass screening. Pour the contents of one of the collecting envelopes on the screen and rub the anthers, etc., through with a thumb or fingertip. Note that the screen and human digits must be thoroughly cleaned and dried from previous use, or the resulting preparation will have contaminants! I favor cleaning the screen by brushing with a toothbrush, followed by flaming in a gas flame (hold square of screen with a longish pair of channel-lock pliers). However, the resultant preparation will then be contaminated with abundant black flecks of charcoal, unless the screen is thoroughly rid of them by vigorously and repeatedly knocking the square against the edge of the bench or other surface while holding it with the pliers.
(e) Wash polleniferous material from the screen and sides of funnel into the test tube with an acetone wash bottle (do not work near a flame! acetone is flammable). Invert the funnel on a labeled paper towel. Centrifuge sample for 3 min (top speed in a table-top clinical centrifuge, or 2500 rpm in a floor-model, tachometer-controlled machine) and discard acetone into running water in a hooded sink. Replace funnel in tube and now working in hood, carefully and slowly add acetolysis mixture to tube. Fill tube to within about 2 cm of the top. Equip tube with narrow stirring rod (about 3 mm (heavier stirrers sometimes break tubes). Put tube with stirring rod in a small beaker of boiling water on a hot plate in hood. A piece of heavy-duty aluminum foil with a hole for each centrifuge tube can be applied to the top of the beaker—this minimizes the chance of water drops getting into the tube. If more than 1-2 tubes are to be processed, I favor using a rack with holes for the tubes that fits into a saucepan of boiling water. (See Traverse, 1965, for description of the virtues of aluminum heating blocks for this purpose: no problem with constantly refilling water baths, no spoiling of acetolysis mixture by water condensate, more readily controlled temperature, e.g., at higher elevations where water boils at too low a temperature. Water baths are more likely to be available and are all right if properly monitored.)

(f) Continuing to work in the fume hood, heat tubes in the water bath at 100°C for 10–12 min (usually 12 min; however, if working at higher elevations, the water bath will not be 100°C and the time must be adjusted upwards). Stir (gently) every 3–4 min, leaving stirring rod in the tube. (Pure samples of pollen can be acetolyzed for shorter periods of time, but if much cellulose from floral tissues is present, longer acetolysis is needed.) Acetolysis mixture turns dark brown during the reaction if the procedure is working. Remove stirring rod, then centrifuge sample in the same manner as for acetone removal, except that this step must be accomplished in a hood. Decant into hooded sink with plenty of water flowing, or into a decant bottle in the hood, depending on your laboratory circumstances. Never decant into an open sink, as the acetolysis mixture fumes are very toxic to people! Centrifuge tubes with a well-packed residue in the bottom end should be decanted in a quick, smooth, inverting movement. Novices make problems for themselves by too deliberate decanting, as this causes the liquid to bite into the sediment at the bottom. However, I would advise anybody who is having a decanting problem and wants to avoid redoing a lot of work, to decant centrifuge tubes into a clean beaker first, and then empty the beaker if all went well. If the decanting hasn’t gone well, the liquid and residue can be poured back into the centrifuge tube for re-centrifugation and another try at decanting.

(g) Add distilled water to the tube. The semi-distilled water in laboratory taps labeled “distilled” is fine. So is water from a dehumidifier or commercial bottled distilled water. It is usually unwise to use the local ordinary tap water, which can be a source of contaminants and sometimes of distressing amounts of calcium salts. Stir thoroughly; I prefer to stopper the tube and shake it, but prior loosening of the residue with a thin stirring rod may be necessary. Centrifuge again. Decant
into hooded sink. Repeat washings followed by centrifugation until no acetolysis mixture remains. Usually this is three washings, unless there was too much plant material. If one is in doubt, after the third washing it is safe (and the best test) to taste for trace acidity with the tip of the tongue. If there is still a lingering acidic taste, repeat the washing. After the first wash it is all right to work in an unhooded centrifuge and to decant in an open sink. After the last decantation keep the tube in the inverted position and place mouth down on a paper towel to drain for about 10 min.

(h) Affix temporary labels to a vial to receive the residue and to the desired number of slides which should be placed along with coverslips on a warming table set at a temperature of 38–40°C. Add warm (about 50°C) glycerin jelly (see section on mounting media below) to the drained residue, the amount depending on the amount of residue and the density of spores/pollen desired on the slides. Start with about five times as much mounting medium as you have residue, and adjust if necessary after inspecting the first slide. To add glycerin jelly, I use a 10 ml commercially available pipette from which I have cut off a section of the tip, as the original tips are too narrow, and soon clog with jelly. Stir mixture of jelly and sample in tube thoroughly with a narrow, warmed (hold under hot water tap for about ten seconds, and shake off water drops) stirring rod, but take care to avoid introducing air bubbles. Keep the tube warm by frequently holding the lower end of it under hot water tap. Make desired slides by inserting a short glass tube (2 mm. diameter) with the end stopped by a finger, about half way to the bottom of the well-mixed jelly-residue, then releasing the finger to admit a few drops of mix. Put a drop of mix on the slide and cover with a coverslip (working on a warming table). To minimize introduction of bubbles, position the coverslip over the drop, resting one side on the slide (hold the top and bottom edges gently with one hand); with the other hand, insert a bent dissecting needle between the open side of the coverslip and the slide, drawing it out slowly as the coverslip descends. I favor placing the drop in the center of the slide, as a centered preparation is more conveniently studied microscopically than is a preparation which is too close to one edge or the other. Leave slides on warming table at least 24 and not more than 72 hours to cure (= lose water, mostly). Then clean the slide carefully with a moist tissue and label them. Although many use peel-off labels, these invariably fall off in time. In my opinion, the best way to label slides is to clean the end to be labelled with 50% alcohol (rubbing alcohol is satisfactory) to remove all traces of finger oiliness and then write the label directly on the glass with an India ink pen or a pen with similarly permanent ink. In a minute or two the label can be painted over with colorless fingernail polish. (Some black ink pens that will write on the glass nevertheless are unsatisfactory because the ink is soluble in the polish solvent.) The coverslip can be carefully ringed with the polish at the same time. Use a “bead” that just gets up onto the coverslip. It is not possible to study specimens critically that lie under the ring. If an important specimen is later encountered, use a little acetone on a folded corner
of tissue to remove the acetate film in that area, and polish the area with another folded corner of tissue moistened with saliva (or water for the squeamish—saliva is better). After studying or photographing the specimen, renew the ring. The ringing greatly prolongs the life of the slide. Oxidation-destruction of specimens on the slide is hastened by oxygen from the atmosphere, including that in bubbles on the slide.

2.2.4 Additional Information and Discussion

2.2.4.1 Contamination Problems. Although some palynologists use elaborate precautions against atmospheric and other pollen contamination in their laboratories, including even frequent vacuum cleaning, my experience is that this is hardly ever a problem. The pollen prepared from dried plant material or from sediment samples should completely overwhelm isolated contaminants for one thing, or the slide should not be used. Atmospheric contaminant pollen will seldom exceed 1-2 per slide even when conditions are relatively bad, for example, with many people coming and going during a flowering season. I have proven this to my satisfaction by many studies of blank slides made with just mounting medium. The relatively few atmospheric spores/pollen falling into the mounting medium or otherwise introduced after processing contain protoplasm with various inclusions and thus are recognizable as foreign to the preparation. This is just not a serious problem, though I advocate a moderate degree of sensible caution, e.g., no extraneous flowering material in the wet laboratory. Vials, beakers, tubes, and other specimen containers should be kept covered when left overnight or longer. A much more serious source of contamination in my experience is insufficiently cleaned glassware, especially centrifuge tubes. Plastic tubes are more likely to offend than glass because of the presence of numerous scratches. Phipps and Playford (1984) advise against using mortar and pestle for crushing, as their surfaces may be pitted and cause contamination. This is true, but is insignificant if only glass, not ceramic, mortar and pestles are used, and if they are carefully cleaned after each use. As noted above, a stray contaminant grain now and again really does little harm, as it will be completely overwhelmed by the palynomorphs that belong in the sample. Results should never depend on very rare specimens for just the reason that contamination cannot be completely excluded. Nevertheless, the Phipps and Playford method of crushing rock samples between two aluminum pie plates which are then discarded, instead of crushing in a mortar, is certainly elegant.

2.2.4.2 Coverslip Thickness, Upside-down Slide Curing, and Coverslip Sandwiches Sometimes one has difficulty with spores/pollen lying too far below the coverslip to be studied with the very short working distance of high-power oil-immersion lenses. Undestroyed chunks of plant tissue or foreign matter exacerbate the problem by holding the coverslip up. In the first place, never use coverslips thicker than no. 1 (some people use the even thinner no. 0, but they are very
fragile). It is possible to cure slides upside down, using coins or wooden strips on the warming table, under the ends of the slides, or slides can be cured upside down in racks in a warming oven. The spores/pollen will mostly sink in the liquid glycerin jelly to come to rest against the coverslip and will stay there if the slides are also cooled upside down while the glycerin jelly jells. (Another way to keep specimens near the plane of the underside of the coverslip is described below under double mounting.) Where really critical microscopy is planned, however, the best idea is to make coverslip “sandwiches,” with the residue between two no. 1 coverslips. These can be fastened to a slide with bits of sticky tape. A specimen can be studied and photographed from both sides in this manner. (I also have used this technique for SEM work: see below.)

2.2.4.3 Centrifuge Tube Breakage  Glass centrifuge tubes, even the best ones, do break. Yet for acetylosis work, they are preferable to plastic: the centrifuging works better, and they are easier to clean than plastic, which accumulate scratches, in which contaminating palynomorphs can hide. (Both glass and plastic centrifuge tubes can be cleaned of possible organic-matter contaminants with strong oxidants such as sodium hypochlorite. Stand the tubes in a beaker of such solution overnight.) Usually a preparation from a centrifuge tube that breaks can be saved, though it is better to start over if there is plenty of material. First, the centrifuge shields in which the tubes are spun must have been clean beforehand: wash and brush them out frequently. If a tube breaks, dump the contents, rubber cushion, broken glass, and all, into a beaker. Use needles and forceps to remove the cushion and glass shards. If the sample was in acetylosis mixture or other strong chemical, dilute with enough water in the beaker to make this possible. If necessary, strain through a small plastic sieve to separate small glass shards. Centrifuge to recover the residue and proceed as if nothing had happened. Obviously, it is tempting to use plastic tubes all the time, taking care to keep them meticulously clean, including treatment with laundry bleach.

2.2.4.4 Non-centrifugation  Occasionally, for reasons I do not understand, an acetylyzed residue will display mutual repulsion of particles and will refuse to “go down” when centrifuged. It may be necessary to basify the mixture with some 10% potassium hydroxide to make the residue pack down normally. The alkali can then be washed out by a couple of water changes and centrifugations before proceeding. Addition of ethyl alcohol to reduce the specific gravity of the hydrous liquid has been used to encourage centrifugation in such difficult cases. It is interesting in this connection that Clarke (1994) found that some pollen forms, such as Tsuga, characteristically resist centrifugation, causing under-representation in analyses.

2.2.4.5 About Mounting Media  Spores/pollen are mounted on microscope slides in a wide variety of transparent media. Some have even advocated corn syrup or various self-prepared plant gums. Today there are only a few preferred
mountants. The most common is glycerin jelly. Canada balsam, a natural resin from coniferous trees, is popular. It is soluble in xylene. Its index of refraction is good for pollen study (see Table A.1). The ideal index of refraction should be a little different from that of sporopollenin but not too different. Glass has an index of refraction of 1.54. Water, at 1.34, is too different from sporopollenin ($RI = 1.48$); specimens in water show too much contrast and a very dark outline. Glycerin jelly, a little below, and Canada balsam, a little above sporopollenin’s $RI$ are both good. However, specimens must be run through alcohol and xylene changes before they can be mixed with balsam, which is considerable extra labor, and the liquid balsam remains liquid (especially in the center of a preparation) until the xylene gradually evaporates, sometimes after many months.

Specimens can and do change position and location during the solidification process. In time, the originally almost colorless balsam turns dark, but balsam preparations are good for many decades. Elvacite, now used by many palynologists, is also dissolved in solvents and thus has the disadvantages of Canada balsam, but it does not discolor with age. Its $RI$ of 1.49 is very close to that of sporopollenin, suggesting that it would not give as good definition as either balsam or glycerin jelly.

Although I have tried to find a satisfactory synthetic substance, I keep coming back to glycerin jelly. Despite the fact that it is not really permanent (most of my 40-year-old slides are spoiled—to say nothing of those that are now 60 years old—apparently by autoxidation of the sporopollenin), it is fairly durable: a well-sealed preparation will stay in good condition at least 10 years. J. Jansonius writes me that perhaps insufficient water-washing at the end of my procedures accounts for degradation over time of my glycerin jelly preparations, and that keeping residues slightly acid with a few drops of dilute HCl at the end of processing guards against destructive reactions. In any case, he states that glycerin jelly slides from the former Esso labs in Calgary are still good after several decades. D. M. Jarzen writes me that his 40-year-old slides are still good and asserts that careful sealing of the coverslips with varnish is probably the reason, but I also seal all coverslips. As stated elsewhere, the fact that the pollen in my vials of the same preparation as the slides is apparently good for at least 60 years, tells me that it is the slide-coverslip housing that is the problem somehow. Glycerin jelly has additional virtues: for example, its refractive index is perfect for photomicrography. It is thermoplastic at a lowish temperature (about 45°C, depending on how it is made), so that residues can simply be stored in it, melted when needed, and new slides made. It is water soluble, so that no extra steps are needed to go from final water washes of a residue, before combining with mountant. As an alternative storage method, residues can be stored in water containing a biostatic compound, and slides made by mixing glycerin jelly with drops of the stored residue. Because of thermoplasticity, the mountant in the vicinity of a specimen on a slide can be touched with a warm instrument to melt the mountant locally and permit
Table A.1 Refractive indices (RI) of some palynological mounting media

<table>
<thead>
<tr>
<th>Substance</th>
<th>RI</th>
</tr>
</thead>
<tbody>
<tr>
<td>air</td>
<td>1.00</td>
</tr>
<tr>
<td>water</td>
<td>1.34</td>
</tr>
<tr>
<td>silicone oil</td>
<td>1.4</td>
</tr>
<tr>
<td>glycerin jelly</td>
<td>1.43</td>
</tr>
<tr>
<td>AYAF (vinylite)</td>
<td>1.46</td>
</tr>
<tr>
<td>glycerol (glycerin)</td>
<td>1.47</td>
</tr>
<tr>
<td>sporopollenin, acetolyzed or fossil</td>
<td>1.48*</td>
</tr>
<tr>
<td>Elvacite</td>
<td>1.49</td>
</tr>
<tr>
<td>Canada balsam</td>
<td>1.53</td>
</tr>
<tr>
<td>quartz glass</td>
<td>1.54</td>
</tr>
<tr>
<td>Lakeside 70**</td>
<td>1.54</td>
</tr>
<tr>
<td>polyvinyl alcohol (PVA), as solid film</td>
<td>1.55</td>
</tr>
</tbody>
</table>

$RI = 1.55 - 1.62$ for fresh sporopollenin, according to Christensen (1954) and Jones (1984).

** Used as adhesive for rock thin sectioning.

Note: As has been frequently explained (Berglund et al., 1959), palynomorphs give poor definition in transmitted light if mounted in a medium with refractive index either too different from or too similar to sporopollenin. An $RI$ moderately above or moderately below that of the specimens is best. For example, water mounting gives very harsh contrast and a black outline to palynomorphs. Further, refractive index too close to that of sporopollenin gives poor definition without sufficient contrast. The relatively good definition of sporomorphs in Canada balsam would be difficult to explain if the $RI$ for acetolyzed or fossil sporopollenin were as high as Christensen (1954) and Jones (1984) have reported for fresh sporopollenin. Polyvinyl alcohol, the usual primary mountant in double-mounting techniques, also gives good resolution at $RT = 155$. That glycerin jelly, Canada balsam, and PVA all give very good resolution with palynomorphs tends to support the measurement of 1.48 for acetolyzed or fossil sporopollenin.

turning of a specimen with gentle pressure of a needle. Because glycerin jelly’s constituents can be purchased almost anywhere, one is independent of scientific suppliers, though very good glycerin jelly can also be purchased from them. Residues stored for many decades may have the glycerin jelly become as tough as leather and no longer readily soluble in water. These residues can be recovered by heating them in 20% HCL for varying periods of time, depending on the state
of the mountant. The residue can then be centrifuged, washed and recombined with fresh mountant.

In our laboratory, we have generally made our own glycerin jelly, using the following recipe: 50 g. plain gelatin (ordinary Knox’s gelatin from a grocery store works fine), 150 gm. glycerin, 7 gm. phenol, 175 cc. distilled water: dissolve phenol in warm glycerin; dissolve gelatin in warm water (add gelatin gradually to water while stirring, then allow time for dissolving); mix both liquids together and warm gently to 80°C (do not allow to get hotter), bottle in wide mouth jars, and store at room temperature.

Many palynologists who study and count late Pleistocene and Holocene pollen and spores find it essential to be able to turn over their specimens during counting to verify morphological features. They therefore prefer to use silicone oil, as it remains liquid, does not evaporate, and has a satisfactory index of refraction. It is true, however, that specimens will wander, especially if the slides are not stored horizontally. Glycerin (= glycerol), a liquid constituent of glycerine jelly, can be used in a similar fashion, but the refractive index is less satisfactory. (Tacking down the coverslips with nail polish retards but does not prevent wandering of specimens.) Silicone oil can be purchased from: Accumetric, Ring Road, Elizabethtown, KY 42701, USA. It is manufactured by Dow Corning Corp. as: 200 Fluid Dimethylpolysiloxane (viscosity: 2000 centistokes). This information is from Dr. Cathy Whitlock, Department of Earth Sciences, Montana State University, who uses the following modification of Faegri and Iversen’s (1989) method for mounting fossil pollen residues in silicone oil:

(1) Wash with water.
(2) Wash with a few drops of water and 95% ethanol.
(3) Wash with 99% ethanol; stain with safranin-O or fuchsin if desired.
(4) Wash with t-butyl alcohol.
(5) Add about 1 ml t-butyl alcohol, transfer to small vial, add silicone oil, leave for evaporation for about 24 h. The vials may be kept for future use.
(6) Add the amount of silicone oil needed for optimal concentration of the pollen.

In making the slides the smallest possible amount of silicone oil should be used. The droplet spreads under the coverslip very slowly. For fossil slides small coverslips (18 × 18 mm) are to be recommended. Reference slides of recent pollen may be sealed with nail polish. (Paraffin is preferred by some, as there is some deterioration over a period of several years caused by a reaction between nail polish and the silicone oil.)

As I have noted elsewhere, I am not convinced that the mobility of palynomorphs in oil is really necessary, as the microscopist who has seen thousands of specimens of, say *Fraxinus* pollen will have no difficulty recognizing
it any position it is likely to assume in solidified glycerin jelly. In critical cases where moving the grain is absolutely necessary, this can be done by local melting of glycerin jelly with a very warm to hot pointed metal object, without losing the many advantages of a solid mounting medium.

2.2.4.6 “Double-mounting” Many laboratories use a technique for slide preparation that results in specimens closely adhering to coverslips, using two mountants, one a thin film in which the palynomorphs are enclosed, and the second to fasten the coverslip containing the specimens to the slide. The following is an example of double-mounting which was used in the palynological laboratory of the Geological Institute, Swiss Federal Technical Institute (“ETH”), Zürich, when I was there, 1980–81. It was adapted from procedures followed in palynological laboratories of the Geological Survey of Canada.

Ingredients:

(1) Polyvinyl alcohol solution: 50 gm polyvinyl alcohol in 500 ml distilled water. Mix and heat until solution clears—do not boil. Stir constantly, otherwise solution will form crystals. After PVA has dissolved, filter through filter paper and add a few drops 37% formalin to prevent fungal growth. Store at room temperature. (It should be rather viscous, like syrup.)

(2) Epofix™ (tradename for an epoxy resin; check on-line for current suppliers): mix with Epofix hardener as outlined by manufacturer. Mix only small amount needed, as it hardens within 30 min.

Procedure:

(1) Drain excess liquid remaining on the surface of the centrifuged, finished residue, and on the inside of the centrifuge tube, by inverting tube for a few minutes on a paper towel.

(2) Add few drops distilled water and one drop phenol (5% solution) to residue in test tube.

(3) Prepare coverslips to receive residue by affixing tiny numbered bits of press-on label to one side of coverslip, and inverting, so that unlabeled side will receive residue.

(4) Using capillary pipette, put one drop PVA on coverslip (two drops if coverslip is larger than 22 mm square).

(5) Using another capillary pipette, mix residue thoroughly with its few drops distilled water and drop of phenol (see step 2). Put one drop of residue on coverslip—mix thoroughly with PVA, and spread evenly, using side of pipette, being sure to get to edge of slip, and to eliminate areas of thick residue. Hold slip by edges with fingers while doing this. Set aside on sheet of white paper overnight. (It is desirable to cover all prepared coverslips
with a box lid or similar item to exclude dust or other contamination.) Be certain all coverslips are labeled (see step 3).

(6) Proceed to next residue, using another pipette, of course. Discard pipettes after use. You can use the same pipette in PVA for all samples being mounted at one time, provided you do not touch any of the residues with this pipette, i.e., always mix on coverslip with residue pipette. The easiest way to manage the PVA is to pour amount you intend to use for the job (25–50 ml perhaps) into a very small (100 ml) beaker. As long as you are certain you have not contaminated the PVA, you may return unused portion to your primary container.

(7) When job is done for the day (and it is best to save up residues until you have eight or ten to do), put a large box lid or other protection over the coverslips you have just coated with residue, as mentioned in step (5).

(8) Next day, or when convenient, mount coverslips on slides as follows:

(a) If an adhesive such as Epofix is used, mix just the amount you need, as explained above. If a resin type mountant dissolved in a solvent, such as Elvacite, is used, such precaution is not necessary.

(b) Using a capillary pipette, disposable probe wooden stick or other disposable utensil, put two drops of Epofix on slide and then lower the coverslip, residue side down, onto slide, using the same method (with needle, lowering coverslip slowly) that is used when mounting coverslips with glycerin jelly.

(c) Set aside to harden completely (several days) before removing the tiny labels and affixing permanent labels. It is not necessary or desirable to ring the coverslips with fingernail polish, as is usually done with glycerin jelly preparations.

(9) Storing of residue still remaining in test tubes should be done as part of the first day’s procedure, when all coverslips have been coated with that day’s samples. Leftover residue may be stored upright in small glass vials with screw tops (taped shut for additional protection). An extra drop of phenol may be added. Residue liquid may evaporate, and this should be checked frequently.

Further notes on double mounting: There are many variants on this theme:

(1) Some do not use a primary mountant at all, but evaporate a residue in water or an organic solvent onto the coverslip, which is then mounted directly on a microslide with a drop of mountant. When this is done, the $RI$ of the single mountant used is what counts optically, not the $RI$ of the primary mountant, such as PVA.
(2) The secondary (or only, if no primary mountant is used) mountant can be any clear liquid that can either be polymerized, as Epofix, or can be a solution of a resin, such as a number of methacrylate compounds in use, for example Elvacite 2044 (formerly Lucite 2044), dissolved in xylol, which solidifies as the solvent evaporates. These substances have advantages and disadvantages, as for Canada balsam. Elvacite and other such synthetic resins have the advantage over Canada balsam of not discoloring with age. Elvacite has the apparent disadvantage of $RI$ too close to that of sporopollenin for optimal definition (See Table A.1).

2.2.4.7 Bleaching Some spores/pollen are thick-walled or otherwise end up too dark (e.g., some Malvaceae become almost black, as mentioned earlier) in an acetolysis long enough to disintegrate the cellulosic tissues. Sometimes preparations are accidentally over-acetolyzed, and the pollen is rendered too dark. In these cases the preparation can be bleached after acetolysis, as follows:

Add to the washed residue in a 15 ml centrifuge tube enough laundry bleach (sodium hypochlorite solution, such as Clorox®) to fill the tube about one-third full. Reaction time and concentration of solution determines degree of bleaching. About 2–3 min is usual. After this time, fill the tube with distilled water and centrifuge. If desired, the reaction can be stopped rapidly by adding 5% KOH to basify, as the hypochlorite solution has to be acidic to bleach. Water wash the residue until clean (no trace of bleach odor or taste in water—usually two or three water changes).

2.2.4.8 Staining People who prepare spores/pollen by potassium hydroxide cooking usually stain. KOH-treated specimens look as if they had been acetolyzed and then strongly bleached. Some sorts of pollen, e.g., sedges such as *Juncus*, are so sensitive to acetolysis that KOH boiling is preferred. For these specimens, also for the relatively few things that come through acetolysis very pale, or for grains that were overbleached, staining is very helpful.

To a few drops of residue in neutral water, add a drop of basic fuchsin stain (saturated water solution of the stain, using 0.5 ml ethyl alcohol per 100 ml water). Centrifuge and add mountant, etc. Also frequently used is safranin-O, but it is not as good as staining in combination with glycerin jelly. Proceed as for basic fuchsin, except that safranin-O is normally dissolved 1:100 in 50% ethyl alcohol. Allow residue to stand in the stain solution for 1–2 min after stirring thoroughly. Then centrifuge and follow with one water wash. Safranin-O is a more general stain than basic fuchsin and will make nearly all organic matter on the slide reddish. Red stains are preferred, because optical systems are said to be corrected for green light, and it is felt that definition is best with reddish-orange color. However, malachite green and Bismarck brown have also had some popularity as pollen stains. Addition of a little basic fuchsin to the glycerin jelly used will counteract the tendency of the jelly to destain specimens when basic fuchsin is used.
3 Fossil Palynomorphs

3.1 General Instruction

Collection of suitable rock samples for paleopalynology requires the collector to understand the basic natural history of palynomorphs, discussed at various places in this book. Spores/pollen exines, other sporopolleninous palynomorphs, and chitinous/pseudochitinous palynomorphs occur in sedimentary rocks as organic, silt-sized particles, subject to certain constraints. They are sensitive to high pH over long periods and are thus not usually common in limestones. They are sensitive to oxidation even for short times, and are thus not usually found in redbeds or deeply weathered rocks. They are sensitive to heat alteration (carbonization = coalification, darkening of color, ultimately becoming opaque and otherwise devoid of sporopolleninous-chitinous characters such as flexibility), thus not occurring in rock that is or has been deeply buried (about 5,000 m or more) or much metamorphosed (palynomorphs cannot be macerated out of slates or anthracites, even though examination of polished surfaces demonstrates their presence), or subjected to heat from lava flows or intrusions. They are sensitive to re-crystallization processes, thus are very seldom found in dolomites, because dolomites are normally formed by re-crystallization as calcium magnesium carbonates from the calcium carbonate limestone. Palynomorphs are rarely found in heavily cemented, indurated rock. As to size, they are silt to very fine sand particles and thus are not found in well-sorted claystones and well-sorted coarse sandstones. It should be emphasized, however, that many claystones and sandstones are “dirty” (= not well sorted), contain some silt-sized particles, and may contain palynofloras. I find the chewing method of detecting silt by its feel between the teeth to be very helpful in selecting the most promising samples when one must be selective in order to limit the number of samples collected–see below under field methods.

The field collector should therefore look for “fudgy” siltstones. All in all, cores are the best sample source when available. Fresh, unweathered roadcuts are just about as good and offer more possibility to study the geological environment, collect megafossils, etc. Well cuttings are poor because they are often contaminated with drilling mud containing rock fragments from up-well, and usually additive pollen from the drilling mud. Also, the bagged sample of cuttings is not exactly referable to the listed depth. Sidewall cores made by shooting into the wall of the hole are excellent but seldom available. Pieces of rock from museums are sometimes very good, usually associated with good collection data, and frequently tie in with important research projects. However, they are subject to bias because they were almost never collected with palynology in mind. For example, a palynologist once reported the near absence of palynomorphs in rocks of a certain age in North America, based on study of museum fossil matrixes. The rocks were collected mostly for fossil vertebrates and vertebrate
footprints and were mostly redbed coarse shales and sandstones. Non-redbed siltstones from most of the same areas are productive. Sometimes great perseverance is required. Leopold and Wright (1985) report that they processed over 450(!) rock samples to obtain 35 which were productive, some apparently only marginally so.

The dispersed palynomorphs in a sedimentary rock are actually “nanno-range” pieces of coal, and the rock in question would constitute a fossil fuel if palynomorphs instead of mineral clasts overwhelmingly predominated. (Cannel coal is such a palynomorph rock.) The principle of palynological maceration is to separate out these “nanno-coals” from the mineral clasts, and then further treat them for microscopy, as necessary—and no more. The initial treatment of a prevailing mineral sample will ordinarily be with hydrofluoric acid to break down siliceous minerals. Concentration of the palynomorphs may then be required, for partial elimination of other “nanno-coals,” such as wood, leaf cuticles, and amorphous organic matter. The most commonly needed additional treatment is oxidation to break up massive organic matter in order to release included palynomorphs, or to lighten very dark palynomorphs. This oxidation procedure must be applied as little as possible and with great caution because sporopollenin/chitin are quite oxidation-sensitive themselves. The oxidation makes humic acids available, and these must then be removed by solution in bases such as KOH solution. Sometimes pH 8 is enough. In other cases acetone or even hot 10% potassium hydroxide must be used. If the sample itself is already carbonaceous—a peat, coal or very carbonaceous shale—the initial treatment will have the purpose of structural breakdown of the organic mass by oxidation, which is then followed by hydrofluoric acid to remove the mineral matter remaining. Fig. A.1 shows the normal sequence of treatments for a sedimentary rock other than such a coal. Fig. A.2 shows the sequence of treatments for oxidation of coaly material, whether from coal or from an acid-treatment residue of carbonaceous sedimentary material generally. The oxidation procedure produces artificially “regenerated humic acids,” which are soluble in alkaline solutions such as KOH, NaOH, or NH₄OH. Naturally occurring humic acids or naturally (by weathering, etc.) regenerated humic acids are also alkali-soluble.

In my experience, almost every suite of samples presents some unique problems, and the following directions are only a general guide. Modifications will constantly be necessitated by observations “in the kitchen,” and indeed a kitchen is a better analogy to a paleopalynological laboratory than is a geochemistry laboratory. Different samples will behave quite differently under the same treatment. Further, there are usually alternative methods that one can use, as required by circumstances. For example, because HF was not allowed in the laboratory on the Glomar Challenger, when I worked on that vessel for the Deep Sea Drilling Project in 1975, I used wet physical disaggregation of the shales in an electric blender, followed by alternate phases of cooking in 10% hydrochloric acid and a laundry detergent (Calgon®). This freed enough palynomorphs so that
they could then be floated off from the mineral clasts in a heavy liquid solution (zinc chloride, specific gravity 2.1).

There has been considerable interest in this sort of non-HF processing as a substitute for HF and other strong acid-based procedures because of stringent environmental requirements in some laboratories and in some special situations such as the one I faced on the Glomar Challenger. Riding and Kyffin-Hughes (2004) describe in detail a processing method based on use of physical disaggregation, plus treatment with the surfactant/dispersant substance sodium hexametaphosphate, plus sieving techniques. The substance is the active ingredient of the commercial product, Calgon®, which I used on the Glomar Challenger because
it was the surfactant that the ship’s laundry had. Williams et al. (2002) reported on oil company use of well-site processing for palynology, using only physical disaggregation, plus heating in hydrogen peroxide, followed by gravity separation using only swirling and settling techniques in water, and surfactants for additional cleaning. Those interested in trying different approaches to acid-free process should certainly consult the manual on techniques in paleobiology by Green (2001: 124–5, 178–9, 290–1), in which some interesting ideas of breaking down rock structure after preliminary physical disaggregation by freezing, with and without addition of various salts, and accomplishing the same result by alternate kerosene and water (with and without surfactant) treatments, or by treatment with mineral spirits, followed by boiling water. I haven’t tried these methods in the context of palynological processing, but combined with sieving and/or gravity methods, they are certainly worth experimentation.

Some samples will contain a great deal of very fine particulate matter, and the major preparation problem will be to disperse the fine particles after acid treatment with a dispersing agent (surfactant), sodium pyrophosphate, followed
by screening on very fine screen (or cloth mesh) that will pass the fine particles but not the palynomorphs (see Cwynar et al., 1979 and section 3.2.4 in this Chapter).

Hardly anything is absolutely essential to palynological processing. Good results can be and have been achieved without most procedures we regard as routine. Few of the chemicals except for HF are particularly dangerous and if diluted sufficiently can go into any sewer. Instead of an electric centrifuge, a hand centrifuge can be used. If enough time is available, repeated decantation will work, using centrifugation only in the final, washing, steps of preparation. A student of mine even used this approach for simultaneous treatment of large numbers of samples, each in a labeled styrofoam cup. Batten and Morrison (1983) have shown that membrane dialysis can be used to rid a sample of acid without centrifuging or decanting. It is possible to use no centrifugation, and no agitation of the organic residue from acid-digestion of mineral matter at all, substituting great patience with the time required, for the efficiency of normal palynological processing. When this is done, very delicate specimens that would be completely destroyed by conventional processing can then be carefully pipetted out of the residue in water (cf. methods section of Butterfield, 2005). Such specimens are not technically palynomorphs, and their study is not palynology, which by definition depends on preparation and manipulation of large numbers of robust specimens. That does not denigrate in any way the study of ultra-delicate organic specimens for sometimes important paleontological purposes. Indeed, reasonable steps to prevent destruction of somewhat weakly robust palynomorphs are occasionally required in our field.

I have used the chart displayed in Fig. A.3 and associated instructions, to teach new laboratory assistants and students how to process rock samples of unknown character. As has been emphasized, this is only a general guide and must be modified in one way or another for almost all sets of samples. For example, if concentration of palynomorphs is very low one may use massive samples (hundreds of grams) and physical disintegration in a large container, followed by large scale “swirling” to get off a silty fraction which will include the palynomorphs. This silty fraction can be drawn off, centrifuged to get rid of excess water, then processed conventionally. Some pollen-bearing samples seem more or less impossible. For example, chitinous insect parts make up most of the organic matter of bat guano. After demineralization, it is next to impossible to separate the matted mass of insect mouthparts, etc., from the spores/pollen. Many of the mouthparts are in the same size range as spores/pollen, preventing screening. Chemical techniques that destroy chitin (oxidation) also destroy sporopollenin.

There is plenty of pollen in Baltic and other amber, but no technique I have tried is really successful in dissolving the amber and leaving the pollen. (Marshall, 2005, described success with anisole as a solvent for terebinth resins for palynological purposes, and this breakthrough should be tried on ambers
Figure A.3 (See caption on page 638)
VI. Oxidation:
(with Schulze's sn.: sat. K₂ClO₃, conc. HNO₃)
Note: water wash residue immediately after Schulze treatment (3 washes); then proceed to step VII.

VII. Removal of humic acids:
(with 5% KOH, dilute NH₄OH, 20% K₂CO₃, or acidozone); this normally follows VI, but see instructions.

treat with "Schulze’s sn." as follows: mix with residue (in test tube or beaker, depending on volume of residue: about 3x as much sat. K₂ClO₃ as you have residue; now working in hood, add about 8x much conc. HNO₃, as you have K₂ClO₃ to make the proportion 50/50. Note! Varying proportions of these two components, e.g. 70/30, also generally give good results. Heat in water bath (tubes) or on hot-plate (beakers) gently, stirring occasionally: 2-45 min. for shale residues, 15-30 min. for limestones, 3-5 hrs. for bituminous coals; proper oxidation is the point at which the pollen and spores are comparatively light and transparent; check residue (in water!) frequently during oxidation to avoid over-processing.

Removal of very coarse: before oxidizing, add a little 10% KOH to a tiny fragment of the coal to assist in determining how much oxidation to employ. In some few instances of low rank, already oxidized (weathered) coal, only KOH and no Schulze treatment is necessary. At the other extreme, there may be no reaction with KOH, indicating considerable oxidation (up to 5 hours) is necessary.

Note re coals: before oxidizing, add a little 10% KOH to a tiny fragment of the coal to assist in determining how much oxidation to employ. In some few instances of low rank, already oxidized (weathered) coal, only KOH and no Schulze treatment is necessary. At the other extreme, there may be no reaction with KOH, indicating considerable oxidation (up to 5 hours) is necessary.

VIII. Optional additional demineralization:
(ZnCl₂, float/sink technique, or 30 min. HF treatment)

IX. Staining (optional) and making slides:
(remember to weigh slides, etc. if calculating spores/pollen per g)

(USE basic fuchsin or safranine-O: for basic fuchsin, first add a drop of dil. NH₄OH, then several drops conc. basic fuchsin water snl. to residue, shake or mix, centrifuge, decant liquid, drain; for safranine-O, use eye-dropper of conc. stain in water), stir thoroughly with residue, let stand 1 min., add water to fill tube 1/2 full, centrifuge, water-wash twice, decant liquid, drain.)

add to stained or unstained drained residue in test tube enough glycerin jelly (preferably stained, if residue is stained) to insure a high concentration of palynomorphs on slide; this is best ascertained by examining residue in water until suitable concentration is noted, and then (after, of course, washing and draining residue), adding the same amount of glycerin jelly; transfer thoroughly stirred residue to storage vial (weigh before and after introducing residue, if spores/pollen per g is being calculated).

using small glass tube and precleaned, labelled slides (weighed if pollen/g calculations will be made; also weight coverslip), place two or three drops of well-mixed residue on center of slide (on warming table at 38-40°C); touch jelly drop with edge of coverslip and gently lower slip so that jelly drop is centered in middle of coverslip (a bend needle is useful for this); release coverslip and allow jelly to flow to margins before attempting to adjust coverslip; allow slides to cure for 24-48 hrs. on warming table (if desired, slides may be cured upside down by supporting the edges of the slide with coins or thin strips of wood; this makes fossils lie close to coverslip); ring coverslip with colorless fingernail polish to seal and prolong life of preparation.

Figure A.3 Flowsheet for paleopalynological processing.
and other difficult resinous materials.). True oil shale, such as the Mahogany Ledge of the Green River Oil Shale, is also well nigh impossible. The “kerogen” matrix of the oil shale holds it together against all maceration processes I have tried.

3.2 Maceration and Slide Preparation

To supplement the schedule shown in Fig. A.3 consult the references mentioned at the beginning of this appendix. Use common sense and observe carefully what is going on.

3.2.1 Additional Cautions and Reminders

1. Make complete notes of each process used, as to the amounts of chemicals, time, temperature, results, etc. Use a permanently bound notebook, not loose pieces of paper. Keep all notes about the sample together by allowing sufficient space in the notebook. Such note-keeping is of paramount importance.

2. Many rocks will require different and/or additional procedures. Remember that the basic principle (Fig. A.1) is to separate first the total organic residue from the mineral matter present, then the pollen and spores from the other organic matter. Coal and very highly organic shale are exceptions; removal of residual mineral matter in such cases is one of the final steps, not the initial one. Follow progress of a maceration by using a rough scope in the wet laboratory to look at a drop of the maceration in progress (never from HF or other strong acids without thorough water-washing first!). When palynomorphs are easily studiable, it is best to stop processing and begin studying. When in doubt about the wisdom of applying an additional procedure, it is best to divide the residue and experimentally further process only a part of it. Avoid “heroics” of processing. Too much processing often destroys the palynoflora, or selectively destroys it, so that it is no longer representative. (On the other hand, there are limits as to how “dirty” a preparation can be and still be studied effectively!)

3. Never apply a float-sink procedure after HF digestion, if the residue is richly organic. All of the organics will float, and a grand mess will result.

4. Never “store” a residue (overnight, over a weekend) in an oxidizing (e.g., nitric) acid, or in a strong alkali (e.g., potassium hydroxide mixture). However, it is all right to leave a partly processed residue at any stage in water, or even in a non-oxidizing acid (HCl, HF), for days or weeks.

5. Do not use Schulze’s mixture or other oxidizing technique on a residue that is already partly alkali soluble–test a bit of washed residue with 10%
KOH—a dark coffee color will be imparted to the solution if the residue is in part alkali-soluble.

(6) Label everything—especially beakers, slides and other things left unattended overnight.

(7) Always balance centrifuge heads carefully.

(8) Use distilled water for sample-washing to prevent contamination, and because tap water contains too much dissolved and suspended mineral matter, especially calcium salts.

(9) Hoods must have exhaust fans turned on all the time, not intermittently. HF is very bad for humans, as well as for equipment, even in tiny amounts. The hoods also should be checked on a regular basis for efficiency. A hood with poor suction is almost as bad as no hood.

(10) Do not put HF beakers on stirring warm plates until reaction has ceased at room temperature. Otherwise the reaction may become violent when the temperature is raised.

(11) If a reaction becomes too violent, cut it with alcohol (95% ethyl alcohol is good) from a spray bottle kept at the ready. This will knock down the reaction without significantly diluting the components.

(12) If it is not convenient to remain in the laboratory until a reaction is complete, the total treatment may be administered in increments—it never hurts palynomorphs to sit in HF, HCl or water, as mentioned above.

(13) Always decant spent acids, etc., into decant bottles with plenty of water in a fume hood. In our laboratory, we used decant bottles half-full of saturated calcium chloride solution for spent HF; the CaCl₂ converts the fluorides of HF used in rock digestion to relatively harmless CaF₂. Local authorities may have set up procedures for the regular collection of decant bottles of hazardous wastes such as spent acids. Always carefully check on the local regulations and follow them explicitly. If regulations permit, it is possible, using great care and a great excess of running water, to pour contents of decant bottles (the bottles should be no more than 3/4 full) down a hooded sink.

(14) Do not neglect to put a little concentrated HCl in the HF for stage IV in the Fig. A.3 flowsheet. This is very important to prevent accumulation of fluorosilicate gels, which once formed are difficult to eradicate, though heating in con. HCl may help.

(15) Clean all equipment after use. You may use it next!
3.2.2 Calculation of Pollen/Spores Per Gram of Sample: Traverse Weighing Method

This is simple if the vial is very well mixed before placing part of its contents on a slide. But you must remember to do some weighing as you go along and record the measurements.

1. Weigh the original (dry) sample.
2. Weigh the vial in which you store your residue, both before and after putting the residue in it.
3. Weigh the slide and coverslip which will receive a drop of the residue both before and after putting the residue on the slide. A microanalytical balance is needed for this step.
4. Use the equation $X = \frac{BD}{CA}$ outlined in the previous chapter to calculate the number of palynomorphs per gram of sample, where $X =$ number of microfossils per gram, $A =$ grams of sediment sample, $B =$ total grams of maceration residue plus glycerin jelly, $C =$ grams of residue plus glycerin jelly on slide, and $D =$ number of microfossils on slide. Obviously, this also requires that all the specimens on the slide be counted. One should therefore aim at a slide that has less than 1,000 specimens, as counting more than 1,000 is too time-consuming. If necessary, a line may be ruled in indelible ink, connecting opposite corners of the coverslip, and only half (or a quarter) of the slide counted, and the counts multiplied by 2 (or 4) before running the calculation per above equation. (See also Chapter 17 for a more extended explanation of this method and of the competing, more popular Lycopodium spore (or other microscopic “stick” or “spike”) method.

3.2.3 Additional Comments on Gravity-Separation Technique

Gravity separation methods are commonly used in palynology to improve concentration of organics for spore/pollen analysis. Many methods or techniques are applicable. We have normally used the ZnCl$_2$ method in our laboratory, occasionally substituting ZnBr$_2$. Both are relatively safe: no dangerous fumes exist compared with bromoform-alcohol mixtures of the correct density, although the latter may be used with separatory funnels to get off the organic float very neatly. Bromoform, however, is expensive and very poisonous. Also, residues must be water-free before going into bromoform-alcohol.

Although ZnBr$_2$ costs more than ZnCl$_2$ per gram, it has a specific gravity of 4.2, as against 2.9 for ZnCl$_2$, meaning that it takes 1.4 times as much ZnCl$_2$ to make up a 2.1 specific gravity solution. (Some who use zinc bromide solution report using solutions of 2.4–2.5 specific gravity, which is easy to achieve with the heavier compound.) This makes ZnBr$_2$ almost as economical as the more
viscous and more difficult to manage ZnCl$_2$. Furthermore, recycling of used ZnBr$_2$ solution by dilution, centrifugation and re-concentration by evaporation is more practicable. In other words, if the relative price of ZnBr$_2$ permits, use ZnBr$_2$.

There is little or no chance of contamination by remnant palynomorphs if the solution is not reclaimed. This also saves time. Although ZnCl$_2$, like ZnBr$_2$ can be reclaimed (by dilution, centrifugation, evaporation to restore specific gravity of 2.1), reclamation works more easily with ZnBr$_2$. The relative cheapness of ZnCl$_2$ makes discarding that used solution practical. Stock solution does not deteriorate if properly stored, but one should always check the specific gravity before use!

The desired specific gravity of 2.0–2.2 is readily adjustable by addition of water or ZnCl$_2$. The basic principle of the method is that chitin-sporopolleninous palynomorphs have a specific gravity of about 1.4, whereas the lightest minerals have a specific gravity of about 2.5. The slow centrifugation that precedes the fast centrifugation is to permit minerals and palynomorphs to “work past each other in the traffic.” An immediate fast centrifugation would cause the minerals to drag the palynomorphs down. “Slow centrifugation” can also be applied in water to separate palynomorphs by causing minerals to centrifuge out while palynomorphs are still suspended in the water. (“Short centrifugation” refers to using a short enough time for centrifugation to throw coarse minerals down, but not long enough to throw down palynomorphs, which can then be decanted off. On the other hand, the method can also be used to throw down spores but not suspended clay particles! See “Darvan” method below.) This may, however, result in differential loss of larger palynomorphs.

Processing can be maintained in a water base, whereas the bromoform-alcohol treatment requires alcohol washes both before and after the separation. The principal disadvantage is the high viscosity of ZnCl$_2$ solution. ZnBr$_2$ solution is much less viscous. However, the viscosity of ZnCl$_2$ solution does not seem to interfere with good organic retrieval.

The use of sodium polytungstate (SPT) solution at 2.2 s.g. as an alternative to the zinc salts for heavy liquid separation in palynology has been described by Simes and Wrenn (1998). This material is water soluble and relatively non-toxic and is thus ideal for situations where toxicity is carefully monitored, but there is a minor problem with insoluble precipitates that makes use of deionized water advisable. It is very easy to recycle the solution by filtration and evaporation, which is obviously an advantage in field localities where replenishment of supplies is a problem.

3.2.4 Dispersion of Fine Clays, Screening

As noted earlier, one often obtains a residue which is more or less unstudiable because of a profusion of very finely dispersed particles (usually clay minerals) in the 1 μm or smaller size range. These can be removed by a variety
of screening techniques, combined with use of dispersants (a better term for the cleaning compounds we use is surfactant = surface active agent). The technique below is simple and inexpensive and usually works acceptably (see also Cwynar et al., 1979).

3.2.4.1 Dispersing Agent/Surfactant Methods The use of Darvan, a defloculant based on polyacrylic acid, the molecules of which attach to clay particles and cause them to repel each other, for dispersing excessive clay minerals, was described in the first edition of this book. Unfortunately, that admirable substance is no longer available. Sodium pyrophosphate can be used in the same general way (see Cwynar et al., 1979). Another surfactant material is “Quaternary O,” a high molecular weight quaternary ammonium surface active agent (see Hills and Sweet, 1972). This dispersing agent is favored by some for megaspore work. N. O. Frederiksen (personal communication, 1996) wrote me that his lab at the U. S. Geological Survey used the commercially available dish detergent, Sparkleen, as a surfactant for palynological processing: 60 cc of Sparkleen were dissolved 1.5 l water, then this mixture was filtered through a Whatman no. 3 filter to remove particulate matter, then more water was added to produce 4 l of the solution for dispersing/surfactant purposes; see Frederiksen (1996), in which this solution is referred to as “soapy water.” I have found that various products commercially available as glassware cleaning compounds work equally well.

3.2.4.2 Procedure (Use after HCl-HF and/or gravity separation.) If you notice that your sample is full of finely divided clay which obscures the spores/pollen, you may disperse the clay at any stage in your maceration sequence.

(1) Start with washed, drained residue in 50 ml (or 15 ml, if residue very small) test tube. (If you have more than about 1 cm of residue in the bottom of a tube, divide into two tubes.) Add a little more than twice as much surfactant solution as you have residue. With stirring rod, stir up thoroughly from bottom of tube, so no residue is left sticking to sides and bottom.

(2) Agitate tube on tube mixer (such as Vortex Genie®) for 1 min to mix surfactant and residue.

(3) While still on mixer, fill tube with distilled water to within 2 cm of top.

(4) Centrifuge at 1,400 rpm (no more!) for 1 min (no longer!). Do not use brake to slow or stop centrifuge. Decant carefully into large beaker (check later for spores inadvertently poured off, although in our experience this practically never happens). This is called “short centrifugation” and will eliminate much clay because the fossils go down, but the clays are kept in suspension by the dispersing agent.

(5) Wash 3-4 times, or until decant is clear, stirring carefully, centrifuging as in step(4), and decanting into the large beaker. Most of the fine mineral fraction will be poured off in this way.
(6) Sieve to separate rest of fine fraction from residue. (If residue still contains large particles, sieve first through a 210 μm brass sieve, washing through thoroughly and saving what goes through for examination.) If no large particles, skip this and go directly to sieving through 7 μm nylon screen ("Nitex® bolting cloth"—go online and look for currently viable sources). Wash thoroughly with warm water. Palynomorphs will be held back on the screen, and unwanted fine particles will go through.

(7) Very carefully, using a funnel, wash residue from cloth into 15 ml test tube(s).

(8) Centrifuge, stain if desired, add mounting medium, make slides.

Discard screen after use for one sample. If you plan to macerate other fractions of the same sample, you may retain the original screen for this after washing it thoroughly. It may be kept between paper towels (labelled!) or in an envelope.

3.2.4.3 Other Filtering Techniques  Several other filtering techniques involving more equipment are used with success in various laboratories. Neves and Dale (1963) described a filtering technique based on a sintered glass disk (porosity 2) in a Büchner funnel mounted on a pressure flask. An air pump reverses the flow of air periodically (50 s filtration flow, 5 s reversed air flow) to keep the sintered glass disk from clogging. Good results have been reported by various laboratories using variations of the method. In our lab, we used a “modified Reissinger apparatus” (M.R.A.), based on sintered glass (= fritted glass) filters attached to funnels; this procedure, can be employed at any stage in palynological processing (see Ediger, 1986a). M.R.A. is particularly useful after heavy-liquid separation and after oxidation. Raine and Tremain (1992) have published an interesting version of M.R.A.-type technique, including illustrations of the relatively simple equipment they use for generating the suction applied to the commercially available, cloth-based filter (7μm mesh) unit, and reverse flushing of it. As of the publication of this second edition, Raine is still able to provide the basic equipment to interested persons.

Caratini (1980) used an ultrasonic generator in combination with nickel filters. The technique has the advantage over sintered glass disk methods of not needing to be constantly unclogged, and over the nylon netting used in the “Darvan” method of being more or less permanent. However, the metal filter unit alone costs hundreds of dollars, and an ultrasonic generator must be added to this cost. Later, Caratini (personal communication, 1986) used the ultrasonic generator with Swiss bolting cloth filters (the Nitex® material mentioned above) on supporting perforated disks. Ultrasonic generators are much used in palynological laboratories, but they pose some problems, especially that they tend to break up brittle palynomorphs. If very carelessly used, they can also damage human retinas.
Batten and Morrison (1983) described the use of ultrasonics for cleaning samples in considerable detail, using vibration of 50 kHz.

3.2.5 “Swirling”

This technique takes advantage of the differential response to turbulence of palynomorphs of different sizes, conformation and specific gravity, and of the “junk” in palynological maceration residues, the same physical properties as form the basis for concentration of palynomorphs in sediments during deposition. “Swirling” involves agitation of palynomorph residues in water in a watch glass rather like panning for gold. The principle in “swirling,” however, is probably based only partially on specific gravity. Sporopollenin is all pretty much the same in this respect, about specific gravity 1.4. However, different proportions of internal spaces can nevertheless give the different sorts of palynomorphs different effective specific gravities. Size, shape, and morphology of the microfossils also play roles. The technique is very helpful in separating palynomorphs from other organic “junk” in a particular residue, without resorting to screening and heavy-liquid gravity separation. As is true of slow (or “short”) centrifugation, however, there is some danger of differential loss of certain palynomorph fractions. Clarke (1994) notes that swirling and sieving recover a larger percentage of large buoyant forms than centrifugation because such forms are routinely lost in decantation, having failed to centrifuge.

3.2.5.1 Procedure  Although simple, it must be learned through experience, as different samples behave in different ways and are best treated by slightly different techniques. I have known a palynologist who could prepare a slide containing almost entirely one species of fossil pollen from a residue containing many species. For the neophyte it can be slow, messy, and frustrating, but with experience one is able to “clean up” a sample in a few moments. It is especially valuable in the separation of spores from large tissue fragments of similar density. Unless great care is used, certain size-groups of spores may be lost. Therefore, it is not generally recommended for quantitative work. The residue should be in a fluid, generally aqueous, carrier, of neutral pH to avoid equipment damage and flocculation.

(1) Place a small amount of residue (usually a few drops, although amount varies somewhat with spore content, degree of “cleaning” to be done, number and size of slides to be made, etc.) in a clean 3 inch watchglass and fill two-thirds full with water. Allow to settle a few seconds.

(2) Gently swirl the contents by moving the watchglass in a circular motion, so that the center of the watchglass circumscribes a small (1–5 mm) circle about a point on the work table. This causes a certain fraction of the residue to be suspended.
(3) Decant the suspended material, or pipet it to another watchglass and inspect both glasses with a dissecting microscope. If one fraction contains debris but no palynomorphs it may be discarded, and the process repeated with the palyniferous fraction to attain a desired concentration. By suitable adjustment of the swirling speed, particles of different size and general morphology from the palynomorphs can be separated from them. It is even possible sometimes to separate one kind of sporomorph from others by very critical “swirling,” to make a super-clean preparation of that kind. This is seldom important, as capillary tube pipetting, working under the microscope to select specific fossils, does it more accurately. However, the most useful application of this technique is to rid a troublesome sample of unwanted minerals and large organic particles.

(4) Inspect separated fractions under the microscope. The scope must have at least a 1” working space. Magnification of 100× or 150× appears to be the best compromise between enlargement and field area. If a fraction is found to be barren (or essentially so in non-quantitative work) it is discarded.

(5) Repeat the process on the sporiferous fraction, using slightly varying swirling amplitude and vigor, until the particles heavier and lighter than the spores are removed. Material of the same density and size as the spores cannot be removed. Particles of different size from the sporomorphs can be separated owing to the difference in energy required for the micro-currents in the glass to “pick up” objects of different size. The very simplest form of swirling, letting the residue and water settle for a minute and then decanting the “discolored” water, is almost always beneficial in removing colloid-sized material. If the remaining residue is then somewhat violently swirled, the spore-bearing fraction may be decanted from the heavy and large “dregs” which escaped earlier processing (often mineral particles and heavy tissues).

Finest degree of separation is accomplished by gently jiggling the residue into the center of the watchglass and then very gently swirling it at a very small amplitude. This generates a column of “smoke” which is of slightly different density-size characteristic from the non-rising residue. In this way separation of different genera can sometimes be made. A very useful description of swirling techniques has been presented by Tripathi (1995), including some helpful illustrations of the method.

A number of techniques have been described which, like swirling, depend on exploiting differential physical properties of what remains after palynological basic maceration. Tschudy’s (1960) “vibraflute” is a mechanically agitated tube with holes along it, permitting collection of fractions at intervals. The differences in size and other properties of various constituents of a residue cause the fractions to contain concentrated, “cleaned up” samples of various palynomorphs.
Forster and Flenley’s (1993) technique of pollen purification, down to producing slides containing almost all one species from a mixed residue by equilibrium density gradient centrifugation clearly is based on the same factors that made the “vibraflute” work. Hansen and Gudmundsson (1979) describe a technique for utilizing the differential take-up of absolute ethyl alcohol by palynomorphs, permitting their separation by specific gravity difference, from organic debris that does not take up the alcohol.

3.2.6 Oxidation Notes

In addition to Schulze’s mixture (see Fig. A.3), other oxidants, such as hydrogen peroxide or sodium hypochlorite (ordinary laundry bleach–NaOCl solution at a concentration of about 5–6%) may be used. Evitt (1984) suggests adding HCl to the NaOCl to intensify the reaction. The reaction can be stopped quickly by basifying the solution with 5% KOH.

Batten and Morrison (1983) point out that treatment with Schulze’s mixture for the purpose of oxidation has the desirable side effect of eliminating pyrite (marcasite) crystals from the treated specimens. This is because of the solubility of FeS$_2$ in concentrated nitric acid (HNO$_3$).

3.2.7 Special Techniques for Megaspores, Chitinozoans, and Scolecodonts

Megaspores and many chitinozoans and scolecodonts have in common that they usually occur one or two orders of magnitude less abundantly than spores/pollen in sediments. Furthermore, they are usually much larger than most miospores and consequently are visible as dots to the naked eye. Therefore, different preparation techniques are required. First, because of low concentration, larger samples of rock should be used—several hundred grams instead of 20-40 g. Second, the preliminary fine grinding used on miospores must be avoided as this will destroy many specimens of macrospores and larger chitinozoans and scolecodonts. Breaking the rock sample into pieces about 1 cm across is as far as one should go. Secondly, strew slides are not acceptable because the concentration is too low. These large palynomorphs are best picked out of the maceration in water, using a brush or a capillary tube. The microfossils are mounted on SEM stubs, on microslides, or on special microfossil (foraminifera-type) slides. Thirdly, all of these microfossils tend to be opaque because of the size and the thick walls, and are best studied by reflected light and by SEM rather than with the LM. The following processing method, modified from Jenkins (1970), who developed it for chitinozoans, can be used also for scolecodonts and megaspores.

3.2.7.1 Preliminary Treatment  
Fragment about 250 g of sediment into pieces about 1 cm in size (smaller fragments yield broken specimens, larger ones require too long for maceration). Discard fines that are produced by the sample fragmentation.
3.2.7.2 Maceration

(1) Working in a fume hood, treat in largish Teflon beakers with 10% HCl until all reaction ceases. Wash and transfer to HF, as in conventional maceration procedure. From time to time, as other activities permit, use gradual decantation to go from one step to the next without centrifugation, as centrifuging damages large, ornate specimens. Thoroughly water wash after no further HF reaction is occurring. Do not move to the water wash without allowing plenty of time in HF.

(2) Sieve, using a brass sieve with openings appropriate to the category of fossil (ca. 125 μm for megaspores, 50 μm for chitinozoans, 100 μm for scolecodonts). Hold the sieve containing the residue in water to within 1 cm of the top of the sieve. Gently move the sieve up and down in the water without allowing the water to flow over the top of the sieve. Fines pass through. Continue this procedure, frequently changing the water, until no material passes through the sieve, which can be checked by collecting small amounts of the wash water in a beaker.

(3) Bleach (if necessary) in commercial laundry bleach, checking the course of the procedure under the microscope: transfer approximately one-fifth of the residue to a white-bottomed petri dish (about 10 cm in diameter), or a clear petri dish on a white card or tile. Adjust water depth to 0.5 cm. Add a few drops of the bleach solution, mix thoroughly and observe under a low power microscope. Stop the bleaching by adding an excess of 5% KOH solution when the correct bleaching level is attained. The bleaching can be precisely controlled in this manner. Wash the residue by repeated addition of water and decanting until a drop of the residue in water leaves no trace of precipitate when evaporated on a microslide.

(4) “Picking” and mounting: spread the residue thinly over the bottom of a white-bottomed petri dish in about .5 cm of water. Search with a stereo- microscopic microscope. Pick up desired specimens with a capillary pipette. A pipette attached to a hypodermic-syringe plunger by a plastic tube can be used, or a simple pipette drawn out at one end to about 1 mm in diameter (larger for some megaspores), closing the other end with a finger until the specimen is near the orifice of the tube. Release of the finger allows specimen to rush into the tube with water. It can then be blown out onto the desired surface. These are the same techniques as described for spores/pollen under single-grain mounts, except that the orifice of the pipette must be larger.

Specimens may be transferred, as picked, to a little distilled water in a second petri dish, e.g. to group similar specimens before mounting. When ready to mount, transfer the specimens to a watchglass containing a 2% aqueous solution
of Cellosize. Take up specimens from the Cellosize solution with a pipette and put out as a small drop on a coverslip. (Up to 30 specimens can be grouped on one large coverslip.) Put the coverslip, face up, on a warming table at 50°C for 1 h, or until dry. Invert the coverslip and carefully lower onto a drop of Canada balsam or other suitable permanent mountant on a slide. Alternatively, megaspores, chitinozoans and scolecodonts can be mounted in glycerin-jelly on slides, or they can be put (dry) on SEM stubs or on cross-hatched microfossil slides of the sort used for foraminifera studies. If it is desired to study and photograph the whole specimens by reflected light, or to study by SEM, this is necessary. In this case, a very small camel’s hair brush is used for picking up the specimens, and, in the case of SEM studies, the cellosolve must be washed off before mounting. Paris (1981) describes a useful method for mounting the specimens on a coverslip, which can be mounted on an SEM stub, and then later removed for LM microscopy.

Collinson et al. (1985) suggest that, after maceration, a panning (“swirling”) process in water can be used to concentrate megaspores. Residues are stirred, allowed to settle for a few seconds, then the supernatant is decanted and passed through a 125 μm sieve. The process is repeated until no more plant material is brought up by stirring. If the original maceration was not done with HF, an HF treatment is applied now if necessary to remove adhering minerals.

Wilde and Hemsley (2000) describe a method for isolating megaspores from Cretaceous sediments consisting of virtually unconsolidated clays. These could be “macerated” by mere soaking in plain water, with occasional use of hydrogen peroxide. The disintegrated clay was then sieved, and the megaspores picked out of the wash water under a dissecting microscope and stored in glycerin for later study by SEM.

3.3 Field Methods

3.3.1 Sample Collecting

As stressed elsewhere, palynomorphs are sedimentary particles in the silt to very fine sand particle-size range with a characteristic set of chemical and physical properties. It is here necessary only to mention those aspects of collecting samples for paleopalynology which long experience has taught me are not always obvious to field geologists.

(1) Palynologists, or geologists well instructed by experienced palynologists, should whenever possible collect their own samples, whether in the field or from cores in a core storage area. This is the efficient approach because laboratory procedures in palynology are labor-intensive, and it is very important to avoid barren samples as much as possible.
(2) Cores or fresh outcrops are better than weathered outcrops. Palynomorphs are very sensitive to oxidation and much time is wasted macerating weathered rock. In hot, dry climates, weathering often extends so deeply into rock outcrops that blasting or bulldozing is necessary to get down to acceptable samples. Where this is not possible, look for places where the target layers are exposed along a stream cut or actually in the stream bed. Avoid collecting on exposed ridges.

(3) The best rock type is relatively unconsolidated “fudgy” siltstone in the gray to light grayish-brown color range. There are exceptions to the relatively unconsolidated dictum. I have had marvelously abundant and beautifully preserved palynofloras from local Devonian siltstones that were cemented so hard that they were difficult to break with a hammer on a lab splitting block. Plenty of samples with all the above desirable characteristics are nevertheless barren. Truly black shales are seldom good because the black color often comes from minerals, or the organic matter may be predominantly non-palynomorph, such as sapropelic material. Coals are often highly vitrinitic (vitrinite is derived from wood or bark and is of course barren of palynomorphs), hard to process, and usually contain an autochthonous flora typical of the original swamp and thus are less satisfactory for stratigraphy than shales. Sporinite-rich coals, however, may yield beautiful palynofloras! Red (and even dark brown) shales usually are oxidized and barren, very rare exceptions being shales reddish from included red minerals where the rock itself is not oxidized. Truly green shales are seldom productive. Because the siltstones we seek are soft, even a comparatively fresh outcrop, say a highway cut, will often yield the best rock for our purposes only in the soft layers that occur between consolidated, un-palyniferous shales or hard sandstones. Furthermore, because they are soft and often thin and hence easily eroded away, it is frequently necessary to get at these soft layers by excavating deeply into the rock face between the hard layers, deeper the longer the outcrop has been exposed to weathering. Avoid rock that shows evidence of post-depositional alteration as evidenced by slickensides, cleat and cleavage, or obvious secondary cementation, or proximity to a lava flow or volcanic intrusion such as a dike. Mottling of surfaces of otherwise promising siltstones is an indication of weathering and is usually a negative indicator.

(4) Test a very small piece of the rock between your incisor teeth for sediment size. If it is really smooth in texture, it is clay and not likely to be good. If it is really gritty, it is no good—sand. If it is on the smooth side, but slightly fine-granular, at least the particle size is acceptable—it contains at least a little silt. Remember that a “fudgy” silty rock is what you are looking for. If there is no problem with running as many samples as you like, by all means include clayey or sandy samples that seem
perhaps marginal – why not? Despite the odds, they sometimes contain floras. However, do not waste time on black shales or any reddish or mottled rocks.

(5) Limestones are seldom good, though marls and calcareous shales can be productive, and there are exceptional cases of beautiful preservation in limestone. Dolomites are nearly always barren, as previously noted. Look for stringers of siltstone associated with limestones/dolomites. These are sometimes productive.

(6) A moderately productive siltstone will yield a very good maceration from 10 g; a richly productive siltstone requires only 2-3 g. It is not necessary to collect large samples, although it is my custom where space or weight is not a problem to collect about 250 g (about half a cup) in labeled cloth bags, in case a future mass maceration might be desired. When visiting places where shipping rock samples is for various reasons a problem, it is possible to send perfectly good palynological samples home, folded flat into pieces of paper, in ordinary letter envelopes. (Because of newer automated sorting and canceling machinery put in service since the publication of the first edition of this book, I would now recommend padded envelopes for the samples.) I have found it useful when forced to have other geologists collect for me to mount a series of pieces of lithologically “super” silty gray shale on a small board for the collector to use in the field for comparison purposes.

(7) Patient searching of outcrops in a sedimentary basin will almost always yield at least stringers of suitable siltstone. An exception in my experience has been the Jurassic/Triassic rock of the Fundy Basin in Nova Scotia, where the prevailing rock type is red, oxidized shale and sandstone, the promisingly green horizons being apparently secondarily reduced, and the few grayish siltstones that occur almost always contain organic matter carbonized by proximity to the overlying North Mountain Basalt. However, even in Nova Scotia, after years of looking, a productive layer was eventually found near Parrsboro, paradoxically only a meter under the basalt (see Fowell and Traverse, 1995).

3.3.2 Field Processing

It is possible to produce adequate slides for study from rock samples by processing in the field, and, of course, to study them there also, if a microscope is available. I have done this by using heavy duty stoppered large plastic jugs for HF digestion, working in a secluded spot in the open, well away from buildings and people, avoiding windy days and working upwind from the work table. Although this is doubtless against some local ordinances, the very small quantities of chemicals needed do no realistic harm. The acids can be decanted
into prepared, heavy-duty plastic jugs (containing CaCl$_2$ and alkali solution) that are taken later to a suitable place for disposal. Working in the open, a hand-operated centrifuge can be used after great dilution of acids by decanting. Final processing steps, slide making and microscopic study can be accomplished in a motel room, or even in a tent, provided that there is power for the microscope illuminator or that a microscope with a mirror for use of daylight is available. Kaars and Smit (1985) describe a method for field maceration based on use of dispersing agents, sieving and decanting, without use of strong acids, similar to that described above and to those outlined in great detail by Riding and Kyffin-Hughes (2004).

3.4 Manipulation of Spores/Pollen

3.4.1 Single Grain Manipulations and Mounts

A century ago, pre-TV, when microscopy was a popular hobby for the well-to-do, there were even folks who made beautiful *objets d’art* that could be viewed only with a microscope, by picking up and glueing down variously colored scales from lepidopteran wings and diatom frustules. Manipulating individual spores/pollen and dinoflagellate cysts under the microscope would not have surprised such folk. However, modern day students usually are appalled in elementary palynology when they discover that they will be expected to pick up and mount for study individual palynomorphs that they can’t see without a microscope. There are several reasons for teaching these techniques.

1. Nothing so dramatically teaches the meaning of the size range of palynomorphs as making single-grain mounts. Until then, when they are only untouched objects on microslides, the actual size of palynomorphs is not really grasped. Furthermore spores/pollen seem to “come alive” for students when they have actually handled them.

2. For reference purposes single-grain mounts are very helpful, e.g., as a reference collection of the constituents of a palynoflora to have near at hand during the course of the study. They are ideal for type-specimens for new taxa although such specimens are very seldom designated. They are perfect for sending to another palynologist for discussion, because there is no question as to identity. (For this purpose I advocate mounting such specimens in a “coverslip sandwich,” so that viewing from both sides is facilitated.)

3. For SEM and TEM work it is often best to isolate single specimens. (For details, see section 3.4.1.3 later in this chapter.)
3.4.1.1 Glycerin Jelly-particle Technique (see Fig. A.4). This is the “quick and dirty” technique.

1. Get some of the residue into glycerin and alcohol (50/50) or glycerin and water (25/75) in a tube or vial. The latter mixture is more viscous, but the former mixture evaporates rather quickly. Put a very small drop of this mixture on a slide and spread it out over the surface of the slide with a needle held parallel to the surface of the slide.

2. Using the 10× objective of the scope, locate a specimen of the desired taxon. Verify the identification at higher power (20× or 24×) if necessary, but return to 10× and clear away mountant and other debris completely from the area of the subject grain with needles and other more or less

Figure A.4 Single-grain mounts by the glycerin-jelly-needle method. (a) under the microscope at low-power, needles are used to clean debris away from the vicinity of the desired palynomorph, which is in a glycerin/water smear on a slide; (b) the palynomorph is picked up with a tiny chunk of solid glycerin jelly on the point of a needle. The block of glycerin jelly is put on a microslide, using the center of an “x” on a slide-mailer as target. Pieces of paraffin wax are put around the glycerin jelly, and the wax and jelly are carefully melted over an alcohol lamp; (c) the wax hardens in about 30 seconds, leaving the glycerin jelly containing the palynomorph in the “window”(arrow).
pointed instruments (Fig. A.4a). I find certain dental explorer-type tools and scalpels with very small blades are especially handy.

(3) Have ready a slide, a circular coverslip, and a one-slide map-holder on which a “target” is ruled, in which the slide is placed. Also have ready a jar of paraffin cut up into tiny fragments, a jar with solid glycerin jelly, and an alcohol lamp.

(4) Take a needle-holder equipped with a fine needle and use the point to cut out a very tiny piece of glycerin jelly (about 200 μm across) and get this firmly onto the very tip of the needle. While watching the process under the 10× objective, bring the needle with the tiny piece of jelly into the field and delicately and lightly touch it to the specimen and remove the needle from the field (check to be sure the grain is gone). Put the tiny piece of glycerin jelly on the slide in the target area (Fig. A.4b).

(5) With a knife point arrange a small quantity of paraffin fragments (melting point about 50°C) around the glycerin jelly blob. Heat slide very gently over an alcohol flame until jelly and paraffin melt. They will appear to have run together. Hold slide level. Put slide on table and carefully lower coverslip. When paraffin cools and solidifies, the glycerin jelly with enclosed specimen will appear as a clear window in the “ropey”, whitish paraffin. If the slide is properly made, the specimen will be almost precisely in the target area (so that all single grains are easily found using the microscope), and the paraffin will flow only to the edge of the coverslip (Fig. A.4c). (If it flows beyond it is easy to clean up with a single-edged razor blade followed by a little xylene on a tissue.) The “window” should be tiny, but if it is too small, there is a tendency for the specimen to be enmeshed in the fibrous paraffin and therefore hard to see. Before discarding such a slide, it is useful to remelt the paraffin and gelatin; when it sets up again, the palynomorph may be visible. The size of the window is governed by the size of the glycerin jelly fragment that was affixed to the picking needle.

3.4.1.2 Capillary Tube Methods  Many palynologists favor a capillary tube technique for single-grain mounts. The simple version Knut Faegri taught me, which I still use to good advantage, is as follows:

(1) Draw out a supply of capillary tubes for the purpose. I use 3 mm tubing in pieces about 15-20 cm long. If one starts with a piece of tubing about 20 cm long and heats the center to melting and pulls carefully, one almost always gets two useful tubes that may be broken apart carefully with a triangular file.

(2) Spread out residue in 50/50 glycerin-water (or water alone, if water is added occasionally; or glycerin alone, but it is quite viscous).
With needles, and other tools as described under the previous method, clear away debris and unwanted palynomorphs from around the specimen desired.

(3) Use 10× objective (about 100× magnification with a stereo dissecting microscope is also good) to observe the capillary as it is brought to the vicinity of the desired specimen. Carefully touch the tip of the capillary tube to the liquid around the specimen. The specimen and some liquid will rush up into the tube, which must be quickly lifted to prevent too much liquid from entering.

(4) Blow the droplet of material from the capillary tube onto a small piece of glycerin jelly which can be arranged on a target area, per the previous method. Paraffin as a sealant can be arranged as in the other technique. If mobility of the specimen is desired, blow the droplet onto a drop of glycerin on a slide or onto a coverslip and cover with another coverslip. Such preparations are not permanent.

3.4.1.3 Variants on Capillary Tube Technique

(1) Pressure tube technique: Instead of using capillary tubes alone, it is more elegant to use capillary tubes attached to a rubber or rubbery plastic (such as Tygon) tube. If the other end of the tube is attached to a hypodermic type syringe, some glycerin may be sucked into the capillary and a negative pressure carefully controlled in the opening of the capillary, so that only a small amount of specimen plus liquid rushes into the tube when it is touched to the area of the specimen. The specimens may be ejected by depressing the syringe plunger. Also this control of the pressure makes it possible to put the capillary tube point into the specimen-liquid without drawing up the liquid until desired. Another advantage of this method for some purposes is that it is easy to pick up multiple (say 10) specimens, one after another, before emptying onto onto a slide, in order to make a mount displaying specimens in different orientations. Evitt (1984) has described this procedure and the “suction” device in detail.

(2) Coverglass-sandwich technique for LM, SEM, and TEM of one specimen: If the specimen is put onto a coverglass in glycerin, and covered with another coverglass, the “sandwich” can be temporarily fastened to a slide with small pieces of transparent tape and the specimen can be studied and photographed from both sides. The sandwich can then be removed from the slide, carefully pulled apart (inserting a razor blade is the best way) and the coverslips placed face up on a microslide. Find the specimen. Discard the empty coverslip. While watching the procedure under the scope, carefully flush the specimen with water, or better with t-butyl alcohol, several times wiping the flush liquid away from the specimen with the corner of a facial tissue. This removes the glycerin, to allow proper
gold-coating. The coverglass with the specimen may now be mounted on an SEM stub with appropriate adhesives, gold-coated and studied by SEM. The specimen may be turned over by squirting alcohol on it from a small hypodermic needle and maneuvering the grain with a small hair on a stick (see Artüz and Traverse, 1980). In this manner SEM pictures can also be made of both sides of the specimen, to match the light pictures (see Fig. A.5). (It is also possible to recover the specimen after SEM, remove the gold with aqua regia and make thin sections for TEM (see Walker and Walker, 1982).

Leffingwell and Hodgkin (1971) have published thorough descriptions of various other techniques for manipulation of palynomorphs in preparation for SEM. Leffingwell’s laboratory used a micromanipulator attached to a microscope objective, for “picking” the fossils. Leffingwell also advocates polyurethane adhesive to stick the palynomorph to the SEM mount surface. In the Penn State laboratory we mostly used no adhesives at all and found that only very rarely did the fossils come off the coverslips mounted on SEM stubs. We stored the preparation (stub plus coverslip) in covered plastic boxes, to assure that air currents were not a problem. See Ambwani (1975 for useful, clear instructions for SEM studies of pollen and other microfossils.

3.4.2 Single Specimen Processing and Study

Sometimes it is desirable to treat a single specimen chemically, in order to isolate the procedure from other influences and to observe the results carefully. Johnson (1985), for example, did this in a study in our laboratory of the effect of oxidation on Silurian palynomorphs. Evitt (1984) has described a method for acetolyzing a single specimen, involving manipulation of the specimen in a syringe-type capillary tube (see above) and treating the specimen in the depressions of a glass cavity-slide. The specimen is passed through two changes of glacial acetic acid, then heated in acetolysis mix, and finally washed, transferring the specimen with a capillary tube each time.

It should be noted that sophisticated micromanipulators can be obtained for attachment to the objectives of microscopes. Several kinds are adaptable to the problem of picking up palynomorphs for the purpose of preparing single grain slides, or single grain mounts for SEM. For the operator with average dexterity and eyesight, such devices are not necessary.

3.4.3 Storage of Bulk Palynomorph Residues

I have always stored my residues in glycerin jelly. As noted elsewhere, glycerin jelly slides have a maximum life of about 40 years, much less in many cases. Long after the slides have disintegrated, however, the original glycerin jelly residues can usually be remelted and new slides made. However, a better storage
Figure A.5 SEMicrograph and light microscope photomicrographs of a single specimen of *Reticulatisporites karadenizensis* Artüz, Carboniferous, Turkey. The specimen was picked with a capillary tube from a glycerin/water preparation, mounted in a coverglass “sandwich” and photographed “front” (a) and “back” (b). The coverglasses were then separated, the water evaporated and glycerin removed by repeated washings with water and t-butyl alcohol. The coverglass with specimen was then mounted on an SEM stub and gold-coated. SEMicrographs were made from both sides of the specimen. Ethyl alcohol applied by hypodermic needle was used to tip the spore over after the first SEMicrograph, and gold-coating was repeated. Note that the light pictures are upside-down mirror images of the SEM pictures. Therefore individual sculptural elements are reversed as to up and down from (a) to (c) and from (b) to (d). The negatives of one set could be printed upside-down to achieve exact correspondence.

method should clearly be sought. Chapman (1985) recommends glycerin with phenol (to prevent fungal and bacterial growth), whereas Phipps and Playford (1984) recommend a 50/50 mixture of glycerin and 3% Cu$_2$SO$_4$ and a small amount of thimerosal (C$_9$H$_9$HgNaO$_2$S), a crystalline substance used in antiseptics
such as merthiolate. Slides are made from these glycerin residues by addition of glycerin jelly. Other laboratories use water plus phenol or alcohol for storage. With either glycerin or water storage, inspection of the storage vials at regular intervals for loss of liquid is essential, as evaporation occurs over time even with very tight vials. If final mounting is to be with a resin substance, residues should be stored in alcohol-water or in the resin’s solvent, so that the storage liquid can either be evaporated on a slide or coverslip prior to adding the drop of mountant, or be mixed easily with the resin (see “double mounting”). Some laboratories (see Felix and Burbridge, 1985) have reported very satisfactory results from dry storage for years of macerated residues, after using the procedures outlined here for maceration of rocks. Felix and Burbridge advocated careful washing of the residue before dry storage, and re-wetting and re-dispersal of the fossils in the dried residue by treatment with KOH solution and washing before subsequent mounting.

3.5 Location of Palynomorphs, Photomicrography, and Related Matters

3.5.1 Location

The finding (refinding) of particular palynomorphs on a strew slide is a recurring problem. As long as one works with the same microscope, and nobody has changed the settings, the mechanical stage vernier-coordinated readings work fine. Also, if other microscopes of the same manufacture are used, in the same laboratory or elsewhere, conversions can readily be calculated by carrying with one a slide on which a reference point is marked. I use a diamond pencil, with which I make a small x on a slide, and use the center of the x as the reference point, for which mark the location readings are known on the original microscope. However, some brands of microscopes have mechanical stages on which the numbers run in directions opposite to those on other microscopes, making direct conversion difficult. In this case, it is possible to find a given palynomorph by marking the slide with a reference point such as an ink dot covered with a dot of clear fingernail polish, from which distances are given in millimeters and tenths of a millimeter upwards or downwards, to right or left. As mechanical stages all read in millimeters and tenths of a millimeter, palynomorphs can be located in this manner, but it can be difficult. Another approach is to use the England Finder (= EF, see Fig. A.6), a microslide on which a grid with reference numbers and letters appears. After a palynomorph is located (record mechanical stage location, in case the stage is accidentally moved), the slide is carefully removed, and the EF placed on the stage. A reading is taken from the EF and recorded. If the EF is then moved to another microscope, and the desired reference point found, the specimen slide can then be put on the microscope, and the fossil located. (In my experience, a small correction factor usually must be used with the EF if the second microscope’s slide-holding device works differently from that of the first microscope, or if the specimen slide is of slightly different dimensions.) In
Figure A.6  England Finder, the most convenient method for stating locations of specimens on microslides. (a) the England Finder, a glass $3 \times 1$” slide on which a grid of letters and numbers is presented; the pattern (b) is upside-down and backwards, since most light, compound microscopes present their images that way. The EF images therefore appear in correct orientation under the scope, as shown in (c). A palynomorph is located and carefully centered, and the EF is put on the scope in the same position (if the stage moves easily, the mechanical stage coordinates must be used to control position). The reading of the center of the field is then recorded, e.g. “upper right of T-60-1” (see asterisk). Reversing the procedure locates the palynomorph on another microscope, providing that the specimen-slide is also $3 \times 1$.” When slide-size differences or (very rarely) the design of the slide-holders on the two scopes is radically different, conversions can always be worked out. The corners of England Finders are easily damaged by the spring clips of slide-holders. If an EF is not available, a specimen can be located by giving its location with reference to a certain point such as a scratched ‘×’ on the slide, e.g. “up 1.6 mm and to the left 2.9 mm,” and this location can easily be found with any mechanical stage, as the stages are always calibrated in mm and tenths thereof.

our laboratory, when moving between Leitz microscopes in the research microscopy room to Olympus microscopes in the teaching laboratory, we found the England Finder to be an ideal locating device. Since the publication of the first edition of this book, however, I have heard from a colleague who reports that EF readings from colleagues don’t work for him because his style of microscope inverts and reverses the image, and thus only EF readings from that sort of microscope are transferable. Other than such rather rare situations, the only disadvantage of the method is that to make use of the published EF readings, one must have an EF reference slide, and they of course can sometimes be hard to find just when needed, and there is a possibility that they will not be available for purchase some day.
Various techniques can be used to mark the surface of the coverglass with pen or brush, to help relocate palynomorphs on a slide. The coverslip can be marked with a circle of ink, and this ink protected with a little colorless fingernail polish. In our laboratory the favorite technique is to cut a tiny pointer from a gummed label, pick this up with a pair of iris forceps, moisten with the tongue and fasten down to the coverslip with the forceps points, while observing under low power of a microscope. While still moist, the tiny pointer can be moved with a fine needle and finally labeled with a fine pen. However, as is true of all paper labels, the adhesive is not permanent, and the labels will one day fall off. Devices are available that can be screwed onto the nosepiece of the microscope in place of one objective, and which have an inking device to make a small “o” around a desired palynomorph. In my experience these devices are hard to keep in adjustment and properly inked, and may accidentally break a coverslip.

Much ink has been wasted in the paleopalynological literature by informing the reader what the mechanical stage coordinates are for illustrated or described specimens. Naturally, these readings are only good on the original microscope.

One would have to visit the subject laboratory to be able to use the readings, hoping that the original microscope would still be there and could be identified. Furthermore, it is a simple matter to reset the mechanical stage of any microscope with a screwdriver, so that none of the readings would agree with those previously recorded, and this is likely to happen, for example when the microscope is cleaned and adjusted or repaired. To summarize, the best methods for “permanent” location of important specimens are to mark the location of the specimens with ink, protected by varnish, on the coverslip, or to use measurements up or down, to right or left, from a reference point such as a scratched “x,” in millimeters and tenths of a millimeter, somewhere on the slide. All other methods have at least one disadvantage.

3.5.2 Photomicrography

This is one part of paleopalynology that has changed dramatically since publication of the first edition of this book. A variety of digital cameras is now available for use with new and with older microscopes. The images thus produced can be fed into a computer, and manipulated in various ways, enlarged, reduced, arranged into plates, etc., using for example Adobe Photoshop. They can be sent as e-mail attachments to others for comments. They can be burned onto CDs or, better, onto electronic “memory sticks” for carrying to a conference or convention. Existing hard copy illustrations, whatever the technique used in preparing them, can also be made available for manipulation as if they were digital in the first place, with the use of a scanner (although if the original available is a half-tone dot matrix photo, the scanned copy is not very good). It seems to this observer that the quality of digital photomicrography illustration has not yet reached the brilliance of the very best film photography, but at the top level, it certainly is good enough.
However, the information in the first edition about film-based photomicrography is still pertinent. I continue to make photomicrographs with these techniques, although I can now scan the results into digital format, in order to combine such images with those digitally produced. Film-based photomicrography will remain useful for some time to people who still possess film photomicrographic equipment, which they will presumably use along with scanners and computers. As of the date of publication of the second edition of this book, even Polaroid film is still available.

For routine film-photomicrographic purposes, I favor 35 mm automatic cameras or simple attachment cameras. Automatic cameras make exposures and advance film automatically and are therefore much speedier in comparison with simple attachment cameras, but they present problems regarding cleanliness of almost inaccessible internal parts. Some authors using automatic photomicrographic cameras have even published photos that show the very same dust flecks on every picture! With automatic cameras it is difficult to cope with this, because there are prism surfaces inside the camera that are in the plane of focus and cannot readily be cleaned by the user. With simple attachment cameras all surfaces that are in focus are available for operator cleaning. A small piece of fine chamois attached to a small stick is good for cleaning the surface of an offending prism in the attachment camera.

For producing fine quality photomicrographic prints in connection with a study of slides for a small project, I still find Polaroid sheet film cameras very useful. Undoubtedly, the film will one day be no longer available, but in the meantime if you have an existing microscope such as a Leitz Ortholux with an Aristophot sheet film camera with a Polaroid adapter, keep using it! When I do, I am reminded that the best photomicrographs I have ever prepared were made at Harvard in the 1940s, using a Zeiss horizontal microscope and camera that filled most of a darkroom, and glass plates. That camera-microscope setup was obtained by Harvard from Germany about 1912. No camera film or digital camera has ever fully matched the perfect registration of a glass plate. (A useful book for explanation of particular techniques in photomicrography is Rost and Oldfield, 2000.)

3.5.2.1 Magnification Magnifications of 1,000, 750×, 500× or 250× should be standard for most published paleopalynological photomicrographs (100× or 150× for megaspores and other large palynomorphs). One reason for use of 1,000× is that a preponderance of palynomorphs are in the 30–50 μm range, and 1000× produces a picture 30–50 mm across, which is about right as a compromise between the largest possible picture and the usual space restrictions. Another great advantage of 1000× is that the size of the original fossil in micrometers can be read by measuring the photograph in millimeters. Within one paper an effort should be made to keep the number of different magnifications to a minimum. A bar should be placed on plates of photomicrographs showing the size of
specimens in micrometers, because enlargement or reduction in printing will not affect the magnifications represented by the bars, whereas “500×,” etc., is effected by changes of size in printing.

It is easy to calculate the magnification from the measured size given in descriptions. The ratio between the photo in millimeters and the measurement in micrometers × 1,000 is the magnification. With a millimeter scale one can then read off the fossil’s size in micrometers (μm) if the magnification is known:

at 500×, 1 mm on photo = 2.00 μm on specimen
600× “ 1.67 “
750× “ 1.33 “
1,000× “ 1.00 “
1,200× “ 0.83 “

Unfortunately, application of this calculation to published figures frequently proves that the magnification is actually not as stated in the publication!

3.5.2.2 Microscopic Techniques. This is not the place for detailed instruction in the use of the microscope, though years of experience in teaching palynology convinced me that many students have problems in this area. First of all, the student needs to learn how to use the condenser. Close down the field diaphragm as far as possible and then close down the iris diaphragm too. The leaves of the field diaphragm should appear as a clear silhouette. If this circle is not clear, raise or lower the condenser until it is. Then center this circle, using the centering knobs. Then open the field diaphragm until the leaves exceed the edge of the field, and open the iris diaphragm to achieve an amount of light that produces neither too much contrast nor too little. If the microscope is an economy model on which the condenser cannot be centered, the student must still learn to use it at the right level for the various objectives, and to use the iris diaphragm efficiently. A blue filter is the most pleasing and restful for microscopy, but green filters produce the best black and white photomicrographs of most fossil palynomorphs. Color films usually require that no filter at all be used. However, sets of filters to insert in the light path in order to alter the color if necessary are available in camera shops. Do not leave the ordinary blue or green filter in place for color photomicrography. I have found that this dictum is easy to forget. All lenses should be kept absolutely as clean as possible. Immersion oil should be cleaned off of immersion objectives after use with lens paper, as it can damage the tiny exposed lens if allowed to accumulate.

Most palynomorphs are more or less three-dimensional, though most are also more or less flattened. Therefore the student must learn to interpret the three-dimensional structure by focusing up and down. This is apparently very difficult for some people to accomplish. Especially difficult is the interpretation of sculpture. Many students have problems distinguishing between positive and negative sculpture. As pointed out by Erdtman, this is possible by focusing up
and down on the surface (LO analysis). Holes in the surface, for example, appear dark at high focus and lighter at lower focus. I have found it useful to instruct students to examine the outer edge of the grain in mid-focus (edge analysis) to check their observations by LO analysis. Spines or verrucae will stick out! Perforations will show as indentations. If there is time, making clay models of a form being studied is a very helpful exercise. I have found that beginning the instruction using a television camera in a demonstration microscope, with a small, portable monitor is very helpful.

3.5.2.3 Interference Contrast. Ordinary transmitted-light microscopy is bright field. Another of the many varieties of light microscopy is interference contrast or phase contrast. Special condensers and objectives make the examined specimen stand out against the darkened background with an appearance somewhat resembling an SEM image. The effect is especially helpful with specimens that are thin and/or colorless, such as some thin-walled pollen, very thin-walled dinoflagellate cysts, and acritarchs. No special preparation of the specimens is required. Interference contrast photomicrographs have the advantage that, while they show surface features in SEM-like contrast, internal features can also be shown, which is not the case with SEM. (Although broken fragments of exines seen in side view by SEM do reveal internal structure, it is necessary to use TEM to get a good concept of such structure with electron microscopy.)

3.5.2.4 Fluorescence Microscopy. This form of microscopy requires special light and filter equipment that can be used, however, with a regular light microscope. Specimens are illuminated with intense blue or ultraviolet light (either transmitted or incident) and fluoresce in different colors: that is, specimens on UV irradiation emit light of various intensities and wavelengths. For example, different states of carbonization-level yield different colors on fluorescing. The technique therefore has applications in study of coalification level (thermal alteration) and is discussed also in the section in this book on that subject. Some specimens reveal structure in fluorescence microscopy that isn’t otherwise observable. Most palynomorphs fluoresce. Warning: UV and blue light can be dangerous to the eyes, and proper filters are required. One should check with a microscope distributor to be sure that one has the correct filters for the microscope to be used for this purpose.

3.5.2.5 SEM and TEM. Scanning electron microscopy (SEM) provides a three-dimensional appearing view of the surface of palynomorphs. Indeed, as the depth of focus is great, SEM pictures are ideal for stereo pairs, and these have been published for megaspores (Higgs and Scott, 1982: their Plate 1 and Figs. 4, 5) and other palynomorphs. Most people need a viewer to get the three-dimensional effect. Individual palynomorphs can be “picked” and mounted for SEM work, as described in the coverglass-sandwich technique above, or a strew preparation can be gold-coated and studied, even counted, by SEM. However, because SEM
Figure A.7 Determination of standard deviation for pollen counts of various sizes. This graph provides a rough guide for estimating the size of count required for various levels of significance. We illustrate four examples. (a) If a certain pollen type represents roughly 20% of total pollen (based on preliminary counts), this percentage is shown by the sloping line labeled 20 on the right vertical axis. If 130 grains are counted, a vertical line from the base at 130 will intersect the sloping 20% line. Now project a horizontal line from the point of intersection to the left vertical axis to read the standard deviation of 17.4% (of 20%, i.e. 3.5%). This means that about two-thirds of all analyses may be expected to fall in the range of $20 \pm 3.5\%$. (b) If 400 grains of the same form are counted (about 3 times the number counted in (a)), using the same method of calculation shows a standard deviation of about 10%, meaning that two-thirds of all analyses would be expected to fall in the range of $20 \pm 2\%$. For most purposes, the extra labor is probably not justified. (c) Even with a count of 1,000, the standard deviation can only be reduced to 6%, demonstrating that for abundant forms large counts are not worth the extra work. (d) With a form present
equipment is expensive, and should be in the care of a skilled technician, light microscopes will continue to be the overwhelmingly more common instruments of choice for most aspects of palynology. Even more specialized is transmission electron microscopy (TEM). For a close look at internal structure of palynomorph walls, TEM is indispensable. Preparing palynomorphs for this purpose involves special embedding, usually in various plastics, sometimes special staining of the sections, which are made with an ultramicrotome. Naturally, this technique is practiced by only a few palynologists. Walker and Walker (1984) pioneered the elegant study of single palynomorphs by light microscopy, SEM and TEM. Such investigations are very important but are not likely to become routine. A technique suggested by Prössl (1996) seems potentially useful: a combination of SEM and incident (reflected) light microscopy for specimens that are opaque to white light.

3.5.2.6 *Infrared Microscopy.* It has been recognized for decades that objects appearing opaque in transmitted white light are sometimes translucent to infrared illumination. The use of infrared therefore has obvious application to study of opaque palynomorphs, which are frequently a big problem in sediments for which the thermal alteration level of the organics has reached TAI:4 or more (cf. Fig. 19.2). Marshall (1995) presents a technique for accomplishing infrared microscopy with minimal extra equipment beyond a good biological microscope.

3.6 Counting: How and How Many?

Nearly all paleopalynological projects sooner or later involve making a count of palynomorphs. As explained earlier, calculation of fossils per gram of sediment by my weighing technique requires counting all, or a fixed proportion (1/4 or 1/2) of all fossils on a slide. On the other hand, if a “stick” of *Lycopodium* spores is used, the incessant repetition of counting them tires the observer and affects accuracy of all the counts; I proved this long ago by experiments with a variety of individuals doing the counting. More commonly, percentages are used to provide an estimate of relative abundance. The percentage may be of all fossils or of a “pollen sum” that excludes some forms. A ratio between the number of one kind

Figure A.7 only at the 1% level, a count of 1,000 yields a standard deviation of about 30%, whereas a count of 100 yields 100%: two-thirds of samples would then be expected to be between 0 and 2%. It is clear that forms present in amounts less than 1% will yield very large standard deviations, even with counts of 1,000. In other words, counts of such forms are intrinsically unreliable from a statistical point of view. The number of specimens that need to be counted for statistical significance depends on the abundance of the least abundant form of importance to the result. This graph was prepared by multiplying probable-error figures from Rittenhouse (1940) by 1/0.6745.
of fossil and others may be established, e.g., in calculating steppe/forest index, dinocyst/pollen and other such ratios. In any event, a strew slide is prepared, and the count is made by traversing the slide from side to side at a magnification sufficient to recognize the forms. The slide should not be too densely filled, or too many fossils will appear in each field for accurate counting. If only a percentage is sought, successive traverses should be counted far enough apart to prevent overlapping and double counting (especially of large) specimens. Where the whole slide is to be counted, double-counting can be minimized by counting specimens that are only partly in the field only at the top or at the bottom, but not at both. In any event, large forms are more likely to be counted at the edge of the field (see Faegri, 1951). A more serious problem really is that folding, squashing and so forth make many specimens unrecognizable, and this is more true for some forms than for others. For this reason, many palynologists, even though they may also make permanent preparations, as a rule prefer temporary, mobile preparations in glycerin or silicone oil for counting, because the grains can be manipulated for better inspection by tapping with a needle.

The question of how many specimens must be counted for statistical reliability of later calculations has been given far too little attention. Early in the history of Pleistocene/Holocene pollen analysis, it was held that, given the numbers of taxa involved and their relative abundance, counts of about 200 were satisfactory for reliable percentage calculations (see Barkley, 1934; Westenberg, 1947). The statement that “200 specimens per slide were counted” as a satisfactory requirement has ever since been a bit of the palynological folklore, echoed in hundreds of papers, and for most analyses it is based on a solid mathematical foundation. Gordon Rittenhouse of Shell Development Company, who had a few years before made calculations relative to mineralogical counting, showed me about 1957 how to calculate the number of specimens to count in order to get a reliable reading on the percentage of a certain species in a sample. He was convinced that many percentage-based palynological analyses being used for biostratigraphy were not statistically valid.

The Rittenhouse curve as applied to palynological counts is shown in Figure A.7. The gist of the chart is very simple: the number of specimens that must be counted to achieve a desired standard deviation depends on the abundance of the least abundant critical form. For example (not shown), in a total count of 200 (bottom axis), for a taxon that comprises about 60% of the total palynoflora (right hand side of chart), a standard deviation of 6% (of 60%, i.e. 3.6%) is achieved (project to the left the intersection of the vertical 200 count line with the sloping 60% line). This means that two-thirds of all analyses of such a sample would fall in the range of 60 ± 3.6%, a quite acceptable reliability; that is, a calculation of, say, 58% for this form is a meaningful datum. On the other hand, another taxon comprising about 2% of the palynoflora would have 50% standard deviation in a count of 200, meaning that two-thirds of the analyses of such a sample would be in the range 1–3%, so that many analyses would miss the form altogether.
and others would pick up four palynomorphs. Even a count of 1,000 would give a standard deviation of 25%, or two-thirds of analyses would be in the range 1.5–2.5%. To achieve a 6% standard deviation, as for the form that comprises 50% of the palynoflora, would unrealistically require a count of several thousands (off the scale). The reliability in counts of 200 is satisfactory for abundant forms only, or if only a qualitative statement is required.

To put it another way, a decrease of a taxon from 2.4% to 1.6% looks big, especially if plotted logarithmically, but actually does not dependably mean anything at all, except presence/absence. Unfortunately, many published palynological data are in this category. Maher (1972) presents nomograms for calculation of the confidence limits of pollen analytical data, based on calculations by Mosimann (1965). The approach is considerably more sophisticated mathematically than that presented above, but the gist is the same, that large total counts are necessary to achieve meaningful data for uncommon forms. As a generalized endorsement of the principle, Dorning (oral statement recorded in my notes: 2005) observes that high diversity acritarchs require counts of a thousand, but the truth is that counts of forms that comprise less than 1% of the palynoflora would require counts even larger than 1000 for statistical reliability. Birks and Birks (1980) and Faegri and Iversen (1975) present discussions of this and related matters.
Glossary

The author wrote the spores/pollen palynological definitions for the 1972 first edition of the AGI Glossary of Geology, and I was again editor of the palynological definitions for the fifth edition of that compilation (Neuendorf et al., 2005). The following definitions derive partly from those two projects. Other sources used in compiling definitions include: Beug (1961); preliminary versions of a glossary of fossil fungal spores morphology by Elsik et al.; Erdtman (1952); Evitt (1985); Evitt et al. (1977); Grebe (1971); the glossary of scolecodont terms from Jansonius and Craig (1971); for fungal spore terms, Kalugtkar and Jansonius (2000); Kremp (1965); the extensive, well illustrated general pollen and spore glossary of Punt et al. (1994); Smith and Butterworth (1967); Walker and Doyle (1975); for dinoflagellates, acritarchs and algal groups, Williams et al. (2000); and other references cited separately in the following glossary. This glossary aims to cover all terms used in this book. For others, please refer to the more recent of the abovementioned publications. It is also useful to check the index of this book, as that frequently will direct one to a desired description or definition.

aboral pole The end of a flask-shaped chitinozan that includes the chamber of the body and the base. See oral pole, apertural pole, antiapertural pole.

absolute pollen frequency The estimate of the actual amount of pollen deposited per unit area in a given length of time, achieved by correcting the amount of pollen per gram of sediment by factors based on rate of sedimentation. Abbrev. APF. The expression has been mostly replaced by pollen influx (= pollen accumulation rate).

acalyymmate Of the adhesion mode of members of a polyad or tetrad, characterized by lack of direct contact between exines of adjacent grains. Ant. calyymmate.

acanthomorph acritarch An acritarch with clear differentiation of the central body and radially oriented processes.

accessory archeopyle suture An archeopyle suture that consists of a short cleft in the wall adjacent to the principal suture, or that may be more fully developed on the operculum of the dinoflagellate cyst, dividing that structure into two or more separate pieces.

accessory spore A spore present in a rock sample only in small quantities. Accessory spores include types with a very restricted range, and they have been used for correlation.

accumulation body (Also called “eyespot”, and other terms.) Of dinoflagellate cysts, a small clump of resistant matter within the cyst, usually interpreted as waste metabolic matter.

acetylosis A chemical reaction in which acetic anhydride lyzes plant tissues, a sort of maceration in which peat or palyniferous material from extant plants (e.g., angiosperm flowers) is heated in a mixture of nine parts acetic anhydride and one part concentrated sulfuric acid. The reaction breaks down cellulose and other organic compounds and thus concentrates sporopollenin.

acme zone In palynostratigraphy, a zone which is of value for correlation based on dominance in percent of a palynomorph taxon or a related group of taxa, e.g., certain Classopollis spp. for the lowest Jurassic.
acolpate Of pollen grains without furrows (colpi) or other apertures. In practice, such pollen grains are sometimes difficult to distinguish from alete spores. Code POO. See inaperturate.

acritarch A unicellular, apparently unicellular, rarely multicellular, presumably algal, resistant-walled microscopic organic body of unknown or uncertain biologic relationship and characterized by varied sculpture. The substance of the wall is similar to sporopollenin. Acritarchs are assumed to be of algal affinity, but the group is artificial. They range from Precambrian to Holocene, but are especially abundant in late Precambrian and early Paleozoic. The term was proposed by Evitt (1963, pp. 300-1) as “an informal, utilitarian, ‘catch-all’ category without status as a class, order, or other suprageneric unit” consisting of “small microfossils of unknown and probably varied biological affinities consisting of a central cavity enclosed by a wall of single or multiple layers and of chiefly organic composition”. See also hystrichosphaerid.

actuopalynology Study of extant spores and pollen and their distribution in atmosphere, hydrosphere and sediments, and related matters. See paleopalynology, pollen analysis, and aerobiology.

aerobiology Study of organisms and parts of organisms in the atmosphere. Spores and pollen are a major concern of aerobiologists, especially in their role as pollutants and causes of pollinosis. See iatropalynology.

air sac See saccus.

akinete Modified, thick-walled vegetative green algal cell, e.g., in Zygnema. Some acritarchs are probably akinetes.

ala An equatorial flange found in the phycomata of some modern prasinophytes and fossil pteromorph acritarchs.

alete Of a spore without a laesura. In practice, such spores are sometimes difficult to distinguish from acolpate pollen. Code SOO. See inaperturate.

allochthonous In palynology, palynomorphs that are produced at considerable distance from the site of their deposition. Ant. autochthonous.

alveolate Of pollen or spore structure characterized by sponge-like compartmentalization, as in saccate pollen.

amb The contour or outline of a pollen grain (less commonly of a spore) as viewed from directly above one of the poles. Also called equatorial limb. (It is possible but uncommon to describe also a polar limb or profile, the outline of a grain from a “side view”, at right angles to the equatorial limb. However amb is used almost exclusively for the outline from the pole.) See also profile.

ambitus A less favored synonym of amb.

amerospore of Fungi, a single-celled, aseptate spore.

amoeba See testate amoebae

amphiesma Of dinoflagellates, the cell covering in general.

ana- A combining form used to indicate position on the distal surface of a pollen grain or spore, as anasulcate, having the sulcus on the distal surface. See cata-

ananomorph Of fungi, the asexual form of an ascomycete. Cf. holomorph, teleomorph.

anemophilous Pollination by wind. Adj. anemophilous. See entomophilous and zoophilous.

annulus A ring bordering a pore of a pollen grain, in which the ekteixine is modified (usually thickened). See margo and endannulus.

antapex Of dinoflagellates, the area at the posterior end of theca or cyst.

antapical series A series of antapical plates posterior to the postcingular series in dinoflagellate theca or cyst. See apical series.

antapertural pole Term introduced by Paris et al. (1999) to replace aboral pole for chitinozoans. See oral pole, apertural pole.
anteturma One of the two major groupings in which turmae are classified in the turmal system for fossil sporomorphs: Sporites (for spores) and Pollenites (for pollen).

AOM Term used in palynofacies studies: amorphous organic matter, a subset of USTOM, unstructured organic matter.

AOMA Term used in palynofacies studies: amorphous organic matter of aquatic origin, a subset of AOM.

AOMT Term used in palynofacies studies: amorphous organic matter of terrestrial origin, a subset of AOM.

AP arboreal pollen.

aperture Any of the various modifications in the exine of spores and pollen that can be a locus for exit of the contents; e.g., laesura, colpus, pore. See also germinal aperture. Also, the oral or apertural opening of chitinozoans.

apertural pole Term introduced by Paris et al., 1999, to replace oral pole, for chitinozoans. See antiapertural pole, aboral pole.

APF absolute pollen frequency. See pollen influx and pollen accumulation rate.

apical archeopyle An archeopyle formed in a dinoflagellate cyst by the loss of the entire apical series of plates. See also haplotabular archeopyle and tetratabular archeopyle.

apical area Of an embryophytic spore, the proximal area associated with the laesura. See contact area.

apical papilla A dot-like thickening of an interradial area of a spore. When present, there is generally one apical papilla per interradial area, hence three per spore.

apical prominence In megaspores, mostly Paleozoic, variously constructed proximal projections formed by the intersection of the expanded contact areas.

apical series The series of plates forming an apical cluster in the epitheca or epicyst of a dinoflagellate. See antapical series.

apocolpium Area at pole of pollen grain delimited by a line joining the ends of the colpi. Syn. polar area.

apoporium Area including the pole of porate pollen grain, delimited by the poleward limit of a line connecting the poleward limit of the pores. Cf. mesoporium.

aporate Of fungal spores without pores.

appendage An elongated sculptural element; a process.

arboreal (arborescent) pollen The pollen of trees. Abbrev. AP. Syn. tree pollen. See non-arboreal pollen.

Archaea One of the three domains of organisms. Prokaryotic, mostly anaerobic, many found in extreme environments. Cf. Bacteria, Eucarya.

Archeophytic An informal division of geologic time, before the regular appearance of robust-walled acritarchs (about $1.0 \times 10^9$ years ago = beginning of Proterophytic).

archeopyle An opening in the wall of a dinoflagellate cyst by means of which the motile thecal stage emerges from the cyst. It is usually more or less polygonal in shape, and the plate (or plates) that drops out is the operculum. See also apical archeopyle, cingular archeopyle, precingular archeopyle, combination archeopyle, and operculum.

archeopyle suture A line of dehiscence on the dinoflagellate cyst that more or less completely separates a part of the cyst wall to form an operculum. See also accessory archeopyle suture.

arcus A band-like thickening in the exine of a pollen grain (as in Alnus), running from one pore apparatus to another.

armored Of dinoflagellate thecae (such as those of the order Peridiniales) possessing a cellulose envelope or cell wall that is subdivided into articulated plates. Ant. unarmored.

ascocarp Of fungi, any fruiting body containing asci.

ascospore A fungal spore produced sexually in an ascus.
ascus Of ascomycete fungi, an enlarged sac-like body containing a specific number of ascospores (usually eight, often four).
aseptate Of fungal spores, lacking a septum.
aspidate (Also spelled aspidote.) Having the apertures on dome-like protrusions (example Betula). Grains with aspidate external form are often vestibulate internally.
atectate Of an outer exine lacking columellae and hence also lacking a tectum. But compare intectate.
atrium A space between the external opening (pore or ectopore) and a much larger internal opening (endopore or os) in the endexine of a pollen grain with a complex porate structure. The internal opening is so large that the endexine is missing in the endopore area. Atrium is usually reserved for the space immediately around the endopore, and vestibulum for lateral space between pore and os. (Thomson and Pflug, 1953, define atrium and give Myrica as an example. Betula, by contrast, is vestibulate.) Pl. atria. See pororate.
attached operculum The operculum of a dinoflagellate cyst, not completely surrounded by archeopyle sutures and hence remaining joined to the main part of the cyst where the suture is not developed. Syn. attached opercular piece. See free operculum.
auricula One of the thickened “ears” of auriculate spores. Pl. auriculae. See zone.
auriculate Of zonate spores having exine thickenings in the equatorial region that project like “ears”, generally from the area of the ends of the radii of the laesura. See valvate.
auto- In dinoflagellate cysts, single, such as autophragm (single wall).
autochthonous In palynology, palynomorphs that are more of less locally produced in or near the site of deposition. Ant. allochthonous.
avenous Of spores without a zone or a similar (usually equatorial) extension.
bacteria One of the three domains of organisms. All of the non-Archaea prokaryotic microorganisms. Cf. Eucarya.
baculate Of sculpture of pollen and spores consisting of bacula (sing. baculum).
baculum One of the tiny rods (not thickened or thinned at either end), varying widely in size and either isolated or clustered, that make up the ektexine sculpture of certain pollen or spores. Also used for baculate-like, internal structures of Normapolles germinals. Pl. bacula.
basal plate In scolecodonts, a small to medium-sized right-hand jaw closely fitting into a posterior concavity of a simple jaw (“Mld”). See maxilla.
basidiospore A fungal spore produced by the basidium of a basidiomycete. Fossil fungal spores are apparently rarely from basidiomycetes.
biform process A sculptural element with two different thicknesses. Term is usually restricted to elements with a broader base and abruptly constricted, spiny tip.
biome as used in palynology, a particular type of vegetation based on climatic requirements and dominant over a wide geographic area. Fossil biomes are best detected by pollen analysis.
bisaccate Of pollen with two sacci. Usually occurs in conifers but also found in other gymnosperms, such as Caytoniales and seed ferns. Code Pv2. Syn. bivesiculate and disaccate.
bivesiculate See bisaccate. Syn. bisaccate and disaccate.
bladder Syn. of saccus, vesicle, and wing.
body Of saccate pollen, the corpus; also loosely the central body of the saccate or saccate-like pollen of various spores and pollen grains. Of chitinozoans, the main, larger part of the unit (vesicle), which lies below the neck.
BP Before present, “present” conventionally taken to be 1950.
**Brevaxones** A group of mid-Cretaceous and younger dicot angiosperm pollen in which the polar axis is shorter than the equatorial diameter, representing an apparent evolutionary advance over Longaxones, and including such forms as Normapolles.

**brochate** See heterbrochate and homobrochate.

**callose** A carbohydrate component of cell walls in certain plants; e.g., the amorphous cell wall substance that envelops the pollen mother cell during pollen grain development and acts as a barrier between mother cells, and subsequently between developing members of the tetrad, but that disappears as the ektexine structure is completed and impregnated with sporopollenin.

**calymmate** Adhesion mode of members of tetrads and polyads, in which the ektexine of the individual monads form a continuous envelope around the outside of the multicellular unit. Ant. acalymmate.

**camerate** As originally defined (Neves & Owens 1966), describes spores in which outer and inner exine are separated to various degrees by a chamber (=camera), but which lack infrareticulate structure. Includes pseudosaccate, which refers to spores with extensive separation of exine layers. In common usage, a syn. of cavate. Camerate (or cavate) is also used by some authors for spores with barely detectable or partial separation of wall layers. For acritarchs, the term is used in a similar sense. Camerate is also used for dinoflagellate cysts, in a quite different sense, to describe the condition in which a plate has five sides, with one side parallel to the cingulum and two sides away from the cingulum form a point resembling a roof or gable. Cf. cavate.

**capillate** A term for sculpture consisting of capilli. Favored terms are now fimbriate and fimbriae.

**cappa** The thick-walled proximal side of the corpus of a saccate pollen grain. See cappula.

**cappula** The distal, thin-walled region of the corpus of a saccate pollen grain. Unfortunately, the term is easy to confuse with cappa, the thick-walled proximal area.

**cata-** Combining form indicating position on the proximal surface of a pollen grain or spore, as catasulcate, having the sulcus on the proximal surface, as for example in some Annonaceae.

**cavate** (a) Descriptive of pollen (or, less precisely, of spores) whose exine layers are separated by a cavea or cavum (=cavity). The separation may be rather slight or more extensive, or eventually producing a bladder-like protuberance approaching the pseudosaccate or saccate condition. (In practice, these three terms are difficult to separate.) This term and camarate are also used of hollow processes. See camarate. (b) Of a dinoflagellate cyst with space or spaces of notable size between the periphragm and endophragm (as in Deflandrea phosphoritica). See chorate and proximate cysts.

**cavea** a cavity or space between two layers of the exine, which extends to the colpus margin; very evident in polar views of some Asteraceae pollen, e.g. *Ambrosia*.

**cella** For fungal spores and hyphae, one chamber within the structure. Pl. cellae.

**-cellate** Of fungal spores, indicating the number or kind of cellae, as pluricellate. This term is used to avoid “cellular” because the cellae of a fungal spore are not necessarily biological cells.

**Cenophytic** An informal division of geologic time, based on the abundant occurrence of angiosperms in the fossil record, therefore equals approximately Aptian-Albian to present. The next older such division is the Mesophytic.

**cenospheres** More or less spherical pseudofossils, sometimes with a bubbly structure, rather commonly found in palynological macerations. Apparently most of them are produced by industrial activities, especially those that carbonize hydrocarbons at high temperatures. See Miller and Jansonius (1996). See linotolypidae.

**central body** The main part of a pollen grain or spore; e.g., the corpus of a saccate pollen grain, as distinct from the sacci; or the central part of a zonate or camarate
spore, exclusive of the zona, pseudosaccus, etc.; or the compact central part of a dinoflagellate cyst from which the projecting structures extend. Syn. body.

chagrenate Somewhat translucent and granular sculpture of pollen and spores. Also spelled shagreen, shagrinate, chagranate. This complex of terms is so confused in spelling and definition that it should be avoided. (The 2001 Random House Webster’s Unabridged Dictionary likens the meaning to both that of the surface of untanned leather and that of rough sharkskin.)

chamber Of a chitinozoan, the central more or less enlarged cavity of the chitinozoan vesicle.

cheilocardioid Of lipped, heart-shaped spores, as Microbacilispora. (The heart-shape results from lateral compression.)

cheno-ams Abbreviation for Chenopodiaceae-Amaranthaceae, the pollen of which families is prevailingly periporate and very hard to distinguish as to genus. In Neogene pollen analysis, it is conventional to lump such pollen under this term.

chevron Describing the laesura of a dilete spore.

chiropterophily A term for pollination by bats.

chitin A long-chain nitrogen-containing polysaccharide, structurally similar to cellulose, having, however, the carbon-2 -OH groups replaced by acetylamine groups (-NH-CO-CH₃). The compound is resistant to acid attack and biodegradation in a manner very similar to sporopollenin. The robust-walled spores, fruit-bodies and hyphae of some fungi consist of chitin, as do the walls of microforaminifera, scolecodonts, and insect exoskeletons, parts of which, such as lepidopteran scales, often occur as palynomorphs. Compare pseudochitin.

chitinozoan A marine microfossil of the extinct group Chitinozoa, having pseudochitinous walls, of uncertain affinity (generally assumed to represent animal remains), shaped in general like a flask, occurring individually or in chains. Stratigraphic range primarily from uppermost Cambrian to Devonian. Chitinozoans have thin, usually black, structureless, opaque walls, but they may be brown and translucent. Named by Eisenack (1931), who noted the resemblance of the walls to chitin.

chlamydospore A thick-walled, non-deciduous spore, such as a unicellular resting spore in certain fungi, usually borne terminally on a hypha and rich in stored reserves.

chorate cyst Encysted, unicellular alga with processes; especially a dinoflagellate cyst bearing little morphological resemblance to the motile theca. The ratio of the diameter of the main body to the total diameter of the cyst is 0.6 or less. Examples marginate chorate cyst, membranate chorate cyst, pterate chorate cyst, trabeculate chorate cyst. See also proximochorate cyst and proximate cyst.

cicatricose Marked with scars; especially said of sculpture of pollen and spores consisting of more or less parallel ridges, curving in the manner of a fingerprint.

cingular archeopyle An archeopyle formed in a dinoflagellate cyst by breakage along and within the cingulum (= girdle).

cingular Having a girdle; especially said of a spore possessing a cingulum.

cingulizonate Of spores with a cingulum to which an outer, thinner equatorial extension is appended.

cingulum (a) An annular, more or less equatorial extension of a spore in which the wall is thicker than that of the main body of the spore. Pl. cingula. See zone and crassitude. (b) In a dinoflagellate theca or cyst, the girdle, a slightly depressed band of small plates separating hypotract from epitract.

Circumpolles A group of spherical gymnospermous pollen, commonly occurring as tetrads, characterized by a subequatorial rimula, a distal pseudopore and a proximal triangular area. Abundant occurrence indicates Late Triassic to Early Cretaceous age. Example: Classopollis.
**clavate** Of sculpture consisting of clavae, i.e., rods with enlarged, club-like ends. See pilate.

**clavus** Of scolecodonts, a lateral rudder-shaped plate or ledge projecting from and more or less perpendicular to the inner face, located at the dorsal part of the jaw, in some types of MI. See maxilla.

**clitellate cocoons** Mesh-like scleroproteinaceous mesofossils of Late Triassic to Cenozoic age, produced by certain leeches and other annelids. They are robust enough to occur occasionally in palynological macerations. See Manum (1996).

**-coel** Of dinoflagellate cysts, meaning cavity, as mesocoel, the middle cavity.

**coenobium** An algal colony with the number and distribution of cells fixed at its origin, as in Pediastrum.

**collarette** Of chitinozoans, the lip-like edge, surrounding the mouth, at the oral pole.

**colony** Of algae, a clonal assemblage of a few to many cells, not of fixed number, as is true of a coenobium. Example: Botryococcus.

**colpa** A non-recommended synonym of colpus. Pl. colpae.

**colpate** Of pollen grains having more or less elongated, longitudinal furrows (colpi) in the exine.

**colpi** Pl. of colpus.

**colpoid** Erdtmanian term for a colpus-like furrow not situated or constructed as are colpus, sulcus or sulculus.

**colporate** Of pollen grains having colpi in which there is a pore or some other organized thinning of the exine (such as a transverse furrow), usually at the equator. See colporoidate.

**colporoidate** Of pollen grains having colpi in which there is no pore or other clearly recognizable thinning, but modifications of the exine, usually equatorial, are present: in other words, colporate but with a weakly developed pore.

**colpus** A longitudinal furrow- or groove-like modification in the exine of pollen grains, associated with germination (either enclosing a germ pore or serving directly as a place of emergence for the pollen tube) and often also important for harmomegathic swelling and shrinking. When the term is used strictly, a colpus must be meridional and will ordinarily cross the equator. In this sense the term is hence practically restricted to dicot angiosperms. In a looser sense, commonly used as synonymous with sulcus (“monocolpate” pollen are as a rule actually monosulcate).

**colpus transversalis** See transverse furrow.

**columella** One of the rodlets of ektexine that may branch and/or fuse distally to produce a tectum on pollen grains with complex exine structure. Pl. columellae.

**columellate** Possessing columellae; of pollen grains with a complex ektexine structure consisting of columellae.

**combination archeopyle** In dinoflagellate cysts, an archeopyle formed by the release of a part of the cyst wall that corresponds to plates of more than one thecal plate series (such as combining the plates of the apical series and of the precingular series).

**commissure** The groove more or less on the center line of a laesura, along which line an embryophytic spore usually germinates. It is essentially equivalent to suture.

**compound operculum** A dinoflagellate cyst operculum that is divided into two or more pieces that are separable from one another. See simple operculum.

**conate** Of sculpture of pollen and spores consisting of coni.

**coni** Pl. of conus.

**conidiophore** A structure that bears conidia; specifically a specialized, typically erect hypha that produces successive conidia in certain fungi.

**conidiospore** A fungal spore, synonym for conidium.
conidium An asexual fungal spore produced from the tip or side of a conidiophore; broadly, any asexual spore not borne within an enclosing structure, such as one not produced in a sporangium. Pl. conidia. Syn. conidiospore.

contact area One of the areas of the proximal side of a spore or pollen grain that contacted the other members of the tetrad before they separated. Contact areas are seldom visible in mature pollen grains but are frequently apparent in spores. Trilete spores have three contact areas; monolete spores have two contact areas.

conus One of the small pointed projections making up the (echinate) sculpture of certain pollen and spores, being more or less rounded at the base and less than twice as high as the basal diameter. Pl. coni.

copula Of chitinozoans, the stalk-like basal part of some species; it may terminate in a foot-like appendage. Both copula and mucron seemingly have to do with linkage of the chitinozoal units into chains.

corona A more or less equatorial extension of a spore, similar in disposition to a zone but divided in fringe-like fashion, such as in Reinschospora. Adj. coronate.

corpus That part of a saccate pollen grain or pseudosaccate spore exclusive of the sacci or pseudosacci. See body.

costa One of the rib-like thickenings in the endexine of pollen, associated with colpi. Costae are most often meridional and border colpi in pairs, but they may be transverse in association with transverse furrows. They are best seen in equatorial view. Example Melia (Fig. 5.7ak). Adj. costal.

crassinexinous Having thick nexine. The usual limit is nexine at least twice as thick as sexine.

crassitude A more or less local, usually equatorial exine thickening of a spore. See cingulum and zone.

crista One of the elevations making up the sculpture of certain pollen and spores, characterized by long, curved bases (sometimes irregularly fused) and variously bumpy apices. Pl. cristae.

cristate Crested, or having a crest; especially said of sculpture of pollen and spores consisting of cristae.

cryptarch According to proposal of Diver & Peat (1979), those of what others call acritarchs, which lack spines, plates or other features suggesting algal affinity. Cryptarchs thus would include sphaeromorph acritarchs, organic filaments, etc., whether or not sporopolleninuous.

cryptopore Term used by some for distal tenuitas of Classopollis and similar pollen grains. Some call the same structure a pseudopore.

cryptospore Early to mid-Paleozoic spore-like bodies, with no haptotypic characters. Cryptospores can be monads, dyads, tetrads.

curvatura A visible line of some (mostly mid-Paleozoic) trilete spores, connecting the extremities of the ends of the laesura and thus outlining the contact areas; a “curvatura perfecta” has three lines complete all around the spore’s proximal face; a “curvatura imperfecta” has fork-like projections from the radial ends of the laesura, not joining with their neighbors (also called “reduced curvatura”). Pl. curvaturae.

cusp Of scolecodonts, the largest tooth in a series of denticles, especially in basal plate, MII, MIII, MIV.

cyst A microscopic resting body with a resistant wall, formed in algae by the breaking up of parts of filaments or by the enclosing of a cell or cell group and investment by a sheath or envelope. Dinoflagellate cysts form within thecae, as part of the normal life cycle. See statospore and hystrichosphaerid.

-cyst Of dinoflagellate cysts, combining form meaning body, as in endocyst, the inner body.
decussate Of tetrads of pollen grains, in which two pairs of elongated grains lie across one another, the pairs at right angles to each other.

demicolpate Having apertures resembling what would happen if ordinary colpi were interrupted in the equatorial area to make sets of two, in-line colpi, not crossing the equator. A 3-demicolpate form would therefore actually have six colpi-like apertures.

demicolporate Like demicolpate, but the demicolpi have pores or pore-like interruptions. A 3-demicolporate form can therefore have six pores (fossil example: Sindorapollis).

densospore A trilete spore, chiefly Paleozoic, with a pronounced cingulum which has a tendency to be “doubled”, with a thicker part toward the center of the spore, and a thinner more external part; e.g., the genus Densosporites and other similar genera such as Cristatisporites.

dentary Of scolecodonts, a series of denticles along the inner dorsal margin.

denticles Of scolecodonts, the individual elements or teeth on the dorsal margin of the jaw.

desmid Single-celled green algae in which the cell consists of two semicells. The zygospores are sometimes resistant-walled (probably sporopolleninous) and occur rarely as palynomorphs.

diacromorph Of acritarchs, forms with sculptured polar area and equatorial areas free of sculpturing.

diad Alternate spelling for dyad.

diatom Usually single-celled algae of class Bacillariophyceae, the siliceous frustules of which occur in paleopalynological preparations if they have not been digested by HF or have been inadequately so digested.

dicolpate Of pollen grains having two colpi. Code Pb0.

dicolporate Of pollen grains having two colpi, with at least one colpus provided with a pore or transverse furrow. Dicolporate pollen are rare. Code Pb2.

dictyospore Of fungi, a conidium subdivided by longitudinal and transverse septa.

didymospore Of fungi, a monoseptate (dicellate) conidium.

dilete Of a laesura with only two radii. This morphological type is rare. See chevron.

dinocyst Contraction of dinoflagellate cyst, more or less synonymous for fossil dinoflagellate. The term is not popular with some dinoflagellate experts, who regard it as “slangy.”

dinoflagellate A one-celled, microscopic, chiefly marine, usually solitary flagellated protist organism with resemblances to both animals (motility, ingestion of food) and plants (photosynthesis), characterized by one transverse flagellum encircling the body and usually lodged in the cingulum or girdle, and one posterior flagellum extending out from a similar median groove, the sulcus. Certain dinoflagellates have a theca (test; usually not resistant to decay), and that may be simple and smooth or variously sculptured and divided into characteristic plates and grooves. Some produce a resting stage or cyst with a resistant, sometimes complex organic wall (e.g., spiny) and may differ markedly from the theca of the same species. The compound composing the cyst walls is called dinosporin. Dinoflagellate cysts exist abundantly as fossils, and have a range primarily Triassic to present. Dinoflagellate cysts are known from the Paleozoic, but are important palynomorphs only from Jurassic to present. Dinoflagellates inhabit all water types and are capable of extensive diurnal vertical migrations in response to light. They constitute a significant element in marine plankton, including certain brilliantly luminescent forms and those that cause red tide. See also hystrichosphaerid.

dinosporin Substance of which the walls of dinoflagellates and acritarchs consist. Presumably chemically very similar to sporopollenin.

diploxylonoid Of bisaccate pollen, in which the outline of the sacci in distal-proximal view is discontinuous with the body outline so that the grain appears to consist of three
distinct, more or less oval figures. See *haploxylonoid*. (Terms come from *Diploxyylon* and *Haploxyylon*, sections of the genus *Pinus*.) The terms have unfortunately been used in different senses from this definition and are best avoided.

diporate Of pollen grains having two pores. Code P02.

disaccate See bisaccate.

distal The parts of pollen grains or spores away from the center of the original tetrad; e.g., of the side of a monosulcate pollen grain upon which the sulcus is borne, or of the side of a spore opposite the laesura. Ant. proximal.

distal pole The center of the distal surface of a spore or pollen grain, thus the very center of the sulcus of a monosulcate grain.

domain a level of classification of organisms above that of kingdom. There are three domains: *Archaea*, *Bacteria*, *Eucarya*.

dyad An uncommon grouping in which mature pollen grains, spores or cysts occur as fused pairs. Code Pdy. See tetrad and polyad.

echinate Of sculpture consisting of spines (echinae).

etextine Variant of ektexine.

eto- Of dinoflagellate cysts, more or less extreme outer location, as in ectophragm, extreme outer wall. Also used for pollen to indicate an outer structure, as in ectoaperture.

etcoaperture Of pollen, an outer aperture where there is a compound aperture, as many triporate, stephanoporate and periporate grains. Cf. endoaperture.

etcoexine Var. of sexine.

etconexine Outer part of nexine.

etcoexine A thin, often discontinuous membrane lying between distal ends of processes on a dinoflagellate cyst. The term is also used in different senses. See endophragm, periphragm, autophragm.

etcopore An outer pore. Used for compound pore structures, in which there is also an endopore (= os).

etcoexine Outer part of sexine.

etktextine In Faegri and Iversen’s scheme (see Faegri et al., 1989), the outer layer of the two layers of the exine of spores and pollen, normally more densely or deeply staining than the endexine, and characterized by richly detailed external sculpture and often by complex internal structure of granules, columellae, and other elements. In contrast to Erdtman’s “geographically” based sexine, the ektexine must be set off from the underneath (endexine) layer by demonstrable staining difference. See ectexine, ectosexine and sexine.

elater The ribbon-like, usually hygroscopic, filamentous appendage of certain spores (as of *Equisetum*), consisting of more or less coiled strips of exine, perhaps homologous with perine. It aids in spore dispersal.

eembryophytic Of plants producing a 2N (diploid) embryo as part of a 1N-2N life cycle–usually restricted to bryophytes and tracheophytes (pteridophytes, gymnosperms, angiosperms). Noun embryophyte. Essentially equivalent to archegoniate.

everannulus An annulus formed by the endexine of a pollen grain. Thomson and Pflug (1953) illustrate it as characterizing some Normapolles pollen.

everexine The inner, usually homogeneous layer of the two layers of the exine of spores and pollen in the Faegri and Iversen scheme (see Faegri et al., 1989), normally less deeply staining than the ektexine. See intexine and nexitexine.

evero- In dinoflagellate cysts means inner, as endophragm, inner wall.

everoaperture Of pollen with compound apertures, the inner aperture. Cf. ectoaperture.

everoblast Of two-walled dinoflagellate cysts, the endophragm and its contents.
endocoel The cavity formed by the endophragm in a cavate dinoflagellate cyst. See pericoel.

endocyst Of more or less cavate dinoflagellate cysts, the separate inner body, of which the endophragm comprises the wall.

endogermlinal Especially used for Normapolles. Essentially equivalent to os.

endonexine Inner layer of nexine.

endophragm The wall of the inner body of a cavate dinoflagellate cyst. See endoblast.

endopore The internal opening in the endexine of a pollen grain with a complex porate (= pororate) structure. Syn. os. See ectopore.

endosexine Inner layer of the sexine.

endospore (a) Syn. of intine, for use in describing the sporoderm of spores, rather than that of pollen. Syn. endosporium. See exospore. (b) Some palynologists have also used endospore for the inner exine body of, e.g., camerate spores.

entomophily A term for pollination by insects. Adj. entomophilous. See anemophily, chiropterophily, ornithophily, zoophily.

epicyst The part of a dinoflagellate cyst anterior to the cingulum (girdle) region. See hypocyst and epitheca.

episome The anterior part of the cell body above the cingulum (girdle) of an unarmored dinoflagellate. See hyposome.

epitheca In a motile dinoflagellate, the portion of the theca anterior to the cingulum. See epicyst.

epitract Syn. of epicyst.

epityche An excystment (emergence) aperture in the acritarch genus Veryhachium. Originating as an arched slit between two processes, rupture allows the folding back of a relatively large flap.

equator An imaginary line connecting points midway between the poles of a spore or pollen grain.

equatorial extension Any equatorial extension of the spore wall, a less encumbered term for the general sense of zone.

equatorial limb A less satisfactory synonym for the term sometimes applied to the amb of a pollen grain or spore, as seen in polar view. See limb and amb.

equatorial view The lateral view of a spore or pollen grain from an aspect more or less midway between the poles and perpendicular to the polar axis.

Eucarya The eukaryote domain of organisms, typified by possession of a vesicular nucleus in the cells and complex protoplasmonic organization.

eudicot Of dicot angiosperms, those that produce either tricolpate pollen, or a form derived from the tricolpate condition, such as Rosaceae, Asteraceae. Does not include magnoliids and other basal angiosperms. See p. 28 of Soltis et al. (2005) for a concise chart.

eukaryote Cf. Eucarya.

eurypalynous Erdtmanian term for taxa with spores/pollen displaying much variety of morphology and/or exine structure. Antonym: stenopalynous.

eusaccate Saccate pollen grains lacking the extensive internal ektexinous webbing characteristic of the sort of fossil, extinct gymnosperm pollen that Scheuring (1974) called protosaccate. See protosaccate, pseudosaccate, saccate.

excystment Having to do with the emergence of the contents of a cyst. The excystment site of a dinoflagellate cyst is the archeopyle.

exine The outer, very resistant layer of the two major layers forming the wall (sporoderm) of spores and pollen, consisting principally of sporopollenin, and situated immediately outside the intine. It is divided into two layers either on the basis of staining characteristics (ektexine and endexine), or somewhat arbitrarily on the basis of being related...
to sculpture (sexine) or not so related (nexine). Syn. extine and exospore. See also perisporem.
exinite Coal petrologic term. Essentially synonymous with sporinite, q. v.
exinous Consisting of exine.
exoexine A less satisfactory synonym of ekctexine.
exogerminal Especially used for Normapolles. Essentially equivalent to pore.
exospore A synonym of exine, mostly applied to the non-perinous portion of the sporoderm of spores. Syn. exosporium.
extine Var. of exine. The term is not in good or current usage in palynology.
exuviation The removal of the theca of a dinoflagellate, either plate by plate, or as small groups of plates.
falx Of solecodonts, a sickle-shaped extension of the anterior part of the jaw, often forming a hook.
fang Of solecodonts, a poorly developed falcal hook.
fenestrate Of pollen exines, those with large open “windows” surrounded by exine wall, such as many genera of the Asteraceae (e.g., Ambrosia), or of Passiflora, in which case the windows are caused by the shedding of sections of the exine.
fimbriate Preferred synonym of capillate. Fimbriate sculpture consists of long, hair-like units (fimbriae).
Fischer’s rule Of triaperturate, tetrad angiosperm pollen, in which the apertures form in pairs at six points on the tetrad, each pair involving two adjoining members of the tetrad. Example: Vaccinium. See Fig. 5.8 Cf. Garside’s Rule.
flagellar pore One of the pores in a dinoflagellate for extrusion of flagella, usually located at the anterior or the posterior junction of girdle (cingulum) and sulcus.
Flandrian Western European term for what is variously called elsewhere “post-glacial”, “recent”, “Holocene”, i.e., approximately the last 10,000 years, the present interglacial.
flange An equatorial extension of a spore; less precisely defined than zone or cingulum.
foot layer A lower part of the ekctexine, partly surrounded by exine. The foot layer can be distinguished from the endexine not only by staining difference, but also by electron density, which is different from that of the endexine.
foraminiferal test linings See microforaminifera.
forb A non-cultivated, dicotyledonous, herbaceous plant; an herb other than grass; a broad-leaved weed. The term appears in some palynologic literature dealing with Quaternary sediments.
forensic palynology The application of palynological methods to legal problems. Even paleopalynology has occasionally been used, for example, to pinpoint source of mud on a suspect’s footwear. (See Bryant, et al., 1996.)
“fossiliferous” This definitely includes all rocks that contain palynomorphs! However, I have found a number of examples in the literature that cite rocks containing plenty of palynomorphs as “non-fossiliferous,” because they contained no megafossils.
fossulate Of sculpture of pollen and spores consisting of grooves that anastomose.
foveolate Means pitted; e.g., of sculpture of pollen and spores consisting of pits in the ekctexine larger than 1 µm. See scrobiculate, perforate.
free operculum Part of a dinoflagellate cyst that is completely surrounded by archeopyle sutures, with no unsutured connection to the rest of the cyst. Syn. free opercular piece. See attached operculum.
fruit body Of fungi, a fructification, i.e. a spore-bearing organ. Chitinous fruit bodies occur as palynomorphs. Fossil fruit bodies characteristically lack spores. Microthyriaceous fruit bodies are more or less flattened and radially symmetrical. Syn. fruiting body.
fungal spore A spore of the usually multicellular, non-vascular, heterotrophic organisms belonging to kingdom Fungi. Such spores include a wide variety of types, from simple
unicellular to multicellular scleriotia; they have a range of Precambrian to Holocene. Those fungal spores preserved in sediments and surviving maceration are chitinous, and such fungal spores range primarily from late Jurassic to present. Examples: basidiospore, chlamydospore, conidiospore, dictyospor, phragmospore, teleutospor and urediospore.

**Fungi Imperfecti** Synonym for *Deuteromycetes* fungi, those presumably ascomycete fungi that have no known sexual stage, of which only asexual spores are produced.

**furrow** A colpus or sulcus.

galeate Of early Paleozoic acritarchs with a helmet-like detachable operculum usually missing from the large excystment structure.

gametophyte The sexual generation of a plant that produces gametes or an individual of this generation; e.g., the haploid generation of an embryophytic plant, produced by germination of the spores. In lower vascular plants and bryophytes, the gametophyte is a separate plant, but in seed plants, it is confined to the cells (several to many) of the microgametophyte in the pollen grain and multicellular megagametophyte in the ovule (the seed consists of the fertilized ovule and investing tissues). See prothallus and sporophyte.

**Garside’s rule** Of angiosperm triaperturate, tetrad pollen, having the apertures formed in four groups of three, each group involving three of the tetrad’s grains. Example: some Proteaceae. Cf. Fischer’s rule. See Fig. 5.8.

gemmate Of sculpture of pollen and spores consisting of more or less spherical projections (= gemma, pl. gemmae).

geminal Of fungal spores, a secondary opening in the spore wall at some point other than the primary or principal pore or furrow. The germinating plasm may emerge here rather than at primary pores. Often also used for porate pollen, especially for Normapolles, for both pore and os (endopore) and their associated structures.

geminal aperture An aperture (such as a colpus, sulcus, or germ pore) of a pollen grain through which the pollen tube emerges on germination of the grain. The term is sometimes used to include also the laesura of spores and prepollen.

geminal furrow A colpus or sulcus.

germ pore A membranous pore or thin area in the exine of a pollen grain through which the pollen tube emerges on germination. As ordinarily defined, a pore cannot have one dimension more than two times another dimension. Where one dimension is two times or more larger than another, the thin area is a colpus or sulcus.

girdle See cingulum.

gonal spine A spine situated only at plate corners on a dinoflagellate cyst.

grain Syn. of pollen grain.

**granular** Of tectate pollen in which the infratectal layer consists of very small granules rather than of columellae. Also used as a sculptural term essentially equivalent to scabrate.

gula A projecting, neck-like, rather ornate extension of the trilete laesura of certain fossil megaspores. Pl. gulae. See trifolium.

gulate Of megaspores, possessing a gula.

**hamulate** Of sculpture consisting of small, irregularly arranged hooks. The term is not widely used.

**haplotabular archeopyle** An apical archeopyle in a dinoflagellate cyst, consisting of a single plate.

**haploxyloonoid** Of bisaccate pollen, in which the outline of the sacci in distal-proximal view is more or less continuous with the outline of the body, the sacci appearing more or less crescent-shaped in polar views, and the outline of the whole grain presenting a more or less smooth ellipsoidal form. See also diploxyloonoid. (Both terms have been
used in other senses and are now best avoided. Pleistocene palynologists, for example, usually define haploxylonoid as having, and diploxylonoid as lacking, verrucae on the distal face or cappula.)

**haplotypic character** A feature of a spore or pollen grain that is a product of contact with other members of the tetrad in which it was formed; e.g., the laesura and contact areas of spores.

**harmomegathus** The membrane of a pore, colpus, leptoma, etc., (of a pollen grain) when it serves to accommodate, by expansion and contraction, changes in volume of the grain, which usually results from the taking up or loss of water. Pl. harmomegathi. Adj. harmomegathic. Noun, for the phenomenon of accommodation to moisture-content change, harmomegathy.

**helicosore** Of fungi, a coiled conidium.

**herkomorph** An acritarch with the surface divided by crests into polygonal fields.

**heterobroachate** A not much used term for reticulate sculpture in which the lumina (and their enclosing muri) are of different sizes. In some sculpture described as heterobroachate, there are small lumina or perforations in the surface of the muri that surround the first order lumina. See homobroachate.

**heterocolpate** Of pollen grains having pores in some colpi, not in others. This term is also used in other senses by some; e.g., for pollen with both colpi and (unassociated) pores.

**heteropolar** Of pollen grains and spores with marked difference between the two poles, as monosulcate pollen or trilete spores. See isopolar.

**heterosporous** Characterized by heterospory; specifically of plants that produce both microspores and megaspores. Also refers to dinoflagellate genera, the species of which produced several different cyst forms.

**heterospory** The condition in embryophytic plants in which spores are of two types: microspores and megaspores. See homospory.

**high-spine** Refers to pollen of Asteraceae (= Compositae), in which the spines of the echinate sculpture are over 3 μm long. Cf. low-spine.

**hilate** Of a spore or pollen grain possessing a hilum. Burgess and Richardson (1995) use the term only for cryptospores, but this is not a practical usage, because the term is in the literature in many other senses.

**hilum** An irregular germinal aperture of a spore or pollen grain, formed by the breakdown of the exine in the vicinity of one of the poles. The hilum in the spore Vestispora is associated with an operculum that may become separated from the spore.

**holdfast** Of fungi, a pad-like process from the hyphal body for attachment to substrate.

When chitinous and dispersed, may mimic a spore.

**holomorph** Of ascomycete fungi, the entire organism in all its facets. Cf. anamorph, teleomorph, Fungi Imperfecti.

**homobroachate** A not much used term for reticulate sculpture in which the lumina (plus their enclosing muri) are of about the same size. See heterobroachate.

**homospore** One of the spores of an embryophytic plant which reproduces by homospory.

**Range** is Silurian to Holocene. Syn. isospore. See microspore.

**homosporous** Characterized by homospory.

**homospory** The condition in embryophytic plants in which all spores produced are of the same kind; the production by various plants of homospores. Syn. isospory. See heterospory.

**hypha** Of fungi, an individual, septate or aseptate, filament that may be part of a mycelium.

**hypnozygote** Algal cell resulting from gamete fusion, often with a thick, sculptured wall. Dinoflagellate cysts and perhaps some acritarchs are probably hypnozygotes.

**hypocyst** The part of a dinoflagellate cyst posterior to the cingulum. See epicyst.
**glossary**

**hyposome** The posterior part of a *dinoflagellate*, below the *cingulum*. See *episome*.

**hypotheca** In a motile *dinoflagellate*, the portion of the *theca* posterior to the *cingulum*. See *episome*.

**hypotract** Syn. of *hypocyst*.

**hystrichosphaerid** A general term formerly used for a great variety of resistant-walled organic microfossils, ranging from Precambrian to Holocene, and characterized by spherical to ellipsoidal, usually more or less spinose remains found among fossil microplankton. These are now divided among the *acritarchs* and *dinoflagellate cysts*. The term has no formal taxonomic status. Syn. *hystrichosphere*.

**hystrichosphere** See *hystrichosphaerid*.

**iatropalynology** Study of *spores* and *pollen* as applied to human health problems, especially *pollinosis*. See *aerobiology*.

**inaperturate** Of *pollen* and *spores* having no *germinal*, *harmomegathic*, or other openings. See *acolpate* and *alete*.

**infrasculpture** The *structure* of *spores* and *pollen* consisting of organized internal modifications of *exine*. See *structure*.

**infratectum** Of pollen exines, the layer beneath the tectum, which may be variously alveolar, granular, amorphous, or columellate.

**intercalary plate** Of a *dinoflagellate*, a plate whose position lies between two major plate series.

**intercolpium** The area of a *colp(or)ate pollen exine* between the *colpi*, therefore delimited by the colpi and the *polar* areas. Syn. *mesocolpium*.

**interloculum** Laterally extensive space between the *sexine* and *nexine*. Term especially used for *Normapolles*. Interloculum connects with the *vestibulum*, if such is present.

**interporium** The area of a *porate pollen exine* delimited by lines tangential to the *pores*, and the pores themselves; thus a comparatively narrow band of *exine* as wide as the pores, extending from pore to pore. Syn. *mesoporium*.

**intratabular** Of features of a *dinoflagellate cyst* that approximately correspond to the central parts of *thecal plates* rather than to the lines of separation between them. See *nontabular* and *peritabular*.

**isopolar** Of *pollen grains* with more or less radial symmetry and no marked difference between the *poles*, as most *tricolpate pollen*. Cf. *heteropolar*.

**isopoll** A line on a map connecting locations with samples having the same percentage or other measure of amount of *pollen* of a given kind. Syn. *isopollen* (not much used).

**isospore** A *spore* of plants such as bryophytes, producing only one kind of spore. Syn. *homospore*.

**isospory** The quality or state of having or producing *isospores*. Syn. *homospory*. 
**jaw** Of *scolecodonts*, syn. for jaw piece, jaw plate, an individual major element of maxillary apparatus.

**Kofoid tabulation system** Of dinoflagellates, the most used method for description of the number and arrangement of the plates.

**kyrtome** A more or less arcuate fold or band in the *interradial* area outside the *laesura* of a *trilete spore*. Some palynologists prefer to use *torus* for separate interradial bands, and kyrtome for a connected figure. A wide variety of other terms are used for modifications of the borders of laesurae. See *torus*, *labrum*, and *margo*.

**labrum** Lip-like thickening of the edges of a *laesura*. Pl. labra. See *kyrtome*, *torus*, and *margo*.

**lacuna** A rarely used term for a depressed space, pit, or hole on the outer surface of a pollen grain.

**laesura** The trace or scar on the *proximal* face of an *embryophytic spore*, that marks the original contact with other members of the *tetrad*. It may be *trilete*, *monolete*, or rarely *dilete*. Pl. laesurae. (Note: Some palynologists speak of each ray of the trilete laesura as “a laesura”. In this usage, a trilete spore has three laesurae. Despite the history of the term, which supports this usage, I find it confusing and think it should be avoided.)

See *suture*, *tetrad scar*, and *Y-mark*.

**laevigate** Syn. of *psilate*. The term is more often applied to *spores* than to *pollen*.

**lalongate** Of pollen, refers to apertures that are laterally (transversely) elongated. cf. *lolongate*.

**lateral tooth** Of *scolecodonts*, a slender element usually formed by a simple single large *denticle*, placed immediately in front of any or all of the regular *jaws* of an apparatus.

**leiosphaerid** A thin-walled, more or less spherical body of probable algal relationship, lacking processes, *septa*, etc., characterized by the genus *Leiosphaeridia*, and usually referred to the *acritarchs*. Mostly Ordovician to Silurian in age.

**leiosphere** Syn. of *leiosphaerid*.

**leptoma** A thin region of *exine* situated at the *distal* pole of a *pollen grain* and usually functioning as the point of emergence of the *pollen tube*. For bisaccate pollen, this is an alternate term for *cappula*. Example of use for non-bisaccate gymnosperm pollen: *Classopollis*, for which *tenuitas* is also used. See also *pseudopore*, *tenuitas*, and *cappula*.

**limb** Syn. of *amb* or *equatorial limb*.

**limbus** A crease at the edge of the *saccus* or *pseudosaccus* where outer and inner *exine* layers are more or less fused.

**linotolypidae** Thread like, sometimes webbed, pseudofossils of uncertain origin, sometimes occurring in palynological preparations. See also *cenospheres*.

**lip** The *labrum*.

**liptinite** Coal petrologic term for macerals derived from spores, pollen, leaf cuticles and related plant matter. cf. *vitrinite*, *sporinite*.

**LO analysis** From Latin *lux-obscurus* (= light-dark), a microscopic technique depending on projecting elements appearing bright in high focus, dark in low focus, whereas holes appear dark in high focus, etc.

**lolongate** Of pollen, referring to apertures that are longitudinally elongated, i.e. in the opposite direction of *lalongate* apertures, which are elongated parallel to the equator of the grain.

**Longaxones** A group of primitive, usually lightly *sculptured*, *tricolpate*, lower Cretaceous and younger angiosperm *pollen*, in which the *polar* axis is as long as, or longer than, the *equatorial* diameter. See *Brevaxones*.

**longitudinal flagellum** A thread-shaped flagellum in a *dinoflagellate*, trailing after the *body* and arising from the posterior *pore* in the *sulcus*. This flagellum propels the organism.
**low-spine** Refers to echinate pollen of the Asteraceae (= Compositae) in which the spines are less than 3 µm long.

**lumina** (singular form *lumen*) The depressions or open spaces between *muri* of positive reticulate sculpture, and similar depressions. See *muri*.

**maceration** The act or process of disintegrating sedimentary rocks by various chemical and physical techniques, in order to extract and concentrate acid-insoluble microfossils (including *palynomorphs*) from them. It includes mainly chemical treatment by halogen acids, oxidants, and alkalis and use of other separating techniques that will remove extraneous mineral and organic constituents.

**macros pore** Unsatisfactory syn. of *megas pore* in the botanical sense, antonym for *miospore* in the proposal of Guennel (1952), in which sense it is all pollen and spores larger than 200 µm.

**magnoliid** Certain basal angiosperms that do not produce tricolpate pollen, or any sort of pollen derived from that form. Cf. *eudicot*.

**main body** Of *dinoflagellates*, the central body.

**mandible** Of *scolecodonts*, a single fixed pair of jaw pieces on the ventral side (not in the pharynx) of the animal, with long posterior shafts, often with an anterior calcareous cap. The mandibles are non-eversible (cannot be everted).

**marginate chorate cyst** A *dinoflagellate chorate cyst*, whose outgrowths are characteristically localized on the lateral margins, leaving the dorsal and more often the ventral surfaces free of outgrowths.

**margo** (a) Modified margin of the *colpus, sulcus* or *pore* of a *pollen grain*, consisting of a thickening or (less commonly) thinning of the *exine*. See *s annulus*. (b) A term sometimes used for marginal features associated with the *laesura* of *spores*. See *krytome* and *labrum*.

**marine influence** An expression for the proportion of a *palynoflora* composed of *palynomorphs* of marine origin. Abbrev. MI.

**massula** (a) A more or less irregular, coherent mass of many fused *pollen grains* shed from the anther as a unit. See *pollinium*. (b) A term sometimes applied to a structure associated with the *laesura* and the attached non-functional spores of certain *megas pores*. Pl. massulae.

**maxilla** Of *scolecodonts*, any major jaw piece of the mouth located in the pharynx. From posterior to anterior they are numbered MI, MII, etc.

**MCT** Of angiosperm pollen, those that are *monosulcate with columellate-tectate exines*. Term used by Hughes (1994) because of the prevalence of this sort of pollen in early angiosperms.

**megas fossil** A fossil that can be studied for identification purposes at magnification of less than 10x. Cf. *mesofossil, microfossil*.

**megagametophyte** The female *gametophyte* or haploid generation that develops from the *megas pore* of a *heterosporous* embryophytic plant. In lower vascular plants, it is a small free-living plant bearing archegonia, but in seed plants it (e.g., embryo sac of angiosperms) is contained within the ovule, and the egg is produced in it. The embryo which develops from fertilization of the egg plus other gametophytic products and the enveloping tissues of the ovule comprise the seed. See *microgametophyte*.

**megasporangium** A *sporangium* that develops or bears *megas pores*.

**megas pore** One of the *spores* of a *heterosporous* embryophytic plant that germinates to produce a *megagametophyte* (multicellular female *gametophyte*). It is ordinarily larger than the *microspore*. Range mid-Devonian to Holocene. Free megaspores were common in the late Paleozoic but are produced only by a few genera of pteridophytes today. Unsatisfactory synonym, *macros pore*, which is antonym of *miospore*. 
**melitopalynology** The study of pollen in honey and in connection with apiculture generally.

Syn. Melissopalynology.

**membranate chorate cyst** A dinoflagellate chorate cyst with a prominent membrane; e.g., Membranilarnacia.

**meridional** Of pollen, features that that cross the equator along lines perpendicular to it.

**meso-** Of dinoflagellate cysts, the middle, as in mesophragm, middle wall.

**mesocolpium, mesoporium** (The “mesocolpus” and “mesoporus” of some authors.) Erdtmannian terms equivalent to intercolpium and interporium.

**mesofossil** A term sometimes applied only to paleobotanical material, for fossils larger than miospores, yet still requiring microscopy at more than 10x magnification, such as megaspores, small seeds, flowers, pieces of cuticle, etc. However, the term would be better applied to a size range of fossils than to their belonging to any particular systematic group. cf. miospore, megafossil.

**Mesophytic** An informal division of geologic time, extending from the coming to dominance of coniferophytes, ginkgophytes, cycadophytes, and other gymnosperms in mid-Permian time, to the Cenophytic.

**MI** Abbreviation for marine influence.

**micro-** A combining form used with sculpture, the elements of which are too small (less than 1 μm) for Faegri and Iversen’s (1989) terms to apply: micropitted, etc.

**microflora** An unsatisfactory syn. of palynoflora. The term is properly applied to an assemblage of microscopic organisms, such as the bacteria of an animal gut.

**microforaminifera** The chitinous inner tests (test linings) of certain, almost always spiral foraminifers, frequently found in palynologic preparations of marine sediments, and generally much smaller than “normal” whole foraminifers, but displaying recognizable characteristics of “normal” species. The proposal of the formal group name “Scytinascia” for these linings should be ignored. The linings are parts of perfectly normal foraminifera, not a separate group of organisms. For more details, see Stancliffe (1996).

**microfossil** A fossil that must be studied at a magnification of more than 100x. (cf. Traverse et al., 2004) cf. mesofossil, megafossil.

**microgametophyte** The male gametophyte or haploid generation that develops from the microspore of a heterosporous embryophytic plant. In lower vascular plants, a multicellular microgametophyte, as well as the sperm cells, develop within the microspore wall; in seed plants, the microgametophyte plus the surrounding microspore wall is the pollen grain, in which the microgametophyte is further reduced, being only 3-nucleate in the angiosperms. See megagametophyte.

**micropitted** sculpture with “holes” in the exine less than 1 μm. Synonymous with foveolate.

**microplankton** In paleopalynology, a term often used collectively for acritarchs and dinoflagellate cysts, to distinguish them from spores and pollen.

**microreticulate** Having reticulate sculpture in which the muri are so tiny that they can only be observed at high magnifications under oil.

**microsporangium** A sporangium that develops or bears microspores; e.g., the anther in an angiosperm or the pollen sac in all other seed plants. See megasporangium.

**microspore** One of the spores of a heterosporous embryophytic plant that germinates to produce a microgametophyte (male gametophyte). Ordinarily smaller than the megaspore of the same species. In seed plants, pollen grains consist of a microspore wall or exine with a microgametophyte contained inside. See also miospore.

“Microspore” should never be used as a general term for “small spore!” Use of “microspore” means that an author is sure the producing plants were heterosporous, not homosporous. Most Mesozoic and Cenozoic ferns, for example, produced homospores, not microspores. When in doubt, say miospore!
miospore A term arbitrarily defined in paleopalynology (per Guennel, 1952) as a spore or pollen grain less than 200 μm in diameter, regardless of biological function. The word is unfortunately pronounced the same as meiospore, a cell stage in meiosis. If “miospore” is used, all spores or pollen grains greater than 200 μm in diameter are called macrospores, regardless of biological function. See macrospore, megaspore, microspore, and small spore.

monad Term used to describe single sporopolleninous- walled units, in contrast to dyads, tetrads, and polyads. Term is especially useful in studies of Silurian rocks, where all of the above-mentioned types occur, and it is desired to use the non-committal monad rather than spore or acritarch.

monocolpate Of pollen grains having a single, normally distal colpus. Monosulcate is preferred in most instances. Code Pa0.

monolete Of an embryophytic spore having a laesura consisting of a single unbranched line or mark. See trilete. Code Sa0.

monoporate Of pollen grains provided with a single pore, as in grasses.

monosaccate Of pollen with a single saccus, usually extending all around the pollen grain more or less at the equator. The monosaccate and bisaccate conditions are not sharply distinct. Many grains that appear bisaccate in one view can be shown to be actually monosaccate. Code Pv1.

monosulcate A term essentially equivalent to monocolpate in ordinary usage. Because the germinal furrow in such cases is practically always a sulcus, this is the preferred term. Code Pa0.

morphon As defined by Van der Zwan (1979), a group of palynological species (formspecies) united by continuous variation of morphological characteristics. Others use the term “complex” in a very similar way. See also palynodeme.

morphotaxon (morphogenus, morphospecies) These terms refer to the concept that fossil plant taxa for isolated parts such as spores and pollen, are not taxa of whole plants, but are taxa referring only to the parts represented by the nomenclatural type. Thus, Classopollis is not a genus of gymnospermous plants, but a morphogenus of fossil pollen that we know to have been produced by a family of gymnospermous trees and/or shrubs. See discussion of nomenclature at the end of Chapter 19 in this book.

mother cell A cell from which new cells are formed; e.g., spore mother cell and pollen mother cell.

mouth Of chitinozoans, the opening at the oral pole (see Fig. 6.11).

mucron Of chitinozoans, the nipple-like extension at the center of the base of some species. Both mucron and copula apparently have to do with the linkage of chitinozoal units into chains.

multisaccate Of pollen with more than two vesicles. Code Pv3, etc.

murus, usually used in plural form, muri. The more or less vertical walls which form positive reticulate sculpture in pollen and spores. Also the ridges that separate the grooves of striate and rugulate sculpture. See lumina.

mycelium The tissue of the vegetative structure (thallus) of a fungus, consisting of hyphae.

nanofossil Very small (mostly 5 μm or less) calcareous fossils, by definition not palynomorphs. The term is usually restricted to platelets of the walls of Coccolithophoridae, marine single-celled green algae (platelets are called coccoliths and discoasters). The term is unfortunately used by a few writers for all tiny fossils, including, e.g., acritarchs and cryptarchs. Sometimes spelled nanofossil.

NAP Abbrev. for non-arboreal pollen. Synonym: NTP.

neck Of chitinozoans, the narrowed region between collar and main body.

negative sculpture A term for sculpture engraved into rather than standing upon the outer surface of the exine; e.g., negative reticulum.
**netromorph** Of acritarchs with an elongate to fusiform shape. May have processes at poles. Examples: *Dactylofusa*, *Leiofusa*.

**nexine** The inner layer of the exine of pollen in Erdtman’s scheme. The nexine is purely “geographic” in definition: the lower unsculptured part of the exine. See endexine.

**non-arboreal (non-arborescent) pollen** The pollen of herbs and shrubs. Abbrev. NAP. Syn. non-tree pollen.

**non-tabular** Of projecting surface features of a dinoflagellate cyst that are neither sutural nor intratabular and that have a random arrangement, or show no apparent relation to a tabulate scheme. See peritabular.

**non-tree pollen** Syn. of non-arboreal pollen. Abbrev. NTP.

**Normapolles** A group of Cretaceous and lower Paleogene porate (usually triporate) pollen with a complex pore apparatus (e.g., oculus) and sometimes other peculiarities such as double Y marks. See Postnormapolles.

**NTP** Abbrev. for non-tree pollen. See non-arboreal pollen.

**oblate** Of pollen, flattened (foreshortened) along the polar axis; e.g., pollen, whose equatorial diameter is much longer than the dimension from pole to pole. Ant. prolate.

**obligate** Of tetrads or polyads of spores or pollen, meaning that such union is typical for the taxonomic unit. Usually this is interpreted to mean that more than 50% of the specimens of the taxon found are so united, not broken up. This condition is sometimes termed “permanent.”

**oculate** A group designation (Oculata) for *Wodehouseia* and similar Cretaceous pollen.

**oculus** A much-enlarged part of the pore structure of (usually triporate) pollen, consisting of a bulging, very thick protrusion of ektexine. Pl. oculi.

**operculate** Having an operculum; e.g., of dinoflagellates, possessing an archeopyle associated with an operculum, or of a pollen grain having pore membranes with an operculum.

**operculum** (a) A lid consisting of the plate or plates that originally filled the archeopyle of a dinoflagellate cyst or the pylome of an acritarch. Also, the lid-like closure of the mouth of a chitinozoan. (b) A thicker central part of a pore membrane of a pollen grain, or a large section or cap of exine completely surrounded by a single colpus. For certain hilate spores and pollen, the operculum is a less well-defined lid of exine associated with the formation of the hilum.

**ora** Pl. of os.

**oral pole** That end of a flask-shaped chitinozoan that includes the neck and the mouth. See aboral pole. Cf. apertural pole, antapertural pole.

**oral tube** Of chitinozoans, the more of less constricted portion of the vesicle, toward the oral or apertural pole, including the aperture or mouth, the collarette, and the neck.

**orate** Of a porate pollen grain having an internal opening (endopore or os) in the endexine.

**orbicle** Alt. spelling for orbicule. See ubisch bodies.

**orbicule** See ubisch bodies, the term I prefer, mostly because I find it easier to recall. It also has the advantage that it is not likely ever be used in another sense.

**ornament, ornamentation** Less satisfactory syn. of sculpture. Modifications in the exines of pollen grains or in the outer walls of other palynomorphs do not have a decorative function, as far as we know.

**ornithophily** A term for pollination by birds (mostly hummingbirds).

**os** Syn. for endopore, an inner aperture of a complex structure. Pl. ora.

**ostiole** Of fungi, the opening in the neck of a flask-shaped fruit body, or a rounded opening in any fruit body, through which the spores are released.

**paleopalynology** A division of palynology concerned with the study of a wide range of fossil microscopic, usually organic bodies, in addition to spores and pollen: animal remains such as chitinzoans, as well as fungal spores, dinoflagellates, acritarchs, and...
other organisms resistant to acids and found in sedimentary rocks of all ages (*nanno-
fossils* and *diatoms* should therefore not be included). The usual criteria for inclusion
are that the bodies be microscopic in size (from about 5 μm to about 500 μm) and
composed of a resistant organic substance (usually *sporopollenin*, *chitin*, or *pseudo-
chitin*), resulting in the bodies being preserved in sedimentary rocks and available for
separation by *maceration* from such rocks. The subject includes a rich panoply of
applications of the subject to various scientific subjects, including evolutionary studies,
stratigraphy, climatology, paleoecology, and even forensics.

**Paleophytic** An informal division of geologic time, extending from the first appearance of
land plant *spores* (Ordovician) to the beginning of the *Mesophytic*.

**palyniferous** Literally, bearing *pollen*. The term in *palynology* usually refers, however,
to rocks or sediment samples that yield pollen, *spores*, or other *palynomorphs* on
*maceration*.

**palynodebris** The *palynomorph*-size particles, other than palynomorphs, in a sediment, as
wood fragments, leaf cuticles, etc. See *phytoclast, palynofacies*.

**palynodeme** An expression for a group of *palynomorph* species that intergrade and probably
represent “…the palynological reflection of a known or hypothetical plant species”
(Visscher, 1971). As originally used, the concept was phylogenetic and referred to
characters changing in time. In practice, the term is used by many as if synonymous
with *morphon* or the less formal term, “complex.”

**palynofacies** (a) the assemblage of *palynomorph* taxa in a portion of a sediment, a
*palynoflora* representing local environmental conditions and not typical of the regional
palynoflora; or (b) the total assemblage of *palynodebris* and *palynomorphs* found in
a certain kind of sediment, and characterizing that sediment and its environment of
deposition.

**palynoflora** The whole suite of plant-derived *palynomorphs* from a given rock unit. The
term *microflora* is sometimes used as a synonym, but should be avoided as it specif-
cically applies to assemblages of extant microscopic algae, fungi, and bacteria. As
palynomorphs do not really constitute a “flora,”—many non-plant items are included–
term such as “palynomorph assemblage” is better, when non-botanical forms are
included. *Palynoflorule* refers to the plant-derived palynomorph assemblage from a
single sample or level.

**palynology** Originally, the study of pollen and spores, extant and fossil, including strati-
graphic and paleoecological applications. Now includes study of a wide range of
other robust-walled, microscopic remains of various plants, animals, fungi and protists.
Term suggested by Hyde and Williams (1944). Etymol.: Greek παλαινω, “to strew
or sprinkle”, suggestive of παλη, “fine meal” cognate with Latin pollen, “fine flour,
dust”. See also *paleopalynology* and *pollen analysis*.

**palynomorph** A microscopic, resistant-walled organic body found in palynologic *macer-
ation* residues; a palynologic study-object. Palynomorphs include *pollen, spores* of
many sorts, *acritarchs, dinoflagellate thecae* and *cysts*, certain colonial algae, *scale-
codonts, chitinozoans* and other acid-insoluble microfossils. See *sporomorph*.

**palynostratigraphy** The stratigraphic application of palynologic methods.

**panto-** *(or pan-)* A prefix indicating distribution spread over the whole surface, a synonym
preferred by many for the prefix *peri-* used in this book.

**pantocolpate, pantoporate** See *pericolpate* and *periporate*.

**papillate** Of sculpture, parallel sided exinous elements with rounded tips, less than 1 μm
in length. *papillate* sculptural elements are a subset of *scabrate*, q. v.

**PAR** Abbrev. for *pollen accumulation rate*. See *pollen influx*.

**para-** In *dinoflagellate* studies, a prefix sometimes assigned to *thecal* terms when these
are applied to *cysts*, e.g., *paracingulum, paratabulation, paraplate*, etc.
**patina** A thickening of the exine of spores that extends over approximately half of the surface, i.e., over the entire surface of one hemisphere. Adj. patinate.

**PDR** Abbrev. for pollen deposition rate. See pollen influx.

**perforate** Of pollen, sculpture consisting of holes less than 1 μm. See foveolate.

**peri** Of dinoflagellate cysts, means outer, as periphragm, outer wall. However, if the outermost wall has supporting structures, that wall is an ectophragm. If there are no supporting structures, it is a periphragm.

**pericoel** The space between the periphragm and endophragm in a cavate dinoflagellate cyst. See endocoel.

**pericolpate** Of pollen grains having more than three colpi, not meridionally arranged (see stephanocolpate). In Erdtman’s terms, this is called polyrugate. Code Px0. Syn. pantocolpate. (However, pantocolpate means the colpi are “evenly distributed”, and pericolpate is not so restricted.)

**pericolporate** Of pollen grains having more than three colpi, not meridionally arranged, with at least part of the colpi provided with pores or transverse furrows. Code Pxx.

**pericyst** Of more or less cavate dinoflagellate cysts, the separate outer body, of which the periphragm comprises the wall.

**perine** Syn. for perinium and perisporium.

**perinium** A sometimes present, more or less sculptured outer coat of a pollen grain. Pl. perinia. Adj. perinate. See perisporium.

**periphragm** The outer layer of a dinoflagellate cyst, usually carrying extensions in the form of spines, and projecting to the position of former thecal wall. It may have served as a support during the period of cyst formation. See ectophragm and endophragm.

**periporate** Of pollen grains having many pores scattered over the surface. In Erdtman terminology, when there are more than 12 pores, the term is polyforate. Code P0x. Syn. polyporate and pantoporate. (Pantoporate means that the pores are “evenly distributed”, whereas periporate is not so restricted. Polyporate is a less favored equivalent of periporate, both meaning more than three pores, not more or less on the equator, and either evenly or irregularly spaced.)

**perispore** Syn. for perisporium.

**perisporium** An additional wall layer external to the exine in certain spores and pollen. It is composed of thin and loosely attached sporopollenin and is therefore not usually encountered in dispersed fossil sporomorphs. Syn. perine, perinium, and perispore.

**peritabular** Of the surface features of a dinoflagellate cyst that originate immediately interior to the margins of reflected plate areas (as in Areoligerina and Eisenackia). See intratabular and non-tabular.

**peroblate** Of the shape of a spore or pollen grain, having the pole-to-pole axis very much shortened, producing a discus-like shape. See oblate and prolate.

**perprolate** Of the shape of a spore or pollen grain, having the pole-to-pole axis very much elongated, producing a cigar-like shape. See prolate and oblate.

**-phragm** Of dinoflagellate cysts, wall, as autophragm, single wall. As a synonym for wall, it is written phragma.

**phragmospore** Of fungi, a spore having two or more transverse septa.

**phycoma** A cyst-like, sporopolleninous-walled body produced by marine prasinophytes. Unlike a cyst, a phycoma can grow during its existence and produces multiple flagellate cells. Pl. phycomata. Example: Tasmanites.

**phytoclast** Plant-derived, more or less resistant-walled particles in a sediment, including palynomorphs, cuticular and wood fragments, etc. See palynodebris.

**PI** Abbrev. for pollen influx. More or less the same as PDR and PAR.

**pila** Pl. of pilum.
pilate Of spores and pollen having sculpture that is similar to that of clavate forms but that consists of smaller hair-like processes (pila) with more or less spherical terminal knobs. Syn. piliferous.
piliferous Bearing or producing hairs; e.g., said of pollen grains bearing pila. The synonymous term pilate is preferred by some palynologists.
pilum One of the small, spine-like rods comprising sculpture of the exine of certain pollen and spores. The rodlets are characterized by rounded or swollen knob-like ends. Pl. pila. See clavate.
pitted Syn. of foveolate.
plate Of dinoflagellates, the individual elements of the thecal wall numbered in Kofoid or Taylor systems. The corresponding plates of the cyst are sometimes called paraplates. Of scolecodonts, an alternative term for jaw.
plate equivalent Of the part of the dinoflagellate cyst wall judged to occupy a position equivalent to that occupied by a certain plate of the corresponding theca. See para-. plate formula In dinoflagellate studies, a numerical expression for the arrangement and number of plates. There are several schemes for such enumeration, of which the most popular is Kofoid's (1907).
plica One of the ridge-like folds comprising most of the surface exine of Ephedra and some other fossil pollen. Also thickened fold-like area in the exine of certain pollen grains; in Normapolles, usually Y-shaped, centered over the pole. Adj. plicate.
polar area The part of a pollen grain poleward from the ends of the colpi and their associated structures. Syn. apocolpium.
polar area index The ratio between the diameter of the polar area of a pollen grain and the diameter of the grain.
polar limb A seldom used term to express the outline of a pollen grain as observed laterally (equatorially). Syn. profile. See amb.
polar view The view of a spore or pollen grain from directly above one of the poles. See also amb.
pole Either termination of the axis of a pollen grain or spore running from the center of the original tetrad to the center of the distal side of the grain; hence, the center of both distal and proximal surfaces. The term is especially useful for angiosperm pollen grains such as tricolpate, in which it is not apparent which is the proximal and which the distal surface. Also of chitinozoans, the two ends of a chitinozoal unit. See aboral pole and oral pole.
pollen The several-celled microgametophyte of seed plants, enclosed in the microspore wall. Fossil pollen consists entirely of the microspore wall or exine, from which the microgametophyte and intine were removed during or before lithification. The term “pollen” is a collective plural noun, and it is incorrect to say “a pollen”; the correct singular form is “a pollen grain”; the correct plural is “pollen,” not “pollens.” Examples: Correct: The pollen of all sections of family Poaceae is monoporate. Incorrect: The pollens of euphorbiaceous plants are eurypalynous.
pollen accumulation rate Syn. for pollen influx, preferred by many.
pollen analysis (a) A branch of palynology dealing with the study of Quaternary (especially late Pleistocene and Holocene) sediments by employing pollen diagrams, isopoll maps, and other graphic displays to show the relative abundance of various pollen types in space and time; e.g., the identification and calculation of frequency of pollen grains of forest trees in peat bogs and lake beds as a means of reconstructing past plant communities and vegetation, thus of paleoclimates. It is used as a geochronologic and paleoecologic tool, sometimes in collaboration with archeology. The former application to dating is mostly superseded by radiocarbon and other absolute methods. Syn. pollen
statistics. (b) A term used prior to the acceptance of the expression palynology, in a manner very similar to the present use of that word.

pollen deposition rate Syn. for pollen influx.

pollen diagram Any diagram of pollen abundance showing the fluctuations in time of concentration of various pollen types, as revealed from studies of cores and other samples of sediment; strictly, the graphical presentation of abundances of various genera of pollen and spores at successive levels of cores of late Neogene sediment studied in pollen analysis. (The expression is rarely used for studies of older rock.) Syn. pollen profile.

definition

pollen grain Singular form for pollen.

definition

pollen influx A mathematical expression for the amount of pollen (and/or spores, or other palynomorphs, as specified) sedimented/accumulated/deposited per year, per square centimeter, of a surface of deposition. In effect, pollen concentration per weight or volume is corrected for the rate of sedimentation to produce pollen influx. Syn. pollen accumulation rate and pollen deposition rate.

pollen mother cell A mother cell in the pollen sac of a seed plant giving rise by meiosis to four cells, each of which develops into a pollen grain. See also spore mother cell.

pollen profile A vertical section of an organic deposit (such as a peat bog) showing the sequence of buried or fossil pollen (essentially synonymous with pollen diagram). Profile is also used for the outline of a pollen grain or spore as seen in lateral (= equatorial) view.

pollen rain The total deposit of spores and pollen in a given area and period of time, as estimated by study of sediment samples and by pollen-trapping devices.

pollen sac One of the pouch-like organs of a seed plant, containing the pollen; e.g., each of the pollen chambers in the anther of an angiosperm.

pollen spectrum A horizontal line in a pollen diagram, showing the relative abundances (percentages) of the various sorts of pollen and spores in a single sample from a single given level.

pollen statistics Syn. for pollen analysis.

pollen sum A portion of the total pollen count (in pollen analysis), from which certain sorts of pollen are excluded by definition, and which is used as the denominator for calculation of percentages. The most usual pollen sum excludes all non-arborescent pollen and sometimes arborescent pollen likely to be over-represented as well. Where pollen sums are used, pollen abundances are calculated as ratios of given sorts of pollen to the pollen sum, rather than as percentages of total count.

pollen symbol An arbitrary sign formerly much used in Quaternary pollen diagrams, representing a genus or other group of plants, and serving as an internationally understood identification for a line in the pollen diagram (see Erdtman, 1943).

pollen tube A more or less cylindric extension that emerges from the wall of a pollen grain and protrudes through one of its apertures when the grain germinates on contact with the stigmatic surface of flowering plants or the megasporangium of gymnosperms. The tube acts primarily as a haustorial (absorptive) organ to nourish the microgametophyte in lower seed plants (such as cycads), but in flowering plants it also conducts the male nuclei to the vicinity of the female gametophyte (embryo sac) to effect fertilization.

Pollenifera A term introduced by Hughes (1994) for the plants that produce pollen, starting with prepollen in the latest Devonian. The term is practically synonymous with Spermatophyta, plants that produce seeds, but puts the emphasis on the development of the microspore into pollen instead of on the development of the megaspore into a seed.
pollenkitt A viscous complex lipid derived from the tapetum, which when occurring on the surface of animal-pollinated angiosperm pollen helps the pollen adhere to an animal pollination-vector.
pollination In general, the fertilization of a seed plant; specifically the transfer of pollen from a stamen (anther) or microsporangium to an ovule or megasporangium.
pollinium A large, coherent mass of pollen, usually the contents of a whole locule of an anther, shed in the mature stage as a unit (as in Asclepias). Pl: pollinia. Code: Ppd (not distinguished from polyad). See polyad and massula.
pollinosis The allergenic disease caused in some persons by adverse reaction to spores and pollen in the air. Syn. “hay fever”. Subject matter of iatropalynology. One of the practical applications of aerobiology has to do with investigation and alleviation of this disease.
polster A small cushion of plant material topped by layers of moss and/or lichen in which silt, sand and palynomorphs are frequently trapped.
polyad A group of more than four mature pollen grains shed from the anther as a unit (as in Acacia). The number of grains within the polyad is usually a multiple of 4. Code Ppd. See pollinium, dyad, and tetrad.
polyannulate Refers especially to germinal structures of Normapolles, in which the sexine of the outer germinal has multiple layers of thickenings.
polyforate See periporate.
polygonomorph Of acritarchs, having a polygonal outline and simple processes.
polymorphic (dimorphic, etc.) Having pollen regularly of more than one size and/or morphological type, presumably as an anti-self-pollination device. The Rubiaceae are especially characterized by this phenomenon.
polyplicate Of pollen grains (such as those of Ephedra) with multiple, longitudinal, linear thinnings in the exine that resemble, but are not, colpi. Code Ppl. See plica, taeniate, and striate.
polyporate See periporate.
polyrugate See pericolpate.
porate Of pollen grains having a pore or pores in the exine.
pore (a) One of the external, more or less circular or slightly oval thinnings or openings in the exine of pollen grains, having dimensions in ratios of less than 2:1. Pores may occur by themselves or in association with colpi. See colpus. See also germ pore.
(b) In fungi, a primary, structural rounded opening in the spore wall. Some “pores” in fungi occur at the point of attachment of the spore, or they may be terminal or otherwise disposed.
pore canal An elongated opening in porate pollen such as Normapolles, connecting the pore proper to the openings beneath, such as atrium and vestibulum.
pororate Of pollen grains with complex pore structures having both external (pore) and internal (os) openings.
positive sculpture A term for sculpture consisting of elements projecting from the surface, such as scabrae, muri, spines, etc. See negative sculpture.
postcingular series The series of plates immediately below the cingulum of dinoflagellate thecae, usually fewer in number and often larger in size than those of the precingular series.
Postnormapolles A group of Cretaceous-Cenozoic (usually triporate) pollen without the usual pore apparatus or other features of the Normapolles group, from which it presumably derived.
prasinophyte Primarily marine green algae, with motile cells having flagella with scales and a non-motile stage that produces highly resistant phycomata. See phycoma, sphaeromorph, pteromorph, ala.
precingular archeopyle An archeopyle formed in a dinoflagellate cyst by loss of the middorsal plate of the precingular series.

precingular series The series of plates between the apical series and the cingulum in dinoflagellate thecae. See postcingular series.

prepollen Functional pollen grains that have haptotypic characters like those of spores, e.g., a trilete mark, and germinate proximally for release of fertilizing nuclei, presumably in anterozooids—thus zoidogamy. It seems probable that some fossil prepollen also had a sulcus from which a primitive pollen tube for haustorial purposes emerged. Prepollen is typical of certain extinct primitive gymnosperms (mostly Mississippian to Permian), but the extant modern gymnosperms, Ginkgo and cycads, also can be argued to have prepollen: germinating proximally for delivery of nuclear material, and distally to produce a haustorial pollen tube. Others would exclude these modern from the category because they lack proximal laesurae. See discussion in Visscher (1997).

prismatomorph Of acritarchs with prismatic to polygonal shape, with more or less sharp edges that may be extended into a flange, entire or serrate, with or without processes at the angles. Example: Polyedryxium.

process A longish element extending from the surface of a spore, pollen grain, dinoflagellate cyst or acritarch. They are much longer than ordinary sculptural elements such as spines. Some have suggested a fixed limit such as 5 μm for minimum length of processes (shorter elements would be sculptural), but this has not been widely adapted.

profile See also pollen profile. Sometimes used term for the outline of a spore or pollen grain as seen in lateral (= equatorial) view.

prolate Extended or elongated in the direction of a line joining the poles; e.g., “prolate pollen” whose equatorial diameters are much shorter than the dimensions from pole to pole. Ant. oblate.

prosome Of chitinozoans, an enigmatic, sometimes complex internal layer extending for some distance from the neck downward, either as a sort of plug or as an annulate tube. Proterophytic An informal division of geologic time, from the first regular appearance of robust-walled acritarchs (about 1.0 × 10⁹ years ago) to the first appearance of spore-like bodies (= cryptospores) (beginning of the Paleophytic, about 440 × 10⁶ Ma. This definition from the first edition of Paleopalynology needs now to be revised downwards, at least to Mid-Ordovician, at about 480 × 10⁶ Ma).

prothallus The gametophyte of a fern or other pteridophyte; usually a flattened, thallus-like structure living on the soil. Pl. prothalli. Syn. prothallium.

protosaccate Extinct form of saccate gymnosperm pollen in which the sacci have extensive ekteinous webbing in the sacci, in contrast to eusaccate pollen, such as modern Pinus, in which the sacci are nearly hollow. See discussion in Chapter 9. Cf. eusaccate, pseudosaccate, saccate.

proximal Of the parts of pollen grains or spores nearest or toward the center of the original tetrad; e.g., of the side of a monosulcate pollen grain opposite the sulcus, or of the side of a trilete spore provided with contact areas. Ant. distal.

proximal pole The center of the proximal surface of a spore or pollen grain, thus the midpoint of a monolete laesura or the point of a trilete laesura from which the radii originate.

proximate cyst A dinoflagellate cyst of nearly the same size as, and closely resembling, the motile theca of the same species. The ratio of the diameter of the main body to the total diameter of the cyst exceeds 0.8. The term refers to the supposed proximity of the main cyst wall to the theca at the time of encystment. See chorate cyst and proximochorate cyst.
proximochorate cyst A dinoflagellate cyst not as condensed (condensation of 60-80%) from the thecal cell as are chorate cysts, and which show some sutural outgrowth evidence of tabulation.

pseudochitin Resistant, C-H-O-N compound of uncertain structure, occurring in the walls of chitinozoans (see chitin). Behaves like chitin but does not give chitin test, e.g., on staining.

pseudocolpus A colpus-like modification of the exine of pollen grains, differing from a true colpus in that it is not a site of pollen tube emergence. A good example is the fossil genus Eucommidites, which has one true colpus and two pseudocolpi. See colpus.

pseudopore An especially thin area in the leptoma of certain coniferous pollen (as in the families Cupressaceae and Taxaceae, and the fossil family Cheirolepidiaceae). See cryptopore and tenuitas.

pseudosaccus An ektexinous saccus-like outer part of a fossil spore or pollen grain (such as Endosporites), resembling the true saccus of some pollen grains but not showing internal alveolate structure characteristic of sacci. The distinction between a pseudosaccus on the one hand and a saccus or the cavate condition on the other hand is often rather slight. Some would limit use of term pseudosaccus to spores only (e.g., Richardson, 1965, in proposing the Subturma Pseudosaccititriletes).

psilate Of the relatively smooth walls of pollen and spores lacking prominent sculpture. The term is usually also applied to exines with pits or reticular openings, mural units, etc., less than 1 μm in diameter. Syn. laevigate.

terate Of chorate dinoflagellate cysts which have processes linked distally in a mesh-like fashion.

pteromorph Of acritarchs, spheroidal, surrounded by an equatorial flange (ala). Most are believed to be prasinophyte algae. See phycoma, prasinophyte, ala.

pynidiospore Of fungi, a conidium (an asexual spore) borne in a pycnidium (an asexual fruiting body).

pylome Of acritarchs, a more or less circular opening, presumably for excystment but lacking clues of plate arrangement present in dinoflagellate archeopyles.

radial Pertaining to trilete spore features associated closely with the arms of the laesura.

See interradial.

radius One arm of a trilete laesura. Also called ray.

ramus Of scolecodonts, any arm-like lateral extension of the face of a jaw, usually pointing posteriorly.

ray One arm of trilete laesura. Also called radius.

resting spore A spore that remains dormant for a period before germination; e.g. a chlamydospore, or a desmid zygospore, having thick cell walls and able to withstand adverse conditions such as heat, cold, or drying out; some are apparently sporopollenin and can occur as palynomorphs. See statospore and cyst.

reticulate A term for sculpture of pollen and spores consisting of a more or less regular network of ridges (muri) enclosing open areas called lumina. Such sculpture is a positive reticulum. See negative sculpture, muri, lumina.

retipilate Of sculpture with a reticulum made up of pila instead of continuous muri.

retusoid Of spores, mostly Paleozoic, with prominent contact areas and curvaturae, such as in Retusotriletes.

ridge Of scolecodonts, the main criterion for recognizing the constituent elements of compound jaws. The ridges indicate the existence of the elements.

rimula Of circumpolloid pollen (Classopollis, et al.), the furrow of thinned exine encircling the grain “sub-equatorially.” Some sources say that the rimula is really pre-equatorial,
that is, where its position can be accurately determined, the rimula is \textit{distal} to the equator.

\textit{Ring furrow} A sometimes-used expression for the continuous encircling \textit{suclus} of \textit{zonisulculate} pollen.

$R_o$ Syn. of $R_{oil}$ A measurement made microscopically under oil of the reflectance of organic matter, usually vitrinite. The numbers, e.g., 0.2 for certain peaty organic matter, are the percent reflectance of vertical incident light, in terms of the reflectance of glass standards. See Fig. 19.2.

\textit{Rugula} In Erdtmanian terms, regularly disposed but not meridional germinal \textit{furrows}. Because of confusion with \textit{rugulate}, it is better to use \textit{colpus}, thus \textit{pericolpate}, not \textit{polyrugulate}.

\textit{Rugulate} Of \textit{sculpture}, consisting of wrinkle-like \textit{ridges} that irregularly anastomose. Often approaches \textit{reticulate}.

\textit{Saccardoan spore groups} A classification for dispersed \textit{conidia} and other asexual spores produced by extant \textit{Fungi Imperfecti}, based on the number of cells, their disposition, and the organization of septa in the spore. See \textit{Amerosporae}, \textit{Didymosporae}, \textit{Phragmosporae}, \textit{Dictyosporae}, \textit{Scolecosporae}, \textit{Helicosporae}, and \textit{Staurosporae}.

\textit{Saccate} Of pollen, possessing \textit{sacci}. Code Pv1, Pv2, etc.

\textit{Saccus} A wing-like extension, or \textit{vesicle} of the \textit{exine} in gymnospermous, especially (but not exclusively) in coniferous pollen. The saccus is an expanded, bladdery projection of \textit{ektexine} extending beyond the main \textit{body} of a \textit{pollen grain} and typically displaying more or less complex internal \textit{structure}. Pl. sacci. See \textit{air sac}, \textit{bladder}, \textit{vesicle}, \textit{wing}, and \textit{pseudosaccus}.

\textit{Scabrate} Of \textit{sculpture}, consisting of more or less isodiametric projections (\textit{scabrae}) less than 1 \textmu m in diameter.

\textit{Schizomorph} Of acritarchs with a spherical, ellipsoidal, or discoidal shape, tending to divide into two symmetrical halves. Most are considered to be \textit{zygosporae} of \textit{zygnemataceae} algae.

\textit{Schulze’s reagent} An oxidizing mixture very commonly used in palynologic \textit{maceration}, consisting of a saturated aqueous solution of KClO$_3$ and varying amounts of concentrated HNO$_3$. Named after Franz F. Schulze (1815-73). The term “Schulze’s solution” is very commonly used for this mixture, but in biological microtechnique this expression means ZnCl$_2$-KCl-I mixture used for staining.

\textit{Sclerine} A term for \textit{exine} and \textit{perine} collectively—useful term for \textit{spore wall} when it is not certain whether a fossil \textit{spore} has a \textit{perine} or not. See \textit{sculptine}.

\textit{Sclerotium} Of fungi, a more or less rounded mass of hyphae with thickened walls. If chitinous, may occur as a \textit{palynomorph}.

\textit{Scolecodont} Any \textit{jaw} piece of a polychaete annelid worm; originally intended only for dispersed, chitinous fossil elements. This glossary includes a few of the most important \textit{scolecodont} terms. For more complete information, see Jansonius and Craig (1971) and Szaniawski (1996).

\textit{Scolecosporae} Of fungi, an elongated “wormlike” spore.

\textit{Scrobiculate} Of \textit{sculpture} having \textit{scrobiculi} (sing. \textit{scrobiculus}). Scrobiculi have \textit{lumina} which are too small, and the \textit{muri} too wide, for the sculpture to be regarded as \textit{reticulate}. Grades into \textit{foveolate} (Erdtman, 1952: “Very small foveolae are termed scrobiculi…”).

\textit{Sculptine} A term for \textit{sexine} and \textit{perine} collectively. Sometimes used if doubt exists whether the outermost \textit{sporoderm} layer may include perine. See \textit{sclerine}.

\textit{Sculptural element} An individual unit of \textit{sculpture}, such as a \textit{spine}, a \textit{clava}, a \textit{baculum}, etc. Contrast \textit{process}.

\textit{Sculpture} The external textural modifications (such as \textit{spines}, \textit{ verrucae}, grana, \textit{pila}, pits, grooves, reticulations, etc.) of the \textit{exine} of \textit{pollen grains} and \textit{spores}. It is usually
a feature of the *ektexine* but may be a *perine* character. Syn. *ornamentation*. See *scultpine*, *sclerine*, and *structure*.

“Scytinascia” This proposed name for chitinous foraminiferal linings occurring as palynomorphs should be avoided. See *microforaminifera*.

**Secondary pollen** As usually applied, e.g., Faegri and Iversen (1989), this means recycled or reworked pollen, e.g., pre-Pleistocene pollen from boulder clays in Holocene sediments. (Some authors, e.g., Bryant and Holloway, 1985, speak of secondary pollen counts, meaning counts from which certain over-represented forms are excluded.)

**Seed megaspore** Refers to the very large (half a centimeter or more across) *megaspores* of some Paleozoic lycopsids, which although true free-sporing *megaspores* were in the size range of seeds and as disseminules presumably acted like seeds.

**Septal pore** Of fungal spores with one or more septa, pore(s) found in the center of the septum or septa.

**Septate** Of fungal spores having septa. See *septum*.

**Septum** Of fungal spores, a cross-wall partitioning the inner space. Septa may be transverse or longitudinal.

**Sequence stratigraphy** Study of sedimentary sequences, based primarily on sea-level changes, with the resulting flooding of surfaces during high-water stands and widespread exposure of land during low-water stands. The subject has many paleopalynological connections, as palynomorphs are sensitive indicators of paleoecology based on sea-level changes: for example, on land through spores and pollen, and in flooded areas through dinoflagellate cysts. See Chapter 18, this book.

**Sexine** The more or less arbitrarily delimited outer division of the *exine* of pollen. See *nexine* and *ektexine*.

**Shadow band** In fungal spores, incomplete septa showing as a shadowy line across the spore.

**Shaft** Of scolecodonts, a posterior extension of a jaw of proportionately large dimensions. Shagreen, shagrenate, cf. Chagrenate

**Shank** Of scolecodonts, a backward extension (without teeth) of the posterior part of the inner face of a jaw.

**Shape class** The general group (*pero blade* to *perprolate*) to which a *pollen grain* belongs in terms of the ratio between the *equatorial* diameter and the *pole-to-pole* dimension.

**Sicula** Skeletal structure of a graptolite. Siculae are apparently chitinous or pseudochitinous, and can occur in early Paleozoic palynological preparations (cf. Plate 18.3e).

**Siphonogamous** Of plants fertilized by means of pollen tubes (cf. *zoidogamous*), such as some gymnosperms and all angiosperms.

**Skolochorate** Pertaining to chorate dinoflagellate cysts that have processes only, not processes and high septa. Low ridges and septa may be present.

**Small spore** An outmoded term that was formerly used to contrast with “large spore” (= megaspore). However, the term has included *pollen* and *prepollen*, as well as isospores and microspores, making it essentially synonymous with the now more common *miospore*, but lacking miospore’s precise size definition.

**SOM** Term used in palynofacies studies: sedimentary organic matter.

**Spectrum** Syn. for *pollen spectrum*.

**Sphaeromorph** A heterogeneous group of acritarchs with spherical to ellipsoidal vesicles lacking processes. Some of them are produced by *prasinophytes*.

**Spine** One element in echinate sculpture.

**Spiraperturate** Of pollen with one or several spiral (sinuous or winding) *apertures*, such as those of *Anemone*, *Coffee* or *Thunbergia* (see Furness, 1985).
Sporae dispersae The spores and pollen obtained by maceration of samples of whole rock, in contrast with those that have been found within the fossil sporangia that bore them (Sporae in situ).

Sporae in situ The spores or pollen obtained from fossil sporangia of megafossil plants.

sporal Being, pertaining to, or having the special characteristics of a spore. The term is not in good or current usage in palynology.

sporangium An organ within which spores are usually produced or borne; e.g., an organ in embryophytic plants in which spores are produced, such as a pollen sac of a gymnosperm or each chamber of the anther of an angiosperm. Pl. sporangia. See also microsporangium and megasporangium.

spore Any of a wide variety of minute, typically unicellular reproductive bodies or cells, often adapted to survive unfavorable environmental conditions. Embryophytic spores develop into gametophytes. Various fungal and algal spores develop into a number of different phases of the complex life cycles of these organisms. As usually used in paleopalynology, one of the haploid, dispersed reproductive bodies of embryophytic plants, having a very resistant outer wall (exine), and frequently occurring as fossils from Silurian to Holocene. See sporomorph.

spore case A sporangium. The term is not in good or current usage in palynology.

spore coat The sporoderm.

spore mother cell The mother cell in the sporangium of a spore-bearing plant, which, by reduction division, produces the tetrad of haploid spores. Syn. See also pollen mother cell.

spore wall The sporoderm.

sporinite Coal petrologic term for the kind of liptinite consisting of spore and/or pollen walls. Essentially synonymous with exinite.

sporocyte The spore mother cell.

sporoderm The entire wall of a spore or pollen grain collectively, consisting of an outer layer (exine/exospore) and an inner layer (intine), and, when present, an extra third layer (perine) outside of the exine. Syn. spore coat and spore wall.

sporogenous Producing or adapted to the production of spores, or reproducing by spores, e.g., “sporogenous tissue” in a sporangium, from which spore mother cells originate.

sporomorph A fossil dispersed pollen grain or spore. Some palynologists disapprove of the use of this term, but it is more specific than palynomorphs and often useful.

sporophyte The asexual generation of a plant (or an individual of that generation), producing spores: therefore, the diploid generation of an embryophytic plant, produced by fusion of egg and spermatozoid in lower vascular plants, or by fusion of egg nucleus and the sperm nucleus (produced by the pollen) of seed plants. See gametophyte.

sporopollenin The very resistant and refractory organic substance of which the exine and perine of spores and pollen are composed. The walls of dinoflagellates and acritarchs consist if a similar substance called dinosporin. It is this substance which gives the sporomorph its extreme durability during geologic time, being readily destroyed only by oxidation or prolonged high temperature. It is a high-molecular-weight polymer of C-H-O, perhaps a carotenoid-like substance, but the exact structural composition has not yet been established. Adj. sporopolleninous.

stato-spore A resting spore, e.g., the siliceous, thick-walled resistant cyst formed within the frustules of various chiefly marine centric diatoms. The term is also used for certain other 2-partite algal cysts in the division Chrysophyta.

stauropore Of fungi, a star-shaped conidium.

stenopalynous A typically erudite Erdtman term for taxa with spores or pollen that are relatively very much alike morphologically and or in exine structure, such as the Chenopodiaceae. Antonym: eurypalynous.
stephano- Of pollen having apertures arranged regularly on the equator, or crossing the equator meridionally in a symmetrical fashion. Syn. zono-, which I regard as less satisfactory because it is used in other senses.

stephanocolpate Of pollen grains having more than three colpi, meridionally arranged. Code Pn0.

stephanocolporate Of pollen grains having more than three colpi, meridionally arranged and provided with pores. Code Pnn.

stephanoporate Of pollen grains having more than three pores, disposed on the equator. Code P0n.

“stick” Term used for Lycopodium spores, Eucalyptus pollen or inorganic spherules added in known approximate numbers to palynological samples before processing, to permit calculation of palynomorphs per gram of sample.

STOM Term used in palynofacies studies: Structured organic matter.

striate “Streaked” sculpture characterized by multiple, more or less parallel grooves and ribs (the ribs are also called muri) in the exine; also used in a general sense to describe polyplicate or taeniate structure, as of the Striatiiti. It would be better to use polyplicate or taeniate, as appropriate, for these morphological features, and to restrict striate to description of streaked sculpture.

Striatiiti Abundant upper Paleozoic and lower Mesozoic pollen with very characteristic taeniate or plicate structure in the exine of the body of the pollen grain, the grooves and “ribs” (taeniae) usually (but not always) oriented perpendicular to the axes of the sacci (if these are present). They are presumably pollen of conifers, gnetaleans, glossopterids, and other gymnosperms.

stroma Of fungi, a mass of hyphae in which fructifications (ascocarps) are formed.

structure (a) The internal makeup of the ektexine of pollen grains and spores, usually consisting of rodlets (columellae) that may be branched and more or less fused laterally. (When the fusion creates a coherent outer surface layer, this is the tectum.) (b) A term that is sometimes, but less desirably, used to describe major morphologic characteristics of spores, especially those of the Paleozoic.

subsaccate Syn. of pseudosaccate.

sulcal plate One of the plates of the ventral furrow region in dinoflagellate thecae. The plates are subdivided as to left or right, and anterior or posterior position.

sulculus Of pollen, an elongate aperture (furrow), more or less parallel to equator, either at the equator or toward a pole, generally distal to the equator but not centered at the distal pole, as is a sulcus. Sulculi may join to form a ring. Adj. form: sulculate. See zonisulculate.

sulcus (a) An elongate aperture (furrow) in the exine of pollen grains. The term is usually restricted to a distal furrow of pollen grains with only one such aperture, when this furrow has the distal pole in its center. See colpus. (b) A longitudinal groove on the ventral surface of dinoflagellate thecae. One of the two flagella runs posteriorly in it and trails behind the organism. The sulcus, reflecting its thecal progenitor, is also a part of the visible morphology of many dinoflagellate cysts.

suture The line along which the laesura of an embryophytic spore opens on germination; loosely, the laesura. More precisely, the commissure.

syncolpate Of pollen grains in which the colpi join, normally near the pole. Code Pns. See zonocolpate.

tabulation Of dinoflagellate thecae, the pattern according to which the constituent plates are arranged. Reflected tabulation is the evidence in dinoflagellate cysts of the arrangement of the plates in the theca from which the cyst was derived.

taeniae Straplike, more or less elongated and parallel strips of exine characteristic of many upper Paleozoic and lower Mesozoic pollen grains. They occur on one or both sides
of the corpus of saccate grains (e.g., *Lunatisporites*) or much less commonly on non-saccate grains such as *Vittatina*. Singular: taenia. Adj. taeniate. See striate, polyplicate and Striatiti.

**TAI** Thermal Alteration Index, a scale based on color and vitrinite reflectance data, indicative of the thermal maturity of organic matter in rocks. Useful in hydrocarbon exploration. See discussion in Chapter 19 of this book, for comparison of TAI with the related SCI and TAS scales.

**tapetum** Tissue of nutritive cells in the *sporangium* of terrestrial *embryophytic* plants, largely used up during development of the *spores*. In angiosperms, it is the inner wall of the anther locules and provides nutritive substances for the developing *pollen*. *Pollenkitt* is a sticky tapetal residue often found on and in *exines*. See ubisch bodies.

**tasmanitid** An informal term for members of the genus *Tasmanites* and related forms, large, spherical *palynomorphs* with thick perforate walls presumably representing the *phycomata* of certain green algae (Prasinophyceae). These fossils range from Ordovician to Cenozoic, and were formerly classed with the *acritarchs* before their assignment to the prasinophytes was established. Certain organic-rich shales (tasmanite) contain enormous numbers of tasmanitids.

**TCT** Acronym for Taxodiaceae, Cupressaceae, and Taxaceae, a term used for the pollen of these families, especially in Neogene paleopalynology, because in routine microscopy the inaperturate pollen of the families are difficult to distinguish from each other (cf. Martin and Gray, 1962). The Taxodiaceae are now regarded by most systematists to be a subfamily of the Cupressaceae, so the expression should perhaps be altered to CT.

**tectate** Of a *pollen grain* whose *ektexine* has an outer surface supported by more or less complicated inner *structure* usually consisting of *columellae* supporting the *tectum.*

**tectum** (a) The surface of *tectate pollen grains.* (b) A term which should now be avoided, formerly used to designate thickened, upward projecting *exospore* associated with the *laesura*, usually of *megaspores*.

**tegillum** Erdtman distinguished between the *columellae*-supported outer surface of angiosperm *pollen* with less than 80% coverage as a tegillum and those with more than 80% coverage as a *tectum*. Most palynologists now call both tectum.

**teleomorph** Of fungi, characterized by presence of only sexual propagules, such as *asci* (in Ascomycetes) or *basidia* (in Basidiomycetes).

**teleutospore** A *fungal spore* developed in the final stage of the life cycle of rust fungi. When the thick walls are composed of chitin they may occur as microfossils in *palynologic* preparations. See urediospore.

**teliospore** Syn. of *teleutospore*.

**tentaculite** Of *zoomorphs*, probably chitinous, forms resembling a stocking, possibly referable to mollusks/pteropods. For example, see Fig. 1.1ao, this book.

**teniuitas** A thin area in the *exine* of a *pollen grain* or *spore*, as the *distal germinal area* of *Classopollis* pollen grains. More regular in form than an *ulcus*, less regular than a *colpus*. Syn. *leptoma*.

**teratoid pollen/spores** Deformed pollen and produced are produced by plants under some genetic, nutritional and environmental circumstances. These are teratoid sporomorphs.

**test** Syn. for *dinoflagellate* *cyst*. See tract.

**testate amoebae** Some amoebae produce a proteinaceous tough test that can marginally be considered a palynomorph, because it survives fairly well in sediments and even under fairly gentle laboratory maceration techniques.

**tetrad** A usually symmetric grouping of four *embryophytic spores* (or *pollen grains*) that result from meiotic division of one *mother cell*. Such tetrads may be *tetrahedral* (most common) or *tetragonal*, rarely of other types. A number of pollen types regularly
remain in united tetrads as mature pollen when shed by the *pollen sacs* (as in some fossil circumpolloid forms). If the grains are always in such tetrads (as in Ericaceae) the tetrads are “obligate tetrads”). See dyad and polyad.

tetrad scar Syn. for *laesura*.

tetragonal tetrad A *tetrad of spores or pollen grains* in which the centers of the individual grains lie more or less in one plane.

tetrahedral tetrad A *tetrad of spores or pollen grains* in which each grain rests atop three others, so that the centers of the grains define a tetrahedron.

tetratabular archeopyle An *apical archeopyle* formed in a *dinoflagellate* cyst by the loss of four *plates*.

thallus Of non-vascular plants in general, the vegetative tissues as a whole; of fungi, the entire assimilative organism.

thanatocoenosis Fossils that occur together as a result of post-depositional sedimentation, not as a result of association as living organisms. The contrast is to *Biocoenosis*, which refers to either fossils that occur where the producing organisms lived or to the living association itself. Palynofloras are almost all more or less thanatocoenoses, but the degree to which this is true is often significant.

theca The outer covering or “shell” of a motile *dinoflagellate*. See amphiesma.

thermal alteration The chemical and physical alteration of organic matter in sedimentary rocks, as a result of pressure and temperature applied over time. Depth of burial is the most important factor. The darkening of color in transmitted light of sporopollenin, dinosporin, and chitin in this process from pale yellow via orange and brown to black, and the concomitant increase in reflectance on surfaces of vitrinite can all be measured, and there is a close relationship to the amount and kind of associated hydrocarbons.

See TAI and discussion at the beginning of Chapter 19, this book.

tintinnid A ciliate protozoan, range Jurassic to present, the probably chitinous test of which can be present in some palynological preparations. Cf. van Waveren (1992, 1993).

torus An arcuate invagination or protuberance of *exine* outside of and more or less paralleling the *laesura* of a *spore* in the *interradial* area. Some palynologists use torus for separate arcs, and kyrtome for a completely connected figure. Pl. tori. See kyrtome and labrum.

TP Abbrev. for *tree pollen*. See arboreal pollen.

trabeculate Of dinoflagellate cysts, having connections between the *processes*.

tract Syn. for *test*, as in epitract, etc.

transverse flagellum A flagellum, often more or less ribbon-like, encircling a motile *dinoflagellate*, usually in a deep encircling groove or *cingulum*, arising from a *pore* in the *sulcus*.

transverse furrow A *colpus*-like thinning in the *exine* of a dicotyledonous *pollen grain*, usually occurring at the *equator* in association with and running perpendicular to a colpus. Syn. *colpus transversalis*.

tree pollen Syn. of arboreal (arborescent) *pollen*. Abbrev. TP.

trichotomocolpate Syn. of trichotomosulcate.

trichotomosulcate Of *monosulcate pollen grains* in which the *sulcus* is more or less triangular, often simulating a *trilete laesura*. Code Pac.

tricolpate Of *pollen grains* having three meridionally arranged (120° apart) *colpi* which are not provided with *pores*, transverse furrows or other such modifications. Tricolpate pollen are produced by dicotyledonous plants, and they first appear in the fossil record in rocks of early Cretaceous age. Code Pc0. See tricolporate.

tricolporate Of *pollen grains* having three *colpi* which are provided with *pores* or other, usually equatorial, modifications. Code Pc3.
tricolporoidate An intermediate state between Pc0 and Pc3, in which some modification of the colpus is present equatorially, but not a pore, transverse colpus, or other organized thinning. Code Pc0.

trifolium Of megaspores, a proximal figure similar to a gula but less massive, with three blade-like divisions and no broad base.

trilete Of embryophytic spores and some pollen grains having a laesura consisting of a three-pronged mark somewhat resembling an upper-case “Y”. The usage of this term as a noun (“a trilete”) is improper. Code Sc0. See monolete and Y mark.

triplan Refers to trilete spores with the radii of the laesura on deeply indented radial lobes. When seen laterally, such spores have a characteristic flapped appearance.

triporate Of pollen grains having three pores, usually disposed at 120° from each other, on the equator. Some palynologists distinguish from this term tripororate, for grains with compound pores, an ectopore and an endopore (os).

triprojectate A group designation (triprojectacites) for Aquilapollenites and similar, presumably related forms of late Cretaceous-early Cenozoic angiosperm pollen, in which the three colpi are borne on the projecting ends of colpal arms, so that typically the three colpal arms (hence, “triprojectate”) and two polar projections give the pollen a five-pronged appearance.

triradiate crest or ridge Of trilete spores, the three-rayed figure on the proximal surface caused by intersection of the contact areas.

tula Of gymnospermous pollen, a relatively small saccus-like inflation at the ends of the distal sulcus or tenuitas. Example: Ovalipollis.

turma An artificial suprageneric grouping of form genera of fossil spores and pollen (mostly in use for pre-Cenozoic forms), based on morphology. Turmae are grouped under two large headings, Anteturmae Sporites and Pollenites. Pollen and spores are functional in meaning, not morphological, which therefore creates some problems for classification. Turmae are subdivided into groups such as “Subturmae” and “Infraturmae”. The system is not governed by the International Code of Botanical Nomenclature. See anteturma.

ubisch bodies Small (about 2-5 μm) pieces of sporopollenin formed from the tapetum after the rest of the sporopollenin available has been built into spore or pollen sporoderm. Ubisch bodies are sometimes rather abundant in palynological preparations. Also called orbicules. The name stems from description in 1927 of the particles by Ubisch (see Rowley, 1963). However, others apparently described them earlier, which is one reason the term orbicules is favored by many. See cover illustration, this book.


ulcus A thin place in the exine, more or less pore-like, but irregular in outline, and often broken up into patches, as in some Restionaceae. Pl. ulci. Cf. leptoma, tenuitas.

unarmored See armored.

urediospore A fungal spore of brief vitality, whose thin walls may be composed of chitin.

Such spores may occur as microfossils in palynologic preparations. See teleutospore. USTOM Term used in palynofacies studies: unstructured organic matter.

valva One of the radial thickenings of a valvate spore.

valvate Of trilete, zonate spores with the equatorial thickenings more pronounced at the “corners”, that is in the areas beyond the ends of the laesural radii. Auriculate can thus be regarded as an extreme valvate condition.

velum Used to describe the “frilly” (convoluted) sort of sculpture/structure of Tsuga pollen exine, also seen in many fossil gymnosperm pollen grains.

ventral Of dinoflagellates, the side on which the sulcus and the ends of the cingulum occur.

vermiculate A sculptural pattern formed by elongate, irregularly placed depressions.
verrucate  Warty, or covered with wart-like knobs or elevations; of spores and pollen having sculpture consisting of wart-like projections. Syn. verrucose.

vesicle  Syn. of saccus. Also, per Paris et al. (1999) the basic flasklike unit of chitinozoans.

vesiculate  Syn. of saccate.

vestibulate  Of porate pollen having a vestibulum.

vestibulum  The space between the external opening (exopore or pore) in the ektexine and the internal opening (endopore or os) in the endexine of a pollen grain with a complex porate structure. The openings in ektexine and endexine are of similar or dissimilar size.

viscin threads  Despite the name, non-viscous, sporopolleninous threads originating in the polar ektexine of a relatively limited number of angiosperms (Onagraceae, some legumes), functioning as attachment-organs for dispersal by animal pollinators. One end is attached to the polar ektexine, the other end is free. Threads on spores, e.g., the megaspore Balmeisporites, not serving for attachment in pollination, and non-sporopolleninous threads (such as in some orchids), or threads not arising from the polar ektexine, or with both ends attached should not be called viscin threads (Patel et al., 1985). Viscin threads have been encountered in fossil onagraceous pollen.

vitrinite  Coal petrological term for organic matter derived from wood or bark. cf. liptinite, sporinite

wing  Syn. of saccus

Y-mark  A trilete laesura on embryophytic spores, prepollen, and some pollen, consisting of a three-pronged mark somewhat resembling an upper-case “Y”. It commonly also marks a commissure or suture along which the spore germinates. The term is also applied to similar marks, which are not laesurae, on some pollen grains.

zoidogamous (or zooidogamous)  Of plants fertilized by means of ciliated, free-swimming antherozoids (or spermatozoids), for example bryophytes and pteridophytes. See siphonogamous.

zonasulculate  Best regarded as a syn. for zonisulculate.

zonate  Of spores or pollen grains, possessing a zone or other similar equatorial extension. Note that some authors would restrict “zonate” to spores with a zone, whereas others use it as here defined, to include other equatorial features as well. (Some specialists in angiosperm pollen use zonate to denote pollen grains with a ring furrow).

zone  A more or less equatorial extension of a spore or pollen grain, having varying equatorial width and being as thick as or thinner than the spore wall. It is much thinner than a cingulum. The term is also used, however, in a general sense for any equatorial extension of the spore wall. Because zone is used in a specific sense, simply “equatorial extension” would be better for the general term. Syn. zona. (Zone is also used stratigraphically, as in biozones, acme zones, etc. (see Hedberg, 1976.) See flange, corona, equatorial extension, auricula and crassiude.

zonasulculate  Here advocated as a general term for pollen having a sulculus that encircles the grain forming a ring (ring furrow). (Some palynologists use zonasulculate specifically for pollen with ring furrows parallel to or on the equator.) Zonisulculate can be used even for instances such as Nypa (Palmae = Arecaceae), in which the ring furrow runs around the grain through both poles.

zono-  Of pollen, apertures occurring at, or crossing, the equator. Cf. stephano-, which I prefer because zono- is used in other connections.

zonotrilete  Of a trilete spore characterized by an equatorial zone or other thickening.

zooanthella  An algal cell living symbiotically in the cells of certain invertebrate animals and protists, e.g., in the endoderm of some coral polyps. Most zooanthellae are dinoflagellates.
**zooclast** a particle of animal origin, in the palynomorph size range, found in sediments, such as pieces of insect exoskeleton, particles of graptolites. Contrast **zoomorph**.

**zoomorph** a palynomorph of animal origin, usually representing an entire organism, as a foraminiferal lining, a chitinozoan, a tentaculite, a testate amoeba.

**zoophily** A term for pollination by animals. See entomophily and anemophily.

**zygnematacean algae** Green algae of freshwater streams and lakes. They produce thick-walled, resistant zygospores with an equatorial line of rupture into two more or less equal parts. Example: *Mougeotia* (see Fig. 1.0, this book). Cf. schizomorph.

**zygospore** A resting spore of various non-vascular plants (such as desmids and Zygnesmataceae), produced by sexual fusion of two protoplasts. The wall is often thick, apparently sporopolleninous, resistant, and can therefore occur as a palynomorph.
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Books such as this are best served by a single index, in which names of taxa are listed along with other keywords. This is a matter of efficiency, not of logic. Main entries in the Glossary are not separately indexed, as the Glossary is its own index. Names of people are also not indexed, except for those persons who are illustrated in various chapters; their names, along with the page numbers on which the illustrations appear, are given. This index, having been generated electronically, differs considerably in format and content from that in the first edition. Relatively few general concepts could be indexed, because they are not always worded in precisely the same way in the text. Perusal of chapter headings and tables of contents should lead the reader to the desired information. Such perusal should also be used to deal with many general words, such as “acritarch” or “paleomorph.” These could be conveniently indexed in the first edition, because the old index card method permitted listing of selected, important pages. Computer indexing yields dozens—even hundreds—of entries. Consequently, these words have been modified in the index by a few appropriate keywords which by no means cover the entire subject. Journals, books and other publications are not indexed, but are listed in the annotated bibliography of such items in Chapter 1. Names of taxa that appear only in illustrations, but not in the captions to the illustrations, or in the text, are not indexed.

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