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DETERIORATED POLLEN GRAINS AND THE INTERPRETATION OF QUATERNARY POLLEN DIAGRAMS

STEPHEN A. HALL

Department of Geography, North Texas State University, Denton, Texas 76203 (U.S.A.)

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ABSTRACT

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Pollen assemblages are often altered by deterioration, which results in biased grain counts and possibly erroneous paleoecologic interpretations. Distorted counts are caused by (1) progressive pollen deterioration (a new preservation category), (2) differential pollen preservation, (3) differential recognition of poorly preserved grains, and (4) different kinds of deterioration in different sediment types. The best indicators that pollen assemblages have been altered are high frequencies of deteriorated grains and low total pollen concentrations.

INTRODUCTION

The writer has recently investigated the palynology of a number of localities in the Plains and the Southwest of the United States where pollen preservation has varied from good to poor. The exact causes of pollen deterioration at these specific sites have not been determined. However, the circumstances of pollen destruction observed at these sites may relate to the more general questions regarding pollen preservation in other regions of drier climate. This paper is not a literature review of deteriorated pollen but rather is a summary of the results from the writer's recent studies and a few other studies and includes discussions of how deteriorated pollen assemblages can affect grain counts.

ALTERED POLLEN ASSEMBLAGES AND DISTORTED POLLEN COUNTS

Nearly all pollen preparations from all types of sediment contain deteriorated pollen grains. The presence of these poorly preserved grains indicates that the pollen assemblage has been altered, thus reducing the interpretive value of the pollen counts from that assemblage.

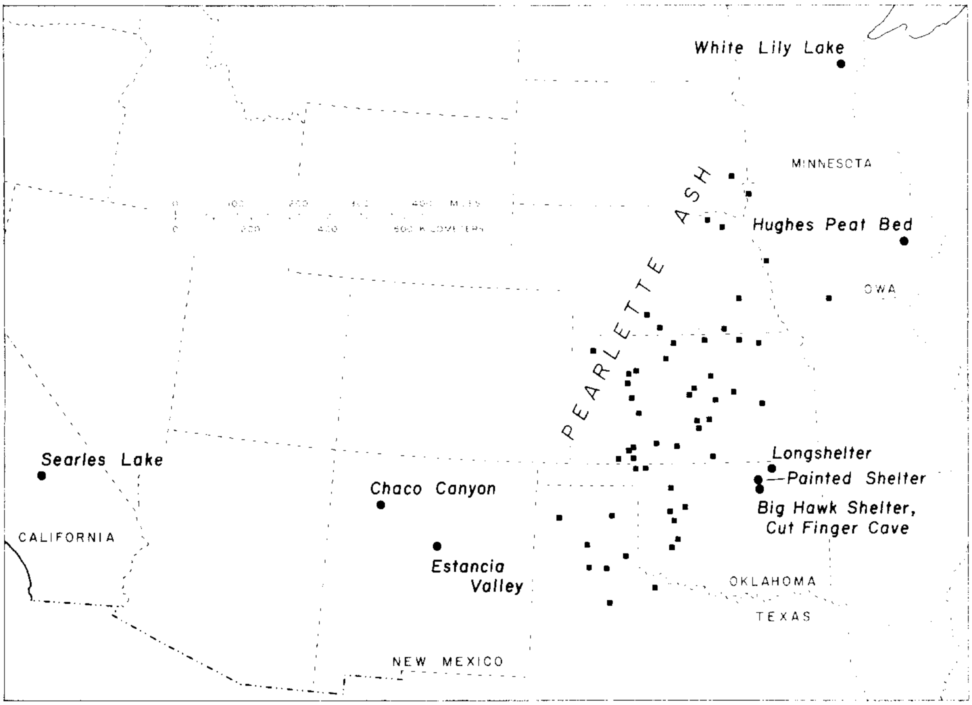

Fig.1. Map of pollen sites cited in text; Pearlette ash localities from Kapp (1970); most ash deposits shown are Pearlette type-O dated 0.6 m.y.; some may be older ashes.

Progressive pollen deterioration

Pollen analytical studies of sediment from four archeologic sites provide information on a new aspect of pollen deterioration. Records from three rockshelters and one cave in northeastern Oklahoma (Fig.1) show continuous large-scale drops in pollen concentration with increasing depth. The decreasing pollen concentration is accompanied by a general increase in frequency of deteriorated pollen grains and is interpreted as indicating increased pollen destruction with depth. The result is a new category of pollen preservation not previously reported that is here called "progressive pollen deterioration." All pollen deterioration is in a sense progressive; that is, an assemblage is at first well-preserved then deteriorates through time. However, the pollen record from each of the archeologic sites shows the transition from good to poor preservation in a single stratigraphic column. This gradation from good to poor preservation in the same section is referred to as progressive pollen deterioration.

The pollen concentration at the Oklahoma rockshelter and cave deposits decreases by factors of 2 to 8 from the uppermost 20 cm to a depth of 80 to 100 cm (Table I). Surface sediments adjacent to the sites contain greater amounts of pollen than the prehistoric deposits. Pollen concentration decreases from the surface to the upper 20 cm of the deposits by factors of 2 to 8, a

TABLE I

Pollen concentration data from Oklahoma archeologic sites[a]

Interval (cm)	Painted Shelter	Big Hawk Shelter	Longshelter[b]	Cut Finger Cave
Surface[c]	41,200	34,100	17,800	17,400
0—20	4660 (2)[d]	3860 (4)	5800 (2)	10,600 (3)
20—40	4170 (3)	1690 (2)	0 (2)	5340 (2)
40—60	2110 (3)	920 (2)	—	4590 (2)
60—80	1360 (1)	510 (2)	—	—
80—100	—	480 (2)	—	—

[a]From Hall (1977a, b, c); Henry (1978); Henry et al. (1979); concentration data in grains per gram (oven-dried) of sediment processed.
[b]5 of 7 samples in 0—20 cm interval are barren of pollen; only the two pollen-bearing samples are averaged.
[c]Each surface pollen collection represents twenty subsamples collected by the pinch method.
[d]Number of averaged pollen spectra in parentheses.

magnitude similar to that of the decrease within the deposits themselves. The implication of these data is that pollen in surface materials, probably representing many years of influx, is comparatively well-preserved and is not yet greatly diminished in abundance due to deterioration. While or soon after these pollen-bearing surface materials are transported by sheet wash and deposited in the rockshelters, the pollen grains become deteriorated. Upon burial of the pollen-bearing layers, pollen deterioration continues until all or nearly all of the grains have been destroyed.

Accompanying the decrease in pollen concentration at the sites is a general increase in abundance of indeterminable grains (pollen grains that are deteriorated beyond any possible identification, here including a few grains obscured by debris). At Painted Shelter, Oklahoma, for example, indeterminable (mostly deteriorated) grains increase with depth from 7 to 37% of the pollen sum (Fig.2). The increase in deteriorated grain frequencies should result in corresponding but opposite changes in frequencies of other pollen categories. This occurs in the *Quercus* profile; *Quercus* abundance drops from 57 to 34% of the pollen sum. However, when the indeterminable grain counts are subtracted from the pollen sum and *Quercus* frequencies are recalculated from a new pollen sum, the *Quercus* profile is altered from an inclined to a near vertical slope with frequency values of 62 to 55%, top to bottom. The initial change in the *Quercus* profile, then, is merely an artifact of the changing indeterminable counts and does not reflect any change in vegetation.

Indeterminable pollen counts at Painted Shelter are included in the pollen sum from which the determinable pollen frequencies are calculated. Cushing (1967a, p.98) points out that when indeterminable grains are included in the pollen sum, the percentages of the determinable grains are

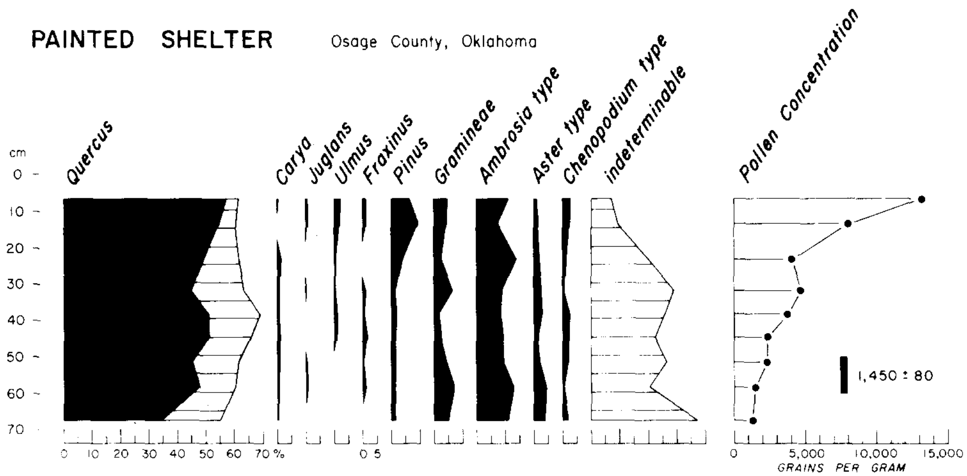

Fig.2. Summary pollen diagram, Painted Shelter (Os-129) on Birch Creek west of Barnsdall, Osage County, Oklahoma; indeterminable grains are included in pollen sum; hatched lines on *Quercus* profile are recalculated *Quercus* frequencies when indeterminable grains are subtracted from pollen sum; recalculated frequencies of other pollen taxa are not shown but the changes would be small (from Hall, 1977b; Henry et al., 1979).

minimum estimates. In other words, the pollen profiles shown in the Painted Shelter diagram are minimum frequencies — had the number of indeterminable grains been smaller, the pollen frequencies would all be slightly higher. Furthermore, if indeterminable grains are excluded from the pollen sum, it is, in effect, assuming that all determinable spore and pollen types are equally susceptible to deterioration and that they all deteriorate at the same rate through time.

The decreasing pollen concentrations with depth at Painted Shelter (Fig.2) could be attributed to a decrease in the rate of sedimentation in the rock-shelter from bottom to top instead of an increase in pollen destruction. Only one radiocarbon date was obtained for Painted Shelter, so, even with archeologic data, the accumulation rate cannot be judged accurately. Big Hawk Shelter, however, has been radiocarbon-dated at nine intervals, the results indicating a nearly constant rate of sedimentation of about eight centimeters per century (Hall, 1977a). A pollen diagram from Big Hawk Shelter shows the same large decrease in pollen concentration that occurs at Painted Shelter. Pollen concentration decreases from 4900 to 600 grains per gram of sediment; a low of 250 grains per gram occurs at 75 cm depth (Fig.3). Surface sediment at and around Big Hawk Shelter contains 34,000 pollen grains per gram. However, indeterminable grains at Big Hawk do not increase with depth as they do at Painted Shelter. As a result of the lack of change in indeterminable abundance, there is a corresponding lack of change in the *Quercus* profile (see Hall, 1977a; or Henry, 1978).

One of the sites, Cut Finger Cave (Fig.4; Table I), contains a greater amount of pollen compared with a much smaller amount of pollen in sediments of

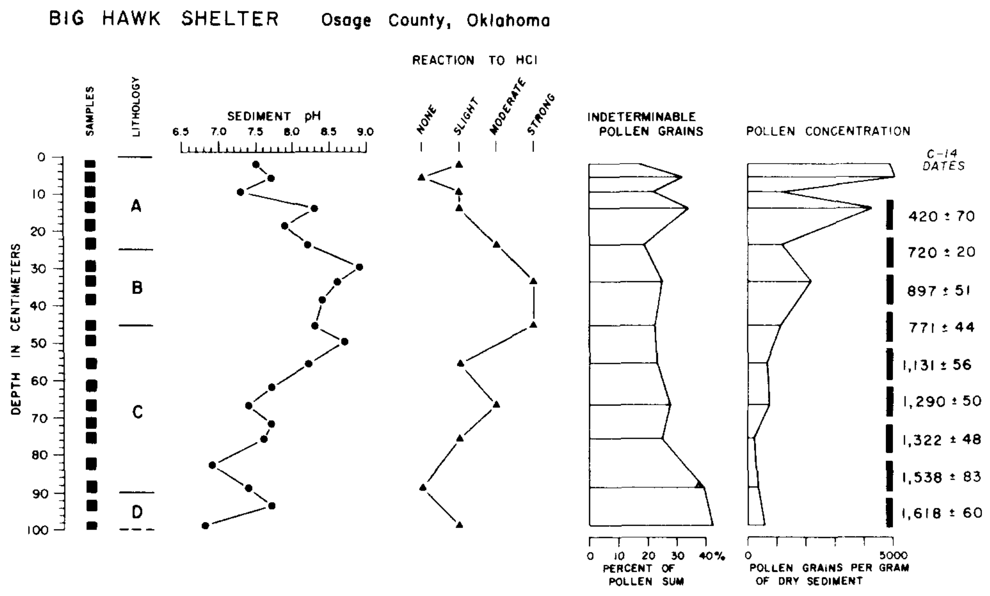

Fig.3. Pollen and pH data from Big Hawk Shelter (Os-114) on Hominy Creek west of Skiatook, Osage County, Oklahoma. Lithology: *A* = reddish yellow to strong brown medium to fine sand; *B* = dark grayish brown silty clay; *C* = dark brown clayey fine sand; *D* = dark brown silty fine sand; high sediment pH corresponds to greater calcium carbonate content; pollen occurs in samples with low and high pH values (from Hall, 1977a; Henry, 1978).

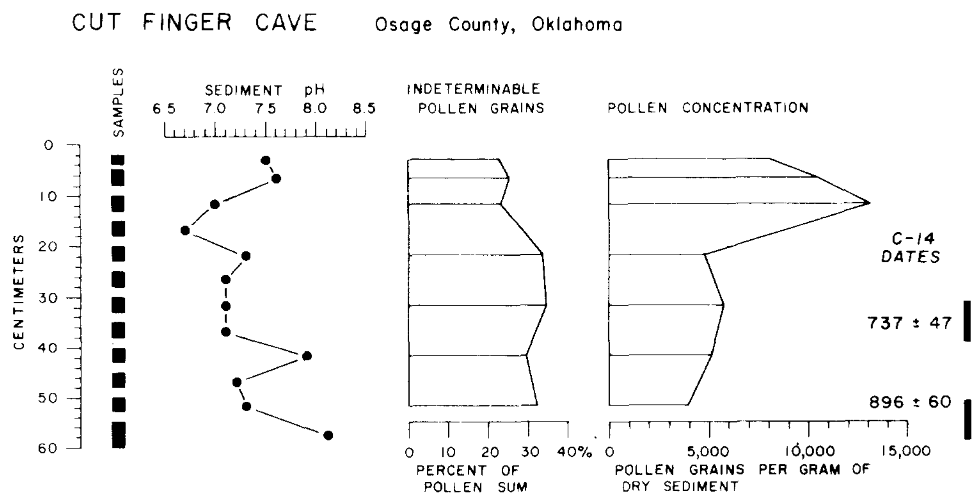

Fig.4. Pollen and pH data from Cut Finger Cave (Os-138) along Hominy Creek adjacent Big Hawk Shelter, Osage County, Oklahoma; high pollen concentrations occur in alkaline sediment (from Hall, 1977a).

the same age in nearby Big Hawk Shelter and in the other two rockshelters. The main difference between the cave and rockshelters is the moisture content of the two habitats. The cave and cave sediments are dry, whereas the shelter deposits, even though protected by rock overhang, are moist.

Differential pollen preservation

Pollen grains have a variety of compositions and structures (Dahl, 1969; Rowley and Prijanto, 1977). Because of these compositional and structural differences, pollen grains are not all equally susceptible to the processes of deterioration. Some pollen types are more easily corroded and destroyed than others in a given depositional environment. This selective deterioration is referred to as differential preservation.

Analyses of the Hughes peat bed in Iowa, for example, show that the upper two pollen spectra have comparatively low concentrations. These low concentrations, together with the pollen frequencies, suggest that differential pollen destruction has occurred, perhaps taking place when the water table was lowered and mollusk shells were leached from the peat (Hall, 1971). Polypodiaceae spores and *Pinus* and Cyperaceae pollen are present, although deteriorated, while pollen of *Quercus, Ulmus, Ostrya/Carpinus*, and *Carya*, and *Sphagnum* spores are nearly all destroyed (Fig.5). A more convincing example of this advanced degree of differential preservation is reported by Bachhuber (1970, 1971) from the Estancia Valley, a dry lake bed in central New Mexico. The upper part of the sequence of lake bed deposits, a red clay with gypsum grains indicating sediment accumulation in an intermittent lake, is characterized by high frequencies of deteriorated pollen, mostly

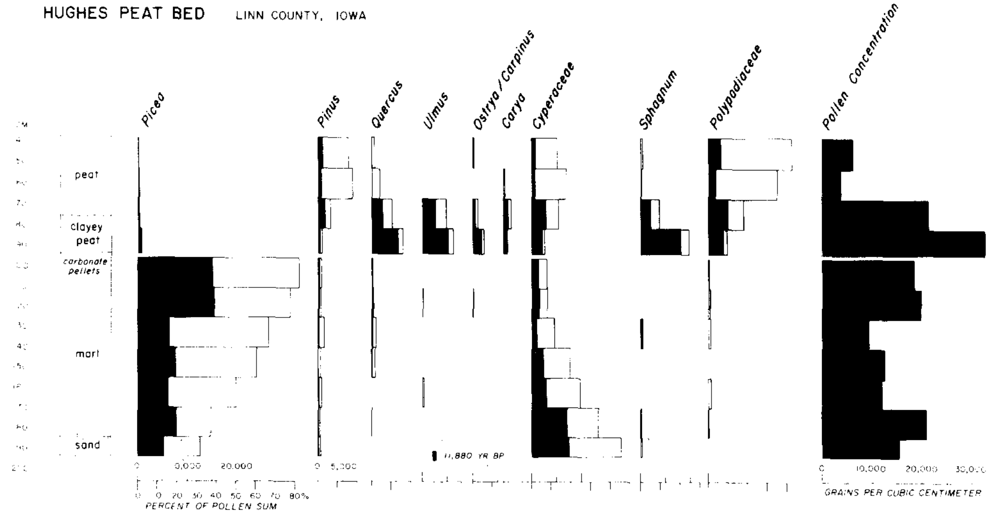

Fig.5. Summary pollen diagram, Hughes peat bed near Marion, Linn County, east-central Iowa; black bars represent pollen concentrations, white bars are relative pollen frequencies (from Hall, 1971).

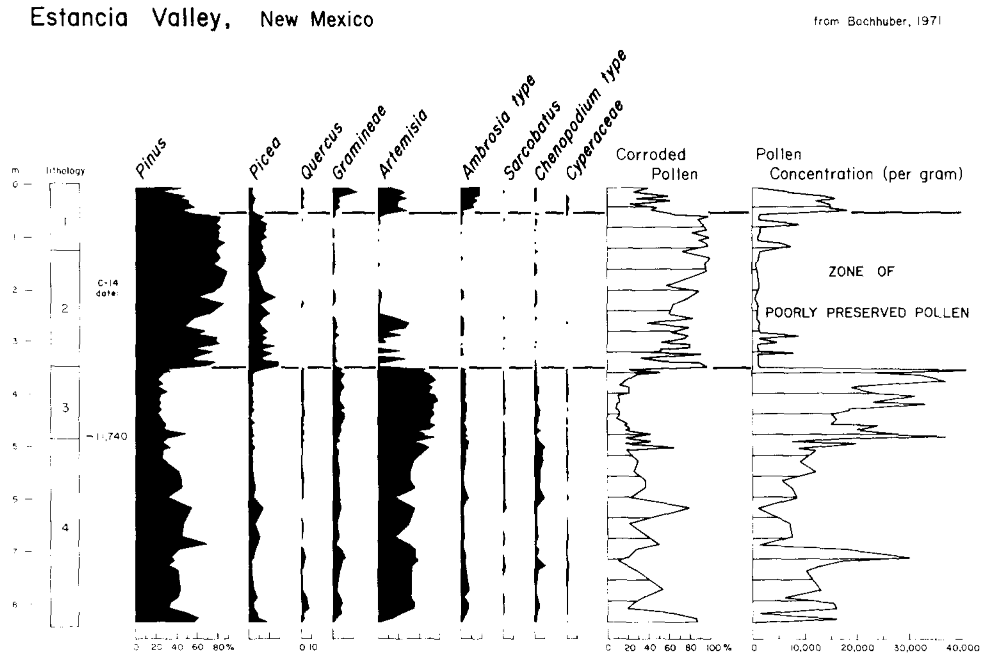

Fig.6. Summary pollen diagram, Estancia Valley, central New Mexico. Lithology: *1* = thin-bedded gray clay; *2* = laminated red sand and clay with numerous gypsum crystals; *3* = gray clay; *4* = gray brown clay and silt with gypsum crystals; pollen assemblages with comparatively high concentrations and low amounts of corroded grains occur in beds containing gypsum (from Bachhuber, 1971).

corroded, and low total pollen concentrations (Fig.6). Coinciding with the zone of poorly preserved pollen are comparatively high frequencies of *Pinus* and *Picea.* Other pollen types, such as *Quercus*, Gramineae, *Artemisia*, *Ambrosia* type, *Sarcobatus*, *Chenopodium* type, and Cyperaceae, are either absent or much lower in frequency than above and below the zone of poor preservation. These grains have been destroyed whereas *Pinus* and *Picea* grains, although deteriorated, are differentially retained in the sediment. The Hughes peat bed and Estancia Valley lake bed studies show conclusively that *Pinus* and *Picea* pollen grains may persist in a sediment after other pollen types have been largely obliterated. They are clear cases of differential preservation and good examples of situations where spurious paleoecologic interpretations could have been made had not pollen concentrations been determined.

Differential recognition of deteriorated grains

In any assemblage containing deteriorated grains the ability to recognize certain distinctive forms will result in slightly higher counts favoring those distinctive grains and slightly lower counts of pollen grains that, owing to their deteriorated state, are more difficult to recognize. *Ephedra* and

Chenopodium, for example, are recognizable even when the grains are corroded, degraded, and broken. Mere ghosts of corroded *Pinus* grains and corroded and broken *Carya* grains are also easily identified, whereas degraded *Ulmus* and *Artemisia* pollen and crumpled grains of Gramineae are sometimes very difficult to recognize in deteriorated pollen assemblages. If all pollen types do not deteriorate equally, and the Hughes peat bed and Estancia Valley sites are evidence that this is the case, the problem of differential pollen representation in diagrams is compounded by differential recognition of deteriorated grains. In practice it is difficult to know when differential grain recognition may have affected grain counts. The effects of differential recognition are probably greatest upon comparison of pollen frequencies from well-preserved and poorly preserved assemblages.

Pollen deterioration and sediment type

In a unique record of poorly preserved pollen, Cushing (1967a) found that the lower two meters of a core from White Lily Lake, Minnesota, contain over 40% deteriorated pollen grains. Although the lower spectra are poorly preserved, fifteen spore and pollen taxa are recorded from the material (Cushing, 1967b). Cushing's study (1967a) shows a correspondence between preservation class and sediment type: corroded grains occurred mainly in moss peat and degraded grains that make up most of the deteriorated pollen were restricted principally to silt. This relationship between sediment type and pollen preservation is a form of differential preservation that, although not yet documented from the Plains or Southwest, promises to provide useful supplemental information on the reliability of pollen spectra.

THE CONFIDENCE LIMIT PHENOMENON

The Painted Shelter pollen diagram shows an apparent decrease in *Quercus* frequencies with depth when indeterminable grains are included in the pollen sum (Fig.2). An apparent decrease in frequencies should also appear in the profiles of other pollen types, but does not. The discrepancy may be explained by the results of a hypothetical pollen diagram (Fig.7). The diagram shows that, as indeterminable grains increase in number, the other pollen categories decrease. In actual frequencies, as indeterminable frequencies increase by 5% increments, pollen types A through J decrease collectively by 5% increments. However, the 5% decrease is distributed over 10 different hypothetical pollen types, thus the magnitude of change in each additional pollen type per increment is much less than 5%. More important, however, is a comparison of the 0.95 confidence limits of each of the hypothetical pollen types, calculated by an equation given by Mosimann (1965, p.643). Inspection of the diagram shows that the greater the initial frequency, the more rapidly changes occur which are significant at the 0.95 level. Pollen type A, for example, initially 40% (40.0; +4.4, —4.2, at 0.95 confidence limits, pollen sum 500) shows a significant frequency change at level 4 (15%

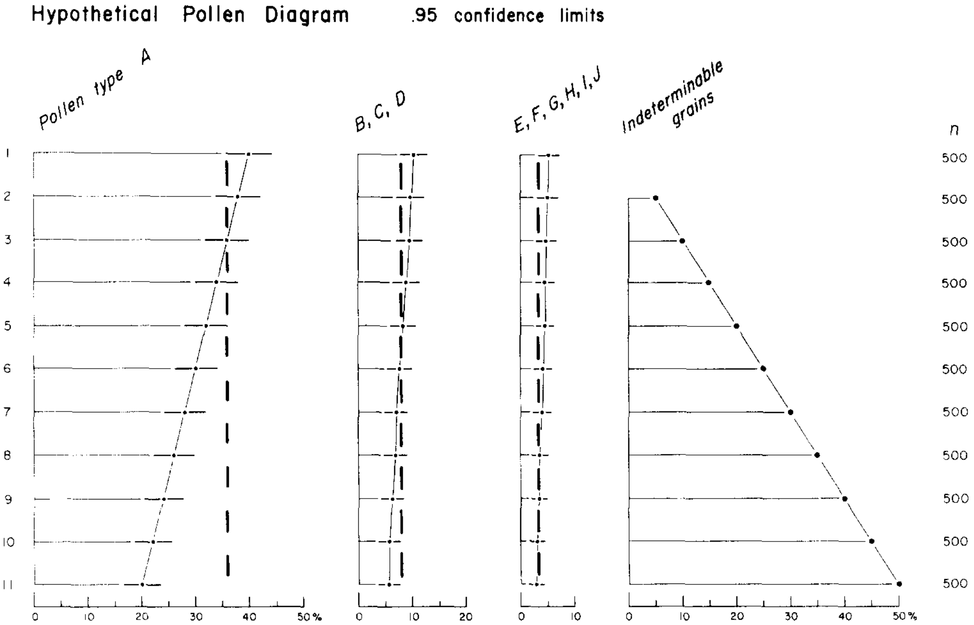

Fig.7. Hypothetical pollen diagram, 0.95 confidence limits (calculated with equation in Mosimann, 1965, p.643). Ten pollen taxa represented by one of 40%, three of 10% each, and six of 5% increments beginning with zero; pollen sum 500; heavy vertical dashed lines mark minimum limit of initial pollen frequencies calculated to 0.95 confidence limits.

indeterminable) in the diagram. Pollen types B, C, and D show a significant decrease in frequency at level 6, and pollen types E through J show significant change in frequency at level 9, where 40% of the counts are indeterminable. Pollen profiles with smaller frequency values may exhibit no significant changes when more than one-half the pollen sum is comprised of indeterminable grains. This relationship is referred to in the paper as the confidence limit phenomenon. The examples shown in the hypothetical diagram are based on pollen counts of 500. If smaller counts were made, such as 200, the 0.95 confidence interval would be larger. Larger confidence intervals mean that higher numbers of indeterminable grains in the pollen counts would have to be present before profiles of determinable pollen types would significantly decline in frequency.

The confidence limit phenomenon produces the effect that profiles of abundant pollen types show greater significant changes when indeterminable counts range widely than do profiles of less abundant pollen taxa. Pollen assemblages altered by progressive deterioration are particularly susceptible to the confidence limit phenomenon. This effect is of course not restricted to occurrences of abundant indeterminable grains but applies as well to abundant determinable pollen types.

STAGES OF POLLEN ASSEMBLAGE PRESERVATION

The various examples of pollen assemblage deterioration discussed in this paper are generalized into four stages of preservation. The stages of pollen assemblage preservation represent steps in a continuum from stage 1 through stage 4 conditions.

Stage 1 is the initial well-preserved, unaltered pollen assemblage often found in peat beds, lake marls, and in most samples of surface duff. Some coprolites and fine-grained alluvium may contain well-preserved assemblages, as well. Stage designations refer only to the preservation of the assemblage in a sediment and do not indicate any particular correspondence between pollen content and vegetation.

Stage 2 pollen assemblages exhibit the first appearances of deterioration. Pollen concentrations are slightly diminished and the abundance of indeterminable grains is increased, such as at Painted Shelter where concentrations are greater than 1000 grains per gram and indeterminable grains are less than 40%. Relative pollen frequencies, even though affected somewhat by overall and differential deterioration, are still basically sound and can be applied to studies of past vegetation. However, this does not hold true when absolute pollen influx from a peat deposit is being determined. Loss of pollen that may not greatly alter relative pollen frequencies will significantly reduce absolute influx values.

Stage 3 pollen assemblages are further deteriorated and are characterized by comparatively low concentrations, perhaps fewer than 1000 pollen grains per gram (or 2500 grains per cubic centimeter) and high frequencies of deteriorated pollen. Some pollen types may be conspicuously absent or of anomalously low abundance, such as at Hughes peat bed and Estancia Valley. Since depositional environments and rates of deposition of pollen-bearing sediments vary greatly, however, actual values of deteriorated grain abundance and pollen concentration at one study site may not be comparable to those of another. Stage 3 shows extreme differential preservation, and paleoecological interpretations may not be warranted.

Stage 4 assemblages are either almost entirely destroyed, with only a few grains remaining in the sediment, or have been completely destroyed with no grains present. If pollen is present, concentrations are very low, often fewer than 100 grains per gram. Assemblages at this stage are judged essentially barren of pollen. Even though a few grains are present, they provide virtually no useful information. A number of Pleistocene deposits fall in this category, including high-elevation terrace alluvium and loess deposits which may contain organic debris and fungal bodies but few pollen grains. The best example of stage 4 preservation is the large number of Pleistocene basin deposits in the Great Plains associated with Pearlette volcanic ashes that have yielded not a single pollen grain (Kapp, 1970) (see Fig.1).

MEASURES OF ALTERED POLLEN ASSEMBLAGES

Two criteria can be used as guides to evaluate the degree of alteration and the reliability of pollen spectra: (a) frequency of deteriorated or indeterminable grains and (b) total pollen concentration. High frequencies of poorly preserved pollen indicate that an assemblage may be partly altered by deterioration and that the pollen counts will be biased in favor of the better preserved and more easily recognized grains. Determination of pollen concentration is a technique developed by Benninghoff (1962) which, in addition to its primary application to absolute pollen influx studies, is also the most important method by which altered pollen assemblages can be recognized. When large numbers of deteriorated grains occur together with low pollen concentrations, the pollen assemblage has almost certainly been partly destroyed.

In nonfluvial environments, such as in lakes and bogs, sedimentation rates strongly influence pollen concentration. The alternating layers of mud and salt at Searles Lake, California, for example, contain vast differences in pollen: mud layers have 40,000 times as much pollen per gram as the salt layers although relative frequencies of pine are about the same in both sediment types. The clay and silt layers probably accumulated much more slowly than the salt layers, resulting in a greater pollen content in the mud (Leopold, 1967).

Pollen concentration data from Hughes peat bed, Estancia Valley, Painted Shelter, and Big Hawk Shelter indicate that some pollen destruction has occurred — the lower the concentration, the greater the amount of pollen that has been destroyed. However, this may not always hold true for fluvial deposits. A study of alluvial pollen from Chaco Canyon, New Mexico, shows a correspondence between pollen concentration and sediment texture (Hall, 1977d). Clay beds contain many times the number of pollen grains that are present in silt and sand units. The average pollen concentration of the clay and silty clay units shown in Fig.8 is 43,300 grains per gram compared with an average of only 3600 pollen grains per gram in the silt and sandy units. While varying sedimentation rates account for most differences in pollen concentration, another important factor determining pollen concentration in alluvium is the settling properties of the pollen and pollen-bearing sediments. Unlike lakes or bogs where sediment influx and pollen influx are independent of each other, the pollen content of alluvium is limited initially by the pollen content of the water—sediment mixture in the flowing stream immediately prior to deposition. The pollen concentration, of a layer of sand deposited by a flowing stream may be low; however, elsewhere on the floodplain or in the channel, a layer of mud originating from the same water—sediment mixture will probably have a much higher pollen concentration. The analysis of a series of samples of historic-age alluvium from Chaco Canyon, for example, shows a general correspondence between small mineral grain size and high pollen concentrations (Hall, 1977d, Chaco Wash I pollen diagram).

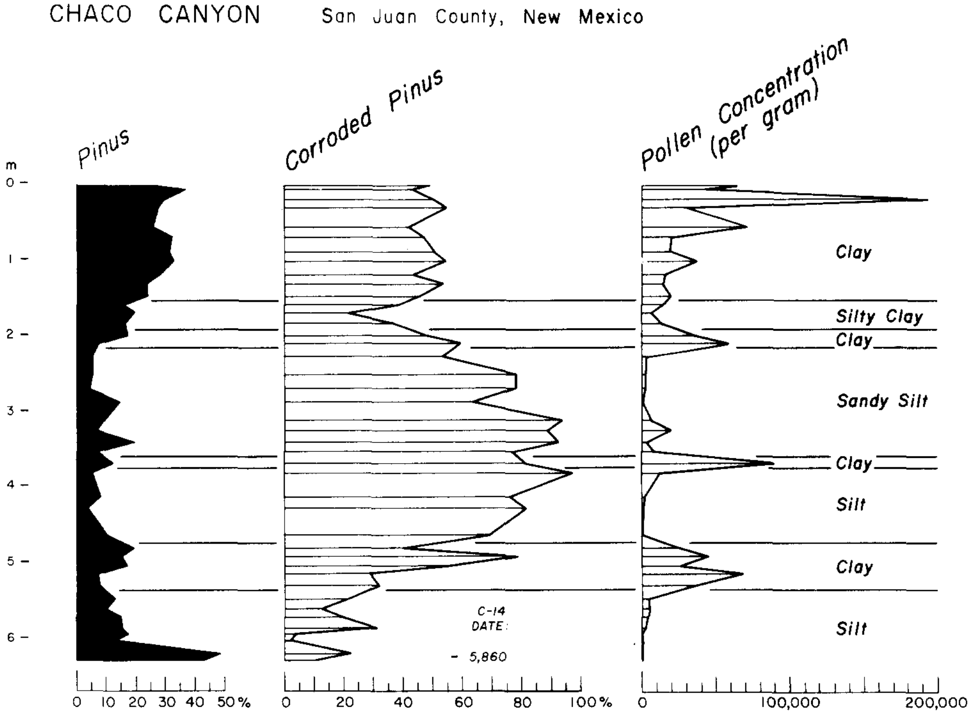

Fig.8. *Pinus* frequencies, corroded *Pinus*, and total pollen concentration diagram, Chaco Canyon National Monument, San Juan County, northwestern New Mexico; high pollen concentrations correspond to finer textured beds, low pollen concentrations correspond to coarser textured beds (from Hall, 1977d, Gallo Wash I pollen diagram).

Finally, a concurrent decrease in frequencies of several pollen taxa in a stratigraphic section may signal the beginning of a zone of altered pollen assemblages, such as at Estancia Valley (Fig.6). The same degree of change in the pollen record at a lithologic boundary may indicate the presence of an unconformity as well as an altered pollen zone. Pollen concentration data from the stratigraphic interval in question can generally verify the existence of absence of a zone of altered pollen.

SUMMARY

The preceding discussions of examples of deteriorated pollen are summarized below, and, although most of the studies are from the central and western United States, the following points may apply to other regions as well.

(1) Four stages of pollen assemblage preservation are proposed; stage 1, well-preserved and unaltered assemblages; stage 2, initial pollen deterioration resulting in slightly altered assemblages; stage 3; advanced deterioration and strongly altered assemblages due to differential preservation; stage 4, complete or nearly complete destruction of pollen.

(2) Four different circumstances resulting in altered pollen assemblages and biased pollen counts are discussed in this paper:

(a) *Progressive pollen deterioration:* gradually increasing alteration of pollen assemblages in a single stratigraphic column with higher frequencies of indeterminable grains and lower pollen concentrations corresponding to advanced deterioration.

(b) *Differential pollen preservation:* owing to the unequal susceptibility of pollen grains to the processes of deterioration, some grains will become destroyed before others in the same assemblage. *Pinus* and *Picea* pollen are retained in sediments while other pollen types, such as *Quercus*, *Ulmus*, Compositae, Chenopodiaceae, Gramineae, and others, are destroyed, resulting in artificially high frequencies of *Pinus* and *Picea* pollen grains.

(c) *Differential recognition of deteriorated grains:* all partly deteriorated pollen grains cannot be recognized equally well, resulting in distorted counts that favor some pollen types over others. For example, deteriorated *Quercus* and Gramineae grains are more difficult to identify than are deteriorated grains of *Pinus* and *Chenopodium.*

(d) *Pollen deterioration and sediment type:* different classes of deteriorated pollen may dominate different sediment types, for example, the occurrence of corroded pollen in moss peat and degraded grains in silt.

(3) Relative frequencies of pollen taxa are minimum values when indeterminable grain counts are included in pollen sum. If indeterminable grains are excluded from pollen sum, the relative frequencies are altered as though all pollen types are equally unaffected by the processes of deterioration.

(4) Increases in indeterminable pollen counts, when included in pollen sums, will reduce the frequencies of the determinable pollen grains. However, pollen categories with lower frequencies are not affected as much as are those with higher frequencies.

(5) High frequencies of deteriorated or indeterminable pollen grains and low total pollen concentrations in a single stratigraphic interval are strong clues suggesting that partial destruction and alteration of the pollen assemblage have occurred.

(6) As a general guide, a pollen assemblage may have been significantly altered if the pollen concentration is less than 1000 grains per gram or 2500 grains per cubic centimeter of dry sediment.

(7) Low pollen concentrations that are not due to deterioration are products of rapid rates of deposition or are a result of the washing of pollen from coarse-grained fluvial sediments.

In conclusion, because of the possible erroneous paleoecologic interpretations that can be made using pollen spectra that have been altered, the writer recommends that: (a) the sediment type, (b) the abundance of deteriorated and indeterminable grains, and (c) total pollen concentration should be determined for each sample, especially in studies involving pollen assemblages that are poorly preserved. Not only can spurious interpretations thus be avoided, but pollen records from important localities that might otherwise be dismissed off-hand as having too few or too poorly preserved pollen grains to study can be more objectively evaluated.

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