1958

THE VALUE AND LIMITATIONS OF PALYNOLOGICAL INTERPRETATIONS

James Schoenwetter

In the literature readily available in the field of pollen analysis, synthetic papers such as this are by no means a novelty. Though still considered a newcomer in the area of scientific inquiry, one of the traditions of the study is the frequent publication of the latest iographic references available, as well as symposia on new interests, areas under study, and new techniques(Erdtman, 1948, 1951). Also, ovements in method and technique, questions of theory, and problems nalysis are still "hot" problems, and each expert wants to make his ws clear. Then too, there has been much discussion on the potentialities he study and its relation to other fields such as geology and archaeology. ons interested in those fields have reviewed the literature and phrased i n their own terms (Cooper, 1942; Eisely, 1939). This paper is added to the list in this last category. Here a specialized question has arisen: what evidence can pollen analysis supply to the study of past climates, and to what degree is this evidence reliable.

An attempt shall be made to answer this question in the following pages, but this introduction asks another question which, logically, takes precedence: what does the paleoclimatologist want to know, and how much does he expect of the palynological data.

The paleoclimatologist is interested in the distribution of climate at all time levels. In a nutshell, he wishes to know when, where, why, and how the climate has existed and changed. Primarily he is a synthesist who draws upon material available from other fields of inquiry and interprets this data in terms of his own problem. One of the difficulties to be encountered in this study is the lack of data at certain, perhaps crucial, points. Another difficulty is the danger in interpreting the data in a manner which may be too broad in comparison to the present state of knowledge in the field involved.

The author believes that this to some extent has been the case with the palynological evidence available today. It seems to be a prevailing opinion , especially among American authors, that pollen evidence alone is sufficient grounds upon which to base assertions of climatic change at various times in the past. It is the opinion of the author that only one of the problems of interest to the paleoclimatologist can be answered with true competance by palynological evidence: that of where the climate has existed and changed. This thesis maintains that the nature of these changes cannot be determined from the pollen record, and an attempt shall be made to show that the problems inherent in the pollen analytical method at its present state of perfection are so great that any interpretations of palynological data other than those of the geographical distribution of previously determined climates are very difficult to support.

PROBLEMS AND SOURCES OF ERROR

The first principle inherent in pollen analytical work is that the pollen of flowering plants and the spores of other floral groups are resistant to decay and will be preserved in the depositional record of an area.

In dealing with this assumption, it is important to first consider the nature of the preservation of such grains. It has been determined that the inner portions of pollen grains decay fairly quickly but the outer membranes are extremely resistant to this natural process under certain conditions. This latter part of the pollen grain is insoluble in all solvents and has a high resistance to most chemical reagents. As a consequence of its being insoluble, very little is known of the chemistry of the material constituting this outer layer, or exine. The substance responsible for the durability can be extracted, however, and has been given the name of sporonine.

In the presence of light and air, sporonine undergoes some kind of chemical change which makes it easily soluble in weak alkalies of the type to be found in decaying vegetation. Also it is known that the sporonine content of various pollen types differs, so it is probable that the preservability of these types differs. Work on the nature of the chemical changds involved and the sporonine content of various species needs to be done before we shall begin to know the range of variation in pollen preservation, however.

If the pollen grains become buried or if they sink beneath a water surface, then, they stand a good chance of preservation as they are no longer exposed to the factors which encourage decomposition. Considering the vast numbers of pollen grains produced by plants, the probability that some grains of each species in an area will be preserved is fairly high if deposition is going on.

The pollen grains now, however, are embedded in a matrix and must be extracted in such a way as to allow identification. There are two methods employed:

1) chemical methods wherein the matrix is chemically elimanated and the pollen (being practically indestructable) remains, and
2) flotation methods wherein the pollen is floated out of the majority of the matrix and then chemical methods are utilized to eliminate the remaining material.

The first of these techniques has been most widely used, for during most of the history of pollen analysis organic deposits were under investigation which contain vast quantities of pollen easily extracted by such methods. Investigators have broken down sufficient matrix to study the grains by simply boiling the sample in potassium hydroxide, by acetolyzing the sample with a combination of sulphuric acid and glacial acetic acid, and with the use of other strong acids and bases. The only problem here is that the use of different extraction techniques gives grains of different sizes, and since the identification is often based upon the size of the grain or the size of its parts, inconsistencies were bound to occur. Most investigators today use the acetolysis method of extraction because the major references as to pollen size and appearance are based upon the use of acetolyzed grains. This chemical method is not completely without fault, however. Some plant types seem to be affected by this procedure and the grains emerge from acetolysis somewhat damaged. In the fresh material (as distinguished from the fossil material) at least, grains in the rush, laural, and other families come out in a wrinkled or shrivelled condition. (Erdtman, 1952)

There are three flotation techniques. The first is most applicable to organic matrices and consists merely of mechanically dispersing the constituents of the sample by centrifugation. The second and third techniques are primarily for use in inorganic material. They consist of floating the grains out of the matrix by using a "carrier" which has a higher specific gravity than the pollen grains, but one which is lower than the majority of materials in the matrix. Bromoform has been used with great sucess for this process (Knox, 1942), and another flotation technique which uses ordinary paraffin oil has recently been announced (Kurtz and Turner, 1957). This last technique has the advantage of using larger samples and is both simple and inexpensive. Since deposition is liable to be more erratic in inorganic than organic material, i.e., since it is to be expected that more of the grains will be exposed to light and air and differential preservation will be likely under such conditions, the oil flotation method will probably find favor with those interested in the flora of most ancient times since larger samples may be most economically utilized with this method.

Another problem associated with the differences in technique is that of the natural differences in the receptivity of the matrices. Most of the work has been done on bog materials, and it appears that the bogs differ in their receptivity to pollen grains. Living bogs in which peat is forming will tend to preserve the grains better than dead ones, or those temporarily inactive due, perhaps, to drought or cold. It can be seen that in continental regions where the bog surface is frozen until late spring, the pollen of early flowering species of plants may not be preserved even though such plants may make up a large percentage of the available vegetative material.

The second assumption of the pollen analyst is that once extracted the pollen grains can be recognized, classified, and identified on the basis of structural and morphological differences.

Though this assumption is the real basis for all pollen work it is not completely free of difficulty. For one thing, the anatomy of pollen grains themselves is somewhat confusing to the botanist. Most identifications are made on the basis of the sculpturing of the exine of the grain, the internal structures visible under the light microscope (compared to the phase or electron microscope), and the size of the grain. As yet, however, there is no agreement on the names of various morphological features to be found and some authors even change the names they have invented themselves and placed in the literature. For example we might mention the outer layer of the pollen grain: the exine.

As revealed by the best light microscopes, the exine is usually found to consist of two layers. Erdtman coined the names endexine and ektexine for them. Later he substituted the names nexine and sexine. Erdtman himself defines these in morphological terms, the former sculptured and the latter not sculptured. Faegri (1956), however, prefers to consider them in chemical terms (though he admits that the chemicals involved are not yet known) and states that the endexine is that which takes the stain and the ektexine is that which remain unstained. He supports this view by showing that in certain species there are more than two layers, only one of which takes a stain. These other layers have names also (ectonexine and endonexine) and sometimes they too have sculpturing. The assumption that the grains of different species are constant is probably true, but there is some difficulty in deciding what factors are to be considered when defining this constancy.

Another problem is that of nomenclature in the taxonomic sense. There are definite rules set up for the naming of plants and it would seem that little trouble would be had in relating pollen grains to the proper mother species. In working with fossil grains, however, especially those of the pre-quarternary periods, there is the constant problem that a grain may be similar to a modern group but no actual relation to it. The great majority of grains found in such old deposits must perforce be given "provisional" names, which have caused not only much discussion but left the field in a present state of complete confusion.

Besides the fact that many who work with pollen grains are not botanists, and even fewer are familiar with the rules applying to taxonomic nomenclature, classifications have already been published which are strictly artificial and have no relevence under these rules. Form-taxa, artificial groups into which pollen grains have been placed on the basis of morphology, have been variously defined by various authors. Pant, 1954, is a good example. Often these classifications are very valuable, for a species which defies identification at the present time, due to lack of standard reference material or adequate pollen herbaria, may be placed in a group to which it is similar. Unfortunately, the well-known caution of some investigators abuses the privilege of the form taxon. A pollen grain that one worker might put into the genus Alnus, for instance, will be placed in the form taxon Alnopollenites by someone else who is perhaps less courageous or less well informed. While the former name indicates a plant about which we have much information, the latter indicates only a morphological similarity which may have no significance.

The fact is that there is quite often little morphological similarity between genera considered to be closely related, and there is often a great resemblance between families which are considered to be hardly related at all. This latter phenomenon is known as "convergence of pollen types". Attention has been drawn (Godwin, 1942) to the similarities between oak and violet, willow and ash, beech and a genus of the rush family, hazel and a species of nettle, and others. The distinctions between such problematical grains are usually worked out on the basis of size, but the ranges of size variation often overlap. In addition, grains vary in size according to the way in which the sample to be studied is prepared. One chemical will make them swell, another will make them shrink. Moreover, there is some evidence that at least with certain species the size of the grain is an environmental factor and not a genetic one upon which identifications can be based.

Even when the genus can be easily recognized, it often happens that the various species cannot be distinguished, though they may have quite different climatic significance.

Conceding that the pollen types are preserved, and restricting our investigations only to known and easily recognizable material, there are still some factors left to be accounted for. Two of the greatest problems are those of long distance transport of pollen grains, especially those of wind pollinated species; andlocal overrepresentation, especially when the species concerned grow close to the area of deposition.

The former problem was under a lot of discussion early in the history of pollen analysis, especially when investigators found that pollen could be carried far out to sea or over arctic areas by the wind. The nature of pollen preservation, however, argues that though the magnitude of transported grains may be large their percentage in the deposited sediments will probably be small. Using present-day forests as indicators, it has been found that transported pollen amounts to only about 5% of the diagram as taken from open-faced slides.

The problem of wind transported arboreal grains at one time seemed great enough to encourage investigators to consider non-arboreal pollen types (NAP) as more consistant with the vegetation pattern and thus base their diagrams on NAP alone. This ran them into the problem of local overrepresentation, however. It is true that the NAP species are closer to the ground, and thus there is less chance that the grains will be blown away or that stray species' pollen will be blown in, but being closer tothe ground there is a greater tendency for the pollen of such species to dominate one particular very small area.

Another source of local overrepresentation is found in marine deposits or bogs where the pollen grains must sink below a water surface before preservation can take place. In such instances it is to be expected that lighter pollen types will float longer than the heavier ones. Experiments have been undertaken on this point, and it has been determined that types such as those in the genus <u>Pinus</u> which are equipped with large air bladders do, in fact, sink more slowly. If the surface of the water is agitated by the wind, these lighter grains tend to float toward the lee shore. Thus there will be two areas in the bog or lake sediment where over-representation of a particular type is very liable to occur.

Considering bog deposits specifically, there is no doubt that the pollen record may be truncate, i.e., that the deposit need not contain a complete record. Even in the same area peat deposition may begin at different times, so there is no reason to consider that the bottom records of the deposits are of the same age. Also, bogs may start and stop or speed up and slow down their deposition.

Sears (1935) has considered that in the North American pollen record the absence of a tundra vegetation complex over much of the area where tundra theoretically should appear may be due to such truncated records. He contends that the basins or kettle holes in which peat accumulation started may have been filled by blocks of dead ice for centuries after the ice sheet itself had retreated northward. Thus peat accumulation may not have commenced until after the tundra had given way to forest.

As to the question of the regional pollen rain being indicative of the forests in question, there has been constant work done. Open-face microscope slided, laid on the ground each day during the pollinating seasons, have been taken. The surface layers of bogs have been investigated. Moss polsters have been collected and their pollen contents tabulated. Usually, it is found that the percentage composition of thepollen types in this material bears little relation to the forest composition. At best, 40 or 50% correlations are to be expected. Some correlations range much lower, but these can usually be shown not to have taken the prevailing wind factor into account. It has been shown by these investigations, however, that the major species to be found in the forest will also be found in the pollen record. Also, these investigations have given some idea of how great an area will be covered by the pollen deposited in a bog, for instance.

In addition, such factors as man, insect or epidemic disease, fire, hurricane, vulcanism, or biotic succession may greatly affect the vegetation (and hence the pollen record) without a climatic change being involved. Conceeding that we were able to discount such factors, knowledge of the changes in vegetation still are not necessarily positive indicators of the changes in climate.

For instance, today the beech tree in England is restricted by an area of late frosts and low summer temperatures. If this was the criterion for the increase in beech pollen during the Sub-Atlantic phase of postglacial time, it would suggest a change towards warmth and continentality almost opposite to that suggested by other lines of evidence. On further investigation, it is seen that the beech inhabit a zone of chalk and limestone soils. The increase in beech pollen may now be interpreted as a function of the moister Sub-Atlantic period which enabled this genus to invade the other soil areas.

We might also consider the situation where three major climatic changes are evidenced by the pollen record, the first and last periods having one species in common:

I Birch-Pine
II Pine-Hazel
III Alder-Oak-Elm-Birch

If we postulate also that birch pollen exists in approximately the same percentages in periods I and III, we may draw two, opposite, climatic interpretations. The first interpretation is that both periods have the same climate. Period III is a re-establishment of the climate of Period I, and the presence of the other species is explained because the re-occupation of an area by species it favors may just as well set up a new competition equilibrium as set up a pre-existing one. The opposite interpretation, that Period III has a different climate than Period I, is equally well maintained. The complete dissapearance of pine, a species favored in Period I, seems to indicate a different environment. The presence of birch in the same percentages in both periods is a happy accident.

This brings us directly to the pressing question of how the pollen analyst himself usually evaluates his data and presents it to the public. We must here enter into a discussion of what the above mentioned percentages signify and how tabulations and pollen diagrams are constructed.

Results of pollen investigations are tabulated in various ways. Usually, tabulations are made for each tree pollen genus (or species if possible), for the other pollen genera, for the spores of fungi and mosses and for other identified groups. Also included is a tabulation of "unknown" grains and spores, and some investigators find it profitable to include seperately fragments of grains which cannot be identified with certainty. These tabulations rarely get into print.

The published material is usually a graph called a pollen diagram or pollen spectrum. The abscissa is marked off from one to one hundred percent, and the depth in the deposition is marked off along the ordinate. A few pollen types are placed on the diagram at the same time so the reader may see the way in which the percentages of these types varies during the course of the deposition.

In the computation of these percentages, however, not all materials identified are included. The common practise is to distinguish between "significant" and "non-significant" pollen types. The total number of significant grains is set as equal to 100%, and the "extras" are expressed as percentages of the total significant material. It is the opinion of most workers that the pollen diagrams reveal forest history and climatic history best when only the pollen of trees which may be considered climatic indicators are employed in the percentages. Thus all non-arboreal types and certain genera of trees considered to be edaphic types of little significance are tabulated seperately.

Obviously, all of the identified groups together play some role in the ecological picture which reflects the climate. The calculation of extras is rather dubious, and considering the statistical nature of the study it is impossible. Still, differential preservation, differential production of grains, and local overrepresentation are problems to be dealt with and this seems like the best answer.

Due to the possibly erratic nature of deposition, it is seen that ~~[illegible]~~ the curves found on the pollen diagram need not be those of a stationary time series. This point is not mentioned in the literature, and those interested in pollen analysis seem to take it for granted that any segment of the curve has the same statistical properties as any other segment. One of the much discussed problems, however, is that of the number of grains necessary for a reliable sample.

Practical experience with the curves involved, and the publication of tables in which increasing numbers of grains were counted, gives some indication as to the number of grains needed. No worker seems satisfied with the reliability of a pollen spectrum based on less than 100 grains. "Experience" has shown that about 150 grains of arboreal pollen is a "safe" count, and the results of tabulation are said to have proved rather conclusively that after 800 to 1000 grains have been counted the percentages are fairly constant.

Faegri and Iversen (1950) present the results of a formal statistical treatment of the problem, based on the fact that sampling errors present a binomial distribution of values. The limits of the sampling error are defined by the standard variation of thebinomial function which is dependent on the value of the observed percentage and on the number of grains counted. The number arrived at is the only one in which the analyst may have 95% confidence, statistically. The author readily admits to a lack of knowledge of the study of statistics, but it seems that this technique would show that a sample was 95% accurate in terms of other samples already accepted as accurate. In such a case the sample need not show "real" values atall.

When the tabulations have been made, it is found that in order to establish very low or very high percentages of grains accurately great numbers of grains must be counted. To establish that any species was 30 to 60% of the total only 100 grains need be counted. To establish that a species was 4 to 6% of the total, however, 1900 grains have to be counted. To those who have studied pollen diagrams it is obvious that such numbers of grains are rarely encountered, no less tabulated. Most workers, in fact, do not include in their published accounts the number of grains counted, but merely draw up pollen diagrams which are made on the basis of percentages. There is no obligation on the part of the reader to conclude that such percentages are accurate at all, no less 95% accurate.

Using the coefficient of reliability method of comparing halves of a count, and a point of sufficient accuracy of 90%, Barkely (1931) concluded that a count of 175-200 grains should be sufficient. When results from two adjacent samples were compared, however, it was found that only a rather mediocre relation of 64% could be determined between them. The conclusion drawn is that it is better to study adjacent samples and obtain an average than to make large counts of a single sample.

PALEOCLIMATIC INTERPRETATIONS

Unless we are to change the nature of the pollen analytical method, it is easily recognized from our foregoing discussion that it is hardly feasable to rely on pollen analysis alone for evidence of the general nature of past climates. Simply, there are too many possibilities for error, and too much probability that errors are likely to be compounded. We may conceed this point, and indeed there is no reason to expect that any one line of evidence is the sole answer to such a problem. The question arizes, then, can the data forthcoming from pollen investigations be relied upon for supporting information on the nature of past climates, and in what way might pollen analysis benefit the investigations of the paleoclimatologist in its own right.

When considering the pollen diagram, i.e., the raw data which the paleoclimatologist has to work with, we recognize the crucial role played by "significant" and "non-significant" species. It has been mentioned that only types which are climatic indicators are supposed to be of value. We have not discussed how such indicator species are determined.

If the literature on pollen analysis is reviewed it will be seen that very few species are considered important. Actually most analyses concern themselves with only about a dozen pollen types. These types have been used since their early determination by investigators working in Northeastern Europe. But these first experiments with the method did not concern themselves with an attempt to explore or explain past climatic conditions; their objective was a more complete knowledge of changing floral conditions acting upon the rough outline of climatic succession as previously determined on the basis of macro-fossil and limnological evidence (the Blytt-Sernander hypothesis). These early investigators were able to determine which pollen types were climatic indicators because they already knew the climates they were dealing with.

The complement of this proposition--that the presence of these types represents a given climate-- does not necessarily follow. We have seen that the presence of these types in the pollen diagram may be due to factors other than climate, long distance transport, local overrepresentation, differential preservation, or other causes. The limitation of the pollen diagram is that it cannot be considered at all accurate until a general knowledge of the climatic succession has already been fairly well ascertained from other sources. It follows from this that palynological data cannot be utilized as a source of relative chronology for the student of past climates, either. Once the diagram is determined as accurate it may be used as a geochronological tool by the archaeologist or floral historian, but this accuracy cannot be determined until paleoclimatic data from other sources has been accepted.

But this does not mean that the palynological data can be of no use to the paleoclimatologist. Once determined as accurate pollen analysis can show the areal distribution of not only climatic indicator species, but ecological associations. The fact that the existance of a plant species in the pollen record may not be due to climatic conditions only still does not deny the fact that plant species are largely geographically limited by climatic conditions. Thus the paleoclimatologist may use these plants and plant groups in determining the finer climatic elements such a photo period, annual and seasonal range of temperature and moisture, etc. It is through such considerations that the paleoclimatologist can determine where one climate leaves off and another begins, spatially, and if dating techniques are available, temporally. Where geological evedence may denote moist or dry conditions, and where tree rings may denote the length of such conditions, only biological evidence such as pollen analysis can denote how dry, or how moist, or the seasonal variations of moist and dry conditions.

In summation, the pollen analytic method is beset by internal difficulties of interpretation. Due to the possibility that each error may exist, and the greater possibility that each error may be compounded, by other errors, the pollen analyst finds it necessaty to place limits on ~~this~~ his investigation. These limits, i.e. the determination of significant and non-significant species as climatic indicators, are dependent upon a general knowledge of climatic succession in the area involved culled from evidence other than pollen analysis.

The student of past climates, then, cannot justifiably utilize pollen analysis as a basis for the determination of past climates or the determination of a relative time scale for past climates. He can, however, utilize pollen analysis for the determination of the geographical distribution of known past climates, and from the more specific ecological data which pollen analysis allows make some interpretations as to the reasons for such given climates and the reasons for their change.

BIBLIOGRAPHY

BARKELY, A. 1931. Statistical Theory of Pollen Analysis. Ecology 15:283-289

CAIN, S.A. 1939. Pollen Analysis as a Paleoecological Research Method. Bot. Review 12:627-634. Problems and sources of error in the field from the botanical viewpoint.

COOPER, 1942. Contributions of Botanical Science to Knowledge of Postglacial Climates. Jour. Geology 50:981-994. A geological approach which considers palynology as sufficient evidence for determination of climate.

DEEVY, E.S. 1944. Pollen Analysis and History. American Scientist 32:39-53. Pollen analysis as a geochronological tool.

EISELEY, L.C. 1939. Pollen Analysis and its Bearing on American Prehistory: A Critique. Am. Antiq. 5:115-139. Considered the study primarily as a geochronological tool, gave some of the difficulties inherent in the study as they would affect the archaeologist.

ERDTMAN, G. 1943. An Introduction to Pollen Analysis.

1948. Palynology, Aspects and Prospects I. Svensk Bot. Tidskr. 42
also
1951. Palynology, Aspects and Prospects II. Svensk Bot. Tidskr. 45
An example of the numerous attempts made to keep palynologists well informed as to bibliography and research being undertaken.

1952. Pollen Morphology and Plant Taxonomy I. Angiosperms. Classic pollen ~~diagrams~~ illustrations included.

GODWIN, H. 1934. Pollen Analysis; an Outline of the Problems and Potentialities of the Method. New Phytol. 33.

1942. Pollen Analysis and Quarternary Geology. Proc. of Geol. Assn. 52:328-361.

1948. Principles and Practise of Pollen Analysis. in The Advancement of Science. Chap. IV, pp. 337-338.

1956. History of British Flora. Cambridge. An excellent example of the utility of the method. Covers the time range from the late glacial to the Roman periods. A massive amount of work.

HANSEN, H.P 1946. Pollen Analysis and Postglacial Climate and Chronology. Scientific Monthly 62:52-62. Equates floral succession with climatic succession and uses palynological evidence for chronology.

HASSAL, A.H. 1841. Observations on Structure of the Pollen Granule Considered Principally in Reference to its Eligibility as a Means of Classification Ann. Mag. Nat History vs. 8 and 9. One of the earliest papers on the subject.

LEWIS, I.F. and COCKE, E.C. 1929. Pollen Analysis of Dismal Swamp Peat. Jour. Elisha Mitchell Sci. Soc. 45. Contains some excellent illustrations of North American pollen types.

ETN , H. 1927. Atlas und Besligmmunschlussel zur Pollenalytik. Bot Arch. 19:380-489. Presents two keys for the recognition of pollen grains; one for forest types and the other for European moor plants. 313 species.

PANT, D.D. 1954. Suggestion for the Classification and Nomenclature of Fossil Spores and Pollen Grains. Bot. Review 20:33-60.

SEARS, P. 1930. Common Fossil Pollen of the Erie Basin. Bot. Gas. 89 Contains illustrations of grains.

1935. Types of Nort American Pollen Profiles. Ecology 16:488-499

1942. Postglacial Migration of Five Forest Genera. Am. Jour. Bot. 29:684-691. Uses same pollen types as European investigators on the assumption that they are climatic indicators in the U.S. too.

1948. Forest sequence and Climatic Change in Northeastern North America since Early Wisconsin Time. Ecology 29:326-334. Correlation of 20 pollen diagrams from this area. Assumes certain genera climatic indicators and fills in the time range on his own.

WENNER, C. 1947. Pollen Diagrams from Labrador. Geografiska Annaler. 29:137-374. One of the few authors toinclude his tabulations in the published article. Also makes may pertinent comments on the size range of various species.

WILSON, 1936. Further Fossil Studies of Two Creeks Forest Bed, Manitowoc County Wis. Bull. Torr. Bot. Club 63:317-325. Feels that plant succession accounts for much of the data Sears considers due to climatic change.

WOODEHOUSE, R.P. 1935, Pollen Grains. New York and London. Good description of some of the methods of extraction and some illustrations of grains. Some authorities feel that Woodehouse makes his grains "too Beautiful".

also

FAEGRI, K. 1956. Recent Trends in Palynology. Bot. Review 22:639-664 An excellent treatise on the present state of co fusion.

________ and IVERSEN, J. 1950. Textbook of Modern Pollen Analysis. Copenhagen.

KNOX, A.S. 1942. The use of Bromoform in the Separation of CalcareousMicrofossils. Science N.S. 95:307-308

KURTZ, E.B. and TURNER, R. An Oil Flotation Method for the Recovery of Pollen Grains from Inorganic Sediments. Micropaleontology 3, 1957.