Reports

Pollen Accumulation Rates: Estimates from Late-Glacial Sediment of Rogers Lake

Abstract. *Absolute pollen deposition in a Connecticut lake over a 4000-year interval has been estimated from pollen frequencies in a core of late-glacial sediment dated by radiocarbon techniques. The rate of total sediment accumulation as measured after burial was statistically constant at 0.036 centimeter per year, but the rate of deposition of pollen grains onto the sediment increased from 600 to 900 grains 14,000 years ago to 9000 per square centimeter per year 10,000 years ago. A major increase in the deposition of tree pollen occurred about 11,500 years ago, at the beginning of the spruce pollen zone. Presentation of data in conventional (percentage) form masks the magnitude of this change and distorts many of the changes in accumulation rates for individual types of pollen; moreover it magnifies statistical variation in the herb zone where all pollen is scarce.*

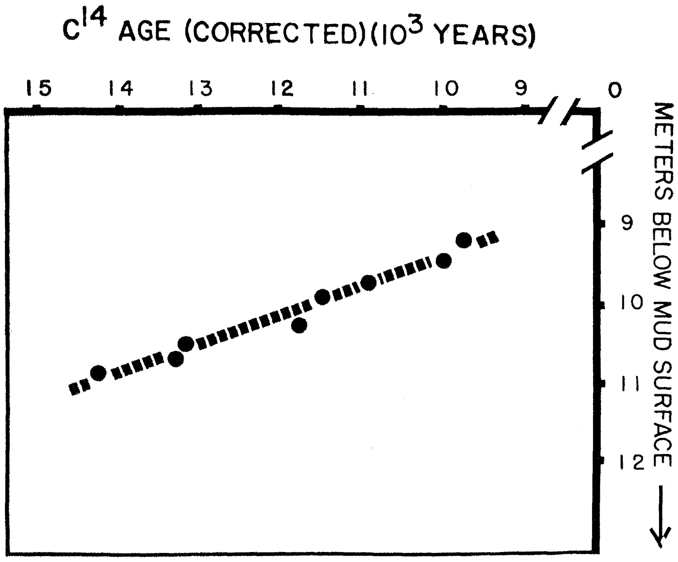
In quantitative analyses of fossil pollen, as introduced by von Post (*1*), the percentage composition of pollen assemblages is used as an indication of past environment. Historical sequences of changes in the pollen percentages preserved in Quaternary sediments have proved to be remarkably consistent from place to place. The subsequent development of pollen chronologies, and their successful application in many contexts, have obscured the lack of quantitative correspondence between the changes in pollen percentages and changes in the vegetation that produced the pollen. Even if allowance can be made for large differences in pollen production and dissemination (*2*), for example, by systematic comparison of older pollen spectra with those found in different modern plant communities (*3*), the difficulty remains that percentage values are interdependent; change in abundance of one type, whether real or an artifact of sampling, causes changes in the values of all others (*4*).

Pollen frequencies need not be expressed relative to each other, but can be made independent by reference to other parameters, such as mass or volume of total sediment. As sedimentation rates can be at least as variable as pollen frequencies, however, there is no necessary gain in meaning, and this mode of presentation has not found favor with most palynologists (*5, 6*). Now, with sedimentation rates determined for eight C^{14}-dated levels (*7*) in the lowest 2 m of a late- and postglacial core from Rogers Lake, we have been able to divide pollen numbers per cubic centimeter of sediment by the years needed to deposit 1 cm thickness of sediment, thus arriving at figures (in grains per square centimeter per year) for the net accumulation rate of each type of pollen. The resulting absolute pollen diagram, though incomplete in that it spans only the first 4000 years of a 14,000-year history, is of interest since it is the first of its kind. It differs from the conventional stratigraphy of percentages in several informative ways.

The core, 5 cm in diameter and 11.5 m long, was collected with a Livingstone piston borer in 1960 from below 10.5 m of water in the south basin of Rogers Lake, Old Lyme, Connecticut. Immediately on extrusion of each 1-m segment of core, pollen samples of known volume (usually 1 ml) were taken at close intervals; duplicates were taken for weighing. The range of wet weight between duplicates at 14 different levels averaged 4 percent of the mean weight of each pair, and the standard deviation of the dry weights of five replicates at one level was 0.9 percent of the mean. Absolute pollen frequency was estimated from pollen counted over a standard fraction of the area of microscope slides prepared with known volumes from xylene-silicone oil suspensions (*8*). A total of at least 250 grains was counted from each sample. Sediment remaining after sampling was divided into 5-cm segments, C^{14}-dates being obtained for samples comprising one, two, or (at the least organic level) four such segments. The depths and volumes of samples from one of the 1-m core segments were calculated, with allowance being made for the compaction in length which accompanied extrusion from the sampling tube. Ninety-five percent confidence limits for accumulation rates were approximated by pooling the variance of the absolute pollen counts with the variance of the least-squares line used to indicate sedimentation rate (*9*).

We have used the C^{14}-dates as published (*7*). These dates have been adjusted by empirical subtraction of 770 years, the C^{14}-age of surface sediment in the lake. As the correction is the same for all samples, it does not affect our use of their relative ages. The enrichment of the surface sediment in C^{12} is attributed to ancient carbonates supplied by groundwater (*10*), although the lake water is relatively soft (*11*). The age was corrected on the assumption that the proportion of total carbon in the sediment contributed by C^{14}-deficient carbonates has been invariant with time. As this assumption is dubious, the absolute age estimates for the samples may be inaccurate. Similarly, we cannot rule out the possibility that a progressive change in the proportion of ancient carbonates has distorted the relationship of C^{14}-ages of samples from widely separated levels. The sediments, however, are not calcareous: 2 to 4 mg of Ca and Mg per gram dry weight, as determined by sodium versenate titration. We are therefore assuming at present that, because the amount of carbonate is small, adjacent samples differ only slightly in their proportion of C^{14}-deficient carbonate. In this case the effect of this source of error on our use of the relative ages of adjacent levels is minor.

Figure 1 shows the depths of the eight samples plotted against their absolute ages. A straight line has been fitted to the points by the least-squares method by regression of depth on age ($r = +0.998$). The mean sedimentation rate, as computed from its slope, was 0.036 cm per year (standard deviation, 0.003) between 14,240 ± 240



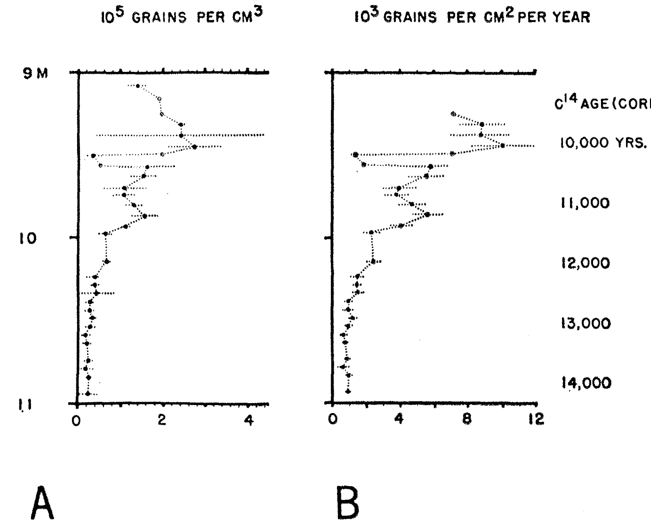


Fig. 1 (left). Depth below mud surface of eight core segments plotted against age determined by radiocarbon dating. Dashed line indicates least-squares line obtained by regression of depth on age (zero represents present surface). Fig. 2 (right). Total pollen from terrestrial plants. (*A*) Absolute pollen frequency: dots indicate the total number of pollen grains from terrestrial plants per milliliter of wet sediment; depth below mud surface is indicated on the ordinate. (*B*) Accumulation rate: the data are shown as the number of grains per square centimeter per year, after the number per milliliter was corrected for the accumulation rate of the sediment matrix. Horizontal dotted lines indicate approximated 95 percent confidence intervals. Estimated absolute age of the sediments is shown on the vertical scale to the right.

years ago at 10.8 to 11.0 m depth, and 9740 ± 160 years ago at 9.08 to 9.24 m depth. The lowest sediment is sandy silt (loss of dry weight on ignition, 3 to 6 percent), grading to organic gyttja (loss on ignition, 17 to 21 percent) above 10.10 m. Sediments above 9 m, in the part of the core not yet studied, were evidently formed at about twice the rate at which they formed in late-glacial times, and the modern rate before compaction and diagenesis, observed in sediment traps or calculated from the accumulation rate of *Bosmina* carapaces, has been estimated at about ten times the late-glacial rate (*12*).

As sedimentation rates throughout late-glacial times are assumed, on the evidence presented in Fig. 1, to have been invariant within the limits of our method of measurement, the trends in the changes in absolute pollen frequencies found from level to level are not altered by conversion of the data to accumulation rates (Fig. 2). Unlike the sedimentary matrix, total pollen accumulated at rates that increased sharply about 11,500 years ago from between 600 and 900 per square centimeter per year to 6000 per square centimeter per year; these rates continued to increase until about 10,000 years ago 9000 pollen grains per square centimeter were deposited per year. Minor reversals in this trend, such as that 10,300 years ago, appear to have resulted from changes in matrix sedimentation rate which occurred during intervals too brief to be measured.

The conventional pollen percentage diagram (Fig. 3*A*) closely resembles others from southern New England, notably the late-glacial diagram from Durham, Connecticut (*13, 14*). The sequence begins with a herb pollen zone (T), where the high percentages of herbaceous plant pollen and, at other sites, pollen and leaves of subarctic tundra plants (*6, 13, 15*), imply a time without trees, or at least without continuous forests. In contrast with pollen

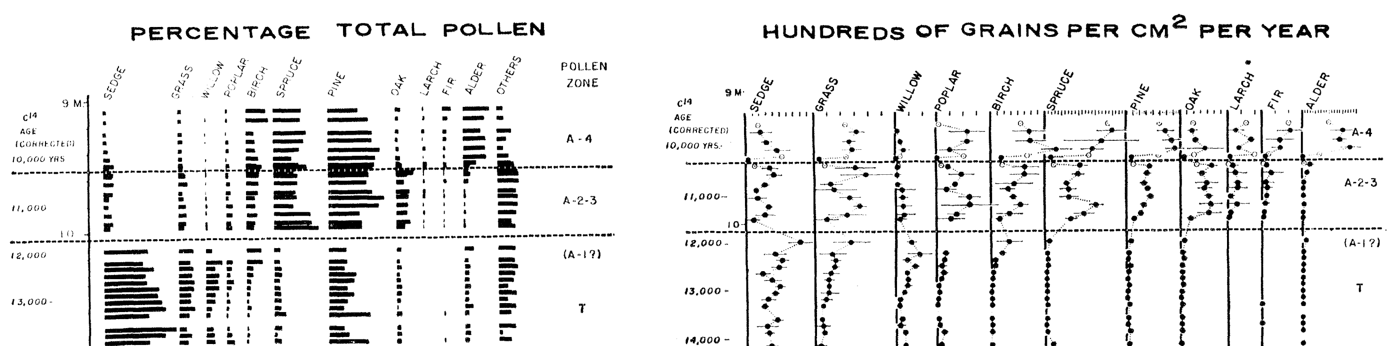


Fig. 3. Pollen rain. (*A*) Percentages of the major types of pollen, calculated as percent total terrestrial plant pollen, are shown plotted as bars; the ordinate indicates depth and absolute age of the sediment samples in which they were studied. (*B*) Accumulation rates of major types of pollen are shown as dots, with approximations to 95 percent confidence intervals indicated by horizontal lines. Open circles represent counts for which no variance estimate was made. Ordinate indicates depth and absolute age; several different scales have been used on the abscissa.

diagrams from sediments of similar absolute age at Totoket and Red Maple Swamp, Connecticut (*13, 16, 17*), there is no indication here of significant changes in the percentages of pine and spruce pollen within this zone. Zone T is overlain by a spruce pollen zone (A), which can be subdivided into a spruce-pine-oak subzone (A-2-3) and a spruce-fir-larch subzone (A-4). (Zone A-1 of Durham was not recognized here.) The increased frequencies of tree pollen and accompanying macrofossils of trees (at other sites) are generally interpreted as representing forest (*13–15*). The maximum percentage of oak and pine pollen in subzone A-2-3 throughout southern New England has been the ground for interpreting this subzone as warmer (mixed boreal and deciduous trees) than the overlying subzone A-4 (boreal trees); our corrected C^{14}-dates, however, do not support the previous belief that the oak-pine maximum of A-2-3, the deposition of which ended 10,300 years ago, correlates with the Two Creeks time-interval ending 11,800 years ago (*6, 13, 14, 17, 18*).

When the pollen frequencies are expressed as accumulation rates, the resulting absolute pollen diagram (Fig. 3*B*) supports the previous interpretation of a major change in vegetation at the time of transition from zone T to subzone A-2-3. The increase in total pollen deposition from 1000 in zone T to 6000 per square centimeter per year in subzone A-2-3 results from a major increase in the number of grains of tree pollen reaching the sampling point, presumably because of the arrival or increase of trees which augmented the pollen productivity of the local vegetation. The implication of the percentage diagram (Fig. 3*A*), namely that incoming trees supplanted nonarboreal vegetation, is misleading; Fig. 3*B* shows that deposition of sedge pollen continued with little change in accumulation rate, while the rate for grass pollen actually increased on an absolute basis along with tree pollen. Within zone A, the major change shown by the absolute diagram, in contrast with the percentage diagram, is a continuing increase in the rate of accumulation of conifer pollen; this rate reaches maximum values in A-4, while the accumulation rate of oak pollen does not change very greatly. The characteristic drop in the percentage values for oak and pine pollen in A-4 has hitherto been considered to indicate a decrease in the abundance of oak and pine trees in response to climatic cooling associated with the end of the Two Creeks interval. The data presented in Fig. 3*B* show, however, that at Rogers Lake the decrease in oak pollen is mainly an artifact of the presentation of data in the form of percentages. The number of grains of oak pollen reaching the sampling site in subzones A-2-3 and A-4 changed very little within the limits of accuracy of our assay; oak pollen makes up a smaller percentage of the total in A-4 largely because the total itself had increased from 6000 to 9000 per square centimeter per year. In a similar manner the percentage diagram masks the continuing increase in the rate of pine pollen accumulation through subzones A-2-3 and A-4. Our new data show further that the increased rate of accumulation of all types of tree pollen at the lower boundary of subzone A-2-3 was of far greater magnitude than is implied by the changes in percentages; in fact tree pollen is so scarce in zone T that changes in the ratios among the different types, indicated in percentage diagrams from Totoket and other sites and previously interpreted as evidence of climatic oscillations, may represent statistical artifacts rather than significant vegetational changes.

The amount of pollen deposited at one point on one lake bottom is not necessarily proportional to that deposited over the whole surface of the lake, nor is the latter necessarily related in any systematic way to the abundance and distribution of vegetation. The successful development of methods for studying the absolute pollen rain in the past, however, provides us with the first step toward more accurate use of the pollen record. The possibility that accumulation rates provide reliable indices of the absolute abundances of plants on the landscape is worth pursuing; it would allow a completely objective interpretation of results such as those from Rogers Lake (*19*).

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References and Notes

1. L. von Post, *Geol. Fören. Stockholm Förh.* **38**, 383 (1916).
2. K. Faegri and J. Iversen, *Textbook of Modern Pollen Analysis* (Munksgaard, Copenhagen, 1950).
3. L. J. Maher, *Bull. Geol. Soc. Am.* **74**, 1485 (1963); L. D. Potter and J. Rowley, *Botan. Gaz.* **122**, 1 (1960); M. B. Davis and J. C. Goodlett, *Ecology* **41**, 346 (1960); W. S. Benninghoff, *Mich. Acad. Sci. Papers* **45**, 41 (1960).
4. M. B. Davis, *Am. J. Sci.* **261**, 897 (1963); F. Fagerlind, *Botan. Notiser* **1952**, 185 (1952).
5. M. Tsukada, *J. Inst. Polytech. Osaka City Univ. Ser. D* **9**, 217 (1958).
6. J. G. Ogden, *Am. J. Sci.* **257**, 366 (1959).
7. M. Stuiver, E. S. Deevey, I. Rouse, *Radiocarbon* **5**, 312 (1963).
8. M. B. Davis, in press.
9. We are indebted to T. Downs and A. Schork for suggesting the following formula for calculation of confidence limits: confidence limit ab =
$$ab \pm 2\,(V_a b^2 + V_b\, a^2 + V_a V_b)^{\frac{1}{2}},$$
where ab is the accumulation rate, a is the absolute pollen frequency, V_a is the variance of the absolute pollen frequency estimate, b is the sedimentation rate in centimeters per year, and V_b is the variance of estimate of the least-squares line.

→ E. S. Deevey and M. Stuiver, *Limnol. Oceanog.* **9**, 1 (1964).

11. E. S. Deevey, *Am. J. Sci.* **238**, 717 (1940).
12. ———, *Proc. Intern. Assoc. Theoret. Appl. Limnol.* **15**, 981 (1964).
13. E. B. Leopold, *Proc. Natl. Acad. Sci. U.S.* **52**, 863 (1956).
14. M. B. Davis, *Am. J. Sci.* **256**, 540 (1958).

→ G. W. Argus and M. B. Davis, *Am. Midland Naturalist* **67**, 106 (1962).

16. N. Beetham and W. A. Niering, *Am. J. Sci.* **259**, 69 (1961).
17. E. S. Deevey, *Verhandel. Geobotan. Inst. Rübel, Zürich* **34**, 30 (1958).
18. W. S. Broecker and W. R. Farrand, *Bull. Am. Geol. Soc.* **74**, 795 (1963).
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Pentaborate Polyanion in the Crystal Structure of Ulexite, $NaCaB_5O_6(OH)_6 \cdot 5H_2O$

Abstract. *Triclinic ulexite crystals contain isolated borate polyanions* $[B_5O_6(OH)_6]^{3-}$ *related to the well known pentaborate polyanion* $[B_5O_6(OH)_4]^-$ *by addition of two hydroxyl groups to two opposite B-O triangles. The isolated ulexite polyanions form the* $[B_5O_7(OH)_4]_n^{3n-}$ *chains previously found in crystals of the related mineral probertite,* $NaCaB_5O_7(OH)_4 \cdot 3H_2O$.

The pentaborate polyanion $[B_5O_6(OH)_4]^-$ consists of a central borate tetrahedron and four $BO_2(OH)$ triangles, each sharing one corner with the tetrahedron and linked in pairs to produce two six-membered alternating B-O rings in approximately perpendicular planes. This polyanion was found initially by Zachariasen (*1*) in the crystal structure of potassium pentaborate tetrahydrate; the structural formula $[B_5O_6(OH)_4]^-$ was proposed by Christ (*2*) and confirmed by Zachariasen and Plettinger (*3*) in their refinement of the structure.