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# PROBLEMS IN THE INTERPRETATION OF POLLEN DIAGRAMS OF MINERAL SOILS

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## SUMMARY

The theories of pollen homogenization and of differential decay of *Quercus* pollen in Pleistocene cover sand soils now showing a podzol profile, adduced in earlier papers, are disputed by some palynologists. In the present article they are supported by various palynological, ecological, pedological and experimental arguments.

Two examples from published evidence, relating to a loess and a cover sand soil respectively, are given to demonstrate that pollen analysis of mineral deposits with a minute pollen concentration may easily lead to the wrong conclusions.

It is now generally assumed that pollen diagrams of mineral soils, particularly more or less acidic sandy soils having little or no biological activity, can provide valuable information on the vegetational history in the close vicinity of the profiles investigated. There are, however, still a number of unsolved problems related to the exact interpretation of such diagrams, e.g. such questions as the development of a pollen profile[2] in a mineral soil and the possible distortion of pollen spectra as a result of differential pollen destruction. These are the main topics discussed below.

There are three current theories as to how pollen may enter a mineral soil, viz.:

1. downwash of free pollen grains;
2. the pollen grains are enveloped in humus aggregates but released by microbial decomposition of these aggregates and then subjected to downwash and microbial attack;
3. mixing of pollen in the soil by the activity of the soil fauna and simultaneous microbial attack (downwash is often an additional process).

Pure downwash of pollen grains occurring as free particles between the mineral and organic soil particles (1) is not likely to be an important process, as microscopic examination of the soil interior revealed that the pollen grains were enclosed in minute aggregates of organic matter which was more or less decomposed, or else enveloped by minute mineral particles (Munaut, 1967, p. 138). It is also known that the depths to which pollen grains may infiltrate a soil is independent of their diameter (cf. Havinga, 1962, p. 62).

The other two theories deserve a more detailed discussion.

Basing their theory (2) on Erdtman's (1943, a,b) hypothesis, Munaut (1967) and Guillet (1972) assert that most of the pollen grains in a mineral soil would hardly be able to move downward when enclosed in the humus aggregates. The latter would gradually decompose as a result of microbial attack, releasing part of the pollen grains. But the more highly degraded (podzolized) the soil, the more slowly would this process proceed. The pollen grains released would sink but be recaptured by other aggregates, and this process could be repeated several times over. During the release phase a certain part of the grains would be attacked by micro-organisms and possibly destroyed.

The process would proceed fairly rapidly in biologically more active soils, e.g. acidic brown soils with mull humus, resulting in a pollen profile which only records a comparitively small fraction of the vegetational history. The cycle is slower in podzolic soils with moder humus and very slow or absent in podzols, corresponding to the severely reduced biological activity. In such cases the pollen history is long or very long.

Starting from the above theory, Guillet (1972, p.31) found an easy explanation of the fact that the pollen diagrams of certain podzol profiles cover a far larger part of the Holocene vegetational history than those of neighbouring brown forest soil profiles, in spite of the fact that the former had the coarsest soil texture, lowest clay content and greatest permeability. Apparently pollen migration was most rapid in the latter profiles.

Unlike Havinga's theory (3) (1962; 1963), this theory takes little account of the soil-mixing activities of earthworms. According to Havinga, homogeneous brown forest profiles may be assumed to have preceded most of the present (dryer) podzol profiles found in cover sand soils. During this earlier stage the pollen profile would also have had a homogeneous character, i.e. it would have consisted of pollen spectra representing one Holocene period only.

The pollen profile would have differentiated during the

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[2] By pollen profile is meant the vertical distribution of the pollen in the soil, as shown by the pollen diagram.

subsequent podzolization stage, when the depth and intensity of the homogenization gradually decreased in accordance with a retrogressive biological activity (cf. Iversen, 1969). Below the homogenization zone, which is being reduced in thickness, the microbial attack of the pollen would have been substantially halted, so that here the pollen spectra would have been preserved instead of being rejuvenated. In this way increasingly younger spectra were added to those already fixed and in the course of time a pollen profile developed covering a larger part of the Holocene period.

Downwash of (free or enveloped) pollen grains would only have become an important factor when finally it was no longer or only partly counteracted by homogenization.

Where the soil profile morphology indicates very wet soil conditions, or other soil conditions unsuitable for the soil fauna since the formation of the vegetation profile, a pollen profile will be formed from the start as a result of downwash (cf. Havinga, 1962, p. 64; 1963, p. 22). (Munaut (1967, p. 141) and Guillet (1972, p. 31) wrongly suggest that Havinga's theory would rule out downwash as a possible contributive factor).

Munaut et al. (1968) partly revive the pollen homogenization theory by stating that its significance has still not been properly assessed because the initial homogenization phase has never been studied palynologically.

However, Guillet (1972) and Billard et al. (1971) did not even find homogeneous pollen profiles during their analyses of biologically fairly active acidic brown soils. It may, however, be doubted whether this is a valid argument against the theory.

As biological activity in a soil usually decreases with increasing depth below the soil surface, an obvious assumption is that the process of rejuvenation of pollen spectra slows down in the same direction, in other words a pollen profile in a soil with fairly intense biological activity may show a certain differentiation in older and younger spectra successively. The range of differentiation will depend on the kind and intensity of the dynamic and (micro-) biological processes occurring at the different depths.

This would seem to tally with Havinga's previous theory of retrogressive biological activity and its effect on pollen homogenization.

The theory of a cyclic process of aggregation and mineralization of humus and entrainment and recapture of released pollen grains runs counter to the findings of various micro-pedologists that the pores between the mineral and organic particles in a cover sand soil usually form a continuous space (A. Jongerius[3], private communication, 1974). Admittedly the system is not entirely free of interruptions, but they are not frequent enough to prevent a continuous water flow washing down the pollen grains (enveloped by humus) and other particles in suspension. Only a small proportion may be stopped as Munaut assumes; this may increase as the soil becomes more highly podzolized.

Iversen (1969, p. 39) agrees with the present author that the differentiation within pollen diagrams of bleached sand of podzolized soils may be largely the result of retrogressive biological activity during an earlier stage of soil formation. From a find of cultural remains of mesolithic hunters (Early Boreal Period) at a depth of about 25 cm, at the top of a hardpan in a podzolized soil in Glacial cover sand, he infers the existence of a mull eco-system on the same site. The remains had sunk into the soil as a result of earthworm activities at the time.

Heim (1966) also described a podzol profile containing mesolithic artefacts. These were found in the bleached eluvial horizon at some distance above the brown illuvial B horizon. For this case the same interpretation was given by the present author (Havinga, 1968).

One should not lose sight of the possibility that in the soil already podzolized some sand may have been carried from below to the original soil surface by the scarce fauna (ants etc.) to be found in such soil (Keilhack, 1899). But Havinga (1962, p. 60), when making a palynological investigation of a dry podzol profile containing a layer of pebbles at some depth below the soil surface, showed that such a process could only have a very slight effect.

Experimental studies of the effect of earthworms on pollen distribution in the soil also favour the homogenization theory. Thus it was shown by Ray (1959), by means of pot experiments, that earthworms ingested pollen added to the soil surface and rapidly distributed it over the soil.

Similarly, Walch et al. (1970) showed that worms also move the pollen grains in the soil in an upward direction.

These results are confirmed by experiments performed by Dimbleby (in press; private communication, 1974) under field conditions.

Bastin (1971, p. 111) after an analysis of the pollen floras in certain loess soils, also concluded that the soil fauna must be an important factor in the formation of a pollen profile. He found a high concentration of pollen grains in the dark grey humic A horizon of the loess profiles and also a high concentration of earthworms. Both decreased rapidly towards the bottom of the A horizon.

Below this horizon the pollen grains appeared in a very low concentration, but there was no reduction further down. In view of this and the fact that the proportion of larger pores (diameter 50-250$\mu$) in the total was constant throughout the entire profile (including the A and the C horizon), Bastin concludes that the pollen in the loess below the A horizon must have been deposited together with this sediment during the Glacial Period.

It should not be forgotten that the total porosity and hence the number of larger pores is much greater in the A horizon than below (a fact which has wrongly been ignored).

Bastin does not, however, rule out the possibility of some pollen grains having infiltrated the deeper soil layers at a more recent date.

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The author's conclusions from the vertical course of the pollen concentration seem rather speculative and in any case they exaggerate in denying the possibility of somewhat greater pollen infiltration. This emerges from the results of Havinga's (1957) pollen analysis of a Pleistocene cover sand deposit in which a podzol profile was found. In this case a comparable course of pollen concentration was encountered. It was high in the upper part of the podzol profile, declined downward, and in the unaltered sand below the profile it was found to be very low without any further decline. Pollen grains were found as far as underneath another, thin, fossil soil profile which occurred at a depth of about 40 cm below the bottom of the podzol profile. It was white in colour and identified as an Usselo profile dating from the Late-Glacial Alleröd Oscillation.

The pollen assemblages found in, above and below the buried profile are shown in Table 1.

The Alleröd layer contained many spores of *Selaginella* and pollen grains, most of the latter being unidentifiable owing to their badly pulverized state[4]. The scarce pollen grains above and below the layer, as well as a minor proportion of the pollen grains inside it, hardly showed any corrosion phenomena.

In this example the thermophilic grains (Alnus, Corylus, Tilia) are obviously due to downwash.

The comparison with Bastin's analyses its not wholly justified, as that author investigated a much more fine-granular sediment to a far greater depth.

Whenever the pollen concentration in a soil is very low, the composition of the pollen assemblages may easily have been influenced even to the extent that it has radically changed, by processes such as long-distance dispersion of pollen and secondary translocation at the time of deposition of the pollen (and the sediment in which it is found), and pollen infiltration in deeper soil layers after the time of deposition. Pollen spectra from such mineral deposits as cover sand and loess (below the vegetation profile) should therefore be interpreted with great caution.

In this connection some discrepancies may be pointed out in the results of Bastin's (1971) palynological investigation of loess profiles, which may partly be due to one or more of these factors.

In his diagram Rocourt I *Pinus* dominates among the trees during the time preceding the Amersfoort Interstadial, whereas *Betula* is the most important tree in the latter period and the thermophilic *Quercus* during the subsequent cold Glacial stage.

Table 1. Pollen assemblages in Pleistocene cover sand, above, in (at 41.5 cm) and below an Alleröd layer several dm below the bottom of a podzol profile.

| cm below bottom of podzol profile | Absolute numbers | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Alnus | Betula | Pinus | Salix | Tilia | Corylus | Ericaceae | Gramineae, and Cyperaceae | Filicinae | Sphagna | Varia | Total |
| 31.5 | 1 | – | 18 | – | 1 | 9 | 1 | 2 | 10 | – | 28 | 70 |
| 41.5 | – | 1 | 26 | 2 | – | 14 | 38 | 13 | 28 | 10 | 88 | 220 |
| 51.5 | 2 | 1 | 3 | – | 1 | 4 | 6 | 1 | 5 | 6 | 8 | 37 |

The pollen spectra representing cold stages during the Early Glacial and Pleni-Glacial in the Rocourt diagram show very high *Salix* and non-arboreal percentages, and very high non-arboreal percentages in the Tongrinne diagram. Apparently the tree pollen, apart from the *Salix* pollen, does not originate from the more local vegetations but represents a regional vegetation. Yet *Alnus, Corylus* and *Quercus* often show values approximating or exceeding those found for the cold species *Betula* and *Pinus* in the same spectra.

These remarks should not, however, be taken as a categorical denial of the possible occurrence of thermophilic tree species during the Würm Glacial Period in the region in question, as assumed by Bastin.

Pollen in mineral soil is usually more or less liable to decay. Various species may show varying degrees of susceptibility, depending, for instance, on the type of soil (Havinga, 1971).

A moot point is the susceptibility to decay of *Quercus* pollen in sand soils. Pollen spectra of podzol profiles in the Pleistocene cover sand regions in the Netherlands and northern Belgium usually show low *Quercus* values (Florschütz, 1941; Havinga, 1962, 1963; Munaut, 1967) except where the morphology of the profiles indicate wet soil conditions (Havinga, 1962, 1963).

On the other hand podzol profiles in sand of a different origin (type) in the hilly regions of central Belgium (Munaut, 1967) and mountainous regions of north-eastern France (Guillet, 1972) yielded pollen diagrams showing high *Quercus* percentages. This seems to support Munaut's and Guillet's theory that *Quercus* is always represented in the pollen record according to its proportion in the former vegetations.

I previously stated (Havinga, 1962, 1963) that the low *Quercus* values in the cover sand soils were due to differential decay, and despite the experience of the other authors I still adhere to this view, which implies that probably even slight differences in soil conditions may affect the behaviour of a fossil pollen flora in a mineral soil.

The following arguments support this theory.

Several pollen diagrams from the Pleistocene cover sand regions show high *Tilia* percentages, indicating the former existence of lime forests. In The Netherlands these existed during the Atlantic, and in Belgium during the Atlantic and Subboreal Periods.

In Munaut's diagrams *Corylus* often dominates in the pollen spectra above the zone with *Tilia* dominance, which he takes to mean that the lime forests were succeeded by

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[4] Fragmentation of pollen grains is also found in Alpine podzols (Pop et al., 1966).

hazel forests. As in a lime forest, the intense shade in the latter type of vegetation would have prevented the growth of young oak trees, so that oak forests could not even have developed after the disappearance of the very shady lime forests.

Several of Munaut's diagrams show high or fairly high *Calluna* percentages in combination with the high *Tilia* or *Corylus* values. His two Lommel diagrams and the Dutch diagrams have high *Calluna* percentages together with a high *Alnus* representation. Here *Corylus* is usually second and only exceptionally exceeds *Alnus.*

If it is considered impossible that differential decay may have contributed to the composition of sand spectra, then we have to assume that their non-arboreal: arboreal ratios correspond to the extent to which the region in question was covered by an open vegetation or a more or less dense forest. This means that the above diagrams with high *Calluna* values must represent a fairly open vegetation. This contradicts Munaut's assumption of the occurrence of dense *Corylus* forests. However, the author does not argue consistently, as he also states that even the lime forests existing during the climatic optimum (Atlantic) would occasionally have had a more or less open character (see p. 46, the Testelt diagram).

It may also be questioned on ecological grounds whether dense *Corylus* forests existed during and after the Atlantic Period. Nowadays they only maintain their hold where pasturage or wood-cutting is practised. Could it be possible that the growth of the shrub was promoted by human intervention in the period preceding Neolithic agriculture (cf. Iversen, 1973, p. 62)? In any case this explanation does not apply to the diagrams showing *Alnus* dominance.

*Betula* is another species which may have come to the fore during and after the disappearance of the lime forests. In the Mechelse Heide diagrams of Munaut (1967, p. 76), for instance, both *Corylus* and *Betula* are abundantly represented in Subboreal spectra with much *Tilia*. It is difficult to image that *Quercus,* which is a less light-demanding tree than *Betula*, did not form a substantial part of the tree growth at the same time.

According to plant ecologists the Querceto-Betuletum is the natural vegetation on the poor Pleistocene cover sand soils of north-western Europe. This occurrence includes the northern part of Belgium (Galoux, 1953; Bodeux, 1954). Nowadays the remnants are very scarce, but their existence should not be overlooked when assessing the significance of palynological research in this area.

Very interesting for the present study is the (former?) existence of oak groves in the extensive (former) heath region of Jutland (Denmark) as described by Müller (in: Ramann, 1886). These must have survived the destruction of the more or less natural oak forests. On the site of the groves the original brown forest soil profile had remained intact, but round about, under the heather cover, a podzol profile had developed.

Remnants of oak forest are also sporadically found in The Netherlands. Thus in the province of Drente, near the village of Norg, we find the Norgerholt forest, consisting of tall oak trees and a luxurious undergrowth of holly. In this province there are also some narrow strips of oak thicket bordering ancient arable lands, which is evidence of former oak forests. These arable lands were made by clearing the oak forests and then gradually raising the land over many centuries by adding manure partly composed of heath turves or forest litter. Below the present tilth layer, which may sometimes be about a metre thick a brown forest soil profile is commonly preserved, as it is below the Norgerholt forest and the oak thickets. Beyond the arable lands and oak vegetations mentioned the cover sand soil has generally podzolized.

Both brown forest and podzol profiles are found below burial mounds. The mounds date from the Neolithic or the Bronze Age, i.e. long before the old arable lands with the present-day layer of tilth had been reclaimed from the forests. The podzol profiles are more common below the latter mounds, and the brown forest profiles below the older ones. (Cf. Waterbolk, 1954).

At many places, however, podzolization may already have begun during the period of the primeval oak forest, long before the development of the anthropogenic heath moors. This must have depended on the special (e.g. wet) soil conditions. Evidence of such a situation was found during an archeological excavation[5]) of an ancient hamlet in the drift sand area of the village of Kootwijk (province of Gelderland). The settlement was blown by a thick deposit of drift sand during the second half of the first millenium A.D. In the podzolized soil below the drift sand several water pits were found made of huge oak trunks. They point to a former primeval oak forest in the neighbourhood of the excavation site.

Clearer evidence was supplied by Iversen (1964, 1969, 1973) who made a palynological examination of the forest floor of the very old Draved forest in Jutland. Analyses of the very thick mor-humus layer and a few samples from the podzolized sand below led to the following conclusions. During the Post-Glacial Warm Period the climax forest on the cover sand soil was dominated by *Tilia* with *Corylus* as pioneer, the humus type being mull, which must have promoted a rich soil flora and fauna. During the following millenia there was a retrogressive succession of the lime forest to an oak-lime and, finally, oak forest, the mull changing to a thick coprogeneous mor-humus (Iversen, 1969, p. 41, 43; 1973, p. 101, 108). Holly was found to be an important component, the role of hazel as a local pioneer after the fall of old trees being taken over by birch.

The pollen spectra representing the lime forest were found by Iversen in the podzolized sand, up to the transition to the covering mor layer. In Havinga's (1962, 1963) and Munaut's (1967) diagrams of podzol profiles they appear far below this point. A possible cause may be that in the Dutch and Belgian profiles, unlike the situation in the Draved forest, the podzolization process lagged considerably behind the retrogressive development of the vegetation. During the oak forest phase pollen infiltration could here apparently go on for some time (we may probably compare the situation in the present Norgerholt forest).

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Evidence of differential decay of *Quercus* pollen in podzolized sand soils is also revealed by a comparison of a pollen diagram from an organic subaquatic deposit in a small lake or small peat bog, with a diagram from a nearby podzol profile in the surrounding sandy soil.

Thus Havinga (1962, 1963) only found low *Quercus* percentages when analysing two podzol profiles near the Uddelermeer lake, whereas the tree clearly dominates in most of the pollen spectra of the diagram of the organic deposit in the lake (Polak, 1959). The same part of the Holocene Period is concerned in both cases. (In his dissertation Munaut (1967, p. 145) wrongly states that the high *Quercus* percentages in the Uddelermeer diagram must be ascribed to local *Quercus* growth at the site of the profiles analysed by Polak. The samples would have been taken from a peat bog containing abundant remains of oak wood. In fact the organic deposit consists of gyttja and dy, however).

*Quercus* also appears underrepresented when we compare Florschütz's (1941) III and V sand diagrams with his IV and VI peat diagrams respectively, and Munaut's Schaffen I sand diagram with the Schaffen IV peat diagram. Whether the tree would have grown on the peat soil, as assumed by Munaut (p. 55), remains to be proved.

In this connection it is also worth mentioning that pollen diagrams of soil profiles consisting of a peat layer on podzolized sand often show lower *Quercus* percentages in the sand than in the peat part (cf. the Epe, Staphorst and Peel diagrams in Havinga, 1962, 1963).

A too low representation of *Quercus* in sand spectra as compared with spectra from humic or peaty soil layers is also shown by Averdieck and Hummel (1974).

Lastly we may quote Jonassen (1950, p. 118), who concluded from his extensive palynological investigations of mud and peat deposits in the heath region of Jutland that the heath must have superseded the forest which on the plains had been predominantly oak.

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