# III BIOSTRATIGRAPHY

## IIIa LOCAL POLLEN ZONES AS A BASIS FOR THE PALEOECOLOGICAL RECONSTRUCTION

Biostratigraphy, like litho- and chronostratigraphy, aids the reconstruction of the paleoenvironmental evolution. Just as in Chs. II and V lithostratigraphy is used in the reconstruction of the sedimentary-geological paleoenvironment, so here and also in Ch. V biostratigraphy is used in the reconstruction of the vegetational development in that environment. For this purpose, palynological investigations of several cores have been carried out. The biostratigraphic zonation of the pollen sections studied has primarily a local significance: the local pollen zone is defined on the basis of the composition of the pollen deposition at a certain place and a certain depth in the sedimentary bed sequence. Because of this, the pollen zone is, in the terminology of the International Stratigraphic Guide (HEDBERG 1976, p. 50), an assemblage zone; one might speak of a local pollen assemblage zone.

The locally deposited pollen may be partly derived from the local vegetation, partly from the regional vegetation, partly, e.g. via rivers, from remote areas (the so-called long-distance transport), and partly from eroded older deposits. The interpretative discrimination of these components is in the first instance not taken into account in establishing the local pollen assemblage zone boundaries, for pollen zonation should be strictly descriptive: 'The pollen zone is a feature of the diagram alone' (FAEGRI 1975, p. 201). Discrimination between the components (local, regional, etc.) requires a comprehensive procedure. The pollen zones within the section should be compared with each other. The section should be compared to neighbouring sections. Additional paleobotanical results can play an important role (e.g. fruit analysis). The pollen zonation should be compared to the regionally established and possibly dated pollen zonation. Knowledge of the ecology of the species concerned is of course a prerequisite. In particular, the geological situation of the section should be known in detail: many variations in pollen sections (pollen diagrams) can be explained as a direct response to changes in the geological environment, especially where there are many vertical changes in lithology.

## IIIb METHODS

Slices of 1 cm thickness were taken from the cores (5 cm in diameter) to be studied by pollen analysis. With a 1 cm sampling interval in most cores consisting of peat, gyttja or peaty clay (see Ch. Ic), this resulted in contiguous sampling. In other cases, especially in clay beds with their usual sampling interval of 5 cm, non-sampled gaps remain. From the slices taken from the cores, the central part (c. 4 cubic cm) has been used for the preparation of the pollen residue. In the case of the standard boring, the remainder was used for fruit analysis.

The preparation of pollen residues from the samples involved the following phases: KOH pretreatment, sieving, light Schulze reaction (to remove as much plant tissue as possible), KOH post-treatment, acetolysis, bromoform separation, light HF post-treatment. The fruit samples were prepared by simply boiling in a 5% solution of KOH.

The pollen analysis was carried out with the aid of phase-contrast microscopes. Pollen grains were counted using manually operated counters (specially designed for this purpose), and accumulators on these allowed a constant pollen sum to be kept.

For each sample, all pollen and spore grains have been counted to a total of 300 tree pollen grains (pollen sum). Since the reconstruction of the local vegetation is central to this part of the study, none of the tree pollen species were left out of the pollen sum, as is sometimes done in more regionally directed studies to avoid local over-representation (e.g. for *Alnus*, see JANSSEN 1959; this is criticised however by TINSLEY & SMITH 1974, p. 562).

The local pollen zonation is in general based on changes in the tree pollen curves, in the AP (tree pollen)/NAP (herbs) ratio, and in the NAP curves of especially Gramineae, Cyperaceae and Umbelliferae. In the tables with the pollen-zone descriptions, generally only those pollen taxa are mentioned whose percentages differ significantly from the under- and overlying zones. These tables should be read from bottom to top. The fungal spores are not mentioned in these tables, but are briefly discussed in Ch. IIII.

It should be stressed that the pollen zonation is literally local for every single section. Thus the zone numbers do not relate to any of the regional zonations (e.g. that by ZAGWIJN & VAN STAALDUINEN 1975, p. 111 f.), nor is there any relation between the zone numbers of the individual sections in this study.

## IIIc POLLEN ANALYSIS OF BORING MOLENAARSGRAAF H1110 (STANDARD BORING)

### IIIc.1 Pollen zones

The lithology and lithostratigraphy of the standard boring of the Molenaarsgraaf study area have been discussed in Ch. IIa.1 (see also Table 1). For the topographical position see Fig. 3. The boring is situated c. 1 km north of the Hazendonk river dune. For the geological situation see Fig.*6 (profile I). The lithological sequence given in the pollen diagram (Fig.*12) and in Fig. 13 can be traced in profile I.

The following are represented from left to right in the pollen diagram: lithology, depth in cm below (mowing) surface, local pollen zones, sampling depths, tree pollen curves, AP/NAP ratio, NAP curves, spore curves. At the bottom, percentage scales are shown. The lines drawn within the shading of some spore curves show one tenth of the real values.

The studied section measures 9.20 m and comprises 466 samples. In the diagram 26 zones have been distinguished; these have been described in Table 3.

### IIIc.2 Some general remarks

Considering the whole diagram, the following zone boundaries can be observed as the main ones:

1. the transition from zone 8 to zone 9; the *Alnus* values below this transition are in general lower than above it, the reverse applies to the values of *Corylus*, *Pinus*, *Tilia* and *Ulmus*.

2. the transition from zone 20 to zone 21; this is characterised by a strong rise of *Fagus* values; the *Alnus* values decrease somewhat, but remain in general higher than below the transition from zone 8 to zone 9.

3. the transition from zone 22 to zone 23; here, the high *Alnus* values are restored.

Using these three zone boundaries, the 26 zones can be combined into four main zones: I (1-8), II (9-20), III (21-22), IV (23-26), as indicated in Fig. 13.

A comparison between the column with the pollen zones and the lithological column (Fig. 13), reveals a strong relationship between pollen deposition and geological development: most zone boundaries coincide with transitions in the lithology. From this comparison it also appears that in the organic beds more pollen zones have been distinguished than in the clastic beds. In the first instance, this may be explained by the fact that the sampling density is higher in the organic beds than in the clastic (clay) beds.

In Ch. II it was mentioned that the deeper organic beds (ol b, ol 1-2, ol 2a-2b, and the bases of ol 2-3 and of ol 3-4) have in general, in as far as plant remains are recognizable, been developed as *Phragmites* peat, whereas the higher organic beds have in general been developed as wood peat. Pollen zones 1, 3, 5, 7 and 9-10 (to a lesser extent also 16), that coincide with the mentioned *Phrag-*

*mites* peat beds (see Fig. 13), are characterised by high values of, among others, Gramineae, of which *Phragmites* is indeed the main component. The determination of *Phragmites* pollen is possible by making use of the phase-contrast adjustment on the microscope; this determination was carried out incidentally as a check. It is not unlikely that part of the Gramineae pollen derives from grasses other than *Phragmites*. For the environment under consideration (generally speaking, a fluviatile swamp environment), *Glyceria maxima*, *G. fluitans* and *Phalaris arundinacea* should be mentioned in particular (cf. VAN DONSELAAR 1961).

Pollen zones 11 to 20 and 23 to 26, coinciding with lithostratigraphic units ol 2-4 and ol u (see the scheme in Fig. 5) contain high *Alnus* percentages. These organic beds are generally developed as wood peat. Because of the high *Alnus* pollen percentages and also of a few wood-sample determinations, it may be postulated that most wood peat is *Alnus* wood peat. In most pollen diagrams from wood peat layers in the Western Netherlands, *Alnus* appears to dominate in the tree-pollen composition. In pollen diagrams Hazendonk I and Molenaarsgraaf I and II, published by LOUWE KOOIJMANS (1974, figs. 39, 66 and 67), — sections only 1 km distant from the standard boring under consideration here — *Alnus* values are high in peat beds that correspond lithostratigraphically with organic beds ol 2-4 and ol u. In pollen diagrams at Goudriaan and Benschop, published by VERBRAECK (1970, figs. 43 and 44; both sections from the eastern part of the fluviatile coastal plain), the *Alnus* curve shows high values in the wood-peat beds. Other examples of an *Alnus* dominance in pollen diagrams of stratigraphically comparable peat layers, can be found in JELGERSMA (1961, especially diagram Alphen aan de Rijn), PONS & WIGGERS (1959-60, fig. 34, a peat profile near Abcoude) and HARTMAN (1968, diagram Schipluiden).

## IIIc.3 Supply of pollen by river water

### Former investigations

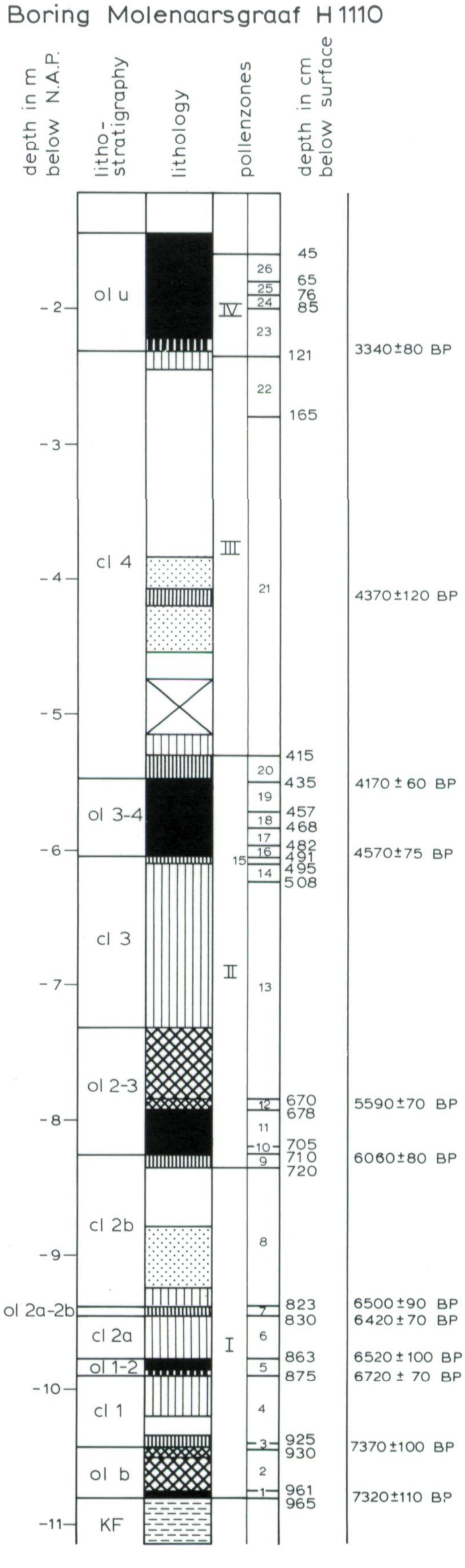
In interpreting the pollen content of river clay beds in the Western Netherlands, one has to take account of the supply of pollen by river water from the hinterland, especially the Rhine catchment area. This has been stressed by FLORSCHÜTZ & JONKER (1939, p. 690), ZAGWIJN (1965, p. 84), HARTMAN (1968, p. 9) and DE JONG (1970-71, p. 76). In this connection, *Picea*, *Abies* and *Fagus* are particularly mentioned, as well as *Pinus*. It is supposed by these authors, that part of the pollen of other species will also have been supplied by rivers. The special mention of *Picea*, *Abies* and *Fagus* is connected with the fact that these tree species did not occur naturally in the Netherlands in the periods concerned.

We think, in agreement with the above-mentioned authors, that part of the pollen in the deposits in the study area has been supplied by the large rivers from the whole catchment area, and thus from Middle Europe. Below, we shall deal with this question in detail, to see which pollen taxa were most strongly influenced by this fluvial transport.

### *Fagus*, *Abies* and *Picea*

The *Fagus* percentages in pollen zone 21 of the standard boring, which is situated entirely in clay bed cl 4, are so high (up to 25%), that, had there been only a slight influence of river-borne pollen, one would have to suppose a local growth of beech, for example on natural levees of the nearby Schoonrewoerd stream. According to the C-14 dates discussed in Ch. IV, the clay bed concerned was deposited during the middle part of the Subboreal. Such high *Fagus* values have never been found for this period in pollen sections from the Netherlands, at least not in as far as these sections relate to the local and/or regional vegetation; *Fagus* does not usually amount to higher than c. 1%. However, high *Fagus* values for the Subboreal are found in pollen sections from Middle- and South-

Fig. 13. Pollen zones in boring Molenaarsgraaf H1110 (standard boring). For lithological legend, see Fig. *9. The cross at 5 m below N.A.P. indicates a sampling hiatus formed by a piece of wood.



ern Germany, thus mainly from the German *Mittelgebirge* which forms an important part of the Rhine catchment area (FIRBAS 1949, p. 229 f.).
*Abies* and *Picea* are the only pollen taxa in the diagram which cannot have been derived from the regional vegetation, but instead must have been supplied from the hinterland. In Subboreal pollen sections from Southern Germany, *Abies* attains high values, as does *Picea* in some regions (FIRBAS 1949, p. 248 f. and 203 f. respectively). In zones 21 and 22, both situated in the Subboreal clay bed cl 4, *Picea* and *Abies* reach relatively high values.

### *Pinus* and *Tilia*

In order to define which other pollen taxa during the Subboreal may have been supplied to a significant extent from the fluvial hinterland, the pollen content of clay bed cl 4 may be compared to that of the under- and overlying (wood-)peat beds. Pollen taxa that occur mainly or nearly exclusively in the clay bed may be attributed more positively to river supply than taxa that attain about the same or higher values in the clay bed than in the peat beds. In this way, for this Subboreal clay bed, besides the pollen of *Fagus*, *Picea* and *Abies*, one may regard that of *Tilia* and *Pinus* as partly river borne. The remaining tree-pollen taxa and also most herb pollen may be regarded as mainly regional and local.
The section covering zones 4 to 8 in the pollen diagram coincides with clay beds cl 1 + cl 2 and the intercalated peat beds ol 1-2 and ol 2a-2b. According to the C-14 dates of the boring, this section can be dated as middle-Atlantic. In the study area three pollen sections of gyttja deposits (organic lake-deposits) have been studied, that correlate chronostratigraphically with this section ( cl 1 + cl 2) of the standard boring. These pollen sections are discussed in Chs. IIIg, IIIh and IIIk. The pollen content of these gyttjas differs strongly from that of the chronostratigraphically correlating clay beds of the standard boring with respect to the *Pinus* and *Tilia* percentages. These are generally much lower in the gyttja sections. Assuming that in principle air-borne pollen will be present in equal amounts in clay and in gyttja, the higher values of *Pinus* and *Tilia* in the clay beds can be explained by river supply.
A strong argument in favour of this, at least concerning *Pinus*, can be found in the simultaneous occurrence of *Fagus* and *Picea* at the depth of the *Pinus* maxima in zone 8 (the Atlantic clay bed cl 2; *Fagus* certainly did not grow in the Netherlands during the Atlantic). Very high *Pinus* values have also been found in the Atlantic clay beds of boring Leerdam S322 I (see Ch. IIId). Such high *Pinus* pollen sections scarcely occur in Atlantic pollen sections from the Netherlands. Again, such high values are mentioned by FIRBAS (1949, p. 133 f.) for certain parts of Middle- and Southern Germany, and thus for the fluvial hinterland. FIRBAS' appendix with pollen diagrams, especially figs. 87-92, is illustrative in this respect: pollen diagrams from lower regions within the *Mittelgebirge* in the western part of Germany show a strong *Pinus* dominance in zone VI (the older part of the Atlantic).
*Pinus* pollen has also been found in important percentages in the intercalating peat beds ol 1-2 and ol 2a-2b. These are however rather clayey developed (as *Phragmites* peat). Possibly, river-borne *Pinus* pollen is easily trapped in such a *Phragmites*-marsh environment because of its floating capacity (see also DE JONG 1970-71, p. 77). TRAVERSE & GINSBURG (1966) stress that aquatic deposition of *Pinus* pollen depends strongly on sedimentological factors such as turbulence. ZAGWIJN (1965, p. 85) noticed concentrations of *Pinus* pollen in the clayey, topmost bed of sedimentary sequences, which also points to increased *Pinus* pollen deposition at decreased turbulence and/or stream velocity.
*Pinus* pollen percentages that should not be ignored also occur in the wood-peat beds (ol 2-3, ol 3-4, ol u). This pollen may also have been partly supplied by river water, as the swamp forests were always influenced by eutrophic river water. But a regional component may nevertheless be present

here, as is recognized for the whole Holocene from most Dutch pollen diagrams.
The *Tilia* curve in the same section of the standard boring (zones 4-8) shows very pronounced maxima in the clay. In the Atlantic clay bed in the Leerdam study area (boring Leerdam S322 I, see Ch. IIId), *Tilia* also attains very high values compared to those in the peat beds. In the previously mentioned Atlantic gyttja sections from the Molenaarsgraaf study area (see Chs. IIIg, IIIh and IIIk) such high *Tilia* values are not generally found. The first two of these sections are situated in the river-dune field in the western part of the study area, and therefore exhibit the dry-tree growth on the river dunes. Moreover, *Tilia* values are generally not particularly high in Dutch pollen sections from Atlantic (organic) deposits.
As in the Subboreal, in the Atlantic an important part of the *Tilia* pollen will have been carried down by the rivers from the hinterland. That the *Tilia* pollen in the zones concerned should partly also have originated from a local source, is apparent from zone IV in gyttja section H2178 (Ch. IIIg): lime trees also occurred to some extent on the river dunes in that period.

With the comparative argument used here it can be shown next, that, during the Atlantic, *Quercus* pollen was partly supplied by river water from the far hinterland, albeit to a far lesser degree than *Tilia*—*Quercus* being the main tree on the river dunes (see Chs. IIIg, -h and -k), and that most other pollen taxa can be interpreted as more distinctly regional and local. Assuming the pollen content of the clastic (clay) deposits to be partly supplied by river water from the hinterland in periods that the Netherlands themselves were also rich in forests implies a very large supply of pollen by rivers to the coast. This conclusion was reached previously by HARTMAN (1968) in a palynological study of several cores of clastic sediment from the Western Netherlands, mainly by establishing pollen concentrations. In studies of marine palynology in Marine Geology 4 (see among others the beforementioned study by TRAVERSE & GINSBURG 1966) it has been shown that a lot of pollen, especially saccate grains such as *Pinus*, is transported by river water into the sea.

### Local circumstances and reworking

In the preceding paragraph, supraregional fluvial supply of pollen was contrasted with local/regional supply. A number of nuances are introduced in the interpretation of the pollen zones in the following sections, especially in connection with the lithostratigraphy and lithology and with paleoecological circumstances such as the structure of the vegetation. An example of the latter concerns the interception of pollen from e.g. the dune vegetation by the local vegetation of the wet areas and by bordering *Corylus*. An example of the former (the lithostratigraphy) is the quite characteristic development of clay bed cl 3 with its dominance of local tree pollen ( mainly *Alnus*) over supraregional tree pollen because of the fact that this clay bed has been deposited in an environment with many swamp-forest stands. Further, on the basis of lithological differences between the clay beds cl 1, cl 2a and cl 2b, the latter may be expected to show the strongest influence of river supply in its pollen content because of a larger density of fossil channel fills.
It will be very difficult to ascertain to what extent the pollen content of the clay beds consists of reworked pollen derived from underlying peat beds. In principle, this might be the case to some extent in every clay bed of the standard boring. This may be supposed in view of the fact that all four clastic beds (cl 1-4) contain channel fillings, indicating small rivers incised into older beds.

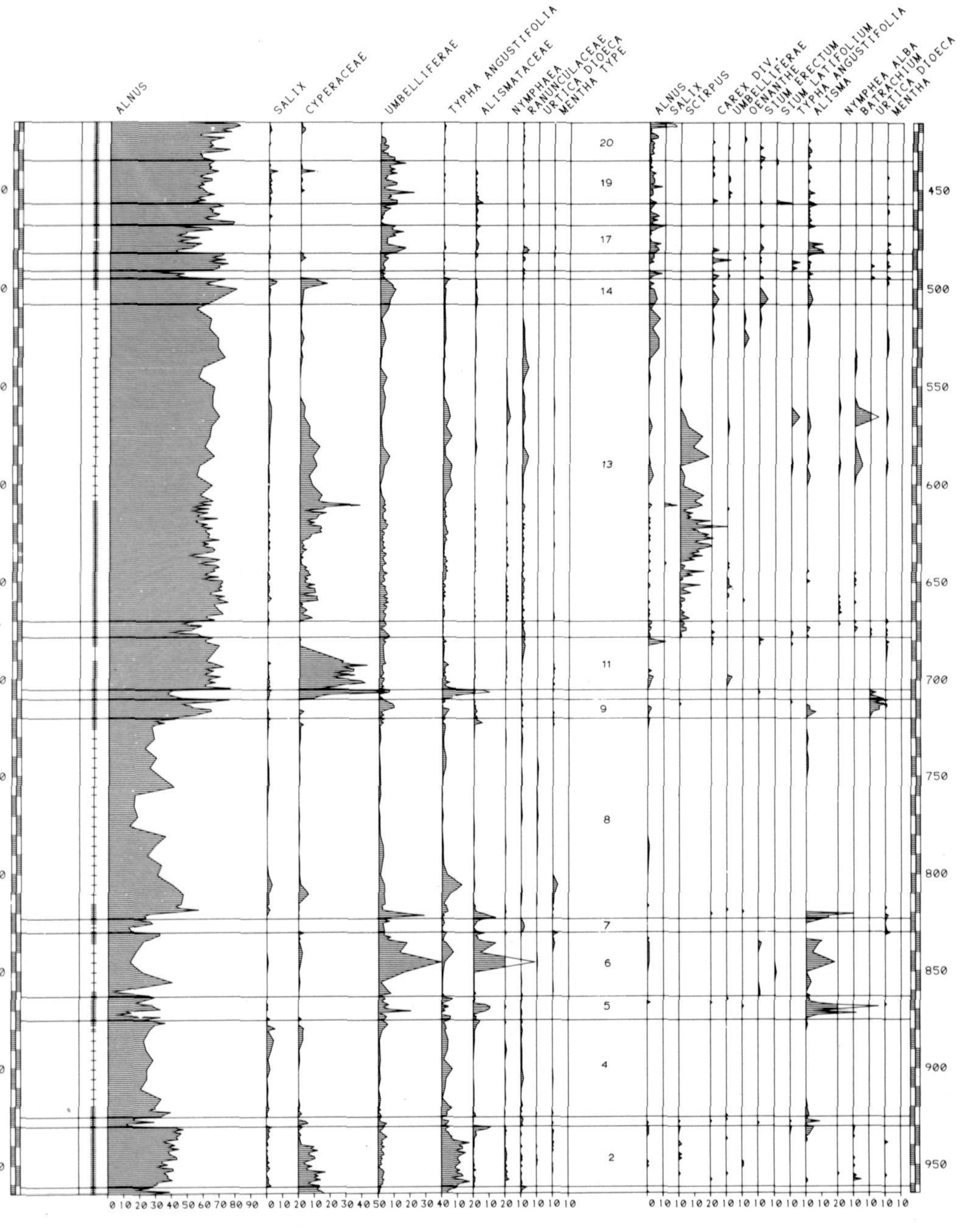


Fig. 14. Fruit diagram of boring Molenaarsgraaf H1110 (standard boring). The left part shows the pollen percentages, the right part the absolute fruit numbers. In between, the pollen zones are indicated.

## IIIc.4 Fruit analysis

### Local supply and depositional circumstances

The results of fruit analysis of the same core as used for pollen analysis (Fig. 14) may yield important supplementary information, especially concerning the local components in the pollen diagram. In view of this, it is supposed that the fruits have not been supplied over very long distances. This will hold for the clastic beds less clearly than for the organic beds. However, the longer the distance of river transport of the fruits, the more they will have been worn, and so the less easily they will be distinguished and counted. In the diagram (Fig. 14), the absolute numbers of fruits have been plotted. To enable comparison with the pollen percentages of identified fruits, the corresponding pollen curves from the diagram (Fig.*12) have been copied in the left half of Fig. 14. Taking into consideration several reservations regarding fluctuations in the fruit diagram due to differences in the volume of material sampled, the following statements and conclusions can be made.

Despite the differences in sampling interval between the clay beds and the organic beds, it can be stated that in clastic beds cl 1, cl 2b and cl 4 strikingly little fruit numbers have been found, especially when compared to cl 3. Clastic beds cl 2b and cl 4 consist generally of weakly humic, slightly sandy clay, cl 1 of weakly humic, non-sandy clay; beds cl 2a and cl 3 consist generally of strongly humic, non-sandy clay. Apparently, the higher energy environment of deposition of clay beds cl 2b and cl 4 was less suited to the production and/or deposition of fruits than the quieter environment of deposition of clay beds cl 2a and cl 3.

### *Alnus*, *Scirpus*, *Alisma*

Most *Alnus* fruits have been found in wood-peat beds ol 2-3 and ol 3-4, and also in the upper part of the intercalated clay bed cl 3. This agrees well with the *Alnus* pollen curve, and moreover confirms the importance of the boundary between pollen zones 8 and 9, which was pointed out above (Ch. IIIc.2) as the most important zone boundary on the basis of the *Alnus* pollen percentages.

*Scirpus* fruits have been found almost exclusively in the gyttja layers and in the lower part of the humic clay bed cl 3. The higher percentages of Cyperaceae pollen in the pollen zones concerned (zones 12 and 13), will have originated from *Scirpus* to a large extent. The most likely *Scirpus* species for the lacustrine environment of deposition of the gyttjas is *Scirpus lacustris*. The continuation of the higher *Scirpus* fruit numbers in the gyttja of organic bed ol 2-3 into the overlying humic clay bed cl 3 provides one of the indications that the clay of bed cl 3 has also been deposited in a lacustrine environment.

The fruits of all *Carex* species have been combined in one curve because of their low values. So far as identification to species level has been possible, the fossils are mainly *Carex disticha*, *C. pseudocyperus* and *C. acuta*, all of which are species of wet, eutrophic environments (HEUKELS & VAN OOSTSTROOM 1968).

One of the most conspicuous examples of the possible value of a fruit diagram in the interpretation of a pollen diagram can be found in the fruit curve of *Alisma*. Virtually wherever peaks occur in the *Alisma* pollen curve, peaks also occur in the fruit curve. This means that for *Alisma* pollen, and probably also for many other herb-pollen taxa, a local origin is more important than a regional one.

### *Batrachium*, Umbelliferae, *Urtica*

Just as *Scirpus* fruits make a narrower identification at genus level possible for a part of the Cyperaceae pollen curve, so do *Batrachium* fruits for the Ranunculaceae pollen. A number of peaks in the Ranunculaceae pollen curve coincides with peaks of the *Batrachium* fruit curve. *Batrachium* fruits

have been found exclusively in the gyttjas of organic bed ol b and ol 2-3 and in the humic clay bed cl 3 (pollen zones 2 and 12+13). *Batrachium* would grow well in the lacustrine environment of deposition of the gyttjas and possibly also of the humic clay bed cl 3.
The large family of Umbelliferae, one of the most important herb-pollen taxa, is represented in the fruit diagram to some extent as *Oenanthe aquatica*, *Sium erectum* and *S. latifolium*. Fruits have also been found of Umbelliferae not specifically identified. The three species named above are typical of a fresh-water marsh environment.
*Urtica* pollen has only rarely been found in the standard boring. Additional information can be obtained from the fruit curve, where, at the depth of pollen zone 9, a large number of *Urtica* fruits have been identified. In a similar way, VAN DER WIEL (in prep.) found *Urtica* fruits in a peat section at the border of the Hazendonk river dune, at a level where high *Urtica* pollen values would be expected (on the basis of archeological arguments) but were absent. She ascribes this to oxidation of the thin-walled *Urtica* pollen because of water-level variations. This explanation, particularly a temporary fall of the average local water level, possibly also applies to the above-mentioned zone 9 of the standard boring (see Ch. IIIc.5).

Several of the most abundant fruits (among others *Alisma* and *Batrachium*) have also been found by FLORSCHÜTZ & JONKER (1939) in a section near Wijk bij Duurstede, situated near the northeastern border of the fluviatile coastal plain of the Western Netherlands.

### IIIc.5 Interpretation of the pollen zones

In the interpretation of the pollen zones of the standard boring, regular reference will be made to the lithological background, especially to the profiles (Figs.*6,*7 and*8) and the lithostratigraphic scheme (Fig. 5). Although in Ch. V an integrated paleoecological reconstruction of the various landscape elements in the study area is given, in this section several of these landscape elements are involved in the interpretation of the pollen zones. This particularly concerns the river dunes, the natural levees and the stream ridges. Stream ridges in the immediate vicinity of the standard boring stand out clearly in profile I (Fig.*6). The position of the river-dune complex is shown in Fig. 36 (Ch. V), which illustrates the extent of dune sand and *loam* in the whole study area. This map also shows isolated small river dunes outside the larger dune complex. Near the standard boring, dune sand was found in a channel fill of bed cl 2b in such quantities, that in the direct surroundings of the standard boring a small, low river dune had probably also been present, but had been eroded away completely by the time bed cl 2b was deposited. At every point in the study area one should appreciate the likelihood that a small, low river dune exists or existed in the immediate vicinity: despite the high density of borings, the probability of hitting just the smallest river dunes is not very large.

**Zone 1** (965-961 cm below land-surface). In these lowest 5 cm of the organic accumulation on the surface of the Kreftenheye Formation, the high *Pinus* pollen values should probably be ascribed to a remnant of (early Holocene) *Pinus* forests on the river dunes. On the highest parts of the *loam*-surface *Tilia* might have been growing, in view of the lower *Tilia* pollen values in the overlying zone, by which time these higher parts of the *loam*-surface became wetter. On the somewhat lower and wetter places *Alnus* stands occurred and on the lowest places grasses (probably mainly *Phragmites*), Cyperaceae, *Typha angustifolia*, *Valeriana* (possibly in connection with the eutrophy of the *loam*-subsoil) and Ranunculaceae (*Ranunculus lingua*?; no finds of *Batrachium* fruits in this zone). In the landscape with its pronounced relief — the lows in the relief of the Kreftenheye Formation had not yet been filled —, *Corylus* would have blossomed along the many forest edges.

**Zone 2** (961-930 cm). At the locality of the boring a small, shallow lake was present. This is shown not only from the lithology (a gyttja), but also from the pollen of *Nymphaea* and *Nuphar*. The limited extent and depth of the lake is indicated not only from the lithology (it is a rather peaty gyttja pointing to shallow water and/or proximity of the shore) and the lithostratigraphic profile (Fig.*6), but also from the nearby presence of *Typha angustifolia*, Cyperaceae, *Sparganium*, Gramineae and Cruciferae (*Rorippa* and/or *Nasturtium*?), which would grow close to the shore and at shallow places in the lake. The fruits of *Batrachium* confirm the open-water nature of the environment of deposition.

Away from the lake, going from low to high on the surface of the Kreftenheye Formation, grew *Alnus* and *Salix*, *Fraxinus* and *Ulmus*, and *Quercus*, with *Corylus* in the undergrowth and along the forest edges. *Pinus* seems to have largely vanished.

The increase of *Alisma* and *Typha angustifolia* in the topmost part of the pollen zone points, together with the lithology (the gyttja is peatier in the upper part), to an environment with less open water, in other words to a partial infilling of the lake by plant growth.

**Zone 3** (930-925 cm). This narrow zone is situated just at the lithostratigraphic transition from the gyttja-like peat to the overlying clay. Both the *Quercus* and the *Alnus* stands seem to have decreased strongly, at least locally. In contrast, *Corylus* occupied a more important place on the somewhat higher parts of the landscape: in the underlying zones *Corylus* was probably found mainly as undergrowth and along the forest edges, but now it may have invaded, together with *Hedera* and *Viburnum*, the open places in the forest. In the lower parts of the landscape the vegetation of *Phragmites* with ferns (probably *Dryopteris thelypteris*) expanded. According to the fruit analysis, in the *Phragmites* vegetation locally occurred *Alisma* as a continuation from the top of the underlying zone.

The isolated peaks of *Pinus* pollen may point to local remnants of *Pinus* on the highest parts of the river dunes, its pollen being probably less effectively filtered out because of the supposed decrease in the *Quercus* stands.

**Zone 4** (925-875 cm). On the river dunes not only had the *Quercus* vegetation apparently been restored, but also *Tilia* had occupied a (more important) place. Along the borders of the dunes, at the transition to a wetter environment, *Ulmus* would have been growing, and there may also have been important *Corylus* growth along the forest edges. *Ulmus*, *Quercus* and *Corylus* may also have been growing locally on possible natural levees of the small gully situated nearby, the filling of which has been found in clastic bed cl 1; zone 4 completely coincides with clay bed cl 1 in the standard boring.

The peak of *Pinus* pollen at 910 cm depth coincides with an isolated find of two *Fagus* pollen grains. As *Fagus* had not yet immigrated into the Netherlands in the period of deposition of this clay bed (c. 7000 BP, see Ch. IV), its pollen had apparently been supplied by river water from the hinterland, and this will also have been the case with part of the *Pinus* pollen as well (see also Ch. IIIc.3).

In the marsh itself, *Alnus* stands would have been present on the somewhat higher parts, with borders of *Salix*, hygrophilous grasses (mainly *Phragmites*), *Sparganium*, ferns and *Typha angustifolia*. At the transition to the overlying zone, and thus towards the end of the clay sedimentation, the vegetation of grasses (*Phragmites*) expanded strongly, together with *Alisma* and Cruciferae.

The most likely Cruciferae for this wet environment are the genera *Rorippa* and *Nasturtium*. However, the possibility that part of the Cruciferae pollen at this depth in the section has been derived from a ruderal vegetation on a small, nearby river dune should not be excluded in view of a presumed Mesolithic prehistoric occupation in the area, dated at 6900 BP (see Chs. IIIi and IVb.1).

Table 3. Description of pollen zones in boring Molenaarsgraaf H1110 (standard boring).

| | |
|---|---|
| 26 | 65-45 cm. Alnus values high, slightly decreasing in the top, where Salix increases. Higher Pinus values. AP/NAP-ratio again as in zone 23; Umbelliferae values still important. |
| 25 | 76-65 cm. Restoration of high Alnus values. Salix values remaining important. Fagus values slightly increased. Decrease of AP/NAP-ratio by very high values of Umbelliferae. Increase of Cruciferae, Alisma and Rubiaceae. |
| 24 | 85-76 cm. High Salix values. Decrease of Alnus. Rather important values of Fraxinus. At 83 cm small peaks of Compositae tubuliflorae and Ranunculaceae. |
| 23 | 121-85 cm. High values of Alnus. Rather low values of Corylus, Fagus and Tilia. Salix and Pinus continuously present. Picea practically disappeared. Rather high AP/NAP-ratio. Some small peaks of Cyperaceae. Important increase of Umbelliferae. Small peaks of Cruciferae, Plantago lanceolata, Ranunculaceae. Fern spores strongly decreased. High values of Bryophyta. Maximal values of Zygnemataceae. |
| 22 | 165-121 cm. Fagus values decreasing to zero. Important values of Pinus and Picea. Salix practically absent. Values of Corylus, Quercus and Tilia decreasing in the top of the zone. There also lower AP/NAP-ratio, due to peaks of Cyperaceae and Cruciferae (together with some Cerealia grains). Rather important values of fern spores; increase of Bryophyta. |
| 21 | 415-165 cm. High Fagus values. Alnus values variable, generally lower than in zones 9-20. Salix nearly continuously present. Pinus values low, rising in the top of the zone. Maximal Picea value in this zone. Important values of Corylus, Quercus and Tilia. High AP/NAP-ratio, fluctuations clearly related to Gramineae curve. Small peaks of Cyperaceae, Umbelliferae, Ranunculaceae and Typha angustifolia. Fern spores continuously present but with strongly fluctuating values. |
| 20 | 435-415 cm. Higher Corylus, lower Quercus values. High AP/NAP-ratio; Umbelliferae values decreasing. Higher Bryophyta values. |
| 19 | 457-435 cm. Slightly higher values of Salix, Pinus, Quercus. Lower AP/NAP-ratio by higher values of Gramineae, Umbelliferae and Cruciferae. Small peak in Alismataceae curve. |
| 18 | 468-457 cm. Restoration of high Alnus values. Very high AP/NAP-ratio. |
| 17 | 482-468 cm. Lower Alnus, higher Corylus values. Fagus continuously present. Increased values of Quercus and Tilia. Hedera slightly more important. Higher values of Umbelliferae, Alisma, Lythrum, Cruciferae, Ericaceae. Practically the only zone with Rumex hydrolapathum (not presented in the diagram). |
| 16 | 491-482 cm. Higher Alnus and Pinus, lower Corylus and Tilia values. Extremely high values of monolete psilate fern spores. |
| 15 | 495-491 cm. High values of Corylus; lower values of Alnus and Quercus. Small peaks in the curves of Fagus, Tilia and Ulmus. Rather high values of Gramineae and Sparganium. Slightly increased values of Zygnemataceae. High values of Bryophyta. |
| 14 | 508-495 cm. Low values of Corylus. Small peaks of Salix and Fraxinus. Increase of Umbelliferae values. Peaks in the curves of Cyperaceae and Rubiaceae. |
| 13 | 670-508 cm. Rather constant values of most AP. High Alnus values; strongly decreased Pinus values. Fagus continuously present in upper part of the zone. Low values of Ulmus and Tilia. High AP/NAP-ratio, slightly lower in the middle part of the zone, in connection with higher values of Cyperaceae, Gramineae and Typha angustifolia. Regular occurrence of Nymphaea, Nuphar and Ranunculaceae. |

12 678-670 cm. Important peak of Corylus opposing lower values of Alnus. Quercus values very low. Small peak of Ulmus. AP/NAP-ratio restored to nearly that of zone 8. Decrease of Gramineae values. Low values of fern spores.

11 705-678 cm. Constant high Alnus values. Corylus values rather low, increasing towards the top of the zone. Continuous occurrence of Fraxinus. Rising AP/NAP-ratio. High values of Cyperaceae. Rather important values of Gramineae, Lythrum, Rubiaceae, Compositae tubuliflorae; increase of Filipendula values in the top of the zone. High values of monolete psilate fern spores.

10 710-705 cm. Minimum in AP/NAP-ratio. Important peak of Quercus opposing lower values of Alnus. Small peaks of Pinus and Fraxinus. Very high values of Gramineae. High values of Cyperaceae and Typha angustifolia.

9 720-710 cm. Strongly increased Alnus values. Increase of Gramineae towards zone 10. Small peak of Umbelliferae. High Bryophyta values.

8 823-720 cm. Rather high values of Quercus, Tilia, Ulmus and Pinus. Contemporaneous occurrence of Fagus and Picea in middle part of the zone. Increased values of Salix in lower part of the zone. Corylus important, with peaks in upper part of the zone. High AP/NAP-ratio. Ericaceae peaking in middle part of the zone. In lower part of the zone rather high values of Cyperaceae, Umbelliferae, Typha angustifolia and Alisma.

7 830-823 cm. Higher values of Corylus and Ulmus, lower values of Alnus and Quercus. Important peak of Gramineae. Small peak of Cruciferae. Increased values of Typha latifolia, Alisma and Ranunculaceae.

6 863-830 cm. Important peaks of Pinus, Tilia, Betula, Umbelliferae, Alisma and monolete psilate fern spores.

5 875-863 cm. Strongly fluctuating values of Corylus, Pinus and Alnus. Rather low AP/NAP-ratio; rather low values of Quercus and Tilia, slightly increased values of Ulmus. Very high values of Gramineae. Decreasing Cruciferae values. Peak of Alisma. Maximal value of Botryococcus; slightly increased Zygnemataceae values. High values of Bryophyta.

4 925-875 cm. High values of Tilia, Quercus, Gramineae and Sparganium. Increased values of Salix in upper part of the zone. Maximal value of Cruciferae in this zone, at the transition to zone 5.

3 930-925 cm. High values of Corylus and Pinus; low values of Alnus and Quercus. Small peak of Viburnum. Important peaks of Gramineae and monolete psilate spores.

2 961-930 cm. Rather high values of Alnus and Quercus. Important values of Typha angustifolia, Sparganium and Nymphaea. Nuphar continuously present. Regular occurrence of Cruciferae and Rumex acetosa. Peaks of Alisma and Typha latifolia in the top of the zone.

1 965-961 cm. Peaks of Pinus, Gramineae, Valeriana, Bryophyta.

**Zone 5** (875-863 cm). This pollen zone also coincides entirely with a lithostratigraphic unit, namely the *Phragmites*-peat bed ol 1-2. The *Phragmites*-peat growth, which was already important in the underlying two zones, expanded strongly. On the somewhat more open places in the marsh *Alisma* (many fruits of this have been found here) and Umbelliferae also grew, as did algae (*Botryococcus* and Zygnemataceae). On the higher, sandier parts of the underlying clay bed cl 1 caused by differential compaction (in profile I, Fig. 6, at 50 to 100 m N of the standard boring H1110) and on the flanks of the river dunes *Ulmus*, *Corylus* and *Alnus* probably grew. The vegetation of *Quercus* and *Tilia* on the river dunes seems to have strongly decreased, possibly to the benefit of *Corylus* in particular.

The strong decrease of *Quercus* and *Tilia* and the expansion of *Corylus* may point to prehistoric influences in the form of wood cutting. The lower *Tilia* values may however also relate to decreased river supply (see Ch. IIIc.3).

**Zone 6** (863-830 cm). This pollen zone coincides entirely with the strongly humic clay bed belonging to lithostratigraphic unit cl 2a. Clay sedimentation took place in quiet, shallow water with abundant growth of ferns (*Thelypteris*), Umbelliferae and *Alisma*, and less abundant (or at a greater distance from the section) *Phragmites* and *Typha angustifolia*. The Umbelliferae fruits found in this bed come from *Sium erectum* and *S. latifolium*, both belonging to an environment of shallow, quiet water, with or without varying water level (WESTHOFF & DEN HELD 1975, p. 129). In contrast to these two species, *Oenanthe aquatica*, another Umbelliferae species characteristic of the fluvial environment, prefers faster flowing water (VAN DER VOO & WESTHOFF 1961, p. 253). In the upper few cms of the zone, the increase of *Typha latifolia* and *Mentha* (Labiatae) points to increasing water stagnation (ibid.).

On the river dunes the *Quercus* vegetation was restored. Also some *Betula* occurred presumably on the higher parts of the river dunes; these might have functioned as pioneers in the regeneration of the (*Quercus*) forest after the supposed wood cutting. *Ulmus* maintained itself probably on the lower parts of the dunes, together with *Corylus*, and, still closer to the marsh, *Alnus*.

**Zone 7** (830-823 cm). The local vegetation consisted of a *Phragmites* marsh with rather open places where *Alisma*, *Typha latifolia* and presumably *Rorippa/Nasturtium* and Ranunculaceae (*Ranunculus lingua* and/or *sceleratus*?) occurred. The rather open nature of the *Phragmites* marsh is also apparent from the lithology: the bed concerned, ol 2a-2b, has been developed here as peaty clay, so there was continuous clay sedimentation during peat growth. The higher *Corylus* and *Ulmus* values might be ascribed to the vegetation of the nearby natural levees of the channel in clastic bed cl 2 (see profile I, Fig.*6). The *Corylus* and *Ulmus* pollen might have reached higher percentages in the sediment concerned because of a decreased supply of especially *Tilia* and *Pinus* pollen by river water. Apart from that, there is the possibility that, by a slight fall of the water table, the levee emerged somewhat, causing a basinward extension of the levee forest; this might apply particularly to *Corylus* since it can function as a quickly invading bush.

**Zone 8** (823-720 cm). In the lower two dm of the zone, a sequence has been recorded from the *Phragmites* marsh of the preceding zone to an environment with large areas of open water: *Phragmites* largely gave way to *Alisma* (pollen and fruits), *Mentha* (fruits), Umbelliferae (fruits of *Oenanthe* and *Sium erectum*), Cyperaceae and *Typha angustifolia*. The higher *Salix* values in the lower part of the zone are probably also to be explained as signifying much wetter conditions (by a relative rise of the water table).

In the upper part of the zone the AP/NAP-ratio is very high, and this is one of the indications of the probably permanently open-water nature of the basins (see also Ch. Vb).

The zone largely coincides with clastic lithostratigraphic unit cl 2b, which comprises a large number of channel fills (see e.g. profile I, Fig.*6). On the natural levees of these gullies, one of which was situated very near the section (see profile I), stands of *Ulmus*, *Fraxinus* and possibly *Corylus*, with *Alnus* along the wet flanks, will have occurred. On the highest parts of the levees *Quercus* may also have grown.

As discussed in Ch. IIIc.3, an important part of the tree pollen, especially in this zone, may have been supplied by river water from the hinterland. This hampers a secure judgment about the vegetation on the river dunes at the time of deposition of this zone on the basis of this section alone. The gyttja sections at the foot of the river dunes (see Chs. IIIg and -h) provide better information on this point.

**Zone 9** (720-710 cm). An intensive filling of the former open-water basins had set in with *Phragmites* marsh as well as *Alnus* swamps. The not yet completely enclosed nature of the *Phragmites* marsh may be indicated by the occurrence of Umbelliferae and *Alisma.* The large number of *Urtica* fruits found in this zone points to a local accumulation of nutrients (phosphates and nitrates). This may have been caused in three ways. Firstly, an accelerated decomposition of plant material on the nearby natural levees or stream ridge of clastic bed cl 2b may have come about by a water-level fall. Secondly, *Urtica* may have been part of the vegetation standing on drifted plant material washed ashore along a nearby lake (cf. WESTHOFF et al. 1971, p. 179; see also Ch. IIIj). Thirdly, human prehistoric activity as a cause of nutrification, e.g. by wood cutting on the before-mentioned stream ridge, should not be excluded.
On the natural levees, or the stream ridges resulting from these, the forest stands consisted of a presumably rather open vegetation of *Corylus* and *Ulmus*, with *Alnus* along the wetter flanks.

**Zone 10** (710-705 cm). The vegetation in most of the lower parts of the area consisted of a *Phragmites* marsh with much *Typha angustifolia* and Cyperaceae. At the transition to the higher parts of the area, at the flanks of the stream ridges and possibly also of the river dunes, probably a temporary decrease in the growth of *Alnus* and *Corylus* took place (perhaps by an anthropogenic cause; another explanation might be a further increased fall of the local water level). Because of this, *Quercus* pollen, coming from the yet higher parts of the area, could reach more easily the locality of the section, i.e. without being filtered out by *Corylus* and *Alnus* trees. Probably the same holds for the pollen of *Fraxinus*, and to a lesser extent also for *Ulmus*. This explanation is based partly on TAUBER's theory concerning the importance of the 'trunk-space transport' of tree pollen: the pollen supply from the interior of a forest may be hampered strongly by a dense bush in the edge of the forest (TAUBER 1977, p. 66). Implicitly this process plays a role in the interpretation of several zones of this and other sections.

**Zone 11** (705-678 cm). The *Alnus* growth had been locally restored and it probably extended to the lower parts of the area, succeeding *Phragmites* in many places as the next stage in the infilling of the basins with peat growth. This is in agreement with the lithology of the bed concerned (organic bed ol 2-3). Generally, and also in this section, this bed is developed as wood peat but with *Phragmites* peat at its base. At the transition to the higher parts of the area (stream ridges and river dunes) *Fraxinus* and *Ulmus* would have been growing,with *Quercus* on the higher parts themselves. The swamp forest was rather open, with continued *Phragmites* growth in many places, probably the lower parts in particular. These stretches of *Phragmites* marsh were however already in a further stage of enclosure, as witnessed by the presence of *Thelypteris*, Cyperaceae, *Lythrum* and Rubiaceae (probably *Galium palustre*); compare with DEN HELD & DEN HELD (1976, p. 132 f.) for a description of a *Thelypteris-Phragmites* community. Some of the fern spores may also have been derived from *Athyrium filix-femina*, known from the undergrowth of *Alnus* forests (ibid., p. 185); besides, *Thelypteris* itself can occur in the undergrowth of *Alnus* forests (WESTHOFF & DEN HELD 1975, p. 250 f.).

**Zone 12** (678-670 cm). On the nearby stream ridge of lithostratigraphic unit cl 2 (see profile I, Fig.* 6) the *Quercus* stands had probably partly given way to *Corylus* and to a lesser degree also to *Ulmus*. *Phragmites* growth had decreased considerably. The peaks of Umbelliferae pollen (presumably *Sium erectum*, in view of the fruit analysis) and of *Filipendula* pollen, probably point to a more open nature of the *Phragmites* marsh; this might also be indicated by the occurrence of *Batrachium*. All this is in good agreement with the lithology. The zone concerned is situated in the transition (within organic bed ol 2-3) of the wood peat to the overlying gyttja. The gyttja, a lake deposit, points to an increased rise of the local water level causing not only large openings in the marsh vegetation, but also important changes in the vegetation on the stream ridge by means of increasingly wetter soil conditions.

**Zone 13** (670-508 cm). At the locality of the section, a lake came into being, in which *Nymphaea*, *Batrachium* and *Nuphar* were growing. At shallow spots, especially near the shore at the transition to the *Alnus* swamp, a vegetation of *Scirpus* (presumably *S. lacustris*, see also Ch. IIIc.4), *Phragmites* (possibly also other hygrophilous grasses), *Thelypteris* ferns, Umbelliferae, *Sparganium* and *Typha angustifolia* existed, with *Salix* probably at the edge of the swamp forest itself. On the somewhat higher parts in the swamp forest *Fraxinus* and *Ulmus* also presumably grew. On the river dunes stood a *Quercus* forest with *Tilia*, and probably also *Ulmus* at the transition to the swamp; there would also have been important undergrowth and edges of *Corylus*.

The interpretation of a lacustrine environment is, so far as the lower part of the zone is concerned, in good agreement with the lithology — a gyttja (lake deposit). As the pollen content of the overlying clay (forming the upper part of the zone) does not differ substantially from that of the gyttja itself, it may be assumed that the clay was also deposited in a lacustrine environment. The clay belongs to lithostratigraphic unit cl 3. This is generally developed as a strongly humic clay bed wedging out in some places in the organic layer complex ol 2-4 (see the lithostratigraphic scheme in Fig. 5).

The tree pollen composition is strongly dominated by the *Alnus* forests, lying as islands or strips between the extensive lakes (see Ch. IIa.3 and profiles I and II, Figs.*6 and*7). The pollen from the *Quercus* forests on the river dunes could reach the locality of the section by wind transport over the lakes.

The higher values of the previously mentioned shore plants in the middle part of the zone may indicate a temporary extension of the swamp forests in the direction of the lakes. In general, the even nature of most pollen curves in this zone may be regarded as an indication of a quiet environment, where no or few sedimentological changes took place.

**Zone 14** (508-495 cm). The vegetation described in the preceding zone along the shore of the lake, had come nearer to the locality of the section, which may point to a decrease in water depth and the beginning of the process of infilling of the lake. To a larger degree than in the preceding zone, Umbelliferae (among others *Sium erectum*, according to the fruit analysis), Rubiaceae (probably *Galium palustre*) and Cyperaceae other than *Scirpus* would have occurred in the shore vegetation.

**Zone 15** (495-491 cm). At or near the locality of the section stood a vegetation of *Sparganium* and grasses; the latter were possibly partly not *Phragmites*, but *Glyceria fluitans*, a species that occurs, in combination with *Sparganium*, in ox-bow lakes (VAN DONSELAAR 1961). Lithostratigraphically the zone is situated just in the transition from clay bed cl 3 to wood-peat bed ol 3-4; this agrees with the infilling nature of the vegetation. In this shallow-water environment, Zygnemataceae algae were floating.

The *Quercus* vegetation on the river dunes had decreased, causing the *Corylus* undergrowth to expand and/or to blossom more effectively. *Tilia* and *Ulmus* are relatively better represented in the pollen diagram because of the *Quercus* decrease. This *Quercus* decease can possibly be ascribed to prehistoric wood cutting.

**Zone 16** (491-482 cm). At the spot stood an *Alnus* forest with an important undergrowth of ferns (compare with zone 11: *Athyrium* and/or *Thelypteris*). According to the fruit analysis, various *Carex* species were growing there too. Only few pollen from the river dunes could penetrate the local forest; *Corylus* pollen may have done so, but these could also have been supplied from the higher parts in the *Alnus* forest.

**Zone 17** (482-468 cm). The swamp forest had become locally more open. At these open spots, in an environment of shallow water, Umbelliferae (various species), *Alisma plantago-aquatica*, Cruciferae (probably again *Rorippa* and/or *Nasturtium*), *Lythrum* and *Rumex hydrolapathum* grew. On higher spots nearby stood *Quercus* and possibly also *Tilia*, with edges of *Corylus* and presumably also *Ulmus*. These higher localities might have been the river dunes, the pollen from which would have been able to reach the locality of the section more easily through the openings in the swamp forest. Besides, there is the possibility that by compaction differences in clay bed cl 3, a certain relief had originated, and that on its higher parts *Quercus* with *Corylus* may have grown instead of only *Alnus*. *Hedera* may also have occurred in such a dry place in the swamp forest. Finally, in view of the increased *Fagus* pollen values, one should consider the possibility of a slightly increased fluvial supply of tree pollen.

**Zone 18** (468-457 cm). The *Alnus* swamp forest had (locally) been closed again, according to the very low herb-pollen percentages. The possible *Quercus* stands in the vicinity (see zone 17) seem to have maintained themselves.

**Zone 19** (457-435 cm). Again, the *Alnus* forest had become locally more open. Apart from the species mentioned in zone 17, grasses and various *Carex* species also grew in these openings, probably in very shallow water. *Salix* also seems to have occurred in these openings. Again, the *Quercus* stands (with *Ulmus* and *Corylus*) on the higher grounds had maintained themselves.

**Zone 20** (435-415 cm). From the consistently high values of *Alnus* pollen and fruits and the very low herb-pollen values, it may be concluded that the swamp forest was locally more closed again. From the lithology and lithostratigraphy (see Fig. 13) it appears that in this swamp forest the clay sedimentation of clastic bed cl 4 had already begun.

The *Quercus* stands on the high grounds in the vicinity (see zone 17) had been strongly reduced, causing the presumed undergrowth of *Corylus* to blossom more effectively. The cause of this strong *Quercus* reduction may have been a local water-level rise, connected with the start of clay sedimentation. Prehistoric wood cutting (namely by the Late-Vlaardingen culture, see Chs. IVb.2 and V) may however also have been the cause. In connection with these possible prehistoric influences, the high *Corylus* values, at least in the topmost part of the zone, may also point to a regeneration of forest on abandoned fields, as GROENMAN-VAN WAATERINGE et al. (1968) presume for prehistoric occupation terrains of the Vlaardingen culture in the Western Netherlands beach barrier region.

**Zone 21** (415-165 cm). An environment with much open, moving water existed in the basins. This may be concluded from the high percentage of river-borne tree pollen (see Ch. IIIc.3), from the high AP/NAP-ratio and from the lithology (an only weakly humic clay). Along the borders of the river dunes and natural levees grew *Alnus*, *Salix*, grasses and ferns. Grasses and ferns probably also grew at shallow points in the basins. On the higher parts (dunes and levees) *Quercus*, *Ulmus*, *Fraxinus* and perhaps also some *Tilia* would have grown.
The impressive change from an extensive swamp forest to mainly open water took place at the beginning of this thick zone.

**Zone 22** (165-121 cm). From the increase of *Alnus* and herb pollen towards the end of the zone it appears that the open-water basins were starting to fill up. The increase of *Pinus* pollen values may be explained by more quiet sedimentation conditions (see also Ch. IIIc.3).
The coincidence of higher values of Chenopodiaceae pollen with a small isolated peak in the Cerealia pollen curve points to prehistoric human influences. Possibly the higher Cruciferae values are also connected with this.

**Zone 23** (121-85 cm). In the area an *Alnus* swamp forest has been established again (compare with zones 16-19). In small open places in this forest pools with Zygnemataceae algae and a vegetation of Cyperaceae and Umbelliferae existed. The presence of *Plantago lanceolata* and of Cruciferae may point to continued human influences, e.g. on the vegetation of the nearby Schoonrewoerd stream ridge.

**Zone 24** (85-76 cm). Increasingly wetter conditions in the *Alnus* forest are apparent from the increase in *Salix*. The expansion of *Fraxinus* might point to the same process on the Schoonrewoerd stream ridge (increasingly wetter flanks).

**Zone 25** (76-65 cm). Locally an opening developed in the swamp forest of *Alnus* and *Salix*, with an abundant growth of Umbelliferae and, to a lesser degree, also *Alisma* and Cruciferae (probably again *Rorippa* and/or *Nasturtium*). The origin of this opening might point to a temporary relative rise of the local water table (see also zone 24).

**Zone 26** (65-45 cm). The *Alnus* swamp forest had locally been closed again. At some distance from the section some openings with Umbelliferae and (edges of) *Salix* probably still existed.

### IIIc.6 Chronological implications

Because of the influence of pollen carried down by the rivers from the Middle-European hinterland, on the tree pollen diagram, it is not well possible to infer pollen-analytical datings merely from this

diagram. Using just this Middle-European pollen for dating purposes (by a comparison with e.g. FIRBAS' zones) would lead to a circular argument; for it was on the basis of datings (C-14 datings) that the presence of this Middle-European pollen was inferred (Ch. IIIc.3).
The dating method mentioned (comparing with FIRBAS' zones for the Middle European pollen) might indeed be used at sections from the perimarine fluviatile coastal plain, if C-14 dates are lacking. It would be interesting to elaborate the possibilities of this method in more detail.
An extensive series of C-14 datings of the present standard section is available for a detailed chronology (see Ch. IVb.1). Nevertheless some general pollen-analytical datings are also inferred (see Ch. IVb.3).

## IIId POLLEN ANALYSIS OF BORING LEERDAM S322 I

### Choice of the sampled section

Boring S322 I is lithostratigraphically representative for the Leerdam study area. The location of this boring relative to the central river dune in this area can be seen in Fig. 4. For the lithostratigraphy of the section see profile IV (Fig.*10) and the scheme in Fig. 11.
The choice of the sampled part of the section (see Fig. 16) has been dictated by the lithostratigraphic correlation with that part of the standard section of the Molenaarsgraaf study area (namely the transition from clastic bed cl 2 to organic bed complex ol 2-4), where the most important pollen-analytical zone boundary (the boundary between zones 8 and 9, see Ch. IIIc.2) is situated.

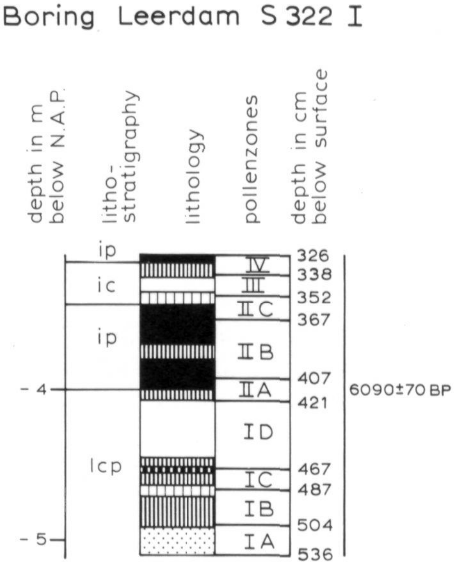


Fig. 16. Pollen zones in boring Leerdam S322 I. For lithological legend, see Fig. *9.

### General remarks

The pollen content of clay bed lcp (zone I, see Figs.*15 and 16 and Table 4) shows a remarkable resemblance to the pollen content of the lithostratigraphically correlative clay bed cl 2 in the Molenaarsgraaf study area (zones 6-8, see Fig. 13). Also in clay bed lcp important percentages of tree pollen carried down by river water from the hinterland (esp. *Pinus* and *Tilia*) occur. The very high *Pinus* percentages are probably connected with quiet sedimentation conditions, as discussed in Ch. IIIc.3.

Peat bed ip (pollen zones II and IV), like the lithostratigraphically correlative organic bed ol 2-4 in the Molenaarsgraaf area, shows a dominance of *Alnus* pollen and low values of river-borne pollen. In the intercalated clay bed ic (zone III) fluvially supplied pollen is present in percentages corresponding to those in clay bed cl 3 at Molenaarsgraaf (zone 13).

### Interpretation of the pollen zones

**Zone IA** (536-504 cm below land-surface). In an open-water basin few local pollen was deposited in proportion to extraneous pollen. On the natural levees and the river dune, *Quercus* and *Tilia* probably grew on the higher parts and *Ulmus*, *Corylus*, *Alnus* and *Salix* on the lower parts.

**Zone IB** (504-481 cm). During a partial filling in of the basin a rich herb community had been locally established (see Table 4), and *Alnus* could expand probably basinward from the natural levees.

**Zone IC** (481-467 cm). In agreement with the lithology (being midway that of zones IA and IB), the pollen content also shows components of both zones.

**Zone ID** (467-421 cm). The pollen of *Corylus*, *Quercus*, *Tilia* and *Ulmus* would have been derived partly from the fluvial hinterland, and, in view of the high values in comparison with the underlying zones, partly also from the local vegetation on the natural levees and river dunes. *Alnus* and *Salix* would have grown mainly at the transition from the natural levees and river dunes to the basins. At shallow spots in the basin Cyperaceae occurred, and to a lesser degree grasses, *Sparganium* and *Alisma*.

**Zone IIA** (421-407 cm). In the basin a swamp forest had been established, consisting of *Salix* and *Alnus*. In the undergrowth Cyperaceae occurred and at somewhat open places Umbelliferae and *Typha* grew. The *Urtica* pollen may have been derived from the undergrowth of the swamp forest, but also from the nearby Middelkoop stream ridge. In the latter case there may have been a similar and simultaneous prehistoric influence as supposed for zone 9 of the standard section of the Molenaarsgraaf area. On this stream ridge, and also on the river dune, stands of *Quercus*, *Ulmus* and *Corylus* would have occurred.

**Zone IIB** (407-367 cm). The swamp forest still consisted, at least locally, mainly of *Alnus*. At open places Umbelliferae and *Solanum dulcamara* grew. The peak of Cyperaceae pollen in the upper part of the zone points possibly to increasingly wetter conditions in the swamp forest. On the nearby stream ridge stood *Quercus* and also *Rhamnus*.

**Zone IIC** (367-352 cm). In the swamp forest *Alnus* had, at least locally, been replaced again by *Salix*. This may point to increasing water depth, indicating a transition to the overlying zone.

Table 4. Description of pollen zones in boring Leerdam S322 I.

| | |
|---|---|
| IV | 337,5-326,5 cm. Restoration of high Alnus values. Decreased Quercus and Tilia values; slightly increased Ulmus values. Very high AP/NAP-ratio. Bryophyta values strongly increased. |
| III | 352,5-337,5 cm. Important peaks of Quercus, Tilia, Fraxinus, Fagus and Picea. Salix values decreasing towards the top of the zone. Important decrease of Alnus values. In lower part of the zone peaks of Typha angustifolia, Solanum dulcamara and Iris. |
| II C | 367,5-352,5 cm. High Salix values in lower part of the zone. Peak of Umbelliferae. |
| II B | 407,5-367,5 cm. High Alnus values and high AP/NAP-ratio. Decreased but still important Salix values. Maximal value of Rhamnus in this zone. Peaks of Cyperaceae, Umbelliferae, Solanum dulcamara and Rubiaceae. |
| II A | 421-407,5 cm. High Salix values. Alnus values increasing. Strongly decreased values of Corylus, Pinus, Quercus, Tilia, Ulmus. Increasing AP/NAP-ratio. Decreasing Cyperaceae values. Peak of Urtica dioeca. |
| I D | 467,5-421 cm. Maximal values of Tilia, Ulmus and Corylus. High Quercus values. Increased values of Salix at base and in top of the zone. Fagus, Carpinus, Picea and Abies present. Slight increase of Fraxinus values. Rather strongly fluctuating AP/NAP-ratio due to peaks of mainly Cyperaceae, also of Gramineae, Typha angustifolia, T. latifolia and Alisma. Increasing values of fern spores. |
| I C | 486,5-467,5 cm. Restoration of high Pinus and Tilia values. Decreased values of Alnus, Quercus and Ulmus. High AP/NAP-ratio. |
| I B | 503,5-486,5 cm. Decrease of Pinus and Tilia values, increase of Alnus, Quercus and Ulmus values. Important peaks of Gramineae, Cyperaceae, Umbelliferae, Typha angustifolia, Sparganium and Cruciferae. |
| I A | 536,5-503,5 cm. High values of Pinus and Tilia. Alnus, Corylus, Salix, Picea, Quercus, Ulmus and Betula present in rather low values. Carpinus present in one sample. High AP/NAP-ratio. |

**Zone III** (352-338 cm). In a large opening in the swamp forest (in an open-water environment), clay sedimentation took place. Along the shore, among others *Typha angustifolia*, *Solanum dulcamara* and Iris would have grown. *Quercus*, *Tilia*, *Ulmus*, *Fraxinus* and *Corylus* would have been present on the stream ridge and the river dune.

**Zone IV** (338-328 cm). The swamp forest had been closed again and consisted once more mainly of *Alnus*. *Ulmus* seems to have maintained itself well on the flanks of the gradually submerging stream ridge.

## IIIe POLLEN ANALYSIS OF BORING MOLENAARSGRAAF H1530

### - in cooperation with G. J. van Dijk -

### Depression filling

Boring Molenaarsgraaf H1530 is situated above a depression in the surface of the Kreftenheye Formation. Fig. 17 shows a lithostratigraphic cross-section at the western rim of this depression; from a comparison with e.g. profile I (Fig.* 6), the rather exceptional nature of this depression becomes apparent: it is the deepest found in the study area. The lowermost organic bed of the Westland Formation (bed ol b, the 'basal peat') has been developed here as a gyttja bed 1 m thick. Overlying this are thick clay beds, belonging to lithostratigraphic units cl 1 and cl 2.
Pollen analysis of the gyttja bed in the lower part of the depression was carried out because it was expected that here an older part of the paleoenvironmental history would have been registered than in the standard section. The lower part of the overlying clay bed cl 1 has also been analysed. Therein a peat bed occurs with a very sharp lower boundary, which points to a non-in situ formation of the peat bed. The sampling interval is 1 cm in the gyttja and the clay, and 3 cm in the peat bed.

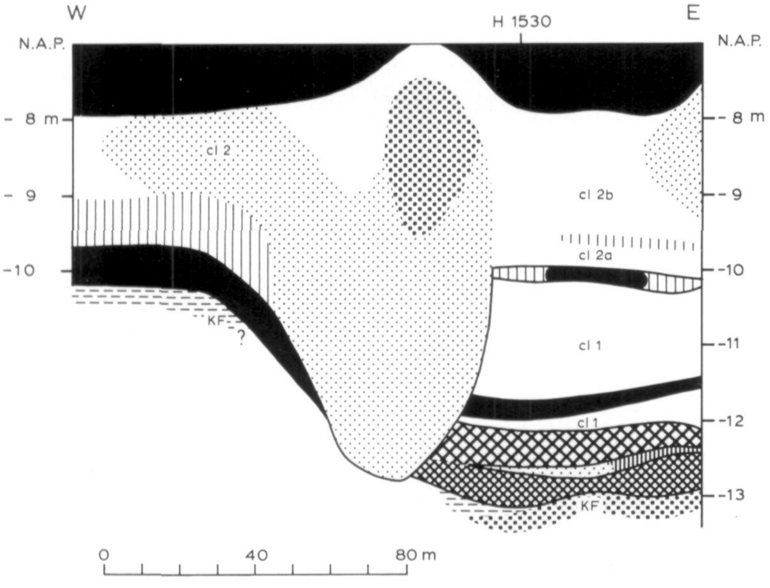


Fig. 17. Profile at boring Molenaarsgraaf H1530. For lithological legend, see Fig. *9.

### General remarks

Zones I and II (see Fig. 18, Table 5 and App., Fig. n) show clear Preboreal and Boreal spectra. A C-14 dating at the base of zone I confirms the Preboreal age (see Ch. IVb.1 and Fig. 28). The (few) pollen of among others *Quercus* and *Tilia* at the base of zone I has presumably been reworked from older, e.g. Eemian deposits, or might have been supplied by percolation through the rather coarse fluvial sand of the Kreftenheye Formation from younger deposits.
Zone II shows spectra characteristic of the older part of the Boreal. Gradually increasing values of *Alnus* and *Ulmus*, as found in section Leerdam S322 II (Ch. IIIf) and characteristic of the younger part of the Boreal, are lacking here.

Zone III can be placed entirely in the Atlantic period. At the sharp transition from zone II to zone III we suppose a rather prolonged hiatus during the younger Boreal and probably also the early Atlantic. In the lithology (see Fig. 18) a clay bed only 1 cm thick has been found at the exact depth of this hiatus; this clay shows affinity to the *loam* (Kreftenheye Formation) because of its dark-grey colour and its stickiness. Superposed on this clay bed is a sand string, likewise only 1 cm thick; on the basis of its variegated colour it may be interpreted as (primary or secondary) dune sand.

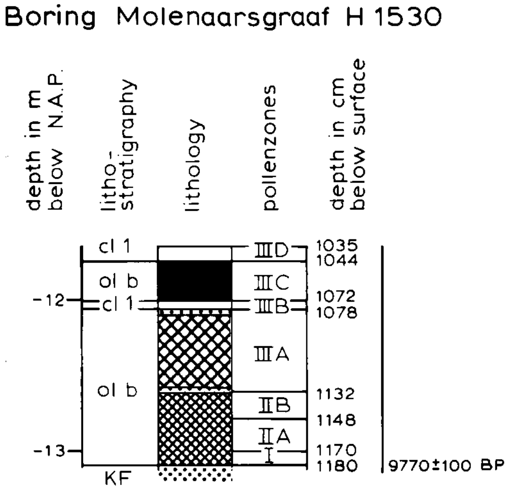


Fig. 18. Pollen zones in boring Molenaarsgraaf H1530. For lithological legend, see Fig. *9.

## Interpretation of the pollen zones

**Zone I** (1180-1170 cm below land-surface). On the surface of the Kreftenheye Formation (dunes and *loam*) stood a presumably rather open forest of *Pinus* and *Betula*. Occurrences of *Hippophae* and *Artemisia* may be regarded as the remains or continuation of a Late-Weichselian vegetation. In view of the lithology (gyttja), a lake must have existed in the local depression. Along its shore grew *Typha angustifolia* and/or *Sparganium*.

**Zone IIA** (1170-1148 cm). The forest was presumably more closed and consisted mainly of *Pinus*. At the shore of the depression, besides *Phragmites* and *Typha angustifolia/Sparganium*, Cyperaceae and ferns also grew. In the lake itself occurred *Nuphar* and *Sagittaria*.

**Zone IIB** (1148-1132 cm). On the dunes and the higher parts of the *loam*-surface *Corylus* expanded, whether only as undergrowth of the *Pinus* forest, and/or (see FIRBAS 1949, p. 152) as substantive Boreal *Corylus* forest. The lower parts of the *loam*-surface were colonised by *Salix* bushes, indicating temporary wetter conditions in the area by inundation and/or rise of the local groundwater level.

**Zone IIIA** (1132-1078 cm). As sedimentation in the depression was renewed after the hiatus, the vegetation in the surrounding area appears to have become quite different: *Quercus*, *Tilia*, *Ulmus*, *Corylus* and *Fraxinus* on the dunes and possibly also on the higher parts of the *loam*-surface, *Alnus* and grasses (probably *Phragmites*) on the lower parts of the *loam*-surface. Along the shore of the lake occupying the depression stood a vegetation of *Phragmites*, Cyperaceae, *Typha angustifolia / Sparganium*, ferns and Umbelliferae. In the lake itself grew *Nymphaea* and *Myriophyllum*.

**Zone IIIB** (1078-1072 cm) and **zone IIID** (1044-1035 cm). At the lowest spots in the area, such as here in the depression, fluvial inundation and sedimentation occurred. Part of the pollen (esp. of *Tilia*, cf. Ch. IIIc.3) was apparently supplied by river water from the hinterland. The vegetation in the area would have been largely the same as during the formation of zone IIIA.

**Zone IIIC** (1072-1044 cm). The zone coincides lithostratigraphically with the non-in situ formed *Phragmites*-peat layer. The sharp lithological lower boundary of the peat layer might point to a floating-mat origin; the varied composition of the herb pollen would agree with this.

Table 5. Description of pollen zones in boring Molenaarsgraaf H1530.

| | |
|---|---|
| III D | 1044-1035 cm. Increase of Tilia (up to 18%), Ulmus (c. 10%), Fraxinus (c. 4%). AP/NAP-ratio c. 65%, NAP mainly consisting of Gramineae, Cyperaceae, Sparganium/Typha angustifolia and Rumex hydrolapathum. Values of fern spores decreasing strongly upwards. |
| III C | 1072-1044 cm. Sharp decrease of AP/NAP-ratio at base of the zone to c. 30%; increasing gradually upwards to c. 65% again. AP as in zone III A, Pinus and Alnus slightly higher, Corylus slightly lower. NAP mostly consisting of Gramineae (more than 100% at base), Cyperaceae (c. 30%), Sparganium/Typha angustifolia (c. 30%) and Typha latifolia (15% at base). Small peaks of Rubiaceae (2%), Chenopodiaceae (3%), Compositae tubuliflorae (7%), Thalictrum (3%), Rumex hydrolapathum (7%). Extremely high values of monolete psilate and echinate fern spores. |
| III B | 1078-1072 cm. Peaks of Tilia (18%), Ulmus (30%), Pinus (35%), Abies (2%), Hedera (4%), monolete psilate fern spores (100%). |
| III A | 1132-1078 cm. Sharp transition from zone II B to zone III A. Nearly all species present in rather constant values: Alnus c. 30%, Corylus c. 25%, Quercus c. 17%, Tilia c. 2%, Ulmus c. 7%, Pinus c. 10%. AP/NAP-ratio decreased to c. 65%, NAP mainly consisting of Gramineae (c. 40%), Cyperaceae (c. 7%), Sparganium/Typha angustifolium (c. 7%), Umbelliferae (c. 2%). Important peak of monolete psilate fern spores at base of the zone (45%). |
| II B | 1148-1132 cm. Pinus gradually decreasing from c. 90 to c. 50%. High Salix values characteristic of this zone (c. 20%, peaks up to c. 40%). Corylus increasing upward to 40%. Quercus increasing in the upper part of the zone to c. 5%. AP/NAP-ratio very high (c. 90%), NAP consisting practically only of Gramineae. Sharp decrease in fern spores. |
| II A | 1170-1148 cm. Constant very high Pinus values (c. 90%). Betula c. 10%; in upper part of the zone slight increase of Corylus and Salix. AP/NAP-ratio c. 85%; Gramineae c. 10%, other NAP mainly Cyperaceae, Typha latifolia, Sparganium/Typha angustifolia, Nuphar, Sagittaria. Important peaks of monolete psilate fern spores (up to 60%). |
| I | 1180-1170 cm. Betula decreasing upward from c. 70 to c. 15%. Pinus increasing upward from c. 30 to c. 85%. AP/NAP-ratio increasing upward from c. 40 to c. 70%, NAP consisting mainly of Gramineae. Artemisia continuously present (c. 3%). Small peaks of Hippophäe (up to 5%). Sparganium/Typha angustifolium in top of the zone (increasing to 20%). |

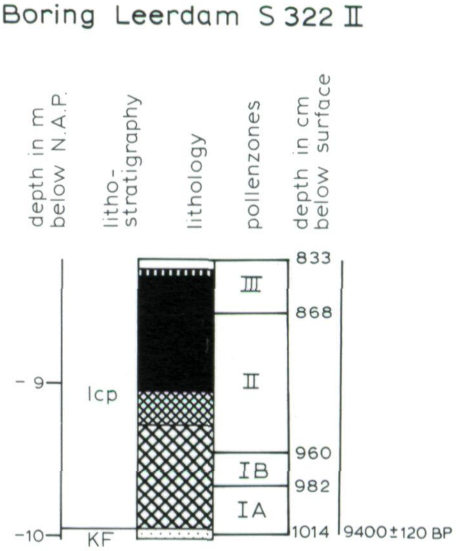
## IIIf POLLEN ANALYSIS OF BORING LEERDAM S 322 II

**- in cooperation with J. Nap -**

### Depression filling

Like pollen section Molenaarsgraaf H1530 (Ch. IIIe), pollen section Leerdam S 322 II relates to an organic deposit (gyttja and gyttja-like peat) in a depression in the surface of the Kreftenheye Formation. The aim of the analysis of the section is to compare the early-Holocene development of the Leerdam area with that of the Molenaarsgraaf area.

Fig. 19. Pollen zones in boring Leerdam S322 II. For lithological legend, see Fig. *9.



The lithostratigraphic position of the section can be seen in profile IV (Fig.*10). The sampling interval is 1 cm in the gyttja, 3 cm in the overlying gyttja-like peat (see also Fig. 19) and 1 cm in the transition from the latter to the overlying clay.

### General remarks

The section shows a gradual transition from the Boreal in zones I and II to Atlantic in zone III (see Table 6, Fig. 19 and App., Fig. o). The section does not show the hiatus (in the later part of the Boreal), as its counterpart, section Molenaarsgraaf H1530.

In its lower part (1014-965 cm depth) the gyttja is rather clayey. Pollenanalytically this part of the section can be correlated with zone IIB in section Molenaarsgraaf H1530, on the basis of the *Pinus* and *Corylus* values. In the top of the latter zone a thin, *loam*-like clay bed was found (see Ch. IIIe). If both clay deposits (in the present and the Molenaarsgraaf section) are correlated with each other and regarded as primary *loam* deposits, then part of this *loam* of the Kreftenheye Formation would have been dated as Boreal (see further Ch. IVc).

Table 6. Description of pollen zones in boring Leerdam S322 II.

| | |
|---|---|
| III | 868-833 cm. Gradual transition from zone II to zone III. Rise of Alnus to c. 35%; fall of Pinus to c. 15% (with strong fluctations). Values of Corylus and Quercus same as in upper part of zone II. Salix c. 10%. Increase of Ulmus to c. 10%; increase of Tilia in top of the zone to 13%. NAP mostly consisting of Gramineae (c. 30%), Cyperaceae (mainly in upper part of the zone, c. 10%), Typha angustifolia (5-10%) and Umbelliferae (5-10%). Peaks of Filipendula (8%, in lower part of the zone) and Solanum (3%, in upper part of the zone). Fern spores reduced to c. 2-3%. |
| II | 960-868 cm. Quercus gradually increasing to c. 25%. Corylus values very gradually decreasing from base to top of the zone (to 10-20%). Pinus in lower part of the zone c. 30%, gradually increasing to c. 50% in upper part of the zone. Betula gradually decreasing from c. 10 to c. 1%. Salix gradually increasing from c. 1 to c. 10%. Alnus discontinuously present in very low values, increasing gradually in the top of the zone. Ulmus values same as in zone I B. AP/NAP-ratio c. 70%; Gramineae c. 20-25%; upward increasing values of Cyperaceae, Typha angustifolia, Umbelliferae, Cruciferae, Nuphar, Chenopodiaceae and monolete psilate spores; important peaks of all these in upper part of the zone, esp. of Cyperaceae (up to 35%), Typha angustifolia (up to 20%) and Umbelliferae (up to 20%). |
| I B | 982-960 cm. Corylus values higher (c. 65%), Pinus values lower and strongly fluctuating. Ulmus values slightly increased (c. 2-3%). Gramineae increased but strongly fluctuating. Maximal values of Thalictrum in this zone (up to 5%). |
| I A | 1014-982 cm. AP dominated by Corylus (c. 45%) and Pinus (c. 40%). Betula c. 10%; Salix c. 1-2%. Quercus and Ulmus nearly continuously present in very low values. AP/NAP-ratio c. 60%, NAP mainly consisting of Gramineae (c. 45%); Cyperaceae c. 5%, Typha angustifolia c. 5%, Myriophyllum c. 5%, Artemisia c. 2-3%. |

## Interpretation of the pollen zones

**Zone IA** (1014-982 cm below land-surface). On the higher parts of the surface of the Kreftenheye Formation (river dunes and *loam*) stood *Pinus*, *Corylus* and some *Betula*. On the lower parts of the *loam*-surface *Phragmites* and *Salix* would have occurred, and during inundations some *loam* may still have been deposited there. In the depression itself a lake formed with a vegetation of Gramineae, Cyperaceae and *Typha angustifolia* along the shore and *Myriophyllum* in the water itself.

**Zone IB** (982-960 cm). *Corylus* temporarily expanded at the cost of *Pinus*, and *Ulmus* established itself in the area. Apart from these changes the vegetation was similar to that of zone IA.

**Zone II** (960-868 cm). On the river dunes and possibly also on the higher parts of the *loam*-surface stood *Quercus*, *Ulmus*, *Pinus* and *Corylus*, and, on the lower parts of the *loam*, *Salix*. In the depression Gramineae, Cyperaceae, *Typha angustifolia*, Cruciferae and Umbelliferae grew in shallow water.

**Zone III** (868-833 cm). *Alnus* had established itself in the area and would have grown, together with *Salix*, on the lower parts of the *loam*-surface, that became increasingly wet. In the forest stands on the river dunes and possibly the higher parts of the *loam*-surface the proportion of *Pinus* decreased strongly, whereas that of *Ulmus* increased markedly. The vegetation in the depression was more or less similar to that in zone II.

## IIIg POLLEN ANALYSIS OF BORING MOLENAARSGRAAF H2178

### Depression filling in dune field

In the western part of the Molenaarsgraaf study area a (completely buried) complex of river dunes is present (see e.g. Fig. 36). In its strongly undulating relief lies, at boring H2178 (see for the position Fig. 3), a small depression, reaching down to 10 m below N.A.P. and partly infilled by gyttja and peat (see Fig. 20). Lithostratigraphically these organic beds belong to the basal peat (bed ol b in the local terminology). This organic depression filling has been studied palynologically in order to reconstruct the older, on the basis of the depth below N.A.P. probably Atlantic, forest cover of the river dunes. Some pollen samples have also been taken from the underlying deposits (*loam* and dune sand). During the sampling it was noted that a thin sand layer also occurred in the organic depression filling, with a lithology similar to that of the river-dune sand (see Fig. 21).

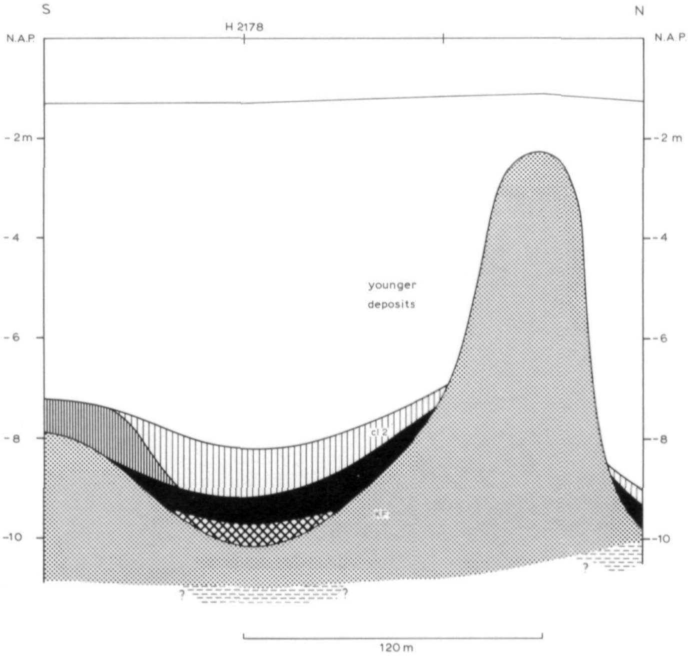


Fig. 20. Profile at boring Molenaarsgraaf H2178. For lithological legend, see Fig. *9.

### Interpretation of the pollen zones

**Zone I** (969-962 cm below land-surface). In the only sample from the light-grey sandy *loam* underlying the dune sand, the pollen seems to be derived from different sources and/or periods (see Table 7 and App., Fig. p). The *Pinus* and *Betula* pollen may be of a local Preboreal origin, the *Corylus* and *Quercus* pollen of a local Boreal origin. An important part of the pollen may also have been supplied from more southern regions by the *loam*-depositing rivers. Part of the pollen may have been reworked from pre-Holocene deposits. In any case there seems to have been a mixing of pollen by bioturbation or percolation. On the basis of the high *Pinus* and *Betula* percentages, it is most likely that the *loam* has been deposited here during the Preboreal (in the case of a synsedimentary pollen influx) or before (in the case of a postsedimentary pollen influx).

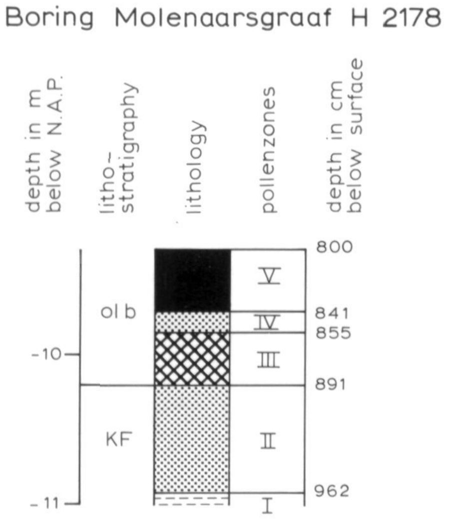


Fig. 21. Pollen zones in boring Molenaarsgraaf H2178. For lithological legend, see Fig. *9.

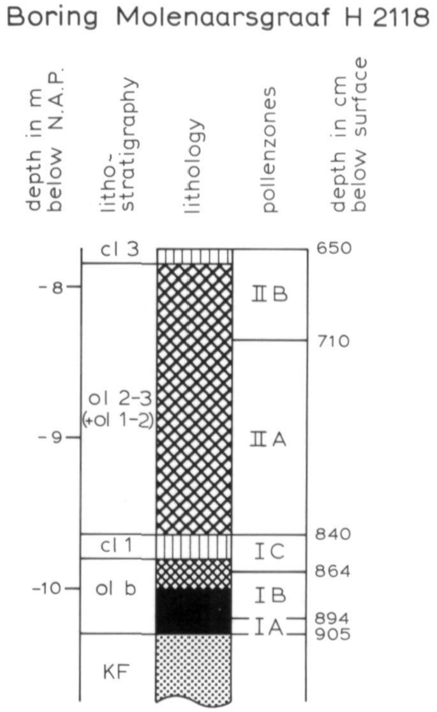


Fig. 22. Pollen zones in boring Molenaarsgraaf H2118. For lithological legend, see Fig. *9.

**Zone II** (962-891 cm). Only in the upper 30 cm of the river-dune sand did sufficient pollen appear to be present for a reliable analysis. It is assumed that the pollen was illuviated after the dune-sand deposition. A detailed discussion of this process of pollen illuviation in sand soils is given by HAVINGA (1974). Also bioturbation may have played a role here; it was shown by AHLBRANDT et al. (1978) that in the surface of sand dunes intensive bioturbation can occur. In accord with the above explanations, it is believed that the pollen was supplied by an Atlantic forest cover on the dune surface: *Quercus* and *Tilia* on the dry places, *Alnus* and *Salix* in the depression which was becoming gradually wetter because of the general water-level rise. The near absence of Preboreal and Boreal pollen (*Pinus*, *Betula*, *Corylus*) might be explained by its disappearance through oxidation, or by assuming a late-Boreal age for deposition of the dune (see further Ch. IVc).

**Zone III** (891-855 cm). According to the lithology (gyttja), a lake had been formed in the depression. Phragmites, Cyperaceae, Umbelliferae and *Typha angustifolia / Sparganium* would have grown along the shore and at shallow spots in the lake. The dune-surface was mainly covered by *Quercus* and *Corylus*.

**Zone IV** (855-841 cm). This zone coincides in the lithology with the thin dune-sand layer situated in the topmost part of the gyttja (see Fig. 21). The sand is mixed with gyttja, so presumably the lake still existed during the deposition of this sand. The displacement of the dune sand may probably be

Table 7. Description of pollen zones in boring Molenaarsgraaf H2178.

| | |
|---|---|
| V | 841-800 cm. Important values of Quercus (c. 45-50%) and Salix (c. 12%). Alnus reduced to c. 30%. Low values of Pinus, Corylus, Tilia and Ulmus. Practically no NAP. |
| IV | 855-841 cm. High values of Tilia, decreasing upward (from 38 to 10%). Low values of Quercus in lower part of the zone, increasing upward from 4 to 23%. Salix increasing upward from 2 to 9%. Corylus decreasing upward from 6 to 1%. Other AP mainly Alnus (c. 47%); Pinus 8%, Ulmus 3%. NAP values very low, mainly Gramineae (decreasing upward from 8 to 3%). Small peak of Typha/Sparganium in top of the zone (2.7%). |
| III | 891-855 cm. Dominance of Alnus (c. 70%), Corylus and Quercus (both c. 12%). Low values of Pinus, Tilia, Ulmus and Salix. Gramineae only NAP of importance (c. 9%), remaining NAP mostly Cyperaceae, Umbelliferae and Typha/Sparganium. |
| II | 962-891 cm. Transition from zone I to zone II based on lithology; sufficient pollen only in upper part of this zone (922-891 cm); three samples with AP-sum = 300. Alnus c. 40%, Quercus c. 25%, Salix c. 10%, Corylus c. 6%. Tilia increasing upward to 16%. Pinus, Betula, Ulmus and NAP in very low values. |
| I | 969-962 cm. One sample only (966-965 cm, AP-sum = 145): Pinus 60%, Betula 22%, Alnus 14%, Corylus 2.7%, Quercus 0.7%, Salix 0.7%, Gramineae 9%, Ericaceae 5%. |

attributed to erosion as a consequence of prehistoric cutting of the adjacent *Quercus* forest. Apparently *Tilia*, occurring here and there in the *Quercus* forest, had been spared during the wood cutting. In view of the depth and the stratigraphical position of the layer concerned, the presumed wood cutting can be tentatively associated with the charcoal dating of 6900 BP at the foot of the Hazendonk river dune (see also Ch. IIIi).

**Zone V** (841-800 cm). In the infilling depression stood a swamp forest of *Alnus* and *Salix*. The *Quercus* forest on the adjacent higher parts of the dune-surface seems to have been restored.

## IIIh POLLEN ANALYSIS OF BORING MOLENAARSGRAAF H2118

### Depression filling at border of dune field

Section H2118 is situated at the northern border of the river-dune complex in which section H2178 (Ch. IIIg) is more centrally located (cf. Figs 3 and 36). Boring H2118 has been incorporated in profile III (Fig.*8). Pollen analysis, with a sampling interval of 5 cm, has been carried out on the lower 2.5 m of the Westland Formation in this boring. The section consists almost entirely of organic deposits that lithostratigraphically (see Fig. 22) belong to beds ol b, ol 1-2 and ol 2-3. Clastic unit cl 1 is present as a thin clay bed; clastic unit cl 2 has not been deposited here. The aim of the pollen analysis of this section is similar to that of section H2178, namely a reconstruction of the older (Atlantic) dune vegetation.

### Interpretation of the pollen zones

**Zone I** (905-840 cm below land-surface). In the small depression at the foot of the river-dune complex stood an *Alnus* swamp forest. A *Quercus* forest stood on the dry dune-surface nearby, probably with stands of *Ulmus* and *Corylus* at the edges. At the beginning of organic accumulation (zone IA, cf. Table 8) a somewhat open area with among others Umbelliferae and *Typha angustifolia* was present at the locality of the section. In the adjacent oak forest some *Tilia* also occurred. During the formation of zone Ic, the swamp forest became more open again and some fluvial clay was deposited. Because of the water-level rise the *Alnus* swamp forest could extend over the dune-surface at the cost of the oak forest. As the fall of the *Quercus* pollen percentage (at the transition from zone IB to zone IC) is rather conspicuous, prehistoric wood cutting might also explain the Quercus decrease. This possible prehistoric activity might, in view of the depth and stratigraphic position of the layer concerned, correspond to that of zone IV in section H 2178 (Ch. IIIg).

**Zone II** (840-650 cm). In the depression a small lake had been formed; it was surrounded by *Alnus* swamp forest. On the dunes *Quercus*, *Ulmus*, *Corylus*, *Viburnum* and some *Tilia* occurred. The small proportion of *Tilia* in the dune vegetation is in agreement with the conclusions from the pollen analysis of the standard boring (Ch. IIIc): in the corresponding pollen zones there (the zones forming main zone I, see Fig. 13) the high *Tilia* percentages have been ascribed to supply by rivers from the hinterland.

The denser herbaceous vegetation in zone IIB (Umbelliferae, *Nymphaea* and Ranunculaceae, presumably *Batrachium*) points to more quiet conditions in the lake. This probably corresponds with simultaneous peat growth in the larger part of the study area (organic bed ol 2-3). This would imply that the period of deposition of clastic bed cl 2 coincides with an important part of the period of gyttja deposition of zone IIA.

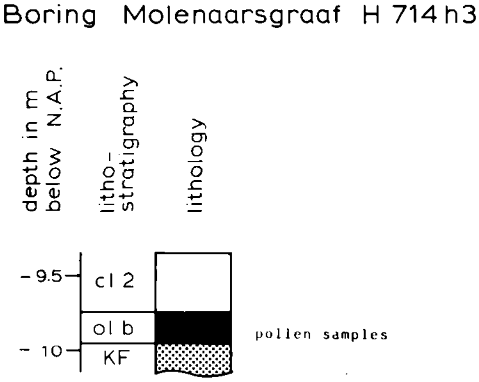
Table 8. Description of pollen zones in boring Molenaarsgraaf H2118.

| | |
|---|---|
| II B | 710-650 cm. AP same as in zone II A. NAP slightly increased, mainly Umbelliferae (c. 10%). Peaks of Nymphaea and Ranunculaceae (both up to 4%). Decreased values of monolete psilate spores. |
| II A | 840-710 cm. Constant values of all AP: Alnus c. 70%, Corylus c. 10-15%, Quercus c. 10-15%, Ulmus c. 2-5%, remaining AP mainly Pinus, Betula, Tilia, Fraxinus and Viburnum. Very high AP/NAP-ratio (90-95%), low values of Gramineae, Cyperaceae and Umbelliferae. Monolete psilate spores in irregular values (up to 8%). |
| I C | 864-840 cm. Fall of Quercus to c. 20%. Corylus peak in lower part of the zone (to 26%), gradually decreasing towards the top of the zone. Increase of Alnus in upper part of the zone to c. 50%. Tilia slightly increased (to c. 4%). Small peaks of Gramineae (max. 7%), Cyperaceae (max. 7%), Typha angustifolia (max. 14%), Alisma (max. 2%), monolete psilate spores (max. 6%). |
| I B | 894-864 cm. Most AP and NAP in same values as described for the top of zone I A. Corylus 10-15%. Peak of Quercus at base of the zone (50%), upward constantly 35-40%. Fraxinus 2% in top of the zone. Umbelliferae c. 3%. Monolete psilate fern spores practically absent. |
| I A | 905-894 cm. Quercus increasing upward from 23 to 46%, Tilia decreasing from 20 to 3%. Ulmus c. 7%, Alnus c. 30%. Peak of Corylus 32%. Pinus c. 5%, Betula c. 2%. AP/NAP-ratio increasing from 72 to 88%; Gramineae c. 5%, Cyperaceae c. 3%, Typha angustifolia c. 5%, Umbelliferae peak of 15%, Alisma peak 1.7%. |

## IIIi POLLEN ANALYSIS OF BORING MOLENAARSGRAAF H714h

During the preparatory geological mapping (see Ch. I), charcoal was found at the foot of the Hazendonk at such a depth and stratigraphic position that it gave rise to the supposition of a Mesolithic prehistoric influence (see LOUWE KOOIJMANS 1976c, fig. 2). In order to sample this charcoal, one of the borings concerned (H714, see for its position Fig. 3) has been gouged several times. One of the cores (H714h3) contained sufficient charcoal for C-14 dating (6900 ± 100 BP, see further Ch. IVb.1 and Fig. 30).

Fig. 23. Pollen zones in boring Molenaarsgraaf H714h. For lithological legend, see Fig. *9.



The sampled charcoal comes from the top of the dune sand (see Fig. 23). From the overlying thin peat bed three pollen samples have been taken. The samples show a uniform pollen composition. The average values of the most important taxa are as follows: *Alnus* 27%, *Corylus* 12%, *Quercus* 51%, *Tilia* 2%, *Ulmus* 3%, Gramineae 12%, Cyperaceae 5%, Umbelliferae 3%.

In agreement with the conclusions drawn in Chs. IIIg and IIIh it is also apparent from this section that in the Atlantic dune vegetation, *Tilia* was of minor importance compared to *Quercus*. This holds true even if generous allowance is made for the fact that the pollen production of *Tilia* is lower than that of *Quercus*.

## IIIj POLLEN ANALYSIS OF BORING MOLENAARSGRAAF H2114

### - in cooperation with R. Steenbeek -

### Wood-peat bed ol 2-3

From boring H2114, situated in the NW part of the Molenaarsgraaf study area (see Fig. 3), peat bed ol 2-3 has been studied palynologically in order to compare it with the corresponding bed in the standard section (see Fig. 13) and with the very thick gyttja layer in boring H2115 situated nearby (Ch. IIIk). The lithostratigraphic development at borings H2114 and H2115 is shown in the profile in Fig. 24. In boring H2114, clastic bed cl 2 is rather thick. Its lower part is a sandy channel fill, but its upper part is a thick clay bed (and thus not to be regarded as stream ridge). The overlying wood-peat bed ol 2-3 is rather thin. The 3.5 m thick gyttja layer in boring H2115 situated 80 m to the North belongs lithostratigraphically to the same unit ol 2-3. The thick development of this gyttja layer can be ascribed to the presence of a local depression in the surface of the Kreftenheye Formation.

The peat bed, including the transition to the under- and overlying clay beds (see Fig. 25), has been sampled every cm. The results of the analysis are shown in Table 9 and App., Fig. q.

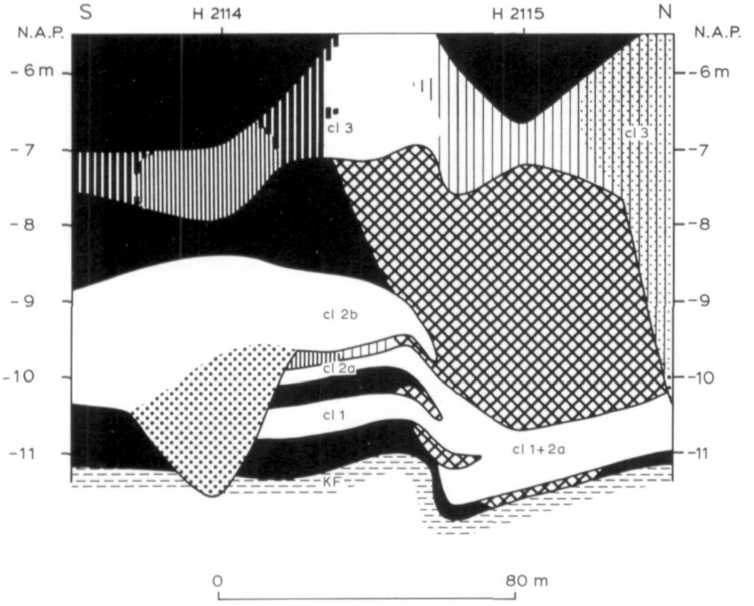


Fig. 24. Profile at borings Molenaarsgraaf H2114 and H2115. For lithological legend, see Fig. *9.

## Interpretation of the pollen zones

**Zone I** (710-691 cm below land-surface). After some *Phragmites* growth during the final clay deposition at the bottom of the zone, a closed swamp forest developed. It consisted mainly of *Alnus* and some *Salix*. During the formation of the upper part of the zone, the swamp forest again became somewhat more open, and because of this, *Quercus* pollen from the dunes and possibly from stream ridges could reach the locality of the section more effectively.

**Zone IIA** (691-675 cm). The swamp forest survived, albeit probably with less *Salix*, at the locality of the section. Not far from it, a vegetation of *Urtica*, *Solanum dulcamara* and *Filipendula* existed. This vegetation would have grown on a nutritious substratum, most probably wasted plant material drifted ashore along the lake, whose existence is evidenced by among others gyttja section H2115. Floating mats may have occurred in this shore vegetation: ZONNEVELD (1960, p. 211) mentions *Solanum dulcamara* as an important component of floating-mat vegetation in the formerly freshwater tidal area of the Biesbosch (prov. of Zuid-Holland).

**Zone IIB** (675-662 cm). The swamp forest had become gradually more open (increase of Umbelliferae, *Nymphaea* and *Salix*). At the same time clay deposition increased; the transition from peat bed ol 2-3 to the overlying clay bed cl 3 is very gradual. The higher values of *Artemisia* and *Rumex* pollen should perhaps be attributed to prehistoric occupation on the river dunes.

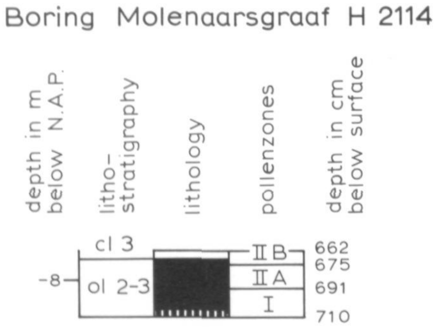


Fig. 25. Pollen zones in boring Molenaarsgraaf H2114. For lithological legend, see Fig. *9.

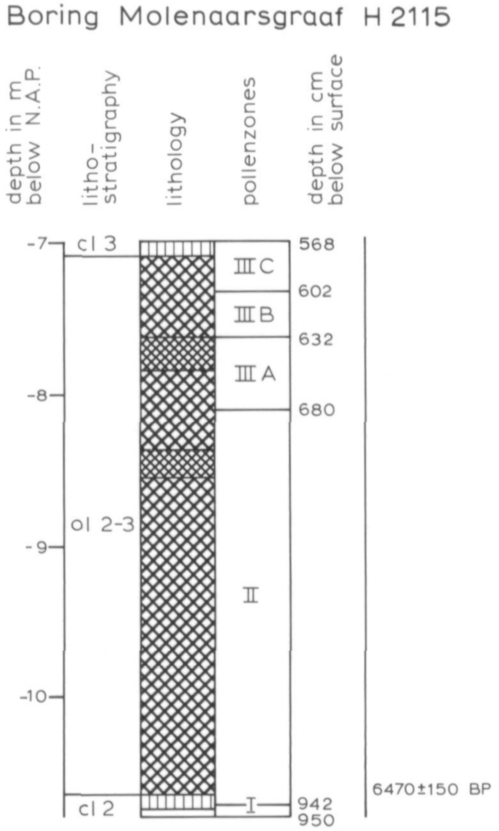


Fig. 26. Pollen zones in boring Molenaarsgraaf H2115. For lithological legend, see Fig. *9.

Table 9. Description of pollen zones in boring Molenaarsgraaf H2114.

| | |
|---|---|
| II B | 675-662 cm. Further decrease of Alnus to c. 60% in top of the zone; increase of Corylus to c. 15%. Slight rise of Pinus, Tilia, Ulmus and Salix. Urtica decreased to c. 2-3%; also decrease of Solanum and Filipendula. Slight increase of Nymphaeaceae, Umbelliferae and Artemisia. Other NAP (Gramineae, Cyperaceae and Typha angustifolia) same as in zone II A. Slight increase of monolete psilate fern spores to c. 5%. |
| II A | 691-675 cm. Transition from zone I to zone II A characterised by increase of several AP. Gradual decrease of Alnus to 70%; gradual increase of Corylus to 10% and of Ulmus to c. 3-4%. Irregular Quercus values c. 10%. Decrease of Salix; small peaks of Hedera. Important values of Urtica (5-10%), other NAP mainly Gramineae, Cyperaceae, Typha angustifolia, Filipendula and Solanum (all less than 5%). |
| I | 710-691 cm. High Alnus values (80-85%); very low NAP values. Quercus increasing from c. 5% in the lower part to c. 10% in the upper part of the zone. Low values of Pinus, Tilia and Ulmus. Rather important values of Salix (max. 4%). Hedera present in lower part of the zone (c. 2%). Small peak of Gramineae at base of the zone. |

## IIIk POLLEN ANALYSIS OF BORING MOLENAARSGRAAF H2115

**- in cooperation with R. Steenbeek -**

### Gyttja bed ol 2-3

The lithostratigraphical position of the unusually thick gyttja in boring H2115 has been set out in Ch. IIIj. The base of this gyttja layer is correlative with organic bed ol 2a-2b, not only lithostratigraphically (see Fig. 24), but also chronostratigraphically (on the basis of a C-14 dating, see Ch. IV, Figs. 29 and 27). Organic bed ol 2a-2b underlies the important clastic bed cl 2b in the general lithostratigraphic scheme. This means that part of the gyttja deposition of the section concerned had taken place at the time of the clay deposition of bed cl 2b. The aim of the pollen analysis of this gyttja section is therefore not only a comparison with the lithostratigraphically correlative peat bed ol 2-3 (see Ch. IIIj), but also a comparison with the chronostratigraphically partly correlative clay bed cl 2b.

In the analysis the transitions to the under- and overlying clay beds (see Fig. 26) have also been studied. The lower 75 cm of the section has been sampled every cm, the remaining part every 3 cm. The results of the analysis are shown in Table 10.

### Interpretation of the pollen zones

**Zone I** (950-942 cm below land-surface). This zone is situated in the top of the clay bed below the gyttja section, and differs from the overlying zone mainly in the *Tilia* percentage. The higher Tilia values in the clay can apparently be explained by river supply from the hinterland (see also Ch. IIIc.3).

**Zone II** (942-680 cm). Whereas in nearly the whole study area basin-clay sedimentation occurred (bed cl 2b), here mainly lacustrine organic (gyttja-)sedimentation took place. At the surface of the lake *Nymphaea*ceae grew here and there. On the shore of the lake, presumably at places where organic material such as wood remains drifted ashore (see also Ch. IIIj), a vegetation of *Urtica*, *Solanum dulcamara* and *Filipendula* occurred. Gramineae, Cyperaceae, *Typha angustifolia* and ferns grew along the shore. Presumably *Salix* occurred locally there too. *Alnus* swamp forest would have occurred mainly along the borders of natural levees and river dunes, on whose higher parts particularly *Quercus*, *Ulmus* and *Corylus* occurred, with *Tilia* and *Fraxinus* to a lesser degree.

**Zone IIIA** (680-632 cm). The water depth of the lake had strongly decreased, as witnessed by the extensive growth of Umbelliferae in the area directly surrounding the section. The decreasing water depth resulted in deposition of a coarser gyttja in the upper part of the zone (see Fig. 25; see also Ch. IIa.3 — Organic deposits). It is plausible that this environmental change corresponds with the origin of *Phragmites* fields and swamp forests in most of the remaining part of the study area (the formation of peat bed ol 2-3; cf. Ch IIIc, zone 9, Ch. IIIh, zone IIB and Ch. IIIj, zone I). The higher *Corylus* pollen values may be attributed to hazel bushes on the natural levees or stream ridges of clastic bed cl 2. Because of the relative water-level fall mentioned above the channel fills of bed cl 2b might have emerged already as stream ridges (cf. Ch. IIIc, zone 9).

**Zone IIIB** (632-602 cm). The water depth of the lake seems to have increased again. The deposition of this part of the gyttja layer coincides with the widespread gyttja deposition in the study area, as recorded in the upper part of organic bed ol 2-3 (see Ch. IIa.3).

Table 10. Description of pollen zones in boring Molenaarsgraaf H2115.

| | |
|---|---|
| III C | 602-568 cm. Strongly resembling zone III A, but lower values of Corylus and Umbelliferae, Betula and Gramineae slightly higher values. At base of the zone peaks of Gramineae, Umbelliferae, Artemisia, Chenopodiaceae, Urtica and monolete psilate fern spores. |
| III B | 632-602 cm. Compared to zone III A lower values of Corylus, Pinus, Tilia, Ulmus and Umbelliferae, higher values of Alnus (c. 70%). |
| III A | 680-632 cm. Important peaks of Corylus (max. 50%), opposing lower values of Alnus. Slightly increased values of Pinus, Tilia and Ulmus. Slight decrease of Quercus. Salix practically absent. High values of Umbelliferae, with peaks rising to 20 and 35%. Sparganium, Nymphaeaceae, Filipendula, Solanum and Urtica decreased; other NAP unchanged. |
| II | 942-680 cm. Comprises the larger part of the section. Rather constant values of most AP and NAP. Alnus dominant (c. 70%); Corylus c. 10-15%; Quercus c. 5-10%. Regular occurrence of Salix (less than 3%). Other AP mainly Ulmus (3-5%), Pinus, Betula and Tilia. AP/NAP-ratio fluctuating between 80 and 90%. Gramineae, Cyperaceae, Typha angustifolia, Sparganium, Nymphaeaceae, Umbelliferae, Filipendula, Solanum, Artemisia and Urtica present in low values. Monolete psilate fern spores c. 10%. |
| I | 950-942 cm. Compared to zone II (see there) higher values of Quercus, Tilia, Ulmus and Corylus, lower values of Alnus. |

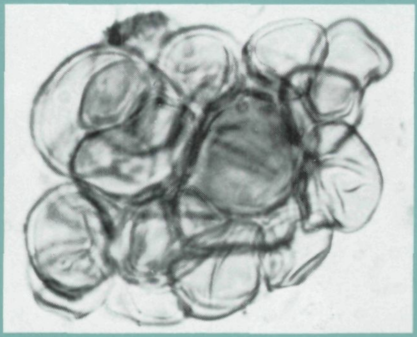
**Zone IIIC** (602-568 cm). This zone is lithostratigraphically situated in the transition from gyttja bed ol 2-3 to clay bed cl 3 (see Fig. 25). Simultaneously with the increase of the clay deposition, the *Alnus* swamp forests decreased in size, and the growth of Gramineae (presumably *Phragmites*) increased somewhat. The higher *Artemisia* and Chenopodiaceae values can probably be ascribed to prehistoric occupation influences on the river dunes.

## IIII FUNGAL SPORES

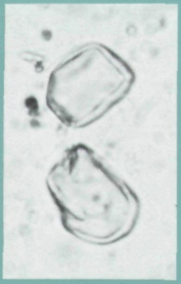
During the pollen analysis of all the sections discussed the fungal spores have also been analysed. Because fungal spores are difficult to identify, informal 'types' have been distinguished. Comparisons of these types with those distinguished by others (see below) are of course useful but cannot lead to precise identifications — no keys exist (cf. FAEGRI 1975, p. 215). Most of the distinguished types are shown in Plate 1.

Some general conclusions are drawn here briefly. Firstly, in all sections the fluctuations in the fungal spore curves often run more or less parallel (see e.g. pollen diagrams Figs.*12 and*15). This means that, to give a general view, all fungal spores might be combined in one curve next to the others. Secondly, the fungal spores occur mainly in clay beds and clayey *Phragmites*-peat beds. This means that the spores may have come partly from fungi growing on *Phragmites* and other herbs. A larger proportion of the spores, however, might have been supplied by river water from upstream areas, in common transport with the clay particles.

Some of the types shown in Plate 1 are comparable with types distinguished by PALS et al. (1980) in a Holocene section in West-Friesland (in the northern part of the Western Netherlands coastal plain). Type A4 strongly resembles type 117 distinguished there, which shows no relation to the



type A

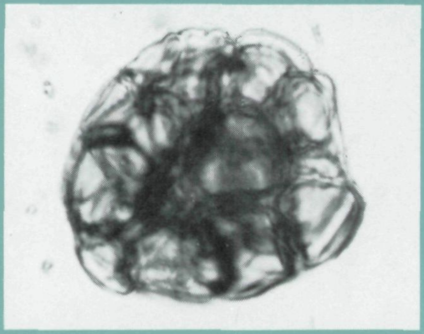


type A

type A

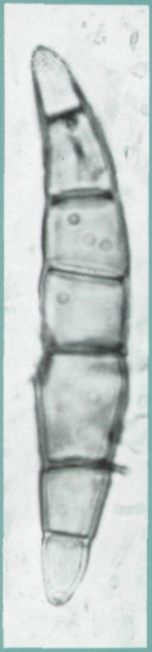
type A4

type D

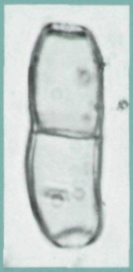


type E

type F

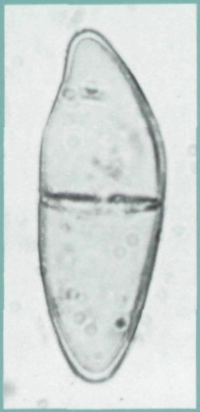


type F

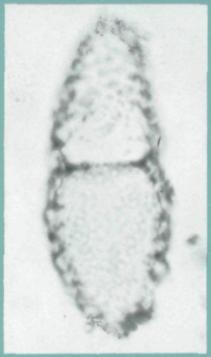


type H’

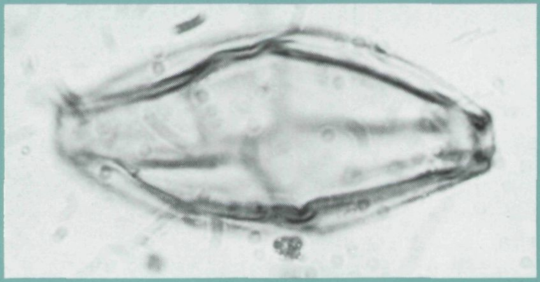
type E5



type H



type HH



type Z

local vegetation and occurs mainly in a clay bed. Type H' is probably the same as type 121, which occurs there in a lacustrine deposit. Type D strongly resembles type 122, which is mainly related to *Salix* swamp forest there.

When more publications appear about fungal spore types occurring in eutrophic environments, especially concerning their identification and their ecological significance, it will be possible to evaluate in more detail the fungal spore type curves in pollen diagrams Figs.*12 and*15.

## IIIm STRAY FINDS OF FRUITS

During the geological field mapping occasionally fruits were sampled from the cores. This only concerns those fruit species, that are easily recognizable in the sediment with the naked eye. Because of the large inherent chance factor, this method is not comparable to the systematic fruit analysis of the standard boring (see Ch. IIIc.4). Nevertheless some qualitative conclusions can be drawn from the analysis of the stray sampled fruits.

Fruits of *Cornus sanguinea* have been found in peat and clay beds at short distances from river dunes and stream ridges. *Cornus* shrubs would have formed part of the forest stands on these higher areas; the fruits may have partly been transported by water.

In wood-peat beds fruits of *Iris pseudacorus* have been found. Apparently, this plant occurred in the undergrowth of the *Alnus* swamp forests.

Fruits of *Nymphaea* alba and *Nuphar luteum* have been found especially in gyttja beds, and underline therefore the lacustrine nature of the depositional environment. Fruits of *Oenanthe aquatica* have also been found in the gyttjas, especially in the upper part of organic bed ol 2-3; this plant may have been growing at shallow points in the lakes, e.g. along the shores.

In connection with these fruit finds in gyttja beds, mention should also be made here of the find — also in gyttja beds — of two specimens of the cocoon of the leech *Pisicola geometra* (type 139 in PALS et al. 1980). This leech prefers an open-water environment without periodical drying out (ibid.).

Fruits of *Scirpus* and *Nuphar luteum* in peat bed ip in the Leerdam study area point to local and/or temporary open-water conditions in the environment of deposition of this peat bed. This would be in agreement with the curves of Cyperaceae, *Nymphaea*, *Nuphar* and various fungal spores in zone IIB in the pollen section containing this peat bed (Fig.*15).

Plate 1. Informal fungal spore types. Scale: 1.2 cm = 10 mu.