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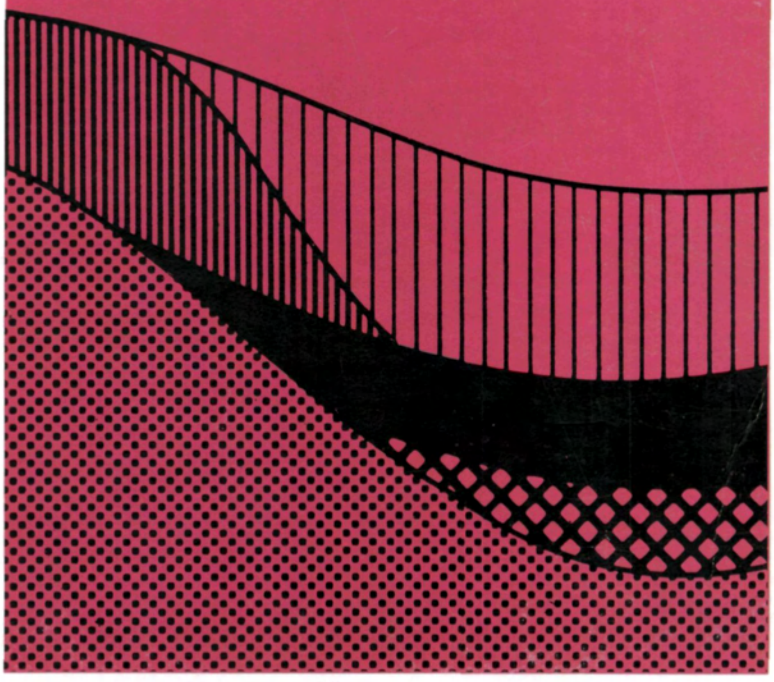

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J.D. VAN DER WOUDE

HOLOCENE PALEOENVIRONMENTAL EVOLUTION OF A PERIMARINE FLUVIATILE AREA

GEOLOGY AND PALEOBOTANY
OF THE AREA SURROUNDING THE
ARCHEOLOGICAL EXCAVATION AT THE
HAZENDONK RIVER DUNE (WESTERN NETHERLANDS)

HAZENDONK PAPER I

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Editorial

In the year 1963 some test pits, dug by a group of amateur archaeologists, revealed traces of Neolithic occupation on a small sandy outcrop in the middle of the Rhine-delta peat district. This site appeared to be unique and certainly deserved more than superficial archaeological attention. The small elevation is locally known as "Hazendonk" (=Hares-hill) and is situated in the municipality of Molenaarsgraaf, which is a part of the polder district named Alblasserwaard. It is the top of a river dune from the Late Glacial/early-Holocene period of which the steep slopes are covered by c. 10 m of Holocene sediments, that were deposited as an indirect result of the postglacial rise of the sea-level in the North Sea Basin.
A prospective investigation was carried out in 1966 and a report published in 1974. The results were so promising that the site was chosen for a large scale and detailed excavation, that took place in the summers of 1974-1976. A series of prehistoric cultural deposits with secondary refuse was documented in the Holocene sedimentary stratigraphy next to the *donk,* covering the complete local Neolithic (3300-1700 BC in conventional C14-dates). Six or seven main phases of use as a settlement site and as an exploitation base for the surrounding wetlands could be pointed out, each seperated by periods of vegetational recovery and human absence. The settlement traces themselves, situated on the top of the dune, were, however, completely destroyed. The research is now being concentrated on a detailed description of the occupation sequence, the evaluation of material culture and on the subsistence economy of the occupants in relation to the changing environment. The detailed field registration, the restricted manpower available, some misfortune in the planned computering, and rescue excavations that had to be carried out in the meantime caused serious delay of the final publications. Some preliminary reports could, however, appear in the last years.
With the palaeo-environmental study of the surroundings of the Hazendonk, presented in this volume, a start is made with the final publication. This will get the form of a number of separate articles and monographs, that will appear in two Leiden archaeological journals: those on ecological and economic aspects will appear in the *Analecta Praehistorica Leidensia*, those on the various artefact categories will appear in the *Oudheidkundige Mededelingen uit het Rijksmuseum van Oudheden*. It is the editor of the latter, the National Museum of Antiquities at Leiden, that formed my working base for the Hazendonk-research and that offered me all opportunities to develop this project. The forthcoming volume of the Oudheidkundige Mededelingen (no. 64, 1983) will contain the analysis of the bone and antler artefacts by P.W. van den Broeke. Separate contributions by various authors on stratigraphy, palaeobotany, archaeozoology, pottery, flint, stone and wooden artefacts and a final synthesis are planned for the coming years. They will all be joined by the label *Hazendonk Paper*. I consider the accomplishment of this task as one of my major jobs for the near future.

L.P. Louwe Kooijmans

Contents

N.B. Enclosures are indicated in the text by means of an asterisk (*)

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I INTRODUCTION

Ia THE PERIMARINE FLUVIATILE COASTAL PLAIN OF THE WESTERN NETHERLANDS

The Holocene geology of the Western Netherlands coastal plain (for location, see Fig. 1) has been studied for many decades. As well as its beach barrier-, dune- and lagoonal/estuarine/tidal flat deposits, research has included its fluvial and organic deposits. Literature reviews have been given by among others DE JONG (1971), LOUWE KOOIJMANS (1974) and ZAGWIJN (1974). Traditionally, the emphasis in the research has been on the marine deposits, but increasing attention has been paid to the fluvial (and related organic) deposits. This study aims to contribute to the last-mentioned development. Before discussing the detailed aims of this study (see Ch. Ib), a short outline of the geological history of the fluvial part of the Western Netherlands coastal plain is given here with reference to the most relevant literature (PONS & BENNEMA 1958, HAGEMAN 1969, VERBRAECK 1970, 1974 and LOUWE KOOIJMANS 1974; older sources, like STEENHUIS, VINK and PANNEKOEK VAN RHEDEN have been largely quoted herein). Most subjects in this outline will be dealt with in more detail in subsequent chapters.

The sedimentary basin

The Western Netherlands coastal plain forms part of the Quaternary sedimentary North Sea basin. During the Weichselian glacial age coarse sands were deposited in this area by the then braided rivers Rhine and Meuse. Where, towards the end of the Weichselian, the rivers Rhine and Meuse were still active — and this roughly coincides with their present-day position — a thin, nearly continuous bed of clayey material was deposited on top of these coarse sands. This top layer varies texturally from clayey sand to sandy clay and is often referred to as (the) *loam* (see e.g. ZAGWIJN & VAN STAALDUINEN 1975, p. 25). On top of this substratum of coarse sands and *loam* many river dunes have been found; where these have not been completely buried by younger sediments, the outcropping, topmost parts of them are locally known as *donken*. For the *loam* and the river dunes in the Western Netherlands coastal plain, the Late-Weichselian as well as the early-Holocene are mentioned as periods of deposition (see also Ch. IVc).
From the beginning of the Atlantic period, extensive clastic and organic accumulation occurred in this fluvial sedimentary basin, as well as in the whole coastal plain. The vertical space for this was offered by the rise of the water table under the influence of the Holocene sea-level rise.

Depositional cyclicity

In the fluvial part of the Western Netherlands coastal plain — mostly in the central part of it, in the region of the lower courses of the rivers Rhine and Meuse —, a pronounced cyclicity in the Holocene deposits has been observed. There is a manifold vertical repetition of river-clay beds and peat- (and gyttja-)beds. The clay beds are connected laterally to many sandy channel fills. These, together with their natural levees, are situated at a less lower depth than the corresponding clay beds, partly as a consequence of differential compaction; they are hence called 'stream ridges'. This morphological term refers equally to those channel fills that are visible as low ridges in the present-day scenery as to the completely buried ones (see among others VERBRAECK 1970, p. 59).
The cyclic sequence of river-clay- and peat beds is supposed by most authors to be litho- and chronostratigraphically largely the same throughout the region and to be correlative with the sequence of clay- and peat beds in the marine part of the coastal plain. The phases of increased marine depositional activity (mostly referred to in the literature as the transgressive phases) are thought to

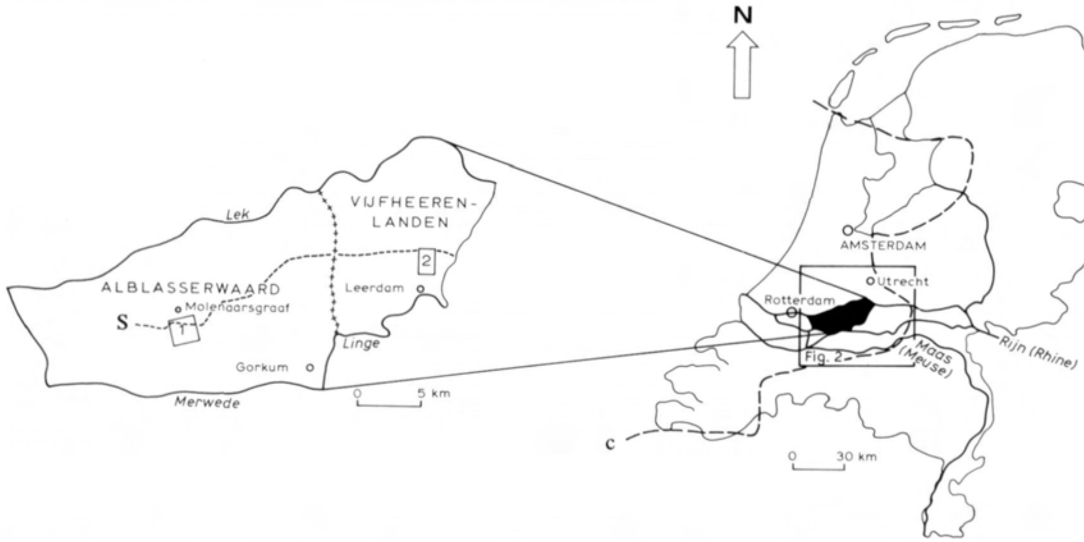


Fig. 1. Location of study areas. 1 = Molenaarsgraaf study area, 2 = Leerdam study area. Line c = schematic landward boundary of Western Netherlands coastal plain. Line S = approximate course of Schoonrewoerd stream ridge.

correspond to phases of increased fluvial deposition in the coastal plain, either as a consequence of a direct or of an indirect causal relationship. In the latter case a climate effect is envisaged, e.g. increased cyclonic activity. In the case of a direct relationship a mechanism involving damming up of river water as a result of shortening of the lower river courses by marine transgression is proposed by HAGEMAN (1969).

The relation of the depositional history in the marine part of the coastal plain to that in the fluvial part of it deserves in our opinion considerable research and discussion (see e.g. Ch. IVe). The earlier mentioned general relation, namely the Holocene sea-level rise as the cause of the general rise of the water table and so the increase of the vertical depositional space in the fluvial part of the coastal plain, is however unquestionable. In the filling of this vertical space not only fluvial sediment but also peat is involved, and beyond the depositional reach of the rivers and the sea peat alone may occur. HAGEMAN (1969) introduced the term 'perimarine area' for the inland part of the coastal plains incurring this deposition of fluvial sediment and peat under the influence of the Holocene sea-level rise. His definition of the term ('the area where the sedimentation or sedentation took place under the direct influence of the relative sea-level movements but where marine or brackish sediments themselves are absent', op. cit., p. 377) mirrors not only the general relation to the Holocene sea-level rise but also the more specific direct relation to marine transgressions. This last notion puts, to our opinion, too much interpretation in the definition. For the time being, we would restrict the term 'perimarine (area)' to the more general relation, and, for the region of this study, combine it with the more descriptive term 'fluviatile coastal plain' (SELLEY 1978, p. 13). The **perimarine fluviatile coastal plain** is therefore that part of the Holocene coastal plain, where, because of the sea-level rise, extensive accumulation of fluviatile clastic and related organic material could occur.

The term perimarine fluviatile coastal plain refers to genetic aspects. The thus defined area is not simply outlined in the present embanked and cultivated landscape. Its seaward boundary may have been subject to shifts during the Holocene. The term also includes the so-called river clay/wood peat region discerned by LOUWE KOOIJMANS (1974). Fig. 2 outlines its surface geology.

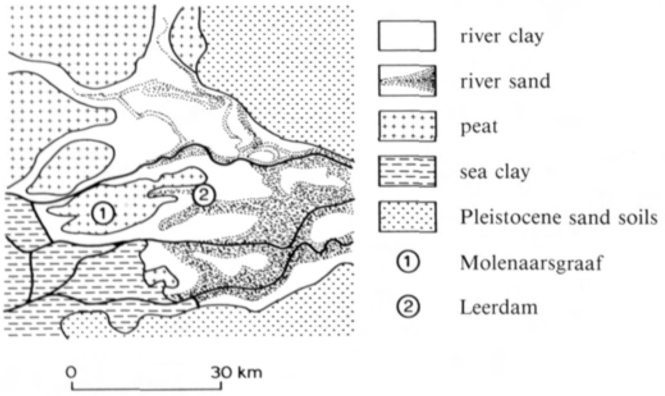


Fig. 2. Fragment of Soil map of the Netherlands, scale 1:200000 (simplified and greatly reduced in scale here). For location, see Fig. 1.

Prehistoric occupation and paleoecology

The river dunes (*donken*) and the stream ridges appear to have been suitable places for prehistoric occupation (LOUWE KOOIJMANS 1974). These high, dry sites amidst the swampy environment were often occupied during a large part of the Holocene. There seems to be a phasing in the prehistoric occupation, related to changes in the geological environment. As at the coast itself prehistoric occupation seems to have occurred mainly during phases of decreased marine depositional activity (mostly referred to in the literature as the regression phases), so in the perimarine fluviatile coastal plain the same seems to hold for phases of decreased fluvial activity.

Little is known about the paleoenvironments of the perimarine fluviatile coastal plain. Paleoecological studies of terrain surrounding archeological excavations have produced valuable information (see e.g. VAN REGTEREN ALTENA et al. 1962, 1963, DE JONG 1970-71, LOUWE KOOIJMANS 1974), but are restricted areally. The scarce, more regionally directed conclusions from these studies have not yet given a coherent picture of the paleoenvironments and their evolution during the Holocene.

Ib AIM AND FRAMEWORK OF THE INVESTIGATION

This study aims mainly at a relatively detailed reconstruction of the former Holocene landscapes of the area surrounding the Hazendonk, a small, almost completely buried river dune in the perimarine fluviatile coastal plain (for location, see Figs. 1 and 3). During the Atlantic and Subboreal periods this river dune had many phases of prehistoric occupation (LOUWE KOOIJMANS 1974, 1978); a request to supply the archeological investigators at the Hazendonk with a detailed geological map of the area, formed the direct inducement for this study, undertaken by the present author at the Institute of Earth Sciences, Free University, Amsterdam, from 1977 (after a preparatory field work in 1976 by others, see below). The study has been directed in such a way that this mapping around the Hazendonk is the basis of a case-study of the geological and paleoenvironmental evolution of the perimarine fluviatile coastal plain in a more regional sense. The Hazendonk river dune is situated in the centre of the region called the Alblasserwaard (prov. of Zuid-Holland; see Fig. 1). The geology of the Alblasserwaard may be regarded as representative of a large part of the perimarine fluviatile coastal plain; consistent with this is the fact that the Geological Survey has named the Alblasserwaard as the type area of the Holocene perimarine deposits (ZAGWIJN & VAN STAALDUINEN 1975, p. 47). In view of the strong differentiation in the geological structure of the

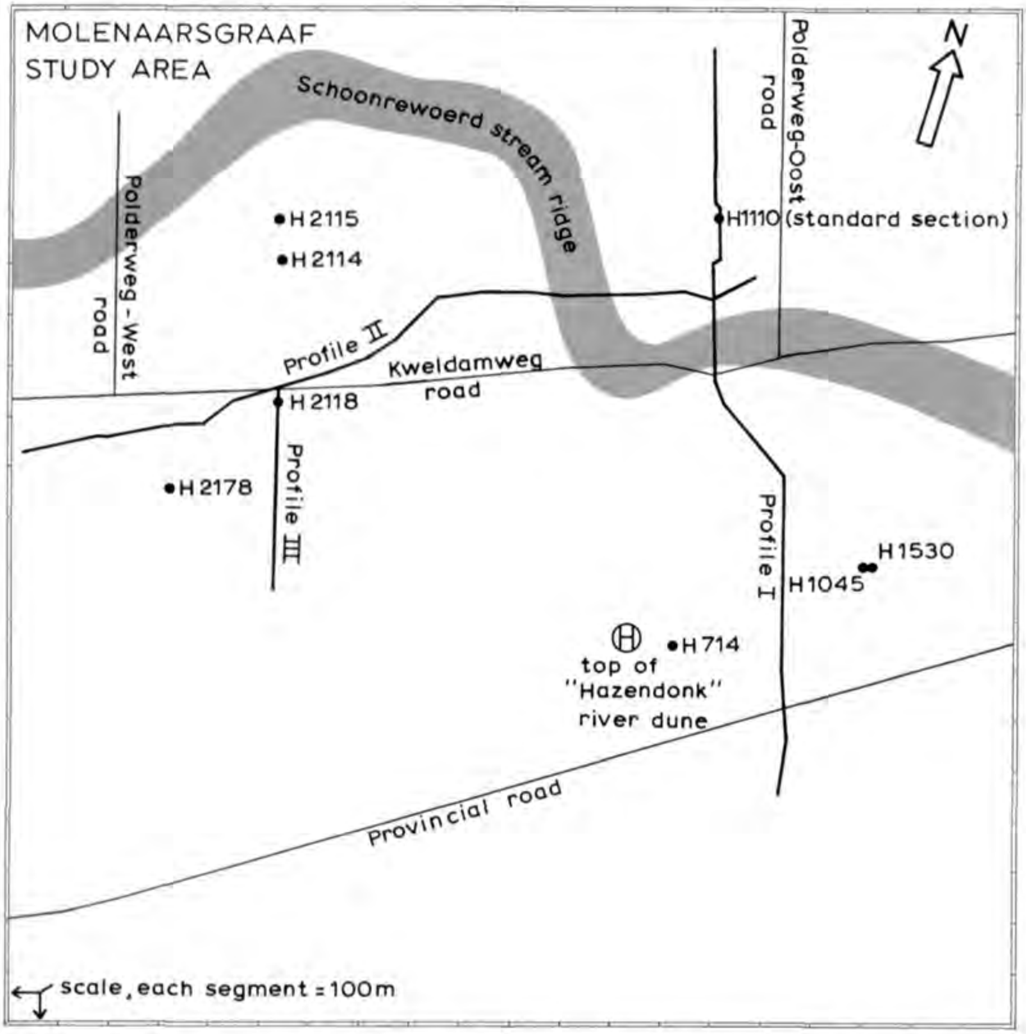


Fig. 3. Location of pollen- and C-14 borings and of selected profiles, Molenaarsgraaf study area.

perimarine fluviatile coastal plain, the detailed mapping facilitates a more fundamental reconstruction of the former landscapes and insight in their genesis than could formerly be achieved for this specific environment. For thematical problems concerning the litho- and chronostratigraphy, this detailed case-study may be regarded as complementary to the more regional approach as used among others by the Geological Survey for the preparation of the Geological map of the Netherlands, scale 1:50000 (see e.g. VERBRAECK 1970). The case-study area at the Hazendonk is referred to in the text as the Molenaarsgraaf study area (after the nearest community, see Fig. 1); in the figures in Ch. V it is also indicated as csa 1.

To facilitate the reconstruction of the former landscapes, the aim is to integrate the detailed geological mapping with elaborate paleobotanical research. This integration facilitates the use of the term **paleoenvironment** for the former landscape, mainly with respect to its geological-sedimentological environment and its vegetation. This combined, paleoecological approach is the main aspect of the framework of this study. Another important aspect is the establishment of the detailed chronology of the evolution of the paleoenvironment. This has been done for the sake of comparison with the

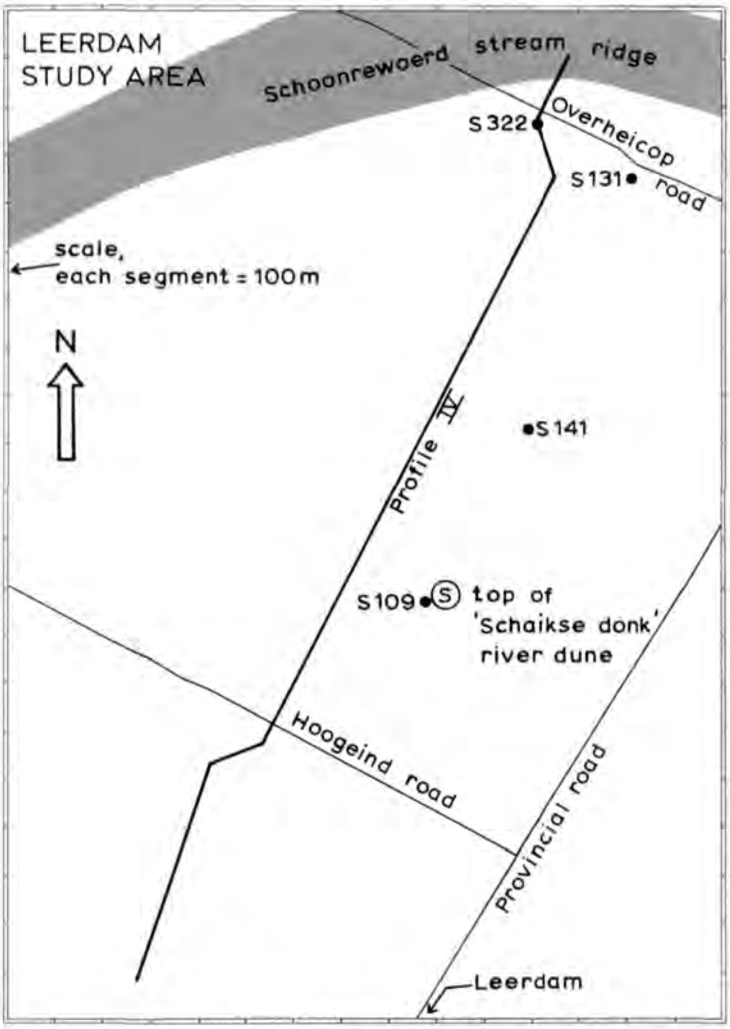


Fig. 4. Location of pollen- and C-14 borings and of selected profiles, Leerdam study area.

prehistoric occupation of the area as well as with the geological history of other parts of the coastal plain and of upstream areas.

Apart from the main case-study area (the Molenaarsgraaf study area), a second one has been chosen, mainly to give a broader regional scope to the geological history and partly also to the paleoenvironmental evolution. This second case-study area is situated near Leerdam (prov. of Zuid-Holland, see Fig. 1), c. 20 km to the east of Molenaarsgraaf, and thus upstream in the fluviatile coastal plain. The choice of this area (called the Leerdam study area, or csa 2) was determined in the first place by the presence of a river dune (the 'Schaikse donk'; see Fig. 4), comparable to the Hazendonk. In the second place, the new geological map 1:50000 that is available for this particular region (sheet 38 Oost; VERBRAECK 1970) shows in the immediate vicinity of the Schaikse donk river dune three stream ridges of partly different age. One of these, the so-called Schoonrewoerd stream ridge, is traceable down to the Molenaarsgraaf study area (see Fig. 1). Presumably, the Schaikse donk river dune also underwent some phases of prehistoric occupation (LOUWE KOOIJMANS 1974, fig. 18).

The study of this second area is less comprehensive than that of the Molenaarsgraaf area, as regards both the geological mapping and the paleobotanical research. In all respects, the emphasis in this study is on the Molenaarsgraaf area.

Ic METHODS

Detailed geological mapping

The geological field data were all obtained by means of hand borings, with the use of gouge-augers measuring c. 3 cm in diameter. Because the groundwater surface is only some dm deep, generally the whole boring profile could be gouged in undisturbed state.

In the larger part of both areas the borings have been placed at intervals of c. 80 m and in parallel rows; also the distance between the rows is usually c. 80 m (see Figs. 33 and 34). The resulting large density of this general boring grid (c. 150 borings per square km) became apparent early in the field study because of the complex stratigraphy and the short distances of the lateral facies changes. For several specific problems the distances between the borings were considerably smaller, especially so along the rather steep flanks of the central river dunes in both areas. Thus, along the border of the Hazendonk river dune c. 500, mostly shallow borings were placed at intervals of 2 to 5 m during the preparatory field work in 1976, mainly for the sake of pursuing stratigraphically the archeological levels (VAN DIJK et al. 1976).

The mapped surface amounts to c. 3 square km in the Molenaarsgraaf area and to c. 2 square km in the Leerdam area. The boring numbers have the prefixes H- and S- for both areas respectively. The total number of borings amounts to c. 1350 at Molenaarsgraaf (including c. 800 borings of the preparatory field work in 1976) and to c. 500 at Leerdam.

Where possible, the borings have been gouged down to the sand- and *loam*-subsoil that forms the basement of the Holocene sequence of clay- and peat layers. In most cases where this could not be achieved, the borings ended in a sandy Holocene channel fill. Outside the river dunes, the sand-subsoil lies on the average c. 9 to 9.5 m below the surface in the Molenaarsgraaf area and c. 5 to 7 m in the Leerdam area.

The aim of the investigations required not only a relatively large boring density, but also a detailed description of the stratigraphy of the bores. Most of the features discerned in the bored material appear in the legend units in Figs.* 9 (Ch. II) and*35 (Ch. V). The discrimination between the various units listed therein, and the quantitative indication of some features all proceeded in the field, without laboratory methods. For example, the discrimination between peaty clay and clayey peat was established by visual estimation of the relative abundance of clay and of plant remains and also by rubbing the material between the fingers. In processing the bore descriptions in order to construct the profiles and maps, a lower level of precision than present in the field descriptions was selected; this increases the reliability of the profiles and maps.

Discerned features that area not listed in Figs.*9 and*35 but nonetheless have played a role in the processing and interpretation of the boring results include among others colour, calcium carbonate content, occurrence of charcoal, occurrence of snail shell remains, and degree of gradualness of vertical lithological changes.

Paleobotanical analysis and C-14 dating

In both case-study areas a number of borings has been selected for paleobotanical analysis and C-14 dating (for location, see Figs. 3 and 4). These borings have been sampled by means of a gouge-auger, 5 cm in diameter. Among them, the standard boring of the Molenaarsgraaf study area (boring H1110) is one of primary interest. In this boring all distinguished lithostratigraphic units (see

Ch. II) are present with the exception of the river-dune sand. The complete section (over 9 m) has been sampled for pollen analysis, and for the larger part of it fruit analysis has also been undertaken. The organic deposits have been sampled continuously per cm, the clay deposits with sample intervals of 5 cm. At all important lithostratigraphic transitions in this boring C-14 samples have been taken.

The other selected borings are intended mainly as support for and supply to this standard boring and therefore have been sampled only partially for pollen analysis and C-14 dating.

The preparation of the pollen-, fruit- and C-14 samples is discussed in the relevant chapters (IIIb and IVb.1). The full pollenanalytic results of the standard boring (Molenaarsgraaf H1110) and of a boring in the Leerdam study area are presented in diagrams (Figs. *12 and *15), drawn by a computer-directed laser plotter; see VELDKAMP et al. for an explanation of this technique. The results of some of the remaining pollenanalytically investigated borings are presented in somewhat simplified diagrams, drawn by a conventional computer-directed ink plotter (see App.). Moreover, the results of all pollen sections have been presented in simplified tables.

Computer maps and landscape-reconstruction drawings

All boring data have been processed for computerized map constitution of thickness and several other characteristics of most of the distinguished lithostratigraphic units (see e.g. Figs. 41 and 42). For this purpose, the boring data were lithostratigraphically interpreted and uniformly coded as regards the diverse characteristics distinguished. Where boring sites occur in very dense concentrations, as at the foot of the Hazendonk river dune, for the sake of clarity only a limited number of them has been presented on the computer maps. These maps have been drawn, as were the main pollen diagrams (see above), by a laser plotter at the Mathematical Centre, Amsterdam. The computer has been involved not so much in computations, but more for the directing of the plotter.

The ultimate integration of the geological and paleobotanical results and the resultant reconstruction of the paleoenvironments, has been visualised in three-dimensional landscape pictures (drawn by drs. D. P. Ooijevaar) for four times in the Holocene history of the Molenaarsgraaf study area (see e.g. Fig.*43).

II LITHOSTRATIGRAPHY

IIa LITHOSTRATIGRAPHY OF THE MOLENAARSGRAAF STUDY AREA

IIa.1 The standard-sequence

The local sequence of beds, as found in the Molenaarsgraaf study area, has been presented in a generalised way in the left half of Fig. 5. The sand-subsoil, including its clayey top (the *loam*) and the locally outcropping river dunes, can be distinguished as a separate unit from the superposed sequence of (minero-)clastic and organic beds. Within this sequence, four clastic fluviatile beds are discerned: cl 1, cl 2, cl 3, and cl 4; the superficial clay bed ('cover') is left out of consideration here. These clastic beds could mainly be distinguished because of their alternation with organic beds consisting of peat and/or gyttja. As ROELEVELD (1974) and GRIEDE (1978) did in the marine districts in the Northern Netherlands, so too, in this study, the organic layers have been named lithostratigraphically: ol b as the basal organic bed, ol 1-2, ol 2-3 and ol 3-4 as the organic beds between the clastic cl- beds, ol u as the upper organic bed.

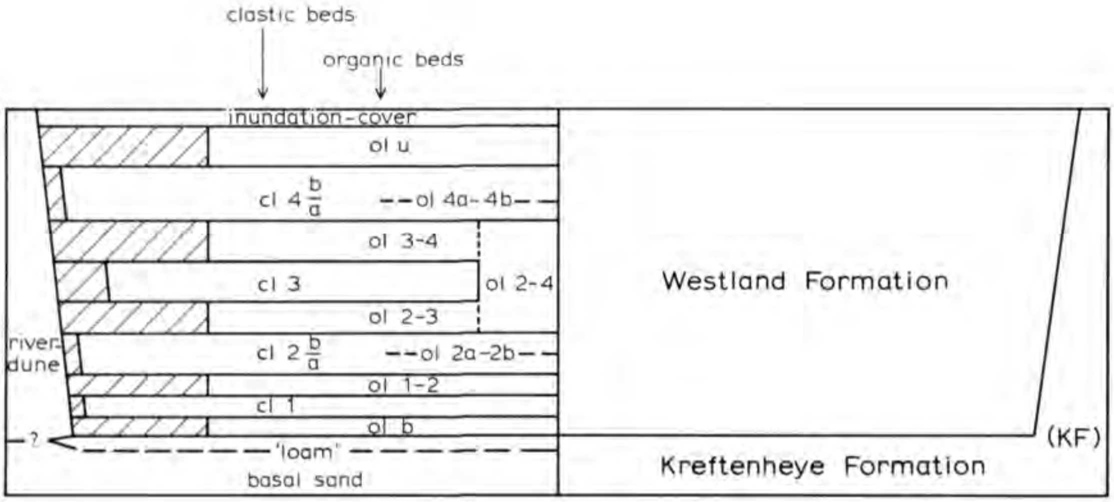


Fig. 5. Scheme of the lithostratigraphy in the Molenaarsgraaf study area.

In the mirroring right half of Fig. 5 both local main units are named in terms of the regional lithostratigraphy, namely the Kreftenheye Formation and the Westland Formation respectively. For references concerning this nomenclature, see ZAGWIJN & VAN STAALDUINEN (1975).

Of the 'predominantly coarse, gravel-bearing sands' comprising the Kreftenheye Formation (ibid., p. 25), the covering *loam* bed and river dunes in particular have been studied here. The Westland Formation consists predominantly of marine deposits, but the fluvial deposits of the coastal plain (the fluviatile perimarine deposits) are also included in it. In addition the intercalated peat beds, both between the marine and between the fluvial deposits, are (as 'Holland Peat') included in the Westland Formation (ibid., p. 47; see also DE JONG 1971, p. 149).

The subdivision of the fluviatile deposits of the Westland Formation into the 'Gorkum I, II, III and IV' deposits and the 'Tiel 0, I, II, IIIa and IIIb' deposits (Geological Survey: HAGEMAN 1963, ZAGWIJN & VAN STAALDUINEN 1975, p. 47) is not used here. This subdivision is not purely lithostratigraphically, but mainly chronostratigraphically defined, namely as chronologic equivalents of the marine 'Calais I - IV' deposits and 'Dunkerque 0 - IIIb' deposits. The objections against the use of these, also mainly chronologically founded lithostratigraphic units have been put forward previously by ROELEVELD (1974). In these matters, one might refer to the International Stratigraphic Guide: the establishment and identification of lithostratigraphic units should be largely independent of time-concepts (HEDBERG 1976, p. 94). The consequence of all this is that in the discussion of the various deposits belonging to the Westland Formation, besides to the local, informal units mentioned above, no reference will be made to the units used by the Geological Survey for the whole region.

As a tangible example of the lithological succession in the Molenaarsgraaf study area, Table 1 shows the detailed description of the standard boring (boring Molenaarsgraaf H1110). We mentioned previously in Ch. I, that the standard boring was chosen so as to comprise all distinguished clastic fluviatile (cl-) and organic (ol-) beds as well as the *loam* bed. This means that no sandy channel fills (stream ridges) and no river-dune sand occur in the boring; these would have resulted in the sequence of clay- and peat beds being incomplete due to erosion of underlying beds or partial non-deposition. In the selected cross-profiles (Figs.*6,*7 and*8) both these elements (stream ridges and river dunes) are however amply represented. The standard boring is incorporated in the northern part of profile I (Fig.*6).

IIa.2 The Kreftenheye Formation

The *loam*

The *loam* is a diamicton of clay and sand, mostly developed as sandy clay, usually with considerable toughness and stickiness. The term *loam* is set in italic to prevent confusion with the pedogenetic term loam: sand soil with more than 32.5% in the grain size fraction smaller than 50 mu (STICHTING VOOR BODEMKARTERING 1965), but also: this grain size fraction itself (ibid.), or: 'soil material that contains 7-27% clay, 28-50% silt and less than 52% sand' (SOIL SURVEY MANUAL 1962). The italic setting also indicates that the term involves a lithostratigraphic unit, not only a lithological description. Notwithstanding the objections against this use of the term loam (PONS & BENNEMA 1958, p. 125), the clayey top of the Kreftenheye Formation is indicated as (the) *loam* in recent literature (VERBRAECK 1974, ZAGWIJN & VAN STAALDUINEN 1975) too. For the sake of its compactness we have maintained the term, although perhaps a more correct expression would be e.g. the 'upper loamy (or clayey) bed of the Kreftenheye Formation'.

The thickness of the *loam* varies from less than 1 dm to over 1 m and is on the average c. 0.5 m. In the profiles of Figs.*6,7*and*8 the thickness has not been shown, because of the often incomplete gouging of the sticky *loam*. The depth of the top of the *loam* varies considerably locally (see e.g. the northern half of profile I, Fig.*6) and amounts on an average to c. 10.5 m below N.A.P. (Dutch Ordnance Datum).

The upper part of the *loam* is, where it is not covered by river-dune sand, dark blue-grey to blackish grey, and non- or poorly calcareous, whereas the lower part (and the *loam* as a whole where it is covered by river-dune sand) is light grey and strongly calcareous. HAGEMAN (1961) concluded, on the basis of preliminary results of the geological mapping of the Alblasserwaard (the region in the centre of which Molenaarsgraaf is situated), that we are concerned here with two different *loam* beds, a dark-grey one and a light-grey one. These and other geogenetic aspects of the *loam* will be treated in Ch. IVc.

Table 1. Lithological description of standard boring (boring Molenaarsgraaf H1110).

depth in cm below landsurface	litho-logical unit	litho-strati-graphic unit	lithological description and subdivision
0-30	**clay**	'cover'	
30-117	peat	ol u	with vertically varying content of fine and coarse wood fragments. 45-55 rather amorphous, decreasing downward. 105-117 no coarse wood fragments. 107-117 downward increasingly clayey.
117-433	clay	cl 4	117-132 non-calcareous, downward decreasingly humic, topmost part somewhat peaty; with some vertical plant remains. 132-268 calcareous, weakly humic, weakly sandy, light brown-grey. 176-180 scattered amorphous plant remains, partly vertical. 188-268 some vertical plant remains, some sand laminae. 268-293 idem, very sandy. 293-305 peaty, laminated. 305-328 sandy, calcareous, somewhat humic, with peat remains. 328-332 sand lamina. 332-360 downward decreasingly sandy; humic, few plant remains. 355-360 non-calcareous. 360-400 wood. 400-433 weakly sandy, downward increasingly humic and peaty. 417, 422 sand laminae 2 mm thick.
433-490	peat	ol 3-4	with fine wood fragments. 461-471 with vertical marsh plant remains. 471-481 with coarse wood fragments.
490-617	clay	cl 3	strongly humic, entirely non-calcareous, non-sandy, few plant remains, with weakly humic laminae. 512-537 some fine wood fragments. 608-613 very strongly humic.
617-677	gyttja	ol 2-3	amorphous, downward decreasingly clayey. 615-677 calcareous. 655-670 with opercula of Bythinia. 667-677 downward increasingly peaty, with tiny plant remains, also leaf fragments.
677-712	peat	ol 2-3	rather amorphous, with some fine wood fragments. 683-690 wood.
712-862	clay	cl 2	calcareous at 720-816 and 855-862. 712-722 downward decreasingly peaty; weakly sandy. 722-823 weakly humic, weakly sandy, with some weak humic laminae, with very few plant remains. 764-809 moderately sandy. 812-823 downward increasingly humic.

			823-830 strongly peaty, with vertical plant remains. 830-847 strongly humic, non-sandy, very few plant remains. 847-862 moderately humic, non-sandy, very few plant remains.
862-875	peat	ol 1-2	amorphous, compact, weakly clayey, with few fine wood fragments. 870-875 moderately clayey.
875-928	clay	cl 1	calcareous 883-924; with few plant remains. 875-878 strongly humic, weakly peaty. 878-905 moderately humic, with indistinct humic laminae. 905-919 weakly humic. 919-925 strongly humic. 925-928 peaty, with some vertical wood fragments.
928-961	gyttja	ol b	amorphous, clayey. 928-935 peaty, with some fine wood fragments. 938-951 with opercula of Bythinia.
961-966	peat	ol b	amorphous. 963-966 clayey.
966-1040	clay	'loam'	sandy ('loamy').
1040-	sand	basal sand	coarse.

In most borings, the *loam* becomes sandier downward, and the transition to the underlying, rather coarse 'basal sand' (see the scheme in Fig. 5) is often very gradual. Locally, remarkably coarse sand was found in the upper few cms of the *loam*.
Outside the Western Netherlands perimarine fluviatile coastal plain the top of the Kreftenheye Formation has been found developed as *loam* in many places; a few of these will be mentioned. SCHELLING (1951) and PONS (1957) described the *loam* in the Eastern Netherlands stream area of Rhine and Meuse. There too, the thickness of the layer varies considerably, and is on the average 1 to 1.5 m. In the northern part of the IJssel valley, WIGGERS (1955) found the *loam* bed to be only a few cms to 2 dm thick.
SCHELLING (1951, p. 94) and PONS (1957, p. 15) also found coarse sand in the upper part of the *loam*. They regard this as mainly of eolian origin. We come back to this in Ch. IVc.

The river-dune sand

The lithostratigraphic position of the river-dune sand in the top of the Kreftenheye Formation is shown in Fig. 5. The larger part of the *loam*-surface is not covered by dune sand; on the other hand, it is not certain that *loam* will always be found below the dune sand, although this was established in a limited number of — sufficiently deep — borings (see Fig. 37).
The characteristic dune topography, with locally steep gradients, can be seen in profiles II and III (Figs.*7 and*8). The dunes in these profiles have no outcrop, in contrast to the Hazendonk river dune, which is not shown in these profiles (cf. Fig. 3; see for geologic profiles across the Hazendonk LOUWE KOOIJMANS 1974, figs. 20, 34, 35 and 36). Most river dunes in the fluviatile coastal plain have no outcrop (VERBRAECK 1974, fig. 2).

The river-dune sand can be distinguished from the channel-filling sand of the Westland Formation mainly by means of its darker colour, caused by a higher content of dark, heavy minerals, and also by means of the absence of micas and nearly everywhere of lime. The fluviatile 'basal sand', that must have been the source material during the dune building, likewise contains many dark minerals (VERBRAECK 1974, p. 4). Also in the northern part of the IJssel valley, source material and river dunes (both also belonging to the Kreftenheye Formation) are characterised by this mineralogic composition, rendering the sand a 'variegated colour' (WIGGERS 1955, p. 39). A concentration of the heavy (dark) minerals relative to the source material, as occurs in the formation of (river-)dunes according to REINECK & SINGH (1975, p. 262), is supposed by us, but has not been investigated.
For details concerning granulometry and sedimentary structures we refer to VERBRAECK (1974 and 1970 respectively).

IIa.3 The Westland Formation

Lateral continuity

Most of the clastic minerogenic fluviatile beds (cl-) and organic beds (ol-) in the local lithostratigraphy of the Westland Formation can be traced nearly continuously in the illustrated cross-sections (Figs.*6,*7 and*8). Interruptions are virtually only found where gullies have eroded underlying beds and where emerging river dunes of the Kreftenheye Formation have prohibited the deposition of a part of the Westland Formation (see also Ch. IIa.1). The minor, very thin, organic horizons within the clastic beds cl 2 and 4 (ol 2a-2b and ol 4a-4b respectively; see the scheme in Fig. 5) have a strongly discontinuous lateral distribution.

Lower and upper boundary of the formation

The lower boundary of the Westland Formation is formed everywhere by the upper boundary of the Kreftenheye Formation. The latter's relief has naturally influenced the sedimentary development of the Westland Formation particularly at the river dunes. An example of this can be seen in profile III (Fig.*8) around boring H2106: due to the presence of the river dune, clastic bed cl 1 has not been deposited, and clastic beds cl 2, 3 and 4 are developed more thinly than outside the river-dune perimeter. In addition, outside the river dunes the relief of the Kreftenheye Formation has exerted a certain influence on the sedimentation of the Westland Formation, especially so where depressions are present in the top of the former. Such a depression can be seen in the northern end of profile I (Fig.*6). Its influence is expressed among others in the lithology of the lower organic beds of the Westland Formation. These are developed largely as gyttja, so in a deeper position with respect to the water table than the lithostratigraphically corresponding peat beds.
The upper boundary of the Westland Formation, the present land-surface, is very flat and consists of a continuous, only few dm thick clay bed, the so-called 'Alblasserwaard cover' (LOUWE KOOIJMANS 1974, p. 130, 182). Only at the highest parts of the previously mentioned Schoonrewoerd stream ridge is this cover lacking,or indistinguishable because of post-sedimentary homogenisation (see e.g. boring H1114 in profile I, Fig.*6). The flat nature of the upper boundary of the Westland Formation is caused not only by the clay cover, but also by the underlying thick organic bed ol u, the so-called Upper Peat (BENNEMA 1949). This peat bed has a widespread lateral extension throughout the Western Netherlands coastal plain and it largely levelled out pre-existing relief features.

Clastic deposits

The sedimentary material of the Westland Formation in the study area is very varied: weakly to strongly clayey sand, weakly to strongly sandy clay, weakly to strongly humic clay, weakly to strongly peaty clay, weakly to strongly clayey peat (wood peat and *Phragmites* peat) and (detritus-)-gyttja. First the clastic (clay and sand) deposits will be discussed.

Sandy, calcareous channel-filling deposits (the stream ridges, see Ch. Ia) have been found, within the study area, mainly in the fluviatile clastic beds cl 2 and cl 4. This is clearly illustrated by profile I (Fig.*6), a section perpendicular to the general stream direction of the filled channels. These sand bodies provide the stable framework between the clay- and peat beds which are instead subject to compaction. Although these channel fills have been completely bored through in only few places (DE FRETES 1979), their lower boundary is supposed to lie on the compaction-free Kreftenheye Formation in most cases. This is very plausible in the case of the stream ridges belonging to clastic bed cl 2, as the top of these lies only c. 4 m above the Kreftenheye Formation (see e.g. the two channel fills at borings H1009 and H1541, Fig.*6). VERBRAECK mentions that the Schoonrewoerd stream ridge (belonging to bed cl 4) lies also on the Kreftenheye Formation, at least for the stretch near Molenaarsgraaf (pers. comm. in LOUWE KOOIJMANS 1974, p. 95). A cross-section of this stream ridge can be seen at boring H1114 in profile I (Fig.*6).

The clay beds that have been deposited from these gully systems belonging to the units cl 2 and cl 4 are generally weakly to moderately humic and non- or weakly, but at some places moderately, sandy (Figs.*6 and*7). Both beds have a nearly continuous distribution in the study area. At many places they show a vertical uniformity; according to ALLEN (1965, p. 150 f.) this is characteristic for flood-basin deposits.

Clearly, the fluviatile clastic beds cl 1 and cl 3 have been developed differently within the study area from beds cl 2 and cl 4. Cl 1 is a thin, discontinuous, usually sand-free, weakly to moderately humic clay bed. Cl 3 is less continuous and less sandy than beds cl 2 and cl 4. Cl 3 is generally moderately to strongly humic; the bed is at several places peaty or traceable as a clayey bed in the peat (see e.g. boring H2106, Fig.*8 and H1009, Fig.*6 respectively). This variation in thickness and facies is to a large extent connected with the facial variations in the underlying bed cl 2: above a stream ridge of cl 2, cl 3 is generally strongly peaty and thin, or absent (see especially profile I, borings H1009 and H1541). Where, in such a case, bed cl 3 has not been deposited, the under- and overlying peat beds (ol 2-3 and ol 3-4 respectively, see Fig. 5) are not separable, and are taken together as the peat complex ol 2-4.

Organic deposits

The organic beds (ol-) of the Westland Formation are developed in the Molenaarsgraaf study area mainly as peat, but partly also as gyttja. The beds ol b, ol 1-2, ol 2a-2b, and the basis of ol 2-3 and of ol 3-4, consist at many places of *Phragmites* peat, or at any rate peat with remains of *Phragmites* and other water- and marsh plants: the German *Schilf* (OVERBECK 1975, p. 88). The beds ol 2-3 (except base and top), ol 3-4 (except the base) and ol u are developed in most places as wood peat. Thus the deeper organic beds of the Westland Formation in the study area appear to consist mainly of *Phragmites* peat, the higher ones mainly of wood peat. A similar bipartition was found by VERBRAECK (1970, p. 75) in the eastern part of the perimarine fluviatile coastal plain.

The lowermost organic beds (ol b, ol 1-2, ol 2a-2b) have been developed occasionally as gyttja (see e.g. profile I, Fig.*6). Important gyttja occurrences have been found in the upper part of organic bed ol 2-3, at the base of the generally strongly humic or peaty clay bed cl 3. It concerns an organic sediment, which can be named, on the basis of field characteristics, as *Feindetritus-gyttja* (fine detritus gyttja), partly also as *Grobdetritus-gyttja* (coarse detritus gyttja), in the terminology summarized by GROSSE BRAUCKMANN (1961) from the older Swedish and German literature (especially

from the works of VON POST and of LUNDQVIST). The material is light- to brownish green, somewhat elastic, and consisting mainly of fine-grained structureless organic material. It contains varying quantities of clay, is mostly somewhat calcareous, and contains shell remains of freshwater snails (*Lymnea*, *Planorbis*, opercula of *Bythinia*). A useful field characteristic is also provided by very tiny, shiny cleavage planes. In general, only very small quantities of coarse plant remains are present in this gyttja. Where there are larger quantities, the sediment may be regarded as the above-mentioned *Grobdetritus-gyttja;* in such cases the transition (lateral or vertical) to peat is gradual.
Detritus gyttja is regarded as a deposit of all sorts of decayed vegetable and animal material on a lake-bottom. Fine detritus gyttja is mainly formed in the deeper, quiet parts of a lake, coarse detritus gyttja in the shallower, less quiet parts (OVERBECK 1975, p. 87). WIGGERS (1955, p. 66 f.) describes detritus gyttja beds in the subsoil of the IJsselmeer area and has evidence that the deposit there consists partly of the remains of eroded, older peat beds ('peat-detritus'). PONS & VAN OOSTEN (1974, p. 21) ascribe a similar genesis to the organic deposits at the bottom of the recent lakes in the peat areas of the province of Noord-Holland. We think that this component of detrital peat is virtually absent in the gyttja of our study area (see further in Chs. III and V).

IIb LITHOSTRATIGRAPHY OF THE LEERDAM STUDY AREA

IIb.1 *General comparison with the lithostratigraphy of the Molenaarsgraaf study area*

The outline of the lithostratigraphy of the Leerdam study area is in its main characteristics similar to that of the Molenaarsgraaf area (compare Figs. 11 and 5). The Kreftenheye Formation is represented by the same components, namely the 'basal sand', the *loam*, and the river-dune sand. The Westland Formation is here also subdivided into clastic fluviatile beds and organic beds. To prevent confusion, the units of the Westland Formation have been coded for the Leerdam area in a different way from those of the Molenaarsgraaf area. Instead of numbering of the beds, the adjectives lower (l), intermediate (i) and upper (u) have been used here. Since all organic beds are developed almost exclusively as peat, the code p (peat) is used instead of o (organic). The main units of the Westland Formation are lcp, ip, uc and up. The unit lcp (lower clastic and peat beds) is a complex of clay beds with irregularly intercalated peaty beds and a broad sandy channel fill. This mainly clastic unit is nearly everywhere separated by a peat bed ip (intermediate peat bed) from the overlying clastic unit uc (upper clastic bed). As is the case with the peat bed ol u in the Molenaarsgraaf area, here too the sequence of clastic and organic beds is closed towards the top by the peat bed up (upper peat). Also, above it there is a usually thin clay cover, comparable to the 'Alblasserwaard cover' at Molenaarsgraaf.
The lithological variation within both formations (Kreftenheye Formation and Westland Formation) is about the same as in the Molenaarsgraaf area. An important difference is however that in the Leerdam area the peat beds are generally more amorphous (i.e., contain less macroscopically recognizable plant remains) and the clay beds have at several places a somewhat tougher consistency than at Molenaarsgraaf.
In the selected profile (profile IV, Fig.*10), all lithostratigraphic units from the scheme in Fig. 11 are represented. The position of the profile (see Fig. 4) can be traced back easily on sheet 38 Oost of the Geological map of the Netherlands, scale 1:50000 (VERBRAECK 1970), on the basis of the most conspicuous elements (stream ridges and river dunes).The northern end of the profile is situated on the stream ridge with code E0g, c. 1 km W of the village Schoonrewoerd; the southern end of the profile is situated on the stream ridge with code A1k, c. 1.5 km N of Leerdam.

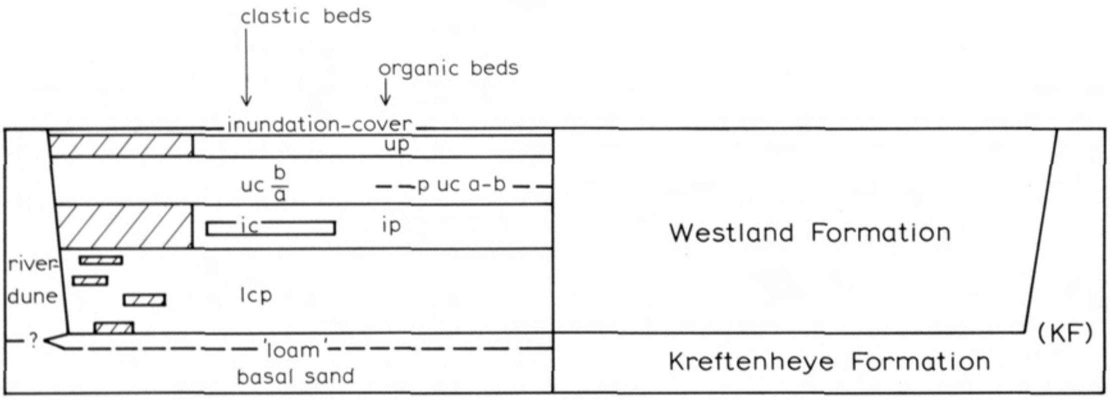


Fig. 11. Scheme of the lithostratigraphy in the Leerdam study area.

IIb.2 The Kreftenheye Formation

The surface of the Kreftenheye Formation has, as at Molenaarsgraaf, a considerable relief, particularly where the river dune is concerned (the Schaikse donk, see Ch. Ib; the place of outcrop of this dune lies outside the profile of Fig.*10, see the location in Fig. 4). The relief of the river dune (see the southern part of the profile, Fig.*10) compares well with that of the western river dune complex in the Molenaarsgraaf study area (see profile III, Fig.*8). At the foot of the dune (at borings S341 and S342 in the profile) the dune sand lies on top of the *loam*. The depth of the top of the *loam* varies in the profile with a magnitude comparable to that in e.g. the northern part of profile I of the Molenaarsgraaf area (see Fig.*6). The depth amounts on an average to c. 6 m below N.A.P., which is more than 4 m higher than in the Molenaarsgraaf area 20 km downstream.
A depression in the top of the Kreftenheye Formation (boring S322, in the northern end of the profile, Fig.*10) descends to c. 10.25 m below N.A.P. Part of this depression is filled with dune sand. Also in the southern end of the profile, dune sand seems to fill a depression in the *loam*-top of the Kreftenheye Formation.

IIb.3 The Westland Formation

Lower deposits

The lowermost lithostratigraphic unit of the Westland Formation in the Leerdam study area, the 'lower clastic and peat beds' (lcp), has not been lithologically subdivided in the profile (Fig.*10), except where the bed is developed as sandy clay or sand. The lithological variation, namely the alternating bedding of clay and peat, is too great to indicate in this schematic profile. With some difficulty four clay beds can be distinguished within the complex lcp, which, as a whole, is mainly clastic. The base of the unit lcp is at the same time the base of the whole Westland Formation. Contrary to the situation in the Molenaarsgraaf area, this base consists in the Leerdam area generally not of peat or gyttja, but of clay, well distinguishable in texture and structure from the underlying *loam*. So the proper basal peat, as usually met with in the coastal areas of the Netherlands (JELGERSMA 1961), is lacking here. Where the basal peat is present though, it is often clayey (see e.g. the northern part of profile IV, Fig.*10). VERBRAECK (1970, p. 62) associates the lack of the basal peat in this region to depositional activity of a river situated in the South of the region.

The variation in thickness of unit lcp is firstly connected with the relief of the top of the Kreftenheye Formation (compare e.g. boring S364 with boring S322 in the profile, Fig. *10). Secondly, the unit has of course a considerable thickness where, in the middle part of the profile, it is developed as a stream ridge (channel fill). This stream ridge is one of the most conspicuous fossil phenomena of the area; the profile shows a cross-section from boring S355 up to S361, over a distance of c. 500 m. Under the profile-type code A3k, this stream ridge, the Middelkoop stream (VERBRAECK 1970, p.84), occupies an important place on the before-mentioned geological map 38 Oost. The (completely buried) stream ridge has a strongly sinuous course on this map, and branches off towards the West.
The sandy nature of unit lcp, where it rests on the buried river dune in the middle part of the profile (Fig.*10), should not be connected to distinct channel deposition, but can be explained by slight erosion of the underlying dune sand.
Unit lcp of the Leerdam area can lithostratigraphically be correlated with the layer-sequence ol b + cl 1 + ol 1-2 + cl 2 in the Molenaarsgraaf area (see also Fig. 5). It goes without saying that the base of both bed complexes is correlative - in both areas it involves the boundary between the Kreftenheye Formation and the Westland Formation. The upper boundary of lithostratigraphic unit cl 2 in the Molenaarsgraaf area is, via profiles D and E belonging to the geological map 38 Oost and the map itself (VERBRAECK 1970), well traceable to the top of the bed in which the westward branching Middelkoop stream ridge is situated. This means that also the top of both bed complexes is lithostratigraphically correlative.

Upper and intermediate deposits

Of the two main clastic fluviatile beds in the Westland Formation of the Leerdam area, the above-discussed unit lcp forms the lower one, the unit uc (upper clastic bed, see Fig. 11) the upper one.
Profile IV (Fig.*10) is, also with regard to the stream ridges belonging to this bed uc, perpendicular to the stream direction. The bed's facies and thickness change rapidly with distance from the stream ridges: the clay bed is thinner and peatier further from the stream ridge. The bed is subdivided into uc a and uc b by an intercalated peaty horizon (bed) p uc a-b (see Fig. 11). This horizon is locally only weakly peaty and remarkably black; on these places, it may perhaps be compared to the so-called *lak* (lacquer) layers, as described by DE BOER & PONS (1960, p. 60) and DE BAKKER & EDELMAN-VLAM (1976, p. 123).
The stream ridge at the northern end of profile IV (at boring S320), with its relatively strong topographic expression, is known as the Schoonrewoerd stream ridge, the smaller one at the southern end of the profile as the Schaik stream ridge (DE BOER & PONS 1960, p. 25; VERBRAECK 1970, p. 85; LOUWE KOOIJMANS 1974; to VINK (1954) the Schoonrewoerd stream ridge was known as the 'Overlek stream'; the names derive from small villages located in the study area). Both stream ridges belong lithostratigraphically to unit uc. As previously mentioned (Ch. Ib), the Schoonrewoerd stream ridge forms the topographically visible link between the Leerdam and the Molenaarsgraaf study areas (cf. Figs. 3 and 4; see also LOUWE KOOIJMANS 1974, fig. 18). In the Molenaarsgraaf area, this stream ridge forms part of clastic bed cl 4. Due to this, unit uc of the Leerdam area is lithostratigraphically correlative with unit cl 4 of the Molenaarsgraaf area.
For this region VERBRAECK (1970, p. 85) indicates that the Schoonrewoerd stream has incised into the Kreftenheye Formation but the Schaik stream has not. In profile IV these data have been processed.
As in the Molenaarsgraaf area, in the Leerdam area the top of bed cl 4-bed uc has been covered by the Upper Peat (coded as 'up' here). In contrast to the Molenaarsgraaf area, here the peat bed (wood peat) is in several places clayey. Along the southern border of the Schoonrewoerd stream ridge it is even absent, so that bed uc passes directly into the superficial clay bed ('cover'). At a few places an iron-stained level can be seen separating the two.

Table 2. Correlation of the lithostratigraphies of the Molenaarsgraaf and the Leerdam study areas. Compare with Figs. 5 and 11.

	Molenaarsgraaf study area	Leerdam study area	
WESTLAND FORMATION	clay cover organic bed ol u clastic bed cl 4	clay cover organic bed up clastic bed uc	upper part
	organic bed ol 3-4 clastic bed cl 3 organic bed ol 2-3	organic bed ip (with intercalated clastic bed ic)	intermediate part
	clastic bed cl 2 organic bed ol 1-2 clastic bed cl 1 organic bed ol b	bed complex lcp	lower part
KREFTENHEYE FORMATION	'loam' basal sand	'loam' basal sand	

By the lithostratigraphical correlations between the Leerdam and the Molenaarsgraaf study areas indicated above (namely the correlation of the top of lcp with the top of cl 2 and the correlation of uc with cl 4), peat bed ip (intermediate peat) of the Leerdam area can be correlated with the organic bed complex ol 2-4 of the Molenaarsgraaf area (compare the schemes in Figs. 5 and 11).
In peat bed ip a thin clay bed locally occurs, the intermediate clastic bed ic, as can be seen in the profile (Fig. 10). It seems plausible to conclude from a comparison of both lithostratigraphic schemes (Figs. 5 and 11) that this clay bed ic in the Leerdam area is correlative with clay bed cl 3 in the Molenaarsgraaf area.

The above correlations of the lithostratigraphies of both study areas have been summarized in Table 2. By this correlation of the lithostratigraphy of the Molenaarsgraaf area with that of the Leerdam study area 20 km away, the latter has made the former in a sense clearer. For the tripartition in the lithostratigraphy of Leerdam can be translated to that of Molenaarsgraaf: the lower and upper parts of the Westland Formation at Molenaarsgraaf are strongly clastic units (leaving the Upper Peat out of consideration here) and, as at Leerdam, they contrast with the strongly organic intermediate part. This gross subdivision is encountered also in the biostratigraphy and the paleoenvironmental evolution (Chs. III and V).

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

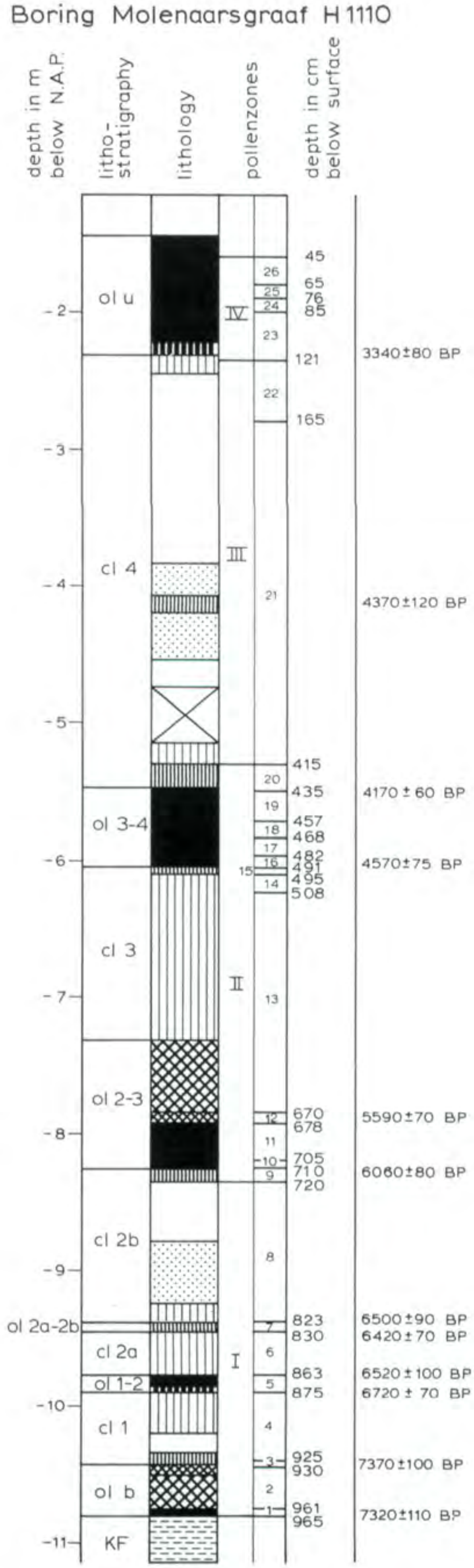
In interpreting the pollen content of river clay beds in the Western Netherlands, one has to take account of the supply of pollen by river water from the hinterland, especially the Rhine catchment area. This has been stressed by FLORSCHÜTZ & JONKER (1939, p. 690), ZAGWIJN (1965, p. 84), HARTMAN (1968, 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.

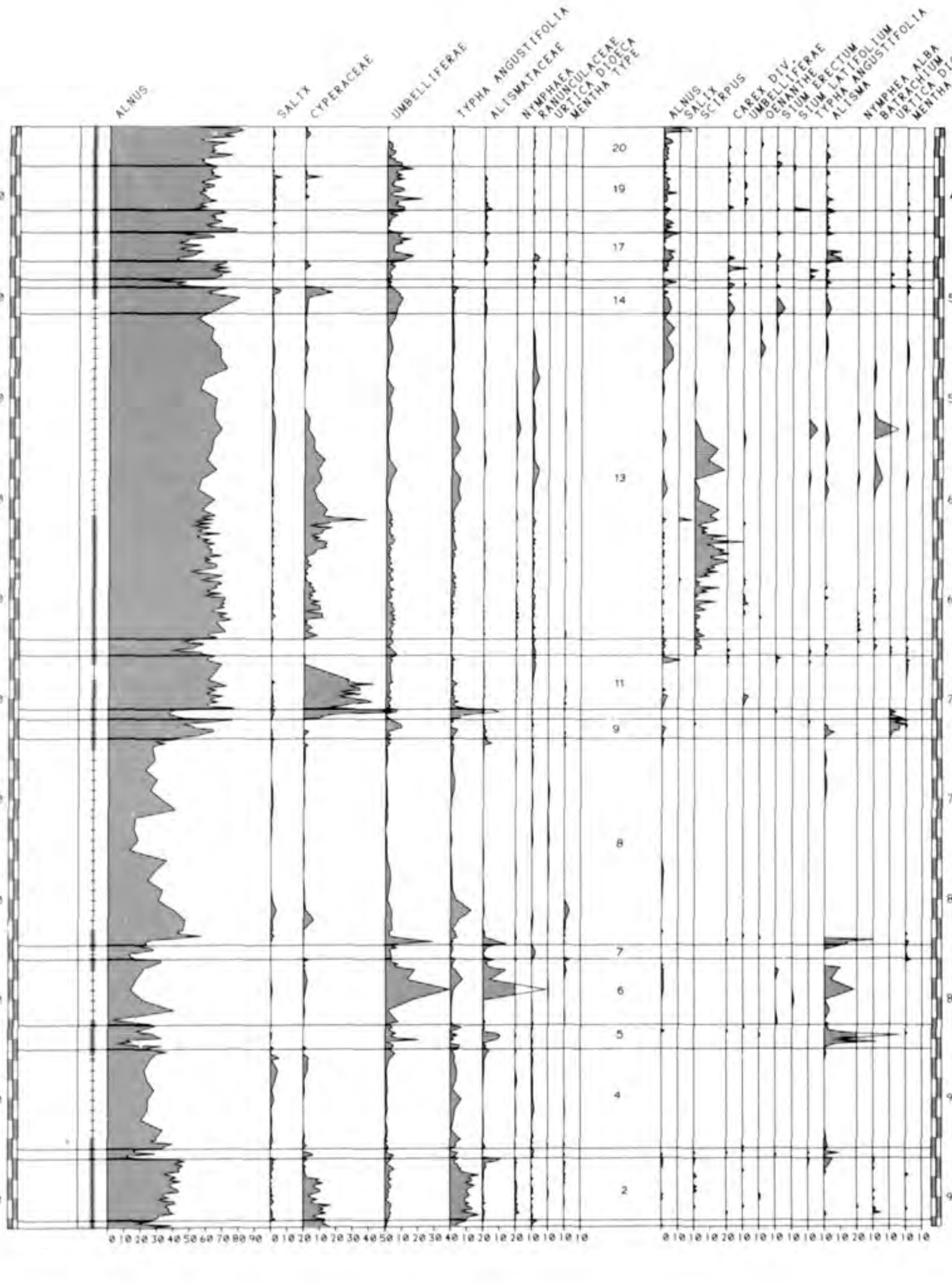


Fig. 14. Fruit diagram of boring Molenaarsgraaf H1110 (standard boring). The left part shows the pollen percentages, the right part the absolute fruit numbers. In between, the pollen zones are indicated.

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 vegeta-

tion 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

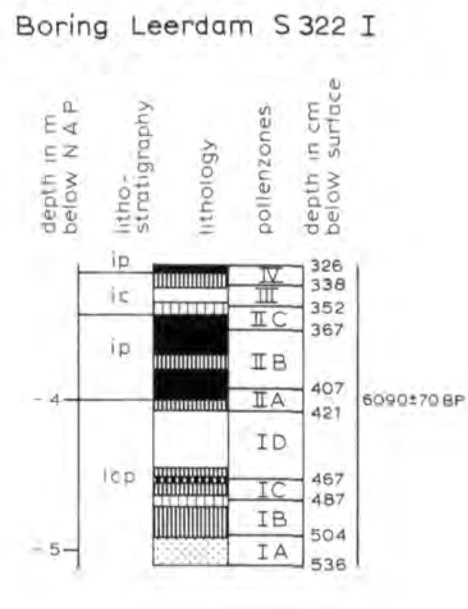
diagram. Using just this Middle-European pollen for dating purposes (by a comparison with e.g. FIRBAS' zones) would lead to a circular argument; for it was on the basis of datings (C-14 datings) that the presence of this Middle-European pollen was inferred (Ch. IIIc.3).
The dating method mentioned (comparing 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.

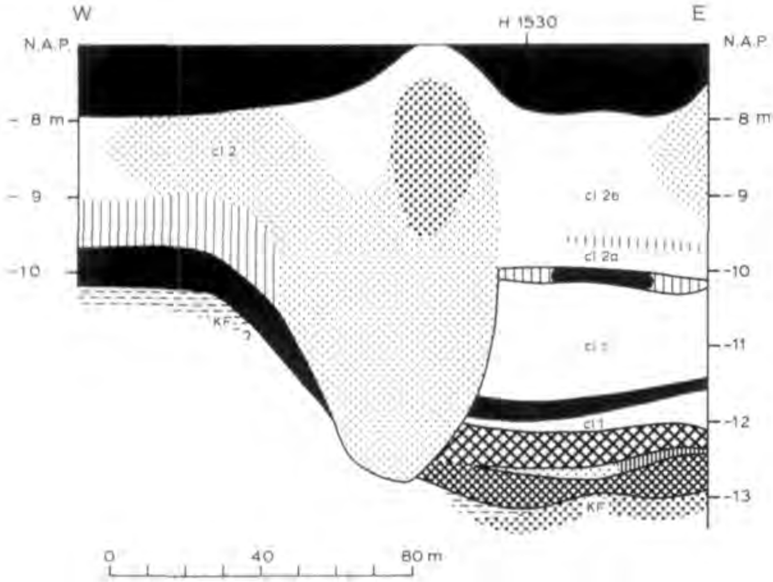


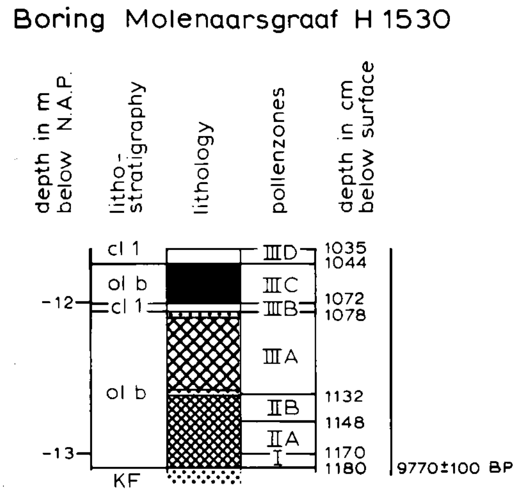
Fig. 17. Profile at boring Molenaarsgraaf H1530. For lithological legend, see Fig. *9.

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.

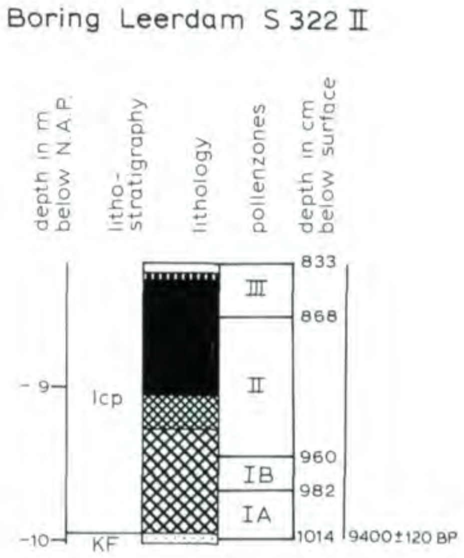
III D	1044-1035 cm. Increase of Tilia (up to 18%), Ulmus (c. 10%), Fraxinus (c. 4%). AP/NAP-ratio c. 65%, NAP mainly consisting of Gramineae, Cyperaceae, Sparganium/Typha angustifolia and Rumex hydrolapathum. Values of fern spores decreasing strongly upwards.
III C	1072-1044 cm. Sharp decrease of AP/NAP-ratio 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.

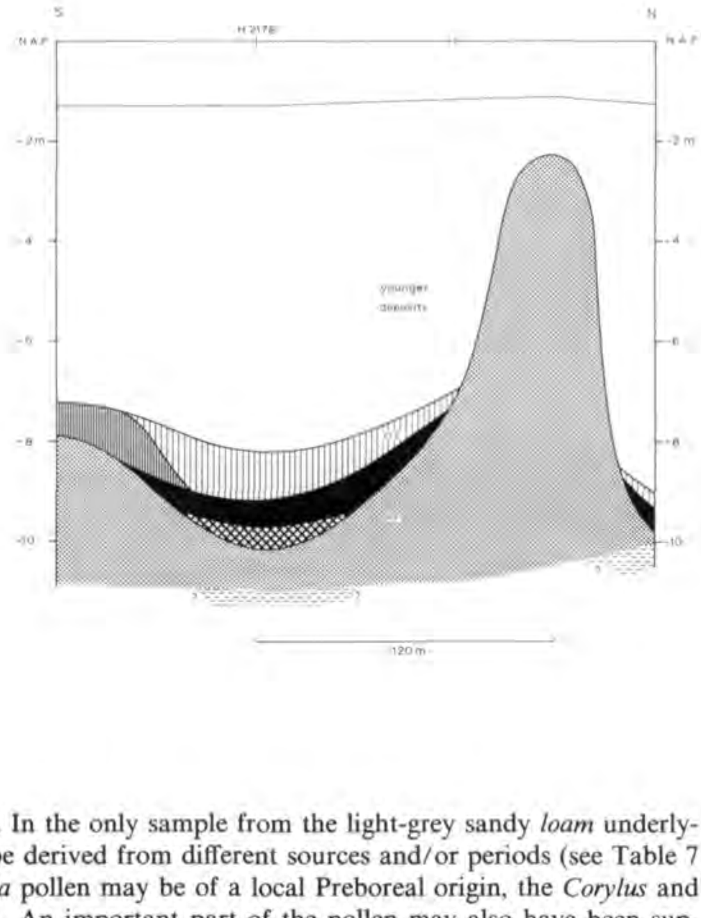
Zone III (868-833 cm). *Alnus* had established itself in the area and would have grown, together with *Salix*, on the lower parts of the *loam*-surface, that became increasingly wet. In the forest stands on the river dunes and possibly the higher parts of the *loam*-surface the proportion of *Pinus* 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).

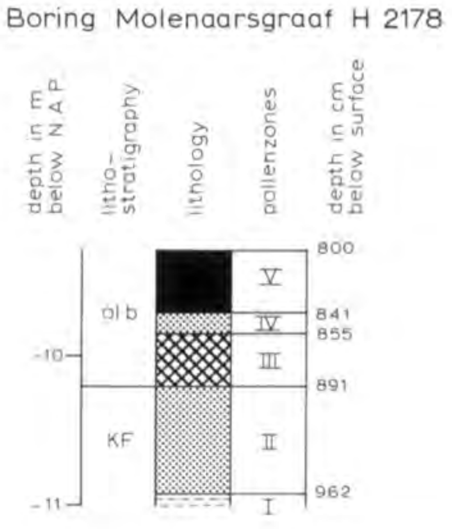


Fig. 21. Pollen zones in boring Molenaarsgraaf H2178. For lithological legend, see Fig. *9.

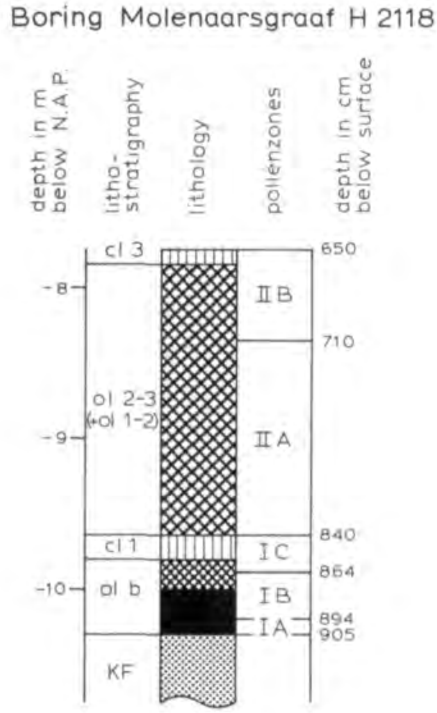


Fig. 22. Pollen zones in boring Molenaarsgraaf H2118. For lithological legend, see Fig. *9.

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.

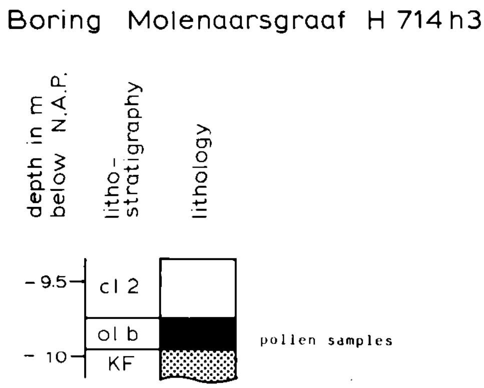
Table 8. Description of pollen zones in boring Molenaarsgraaf H2118.

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.

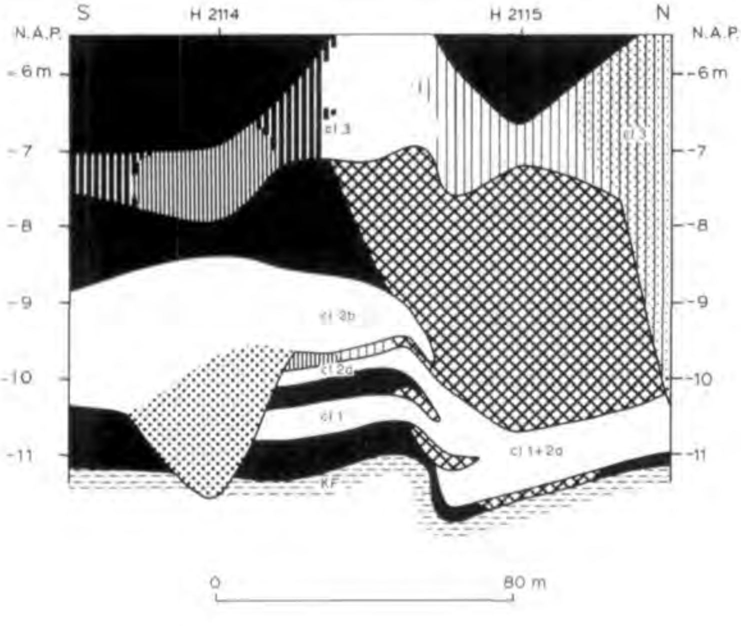


Fig. 24. Profile at borings Molenaarsgraaf H2114 and H2115. For lithological legend, see Fig. *9.

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.

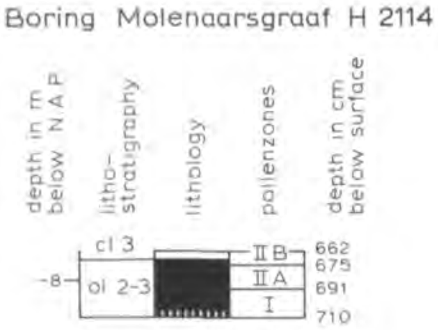


Fig. 25. Pollen zones in boring Molenaarsgraaf H2114. For lithological legend, see Fig. *9.

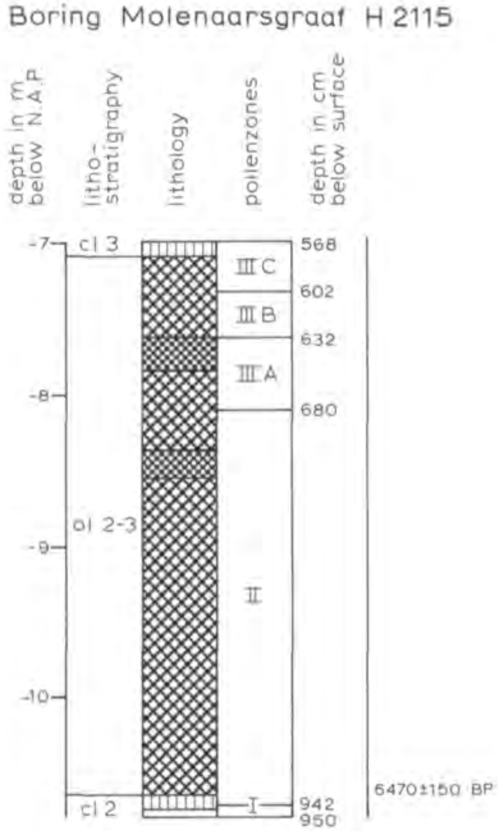


Fig. 26. Pollen zones in boring Molenaarsgraaf H2115. For lithological legend, see Fig. *9.

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.

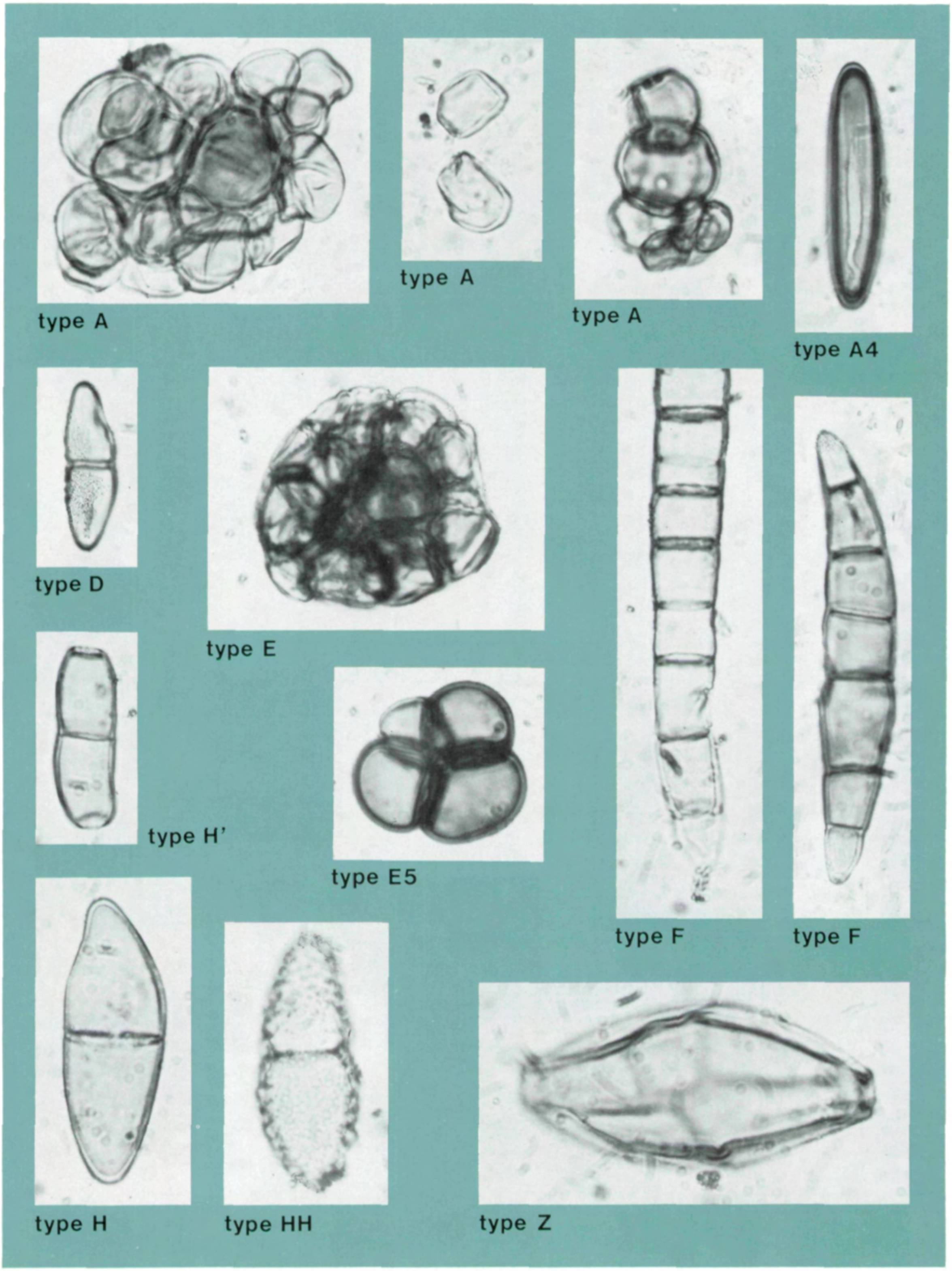
Zone IIIC (602-568 cm). This zone is lithostratigraphically situated in the transition from gyttja bed ol 2-3 to clay bed cl 3 (see Fig. 25). Simultaneously with the increase of the clay deposition, the *Alnus* swamp forests decreased in size, and the growth of Gramineae (presumably *Phragmites*) increased 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.

IV CHRONOSTRATIGRAPHY

IVa INTRODUCTION

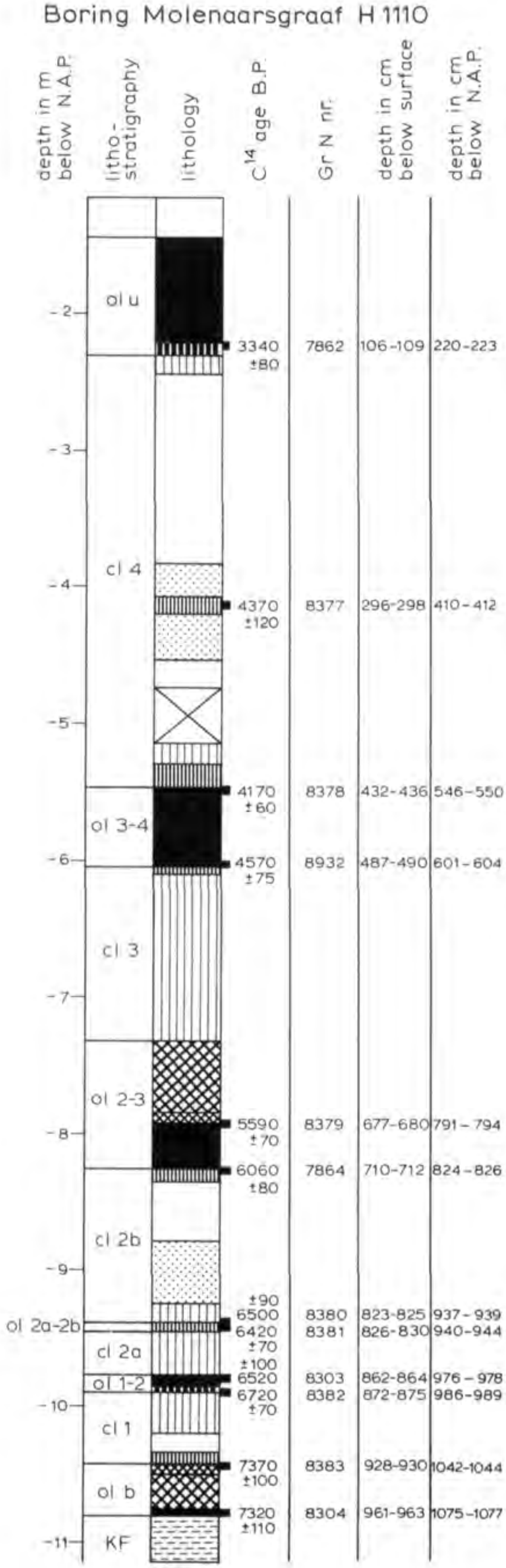
Chronostratigraphy is used here first to establish the chronology of the geological and paleoecological evolution in both study areas. Also, by chronostratigraphical comparisons of both study areas mutually and with the results of previous investigations in the river region, it may be possible to state the degree of regional isochrony (simultaneity) of the phases of geological evolution. This will involve the important question of whether the cyclicity in the clastic sedimentation, as expressed in the study areas in the alternation of clay- and peat beds, has only local significance (autocyclicity, e.g. by shifting of rivers; SELLEY 1978, p. 60) or also regional significance (allocyclicity; ibid.).
The chronostratigraphy of the deposits belonging to the upper part of the Kreftenheye Formation (*loam* and river dunes), as set forth tentatively in Ch. IVc, has been based largely on palynological results and geogenetical arguments (relating to the depositional conditions). The chronostratigraphy of the deposits belonging to the Westland Formation (mainly related to the cyclicity of clay- and peat beds) has been based largely on C-14 dates, but partly also on archeological data.

IVb DATINGS

IVb.1 C-14 dates

Most C-14 dates relate to samples taken at the base and top of peat layers. In the cyclic alternation of clay- and peat beds therefore, it is the peat beds that have been dated. Consequently, these dates are always before and after a period of clay deposition, in the case of peat samples at the base and top respectively of a clay bed. As the lithological transitions between the clay- and peat beds are generally rather gradual — at least in the basin environment, where the dates come from —, it is plausible that there are no important sedimentary hiatuses at the boundaries. This means that in general a date for the end of a period of peat formation may also serve as dating the start of the subsequent clay deposition; and that in general a date for the start of a period of peat formation may also serve as dating the end of the preceding period of clay deposition.
In dating the cyclic clay/peat stratigraphy, the litho- and biostratigraphical standard boring H1110 (Molenaarsgraaf study area) has naturally been given priority. In addition lithostratigraphical representative borings have been taken for the Leerdam study area. The importance of lithostratigraphical representativeness of the dated sections is stressed here, because e.g. at places where clay beds wedge out (especially at the river-dune flanks) C-14 dates might be less representative for the whole study area.
The sampled cores measure 5 cm in diameter; the (vertical) thickness of the samples varies (see Figs. 27-31) and amounts on an average to c. 3 cm. The outer layer of the cores was removed, but no rootlets or other possible contaminating material was removed from the remaining parts. This accords with existing practise in the C-14 sampling of peaty material. For a discussion of this possible source of error, see STREIF (1971), ROELEVELD (1974) and VAN DE PLASSCHE (1979-80). The samples have been dated at the State University Groningen, The Netherlands, under the supervision of Prof. Dr. W.G. Mook. The results are given in conventional C-14 years BP (before present, i.e. before A.D. 1950), with a standard deviation of one sigma; the half life used was 5570 years.
The results of all C-14 datings carried out for the present study are presented in Figs. 27-31. The topographic position of the borings concerned can be seen in Figs. 3 and 4. In Figs. 27-31, age, lithology and lithostratigraphy of all samples are indicated. Several of these figures can be compared directly to those indicating the pollen zones (Ch. III, Figs. 13, 16, 18, 19, 23 and 26); these relate to sections where both pollen analysis and C-14 datings have been carried out.
Some dates require further comment than shown in the figures. These dates are discussed here from oldest to youngest and for the two areas separately.

Fig. 27. C-14 dates in boring Molenaarsgraaf H1110 (standard boring). For lithological legend, see Fig. *9.



In the Molenaarsgraaf study area three datings have been carried out of the base of organic bed ol b (the 'basal peat'), forming also the base of the whole Westland Formation. The oldest date (9770 ± 100 BP) is from the base of the gyttja filling a depression in the surface of the Kreftenheye Formation (boring H1530, Fig. 28a; see also Ch. IIIe, Figs. 17 and 18). A C-14 date from the same depression infilling, but from slightly higher in the stratigraphy, gives a 2000 years younger date (7770 ± 80 BP, see Fig. 28b). The very base of the organic filling, below the latter sample, consists of strongly amorphous peat mixed with sand. In the stratigraphy of boring H1530 (with the age of 9770 BP at its base) the 2000 y. younger date should probably be related to the renewed gyttja sedimentation after the pollenanalytically (Ch. IIIe) established hiatus (in the middle of the gyttja layer, just above the intercalation of sandy clay, see Fig. 28a).

The basal-peat date in the standard boring (Fig. 27) shows an age of 7320 ± 110 BP for the base, and 7370 ± 100 BP for the top of the bed. The dates fall well within each others' standard deviation; arbitrarily, the start of organic accumulation here at this standard depth may be put at c. 7400 BP. Comparable to this, are the basal-peat dates of JELGERSMA (1961, p. 31) from the locality of Brandwijk, situated c. 3 km NW of the Molenaarsgraaf study area: 7540 ± 190 BP (GrN 201, 10.08 m below N.A.P.) and 7240 ± 230 BP (GrN 186, 11.98 m below N.A.P.).

The third date concerning the base of the basal peat in the Molenaarsgraaf study area, is on the charcoal occurring at 9.90 m below N.A.P. at the foot of the Hazendonk river dune (see Ch. IIIi). The age of this charcoal lying directly below the basal peat (see Fig. 28c; 6900 ± 100 BP) reveals a possibly water-level rise-induced difference from the date in the standard boring (7400 BP); the younger sample lies 80 cm higher than the older one. This would fit with the general picture of later basal-peat growth at higher localities because of the Holocene water-level rise (JELGERSMA 1961; see also Ch. Ia).

Two contiguous C-14 samples have been taken from the 7 cm thick peaty bed ol 2a-2b in the standard boring (Fig. 27). The ages obtained, 6420 ± 70 BP for the lower and 6500 ± 90 BP for the upper sample, are averaged here to c. 6450 BP for the whole bed.

The conflicting litho- and chronostratigraphy of the very thick gyttja layer (ol 2-3) in boring H2115 have been discussed in Ch. IIIk. Whereas in nearly the whole study area intensive fluviatile sedimentation occurred from c. 6450 to c. 6050 BP (bed cl 2b, see Fig. 27), lacustrine organic deposition occurred at boring H2115: the base of the gyttja layer dates from 6470 ± 150 BP, see Fig. 29).

During the sampling of the standard boring, the peaty clay intercalation in the sandy section of clay bed cl 4 (see Fig. 27) was supposed to belong lithostratigraphically to organic bed ol 4a-4b. However, the loose structure of the bed, the fact that the peaty clay also contains some sand, and the absence of the bed in the neighbouring borings make its lithostratigraphic interpretation uncertain. The age of the C-14 sample of the bed (4370 ± 120 BP; GrN 8377) is older than the top of the lower lying peat bed ol 3-4 (4170 ± 60 BP; GrN 8378). The lithology of peat bed ol 3-4 leaves no doubt as to the reliability of the latter date. The most probable solution to the problem of the former date (4370 ± 120 BP) is that it relates to reworked organic material, derived by erosion from peat bed ol 3-4.

In the Leerdam study area a piece of wood from the top of the Kreftenheye Formation has been dated as 9400 ± 120 BP (see Fig. 30a). The sample comes from the same depression as the pollen section discussed in Ch. IIIf. The position of the wood is such (in the sand below the gyttja infilling), that the date need not relate to the start of the gyttja deposition. This is in agreement with the palynological dating of the base of the gyttja, namely Boreal.

In the Leerdam area peat bed ip forms the separation between the two main clastic beds, lcp and up (see e.g. profile IV, Fig.*10). The base of this peat bed in a normal situation (i.e. outside stream ridges and river dunes) dates from 6090 ± 70 BP (boring S322; see profile IV and Fig. 30b). A dating from the base of the same lithostratigraphical unit ip in an extremely high position, namely on

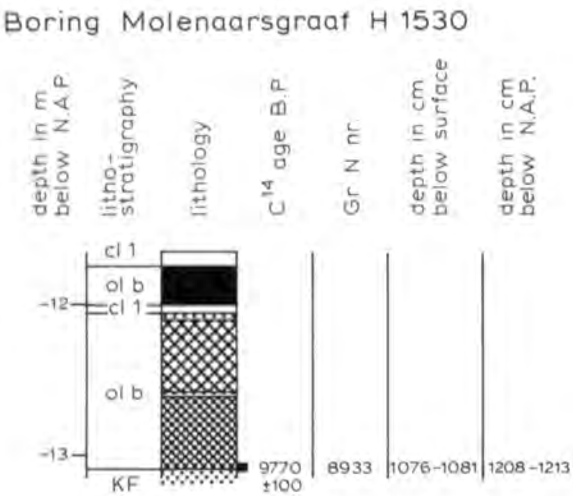


Fig. 28a. C-14 date in boring Molenaarsgraaf H1530. For lithological legend, see Fig. *9.

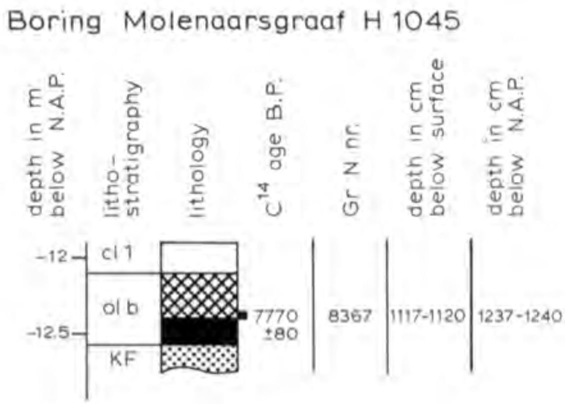


Fig. 28b. C-14 date in boring Molenaarsgraaf H1045. For lithological legend, see Fig. *9.

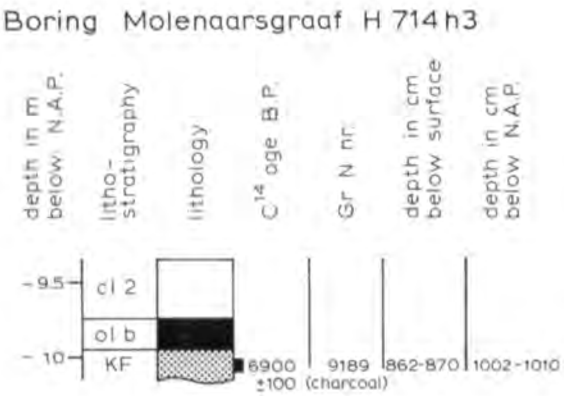


Fig. 28c. C-14 date in boring Molenaarsgraaf H714h3. For lithological legend, see Fig. *9.

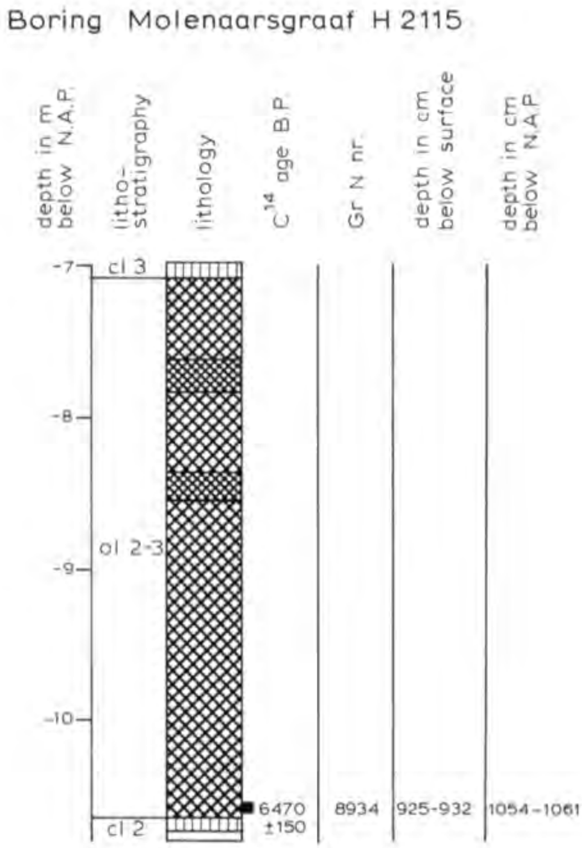


Fig. 29. C-14 date in boring Molenaarsgraaf H2115. For lithological legend, see Fig. *9.

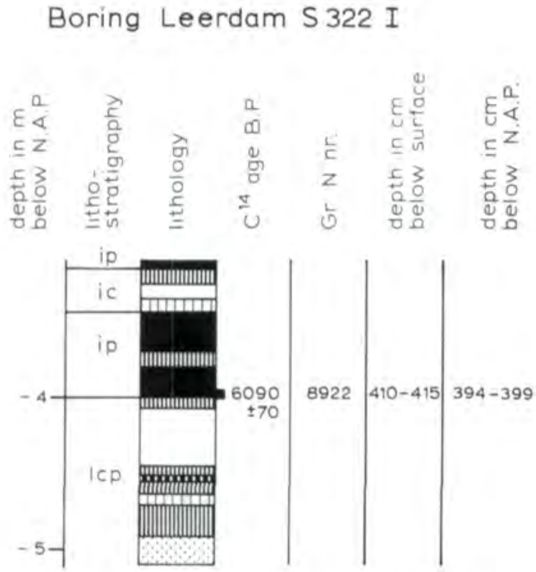


Fig. 30a. C-14 date in boring Leerdam S322 I.
For lithological legend, see Fig. *9.

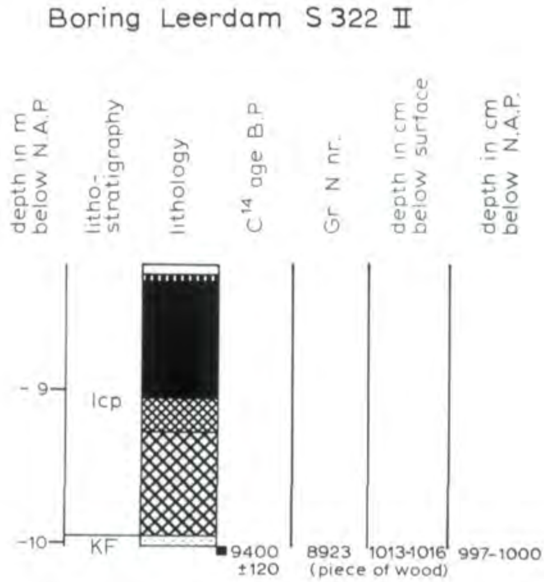


Fig. 30b. C-14 date in boring Leerdam S322 II.
For lithological legend, see Fig. *9.

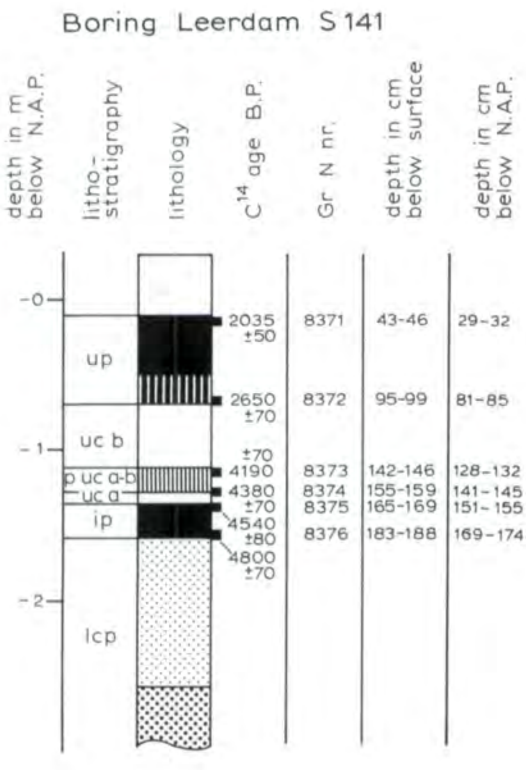


Fig. 30c. C-14 dates in boring Leerdam S141.
For lithological legend, see Fig. *9.

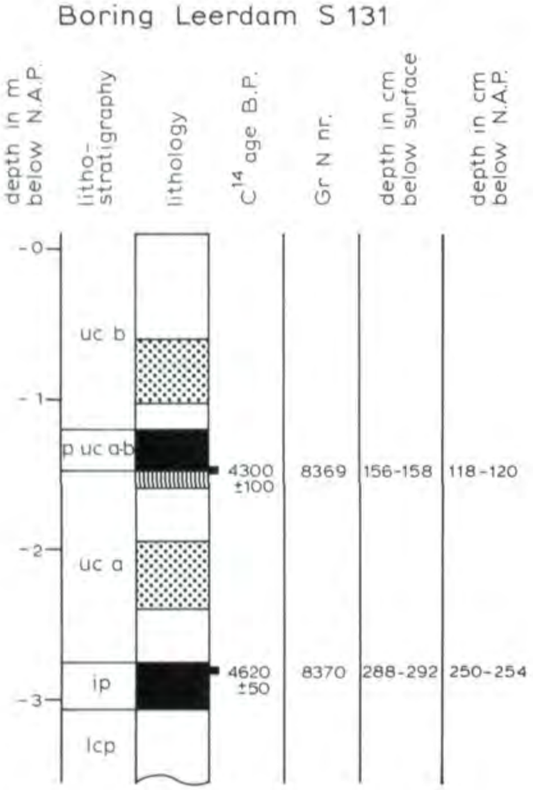


Fig. 31a. C-14 dates in boring Leerdam S131.
For lithological legend, see Fig. *9.

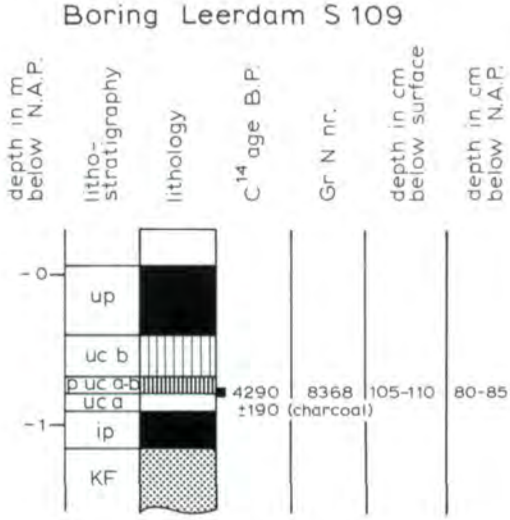


Fig. 31b. C-14 date in boring Leerdam S109.
For lithological legend, see Fig. *9.

top of the highly rising Middelkoop stream ridge, resulted in a much younger age: 4800 ± 70 BP (see Fig. 30c). The lithostratigraphical position of the boring concerned, S141 (see Fig. 4 for location), is about midway between that of boring S357 and that of boring S358 in profile IV (Fig.*10). The diachrony (differences of age within a lithostratigraphic plane) demonstrated indicates that peat growth on the highest parts of the stream ridge started much later than in the basins. Thus, these highest parts of the Middelkoop stream ridge should have remained dry from c. 6100 BP (after the period of intensive fluvial clastic sedimentation of bed lcp) up to c. 4800 BP. Palynological support for this can be found in zone III of section S322 I (Ch. IIId). There are of course interesting implications of this for the archeology of the region.
Partly for the sake of cross-checking, five C-14 samples from three borings have been taken with reference to clay bed uc a (Figs. 30c, 31a and 31b). The resulting ages support each other satisfactorily.

IVb.2 Indirect datings via archeological levels

The very detailed mapping (by means of borings) of archeological levels along the perimeter of the Hazendonk river dune (see Ch. Ic) may be used not only to give a picture of the areal extension of the levels (not published here), but also for slotting the clay/peat stratigraphy into the archeological chronology based on C-14- and typological datings. The levels can be observed in the auger core because they contain charcoal, fish-bone fragments and some dune sand (probably shifted by anthropogenic erosion). The levels could be interpreted archeologically by starting the rows of borings at the excavation pits. By following the archeological levels from the dune flanks to where the thickness and lithology of the clay-and peat beds have been developed normally, these levels could be fitted in the lithostratigraphy. From this special investigation carried out by VAN DIJK et al. (1976, internal report) the following correlations can be concluded:

archeological level (according to LOUWE KOOIJMANS 1976, fig. 2; 1980, pers. comm.)	age in C-14 years	lithostratigraphic position
Vlaardingen 2b	c. 4000 BP	organic bed ol 4a-4b
Vlaardingen 1b	c. 4400 BP	organic bed ol 3-4
Hazendonk 3	c. 4800 to 4900 BP	clay bed cl 3
Hazendonk 1	c. 5300 BP	organic bed ol 2-3

The indirect dates for the lithostratigraphic units mentioned on the right of the above table agree with the C-14 dates discussed in Ch. IVb.1 (cf. esp. Fig. 27). The Vlaardingen-1b level (c. 4400 BP) is situated mostly in the upper part of peat bed ol 3-4. The top of this bed has been dated as 4170 ± 60 BP in the standard boring (Fig. 27). So locally (especially in the area directly surrounding the river dune?) the formation of peat bed ol 3-4 stopped possibly earlier than at the standard boring; this is discussed further in Ch. IVd in connection with C-14 dates published by LOUWE KOOIJMANS (1974).

The locally occurring thin organic bed ol 4a-4b — see the discussion in Ch. IVb.1 in connection with date GrN 8377 — can now be dated indirectly via the Vlaardingen-2b level at c. 4000 BP.

IVb.3 Pollenanalytical datings

In three pollen sections of organic deposits in depressions in the Kreftenheye Formation-surface, an early-Holocene sequence has been found (Preboreal, Boreal, early-Atlantic). These sections have been discussed in Chs. IIIe, -f and -g; they provide important additions to the chronostratigraphic information treated above, which mainly concerns the Atlantic and Subboreal. The results are incorporated in Ch. IVc.

The limitations of pollenanalytical dating of river clay deposits in the Westland Formation have been discussed in Ch. IIIc.6. Nevertheless, taking an overall view of the pollen diagram of the standard boring (Fig.*12), the transition from Atlantic to Subboreal can most probably be placed, on the basis of the gradual decline of the *Ulmus* curve, about midway in zone 13, that is during the deposition of clay bed cl 3. This is in agreement with the C-14 dates concerning this clay bed (see Fig. 27).

The *Carpinus* curve of the standard section (Fig.*12) shows significant values only in wood-peat bed ol u (the Upper Peat). This points to a late-Subboreal/Subatlantic age for this peat bed, and this is in agreement with the C-14 date of the base of the bed (see Fig. 27).

IVc GENESIS AND AGE OF THE *LOAM* AND THE RIVER DUNES

The only absolute certainty about the age of the river dunes at the top of the Kreftenheye Formation, to be concluded on the basis of this study, is that they were formed before the middle-Atlantic — when the covering clay- and peat beds started to be deposited.

As mentioned in Ch. Ia, the published dates of river dunes in the top of the Kreftenheye Formation are not identical for the whole Dutch river area. Limiting the discussion to the stream area of Rhine and Meuse from the Eastern to the Western Netherlands, the older literature might be summarized in the words of DE JONG (1967, p. 396): 'A Pleistocene age [of the river dunes] for the eastern area seems to be based on better evidence than a Holocene age for the western area'. This statement refers mainly to publications by SCHELLING (1951) and PONS (1957) for the Eastern Netherlands, and PONS & BENNEMA (1958; with a pollenanalytical dating by FLORSCHÜTZ) for the Western Netherlands. We shall not discuss these sources in any more detail, but shall limit ourselves instead to the later publications by VERBRAECK (1974) and VAN DE MEENE (1980). VERBRAECK studied river dunes in the Alblasserwaard, the region in which also our main study area (Molenaarsgraaf) is situated; the Alblasserwaard is the most prominent river-dune area of the Western Netherlands. VAN DE MEENE studied a river-dune complex near Arnhem (Eastern Netherlands). On the basis of pollenanalytical results both authors could limit the date of the river dunes to the period from the Younger Dryas (the last phase of the Late-Weichselian) to the Atlantic. Both conclude a Younger Dryas age, mainly on the basis of the argument that the river dunes are likely to have been formed in a practically barren landscape. The validity of this argument should be questioned: the main factor controlling river-dune formation is the availability of channel sand for wind erosion, e.g. by a lowering of the water level; the area where this material is to be deposited need not be barren.

Nevertheless we endorse the legitimacy of geogenetical arguments in discussions on the age of the river dunes, where more direct dates are not available. To that end, we shall stress here a probable genetic relation between the *loam* and the river dunes.

The *loam* is a diamicton of clay and sand with a large lateral uniformity. The usual genetic interpretation of the *loam* as a purely fluvial sediment does not explain this uniform diamictic nature. A clear discrimination between sandier and more clayey parts would be expected. In our opinion, the eolian genesis ascribed by SCHELLING (1951, p. 94) and by PONS (1957, p. 15) to the coarse sand they found locally in the topmost part of the *loam* should be attributed to most if not all the sand in the *loam*. Sand that periodically during or after (also periodical, perhaps seasonal?) fluvial basin-clay deposition was blown on to these clay surfaces might have mixed there with the clay (syn- or postsedimentary) to form the diamicton *loam*. This hypothetical mixed genetic nature of the *loam* might make the name **fluvio-eolian** appropriate. According to this view, the formation of the river dunes may be seen as contemporaneous with the *loam* formation, namely as locally more dominant sand accumulation, especially near to the presumed source of the eolian transported sand, i.e. the channels. The grain-size composition of the sand fraction in the *loam*, as analysed in just one sample, is not in contradiction with the above assumed genetic relationship between the *loam* and the river dunes. There is a remarkable similarity to the average grain-size composition given by VERBRAECK (1974, p. 4) for the river-dune sand in the Alblasserwaard:

	16-50 mu	50-75 mu	75-105 mu	105-150 mu	150-210 mu	210-300 mu	300-420 mu	420-600 mu	600-850 mu	850-1200 mu	1200-1700 mu
Average grain-size composition of river-dune sand in the Alblasserwaard (VERBRAECK 1974, p. 4)	0.4	0.2	0.8	2.9	17.5	27.7	30.1	15.0	4.6	0.5	0.3%
										850-1400 mu	1400-2000 mu
Grain-size composition of sand in 'loam' in Molenaarsgraaf study area (one sample)	9.1	2.0	2.7	4.4	10.7	27.6	22.9	14.5	4.7	1.3	0.1%

The fluvio-eolian hypothesis of *loam* formation still requires to be thoroughly tested. Nevertheless we shall use it here in a consideration of various data from Chs. II, III and IV concerning the *loam* and the river dunes, in order to make a contribution, albeit a speculative one, to the discussion about the age of the river dunes.

Outside the river dunes the *loam* layer shows a differentiation into a light-grey, calcareous lower part and a dark-grey, noncalcareous upper part. Although the pedogenesis of the *loam* has not been studied here, it may be assumed on the basis of the locally considerable thickness of the dark-grey noncalcareous part (up to 1 m) that this vertical differentiation has not been brought about by postsedimentary pedogenetic processes. So, the lithological transition from the lower to the upper part of the *loam* should point to a change in the depositional environment. HAGEMAN (1970a) considers this to be the transition from the sparsely vegetated environment during the Late-Weichselian to the more densely vegetated environment during the early-Holocene.
On the few occasions when was gouged almost completely through the high, thick river-dune sand deposits, the sand appeared to be somewhat calcareous in its lowermost part; all the rest of the river-dune sand is noncalcareous. If postsedimentary decalcification — so many meters deep — may be excluded, this vertical differentiation of calcareous content may be viewed as a parallel development to that in the *loam*. This would mean that the river-dune formation also initially took place in the sparsely vegetated environment during the Late-Weichselian, and subsequently in the more densely vegetated environment during the early-Holocene. In agreement with this (but not supporting it especially) is the fact that, where low river dunes have been gouged through into the underlying *loam*, this *loam* shows the light-grey calcareous facies.
In the gyttja infilling of the depression in the Kreftenheye Formation surface (pollen section Molenaarsgraaf H1530, see Ch. IIIe), in the lower part dating from Preboreal and Boreal (zones I and II) some clay beds, up to 1 cm thick, have been found that show strong similarity in colour and structure to the dark-grey *loam*. This may support the above-mentioned dating of the dark-grey *loam* as early-Holocene. In the same section a hiatus is situated at the transition from zone II to zone III, which points to non-deposition (of the gyttja) during the later part of the Boreal and the very beginning of the Atlantic. This non-deposition may have been caused by a temporary fall of the water table in connection with possible drying out of shallow channels leading to more intensive eolian erosion and river-dune accumulation.
Some observations that by themselves have little diagnostic value, nevertheless agree with the more

intensive dune-sand accumulation during the Boreal supposed above. In the above-mentioned section H1530, a 1 cm thick layer of sand showing the characteristics of river-dune sand is situated just at the hiatus. Primary eolian deposition of this sand during the Boreal is plausible. The uppermost part of the river-dune sand in pollen section H2178 (Ch. IIIg) shows Atlantic spectra; from this it was concluded that accumulation of this dune sand during the (late-)Boreal is not unlikely. Finally, the locally greater sandiness of the topmost part of the dark-grey *loam* (see Ch. IIa) possibly indicates more intensive eolian sedimentation towards the end of the early-Holocene *loam* deposition (or just after it, in the case of postsedimentary mixing).

The above speculative argument for a Late-Weichselian *cum* early-Holocene age of the river dunes at Molenaarsgraaf (with a possibly more intensive dune-sand accumulation during the Boreal) may serve mainly as stimulus to a more elaborate study specially aimed at these matters. Apart from the desirability of more direct dating, the depositional environment should be an important issue.

One important aspect of the *loam* has been left out of consideration above. This concerns the high, thick occurrence of the light-grey calcareous *loam* in the river-dune field, c. 300 m W of the Hazendonk (see Figs. 36 and 37). The *loam* occurring usually at a depth of c. 10.5 m below N.A.P. and with a thickness of some dm up to 1 m, here attains heights up to c. 8 m below N.A.P. and was found to be locally at least 2.5 m thick. Rejecting the explanation of this high, thick *loam* as being of purely eolian origin, or as natural levee, the explanation as an erosional terrace seems unavoidable. If so, this *loam* would have been deposited earlier and at a higher water level than the normal *loam*. In this connection, reference should be made to PONS' (1957, p. 24) reconstruction of a Late-Weichselian incision of Rhine and Meuse in the Eastern Netherlands, and to his supposition (ibid., fig. 16) of an extension of this incision into the Western Netherlands area. If the high, thick *loam* is explained as an erosional terrace — which presupposes Late-Weichselian erosion on a very large scale in this region! —, it is conceivable that this erosional terrace might have served as a nucleus for dune-sand accumulation (on the lee side?), and that possibly in other river-dune fields in this region other such erosional terraces might also be found. If this hypothesis should be confirmed, VINK's (1954) explanation of the *donken* (the regional descriptive term for the river-dune outcrops) as erosional terraces would after all in a way have some validity.

IVd CHRONOLOGY OF THE FLUVIATILE DEPOSITIONAL PHASES

Correlation between the Molenaarsgraaf and Leerdam study areas

The dating results related to the cyclicity of the fluvial clay beds and the peat beds in both study areas, as discussed separately in Ch. IVb, have been brought together in a chronological scheme (Fig. 32). The lithostratigraphical correlation brought about in Ch. IIb.3 between the main clastic and organic beds of both areas appears to be largely also a chronostratigraphic correlation. One of the most important lithostratigraphic levels, namely the top of clastic bed cl 2 (Molenaarsgraaf)/ lcp (Leerdam) has the same age in both areas (c. 6100 BP). The period of deposition of clastic bed cl 4 in the Molenaarsgraaf area falls within the period of deposition of the lithostratigraphically correlative clastic bed uc at Leerdam. The deposition of this bed appears to have started earlier and ended later in the upstream area (Leerdam) than in the downstream area (Molenaarsgraaf). However, the start of the main sedimentation was at about the same time, namely 4100 BP, in both areas.
The phases of clastic fluviatile deposition have, for their primary subdivision, been named after the BLYTT/SERNANDER terminology (see the right part of Fig. 32). This has been done on the basis of the presently accepted radiocarbon calibration of these periods (Atlantic and Subboreal) in the Netherlands (see ZAGWIJN & VAN STAALDUINEN 1975).

Comparison with other dates from the perimarine fluviatile coastal plain

The phases of the fluviatile depositional activity outlined above for both study areas (Fig. 32) agree in general with previously published dates for the fluviatile depositional phases during Atlantic and Subboreal in this region (Alblasserwaard and Vijfheerenlanden, see for location Fig. 1).

Mainly on the basis of prehistoric occupation on stream ridges and of pollen analysis of peat beds beside the stream ridges, DE BOER & PONS (1960, p. 23 f.) concluded that there were separate phases of increased fluviatile depositional activity in the Vijfheerenlanden. For the period of Atlantic and Subboreal they place these phases roughly in the second half of the Atlantic (before the end of the Atlantic), in the transition from Atlantic to Subboreal, and in the middle-Subboreal. Although the datings are not precise, they give about the same phasing as depicted in Fig. 32.

The C-14 dates published by VERBRAECK (1970) in connection with a phasing of fluviatile depositional activity in the area of sheet 38 Oost of the Geological map of the Netherlands (i.e. the Vijfheerenlanden and the eastern part of the Alblasserwaard) derive from the section at Goudriaan (op. cit., fig. *43). The location of this boring is midway between the Molenaarsgraaf and Leerdam study areas. On the basis of the lithology of this section and the depth of the various clay- and peat beds in it, the lithostratigraphical position of the C-14 dates may be indicated in terms of the local lithostratigraphy of our both study areas:

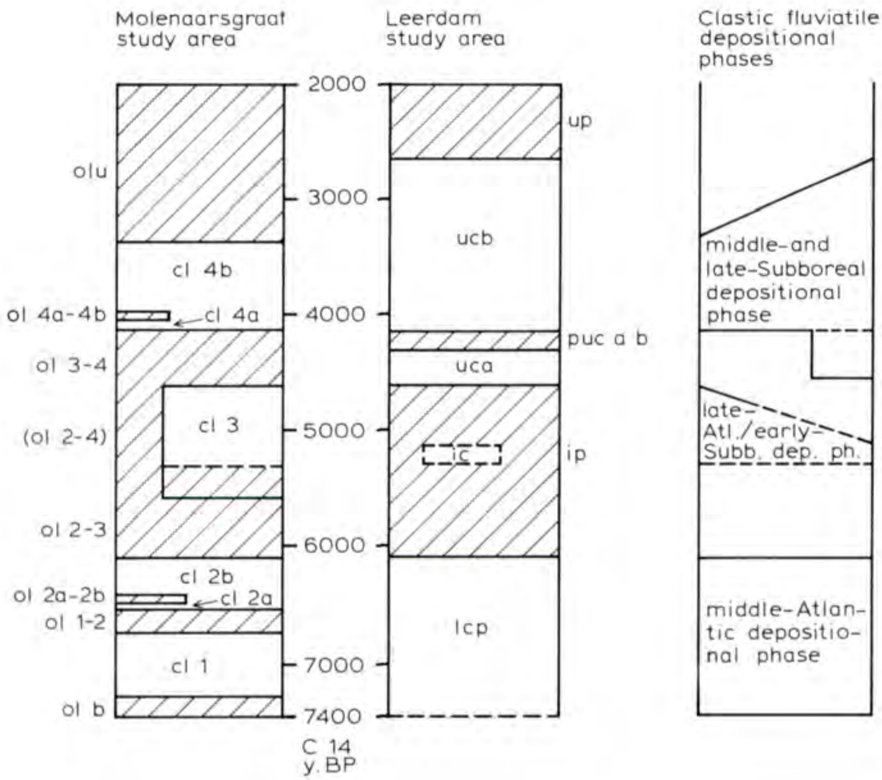


Fig. 32. Scheme of the chronostratigraphy in both study areas. Compare with Figs. 5 and 11, and Table 2.

2820 ± 75 BP (GrN 787) ~ base of peat bed up (Leerdam)
4095 ± 90 BP (GrN 784) ~ peaty level p uc a-b (Leerdam)
4650 ± 95 BP (GrN 785) ~ top of peat bed ip (Leerdam)
5340 ± 90 BP (GrN 786) ~ in organic bed ol 2-3 (Molenaarsgraaf)

The first three dates give good support for the middle- and late-Subboreal depositional phase distinguished in Fig. 32. The fourth date (GrN 786: 5340 ± 90 BP) falls within the late-Atlantic period of organic accumulation in the chronologic scheme of Fig. 32, but on account of the lithostratigraphical position of the sample concerned (in the lower part of the peat bed) it is rather young. The discrepancy might be explained by a locally later start of the peat formation after the middle-Atlantic depositional phase. Such a local hiatus in deposition is not unlikely, as the underlying clastic bed — as shown in fig. 43 by VERBRAECK (op. cit.) — consists of (channel) sand and so possibly has been developed as a stream ridge. A comparable situation has been discussed in Ch. IVb.1 in connection with the C-14 dates GrN 8922: 6090 ± 70 BP and GrN 8376 : 4800 ± 70 BP in the Leerdam study area.
A more regional approach to the dating of fluviatile depositional phases in the Alblasserwaard and Vijfheerenlanden was used by LOUWE KOOIJMANS (1974, see especially tables 5 and 6). It concerns mainly datings of archeological finds on stream ridges. These of course always only give a terminus ante quem for the depositional phase in which the stream ridge concerned was formed. The oldest phase dated in this way concerns the one in which the so-called Gorkum stream was active; a find on top of its stream ridge dates from the period 6000-5400 BP, so possibly the depositional phase ended before 6000 BP. Interpreted in this way, the dating would support the middle-Atlantic depositional phase distinguished in Fig. 32. A comparable date (c. 6050 BP) has also been mentioned by LOUWE KOOIJMANS (op. cit., p. 134) as a possible date (on account of the depth) for the top of a clay bed on the flank of the Hazendonk river dune — the so-called bed clay 1. This bed is the same as bed cl 2 distinguished in this study, the top of which has been dated as 6060 ± 80 BP (see Fig. 27).
In connection with the late-Atlantic/early-Subboreal depositional phase distinguished in Fig. 32, reference should be made to a similar phase mentioned by DE BOER & PONS (1960; see also above) as well as LOUWE KOOIJMANS (1974, table 6). In both sources this phase has been based mainly on archeological finds on and near the so-called Zijderveld stream ridge. However, according to the Geological map of the Netherlands, sheet 38 Oost (VERBRAECK 1970, map and p. 85), this stream ridge belongs to the same pattern to which the Schaik stream and the (western continuation of the) Schoonrewoerd stream also belong. The clay deposits connected with these stream ridges have been dated in the Leerdam study area as middle-Subboreal (see Ch. IVb.1, lithostratigraphic unit uc). This is in agreement with DE JONG's (1970-71, figs. 1 and 13) indication of the Zijderveld stream ridge — in its type locality — as 'Gorkum IV'. The archeological finds, on the basis of which an older age had been concluded, also come from this type locality (see LOUWE KOOIJMANS 1974, fig. 18). However, at this point the Zijderveld stream ridge lies partly on, and directly next to a stratigraphically deeper stream ridge (VERBRAECK 1970, geological map; DE JONG 1970-71, fig. 1). It may be assumed that the older archeological finds mentioned by LOUWE KOOIJMANS do not so much relate to the Zijderveld as to this deeper, older stream ridge. DE JONG (op. cit.) concludes that a late-Atlantic/early-Subboreal age is appropriate for this deeper stream ridge, on the basis of a C-14 dating and pollen analysis of overlying material, and thus on the basis of a terminus ante quem. Comparing the situation here to that in the Leerdam study area we presume that this deeper stream ridge had already been formed long before this terminus ante quem, namely not in the late-Atlantic/early-Subboreal but in the middle-Atlantic. According to the geological map 38 Oost cited above (VERBRAECK 1970), the stream ridge belongs to the same system to which the Middelkoop

stream ridge in the Leerdam area also belongs (see also DE JONG 1970-71, fig. 1). The depth of the top of both stream ridges is the same (c. 2 m below N.A.P., cf. e.g. Fig.*10 with DE JONG's fig. 13; we suppose the sand at the base of DE JONG's section 4A — Zijderveld R.O.B. excavation — to belong to the Zijderveld stream ridge, see also his fig. 1). The formation of the Middelkoop stream ridge was placed in the middle-Atlantic (namely before 6100 BP; see Ch. IVb.1) by means of a C-14 dating of peat on top of the basin-clay bed connected laterally to the stream ridge in the Leerdam area. Organic material on top of the stream ridge itself in our study area also appeared to be much younger than this 6100 BP, namely 4800 BP (see discussion in Ch. IVb.1). It should be stressed again that in dating stream ridges C-14 dates on peat overlying a basin-clay bed are more useful than C-14 dates on peat on top of the stream ridges themselves. In the latter case, considerable depositional hiatuses should be reckoned with. Summarizing, with regard to the late-Atlantic/early-Subboreal depositional phase it may be concluded that at Zijderveld — just as at Leerdam and Molenaarsgraaf — no stream ridges from this phase occur.

The greater part of the clastic sediment of the middle- and late-Subboreal depositional phase has been brought into both study areas by the Schoonrewoerd stream. The start of the clay deposition from this river on the Hazendonk river dune flank was estimated by LOUWE KOOIJMANS (1974, table 8) at c. 4050 BP (2100 BC); this estimation was based on presumed water-level heights connected with the Holocene sea-level rise. Our dating of c. 4100 BP (see Ch. IVb.1) agrees well with this. However, two C-14 dates on peat samples at the base of this clay bed, one on the flank of the river dune and another just outside it, give an older date, namely 4480 ± 40 BP (GrN 6213), and 4290 ± 40 BP (GrN 5175; ibid., p. 140) respectively. So, as noted in Ch. IVb.2, the possibility that at least locally in the Molenaarsgraaf area clay deposition occurred some centuries before 4100 BP should not be excluded. This would then partly correspond to the deposition of clay bed uc a at Leerdam (see Figs. 30c, 31a and 31b).
Archeological finds (C-14 dated) on the stream ridge itself indicate that the Schoonrewoerd stream at Molenaarsgraaf had already been filled up and become a stream ridge in the middle-Subboreal, namely c. 3800 BP (LOUWE KOOIJMANS 1974, p. 97 and table 6). From the position of the finds on the depth-contour maps of the stream ridge (ibid., figs. 57, 58 and 60), it appears that these finds do not just relate to the natural levees of the formerly active river, but definitely to the whole stream ridge (which comprises both the sanded up channel and the former levees).
The sedimentation in the remaining part of the middle- and late-Subboreal depositional phase may be related to the inundations supposed by LOUWE KOOIJMANS as explanations for the 'break-through channels' in the Schoonrewoerd stream ridge (ibid., p. 100 f.). These inundations must have been brought about by rivers situated outside the study area. The fluvial activity in these break-through channels ends at Molenaarsgraaf c. 3350 BP and at Culemborg (c. 5 km NE of the Leerdam study area) c. 2350 BP at the latest (ibid., p. 111, see also fig. 18). Agreeing with these dates are our dates for the end of the middle- and late-Subboreal depositional phase (3340 ± 80 BP at Molenaarsgraaf and 2650 ± 70 BP at Leerdam; see Figs. 27 and 30b). LOUWE KOOIJMANS' dating GrN 6212: 3630 ± 35 BP for the end of the clay deposition on the flank of the Hazendonk river dune (ibid., p. 140) relates in our opinion to just this inundation and clay deposition, after the filling of the Schoonrewoerd stream; in this marginal location near the river dune the sedimentation ended earlier than at the standard boring. The dates GrN 5219: 2880 ± 35 BP at Zijderveld (DE JONG 1970-71, p. 83) and GrN 787: 2820 ± 75 BP at Goudriaan (VERBRAECK 1970, fig. 43; see also above) also refer to the end of this phase. Moreover, all these dates make it clear that there is an important diachrony with regard to the end of the middle- and late-Subboreal depositional phase: in the western part of the region the deposition ended c. six centuries earlier than in the eastern part.

Some relations to upstream regions

In the Betuwe, part of the central-Netherlands river-clay area and situated c. 40 km upstream of Leerdam, HAVINGA (1969) distinguished a vertical sequence of four clastic (clay) deposits. On the basis of archeological dates (op. cit., p. 27) he concluded that the lower two deposits were formed before c. 3800 BP, possibly before 3300 BP in part of the study area. These dates can be related to the middle- and late-Subboreal depositional phase distinguished here. Moreover, the 3800 BP date coincides with the filling of the Schoonrewoerd stream at Molenaarsgraaf (see above).

In the 'Land van Maas en Waal' situated further upstream, PONS (1957) has practically no dates on Atlantic and Subboreal clay deposits. But in a general discussion of the deposits in the central Netherlands river-clay area, he concludes, with reference to MODDERMAN's (1955) archeological dates, that the period of rather intensive occupation from c. 3800 to c. 2800 BP (Bronze age mainly) was a period of decreased fluviatile activity. So again the date 3800 BP is mentioned here as the end of a period of intensive fluviatile sedimentation. Comparison with LOUWE KOOIJMANS' (1974) figs. 7 and 8 also shows that the central Netherlands river-clay area was occupied in the Bronze age more intensively than in the preceding period.

The only study known to us of a phasing of Holocene fluviatile activity in the far hinterland is by BECKER & SCHIRMER (1977) on the paleoecology of the Main valley (Southern Germany). On the basis of among others C-14 dates on oak trunks occurring in the fluvial deposits they established increased fluviatile activity in the middle-Atlantic, the Subboreal and another four periods starting from the Iron/Roman age. The Main represents only a small part of the fluvial hinterland, and according to BECKER (1980, p. 35) various aspects of several river systems should be compared in order to be able to reconstruct the Holocene fluvial activity in the broader region. Nevertheless, a preliminary comparison with at least the middle-Atlantic depositional phase discerned in our study can be made. Thus, notwithstanding the uncertainty attached to correlating over so large a distance, the strong fluviatile depositional activity in our study areas during the middle-Atlantic might somehow be connected to increased fluvial activity in the hinterland (see also Ch. Ve).

IVe CORRELATIONS BETWEEN FLUVIATILE AND MARINE DEPOSITIONAL PHASES

Several of the authors referred to in Ch. IVd in connection with the chronology of the fluviatile depositional phases, assume or conclude a certain synchrony of these phases with the marine transgressive phases. As these transgressive phases have been distinguished on the basis of deposits — namely the alternation of clay- and peat beds —, they may be called marine depositional phases as well. Because of the assumed synchrony, HAGEMAN (1963, p. 219) extrapolated the marine depositional phases Calais I, II, III and IV and Dunkerque 0, I, II and III to the perimarine fluviatile area, and distinguished there as fluviatile equivalents the phases Gorkum I, II, III and IV and Tiel 0, I, II and III. In a later publication a hypothesis was given regarding the mechanism that could have caused this synchrony (HAGEMAN 1969, p. 380 f.); we shall return to this in Ch. Ve.

The Gorkum-/Tiel-terminology has also been used by VERBRAECK (1970) and ZAGWIJN & VAN STAALDUINEN (1975). In a purely geochronological respect it involves only a renaming of the Calais-/Dunkerque-terminology, and thus one might confine oneself only to the latter (as LOUWE KOOIJMANS, 1974, did), in a discussion on the perimarine fluviatile depositional phases.

The marine depositional (transgressive) phases in the period of the Atlantic, Subboreal and early-Subatlantic, to which the fluviatile depositional phases shown in Fig. 32 should be compared, are as follows:

2050-2550 BP: Dunkerque I
2950-3450 BP: Dunkerque 0
3750-4550 BP: Calais IV
4750-5250 BP: Calais III
5250-6250 BP: Calais II
6450-7950 BP: Calais I

The chronology has been established by HAGEMAN (1969) for the Western Netherlands coastal plain. ZAGWIJN & VAN STAALDUINEN (1975, p. 111) suggested some minor alterations to this scheme; however these are not essential for a comparison of the marine and fluviatile depositional phases. No publications have appeared which incorporate an important revision of the chronological scheme for the Western Netherlands. It should be noted that the Calais IV phase is often subdivided into IVa and IVb; the regressive interval between them can be placed in the period 4300-4100 BP (cf. LOUWE KOOIJMANS 1974, fig. 10, summarized from various sources).
As already established in a preliminary publication of C-14 dates from our study at Molenaarsgraaf (VAN DER WOUDE 1979, p. 283), the older Calais phases in particular do not correlate well with the fluviatile depositional phases. During the middle-Atlantic depositional phase (see Fig. 32) the stronger clastic sedimentation occurred in the later part of the phase, namely from c. 6450-6100 BP. This is the very period in which the marine regressive phase between the transgressive phases Calais I and II has been observed. The subsequent period of organic deposition in the fluviatile area (c. 6100-5300 BP, see Fig. 32) coincides with the marine transgressive phase Calais II.
On the other hand HAGEMAN's scheme of the marine transgressive and regressive phases may of course show regional variations; hence the depositional chronology of the perimarine fluviatile region distinguished here might mirror such a regional variant. To check this possibility, all published C-14 dates that refer to the marine depositional chronology up to 2500 BP in the seaward foreland of our study area have been collated in Table 11. This foreland area has been defined rather broadly, namely from the island of Schouwen (prov. of Zeeland) up to Haarlem (prov. of Noord-Holland). All the dates relate to samples from peat beds between or on top of marine clay beds and therefore should fall in the regressive phases (at least the phases of non-clastic sedimentation) of HAGEMAN's scheme. Basal-peat samples are left out of consideration. To a certain extent groups of dates can be discerned in the table. The first group of only three dates comprises the period from c. 6400 to c. 6300 BP and may confirm the regressive interval between the transgressive phases Calais I and II. The second group, from c. 5500 to c. 5200 BP indicates the end of the Calais II phase. The third group, from c. 4900 to 4700 BP, will largely relate to the end of the Calais III phase, and the fourth group (c. 4400-4200 BP) might relate to the regressive interval Calais IVa/IVb. The younger dates show less clear groupings.
It may be concluded that the marine depositional phases in the foreland of our study area fit reasonably well with HAGEMAN's scheme of the Calais transgressive phases. This confirms that a comparison of the fluviatile depositional phases with the Calais phases is valid.
In connection with the negative correlation of the marine depositional phase Calais II and the fluviatile depositional phases, it is interesting to examine in some detail mapping results published by VERBRAECK & BISSCHOPS (1971) on a transitional area between the marine and the perimarine areas (sheet 43 Oost of the Geological map of the Netherlands 1:50000, its centre lying c. 35 km SW of Molenaarsgraaf). In the western part of this area, at about 5-6 m below N.A.P., they found deposits everywhere of marine clay and sand many meters thick. At the top, these deposits were dated as

Table 11. C-14 dates published of peat beds intercalated between or situated on top of marine clay beds in the Western Netherlands coastal plain, between Schouwen island and Haarlem.

GrN No.	C-14 age BP	Locality	Reference	Lithology/ Stratigraphy
6501	6410 ± 65	Schipluiden II	Van Staalduinen 1979	peat bed
639	6330 ± 150	Honselersdijk	Jelgersma 1961	peat bed
1620	6320 ± 70	Nieuwe Wetering	ibid.	peat bed
2268	5930 ± 80	Nootdorp	Zagwijn 1965	peat bed
6497	5470 ± 60	Schipluiden I	Van Staalduinen 1979	base of peat bed
2849	5460 ± 50	Mijdrecht	Riezebos & Du Saar 1969	peat bed
5918	5435 ± 60	Zuid-Beyerland	Verbraeck & Bisschops 1971	base of gyttja bed
1143	5420 ± 60	Zuidland	Jelgersma 1961	base of peat bed
6500	5270 ± 60	Schipluiden II	Van Staalduinen 1979	base of peat bed
222	5200 ± 120	Willemstad I	Jelgersma 1961	base of Upper Peat
3566	4970 ± 75	Vijfhuizerpolder	Riezebos & Du Saar 1969	peat bed
1622	4880 ± 80	Alphen	Jelgersma 1961	base of Upper Peat
3563	4820 ± 100	Beinsdorp	Riezebos & Du Saar 1969	peat bed
2852	4805 ± 60	Bovenkerkerpolder	ibid.	base of Upper Peat
2857	4800 ± 75	Duivendrechterpolder	ibid.	base of Upper Peat
1139	4780 ± 80	Zuidland	Jelgersma 1961	top of peat bed
238	4765 ± 130	Willemstad II	ibid.	base of Upper Peat
1648	4740 ± 60	Nieuwerkerk	Van Rummelen 1970	base of peat bed
6495	4685 ± 60	Schipluiden I	Van Staalduinen 1979	base of peat bed
2267	4670 ± 65	Rijswijk	Zagwijn 1965	base of Upper Peat
3565	4530 ± 90	Vijfhuizerpolder	Riezebos & Du Saar 1969	base of Upper Peat
2119	4515 ± 45	Nieuwe Wetering	Jelgersma 1961	base of Upper Peat
5016	4490 ± 55	Aalsmeer	Riezebos & Du Saar 1969	base of Upper Peat
6499	4405 ± 65	Schipluiden II	Van Staalduinen 1979	base of peat bed
1142	4400 ± 80	Zuidland	Jelgersma 1961	base of Upper Peat
2858	4390 ± 60	Tolhuis Bilderdam	Riezebos & Du Saar 1969	base of Upper Peat
1098	4380 ± 75	Lodderland	Jelgersma 1961	base of peat bed
1646	4360 ± 60	Nieuwerkerk	Van Rummelen 1970	base of peat bed
633	4350 ± 130	Honselersdijk	Jelgersma 1961	base of Upper Peat
3552	4300 ± 80	Beinsdorp	Riezebos & Du Saar 1969	base of Upper Peat
1036	4295 ± 55	Prunjepolder I	Jelgersma 1961	base of Upper Peat
6494	4290 ± 60	Schipluiden I	Van Staalduinen 1979	base of Upper Peat
1035	4280 ± 55	Prunjepolder II	Jelgersma 1961	base of Upper Peat
256	4250 ± 150	Willemstad III	ibid.	base of Upper Peat
1136	4195 ± 55	Renesse	ibid.	base of Upper Peat
315	4130 ± 130	Heenvliet	ibid.	base of Upper Peat
310	4085 ± 150	St. Philipsland	ibid.	base of Upper Peat
202	3985 ± 170	Schiedam	ibid.	base of Upper Peat
286	3820 ± 180	Hekelingen	ibid.	base of Upper Peat
4935	3680 ± 40	Overveen	Jelgersma et al. 1970	base of peat bed
159	3145 ± 150	Vredenheim	Jelgersma 1961	base of peat bed
4933	3010 ± 80	Beverwijk	Jelgersma et al. 1970	base of peat bed
1095	2900 ± 60	Lodderland	Jelgersma 1961	base of peat bed
6498	2795 ± 50	Schipluiden II	Van Staalduinen 1979	base of peat bed
1094	2645 ± 65	Lodderland	Jelgersma 1961	top of peat bed

Calais II. The marine clay- and sand deposits pass eastwards into 'mudclay', regarded by them as fluviatile. The authors conclude from this that during the marine transgressive phase Calais II increased deposition also occurred in the perimarine fluviatile area, in agreement with HAGEMAN's scheme and extrapolation (see above). This would be in contradiction to our negative correlation between the marine Calais II and the fluviatile depositional phases. However, in the NE part of the mapped area, within this mudclay (described lithologically as peaty clay and even clayey peat) sandy channel fills of rivers whose activity had stopped before the end of the marine Calais sedimentation (ibid., p. 55) occur. In our opinion it is not unlikely that these channel fills belong to the same fluvial system as the middle-Atlantic ones (lithostratigraphic unit cl 2) at Molenaarsgraaf. If the channel fills occurring within the (peaty!) mudclay do indeed indicate a middle-Atlantic period of increased fluvial activity, then this would contradict to some extent the positive correlation, as put forward by the authors, between increased marine (Calais II) and increased perimarine fluviatile sedimentation.

The late-Atlantic/early-Subboreal fluviatile depositional phase in both study areas (Molenaarsgraaf and Leerdam) involves a generally discontinuous, strongly organic clay deposit, without clear stream ridges. This phase, in its later part, coincides with the marine transgressive (depositional) phase Calais III.

During the middle- and late-Subboreal fluviatile depositional phase, the strongest sedimentation in both study areas occurred from c. 4100 BP (see Ch. IVb.1) to c. 3800 BP (see Ch. IVd). This period is practically synchronous with the marine transgressive phase Calais IVb. The preceding sedimentation of clastic bed uc a at Leerdam, from c. 4600 to c. 4300 BP (see Fig. 32) coincides with the Calais IVa phase.
Thus there is a positive correlation between certain parts of the late-Atlantic/early-Subboreal and the middle- and late-Subboreal fluviatile depositional phases on the one hand and the marine transgressive (depositional) phases Calais III and IV on the other. Yet there is also a complication. During the period of the marine transgressive phases Calais III, IVa and IVb, the strongest sedimentation in our fluviatile study areas occurred during the phase Calais IVb. In the marine foreland this is reversed: there the phases Calais III and IVa were the most important sedimentation phases (see e.g. RIEZEBOS & DU SAAR 1969, figs, 1 and 2; BOSCH & PRUISSERS 1978, fig. 1).
As mentioned before, the end of the middle- and late-Subboreal fluviatile depositional phase is highly diachronous throughout the perimarine area, at least from the Molenaarsgraaf up to the Leerdam study area. So here a comparison with the marine transgressive phases (the late-Subboreal Dunkerque phases) may be of limited value only. A more extensive evaluation of dates in this younger period in the fluviatile perimarine regional history may be expected from BERENDSEN (in prep.).
Some of the observations and conclusions made in this chapter about the regional chronostratigraphy are briefly discussed in a paleoenvironmental context in Ch. Ve.

V EVOLUTION OF THE PALEOENVIRONMENT

Va AREAL SYNTHESIS AND RECONSTRUCTION

The stratigraphical themes in the preceding chapters (litho-, bio- and chronostratigraphy) are integrated here in a reconstruction of the paleoenvironmental evolution. To the vertical, stratigraphical dimension, the horizontal, areal dimension is added by means of distribution maps of the lithological data for each bed and each boring. Because these maps relate to lithostratigraphic units, there may be a certain diachrony in them: the phenomena shown on a map need not necessarily have been exactly simultaneous at all boring locations. The same holds true for the landscape reconstruction drawings; thus e.g. in a drawing with a strongly branching river pattern not all small channels need have originated at the same time. However, the periodization of the paleoenvironmental reconstruction is such that the phenomena shown on a map or drawing certainly always originated within the period concerned.

The positions of all borings whose data have been processed in the distribution maps are shown in Fig. 33 (for the Molenaarsgraaf area) and Fig. 34 (for the Leerdam area). The precision of the computer-directed laser plotter (see Ch. Ic) allowed the choice of symbols for the distribution maps such that their size is continuously variable (for the maps showing thickness and depth of the beds) and such that they can be superimposed on each other (for the maps with the remaining lithological data; see the legend, Fig.*35).

The following remarks should be made on the construction of the maps with thickness symbols. Where, from the details of a boring, it could be concluded that a certain bed was not formed at the boring site, a small horizontal dash was placed on the map concerned. If a certain bed was not found in a boring, but non-deposition could not be proved (e.g. because of later erosion, or because of gouging to too shallow a depth), no symbol was inserted. If a clastic bed could not be gouged through entirely because the bed is locally strongly sandy, a circle was placed around the dot showing the thickness of the bed so far as gouged through.

On the maps showing the lithological content (inclusive of the organic remains) a symbol was not placed for all borings where a certain bed was found. Namely, where a bed has no marked characteristics, e.g. in the case of a poorly humic, non-sandy clay bed without a moderate or large quantity of plant remains, no symbol was used. This holds also for the organic beds where these have been developed as rather amorphous peat, which has been found in many places. Where an organic bed consists not of peat but of gyttja, a symbol was used (see legend, Fig.*35), except for organic bed ol 2-3 (Molenaarsgraaf), the upper part of which, consisting generally of gyttja, has been represented on a separate map (Fig. 46).

Because of the above-mentioned omission of symbols in certain cases, full evaluation of the distribution maps is only possible by constant comparison with the maps showing the location of all borings (Figs. 33 and 34). Besides, in many places in the specific description of the paleoenvironmental evolution only implicit reference is made to the distribution maps.

An important advantage of the symbol maps is that point-information is presented about a large number of characteristics. Opposing these are maps with plane-information: here fewer characteristics can be shown together, and moreover their construction involves subjective interpretation and interpolation. Nevertheless, for the sake of clarity grey planes have been superimposed on various symbol maps. In all maps except one, these refer to the positions of sandy channel fillings and river dunes. The river dune outcrops were reconstructed for the various maps by comparing the map showing the depth of the river-dune surface with the map showing the thickness of the deposit concerned (see e.g. Fig. 41).

The positions of the river dune and the channel fillings (stream ridges) on the symbol maps of the

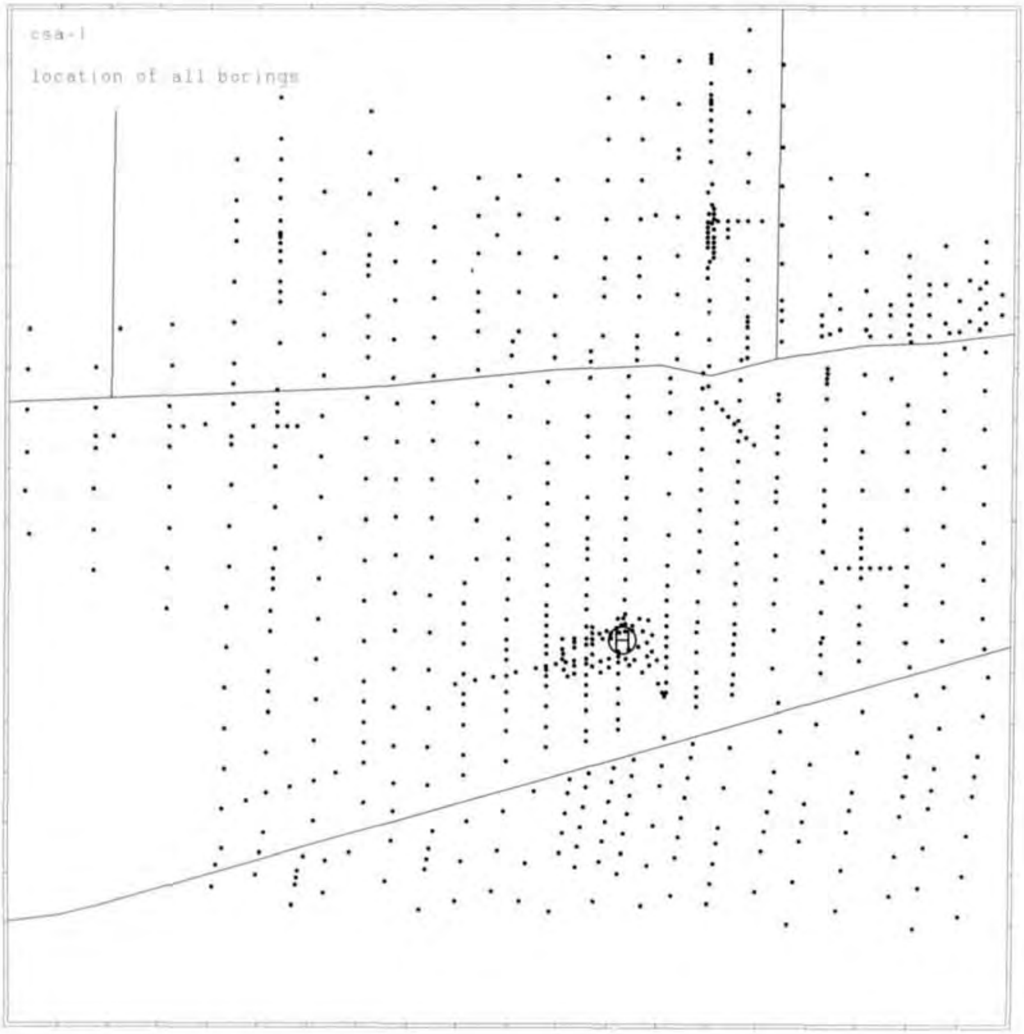


Fig. 33. Location of borings, Molenaarsgraaf. Many borings omitted at flank of Hazendonk river dune. See Fig. 3 for topographic details.

Leerdam study area appear to be in good agreement with sheet 38 Oost of the Geological map of the Netherlands 1:50000 (VERBRAECK 1970). The exact location of our study area on this sheet was indicated in Ch. IIb.1 with the aid of profile IV (Fig.*10). Sheet 38 Oost gives valuable supplementary information about the surroundings of the Leerdam study area; thus, on this map the course of the larger channels can be traced over much wider a distance than in our detailed study. With regard to the main study area (Molenaarsgraaf) the same will hold with relation to sheet 38 West, to be published in due course.

The dune- and *loam* topography

Before entering the subject of the paleoenvironmental evolution of both areas during Atlantic and Subboreal (Chs. Vb, -c, -d and -e) some remarks on the topography of the sand-subsoil (Kreftenheye Formation — *loam* and river dunes) are made here. In Ch. IVc hypotheses on the genesis and age

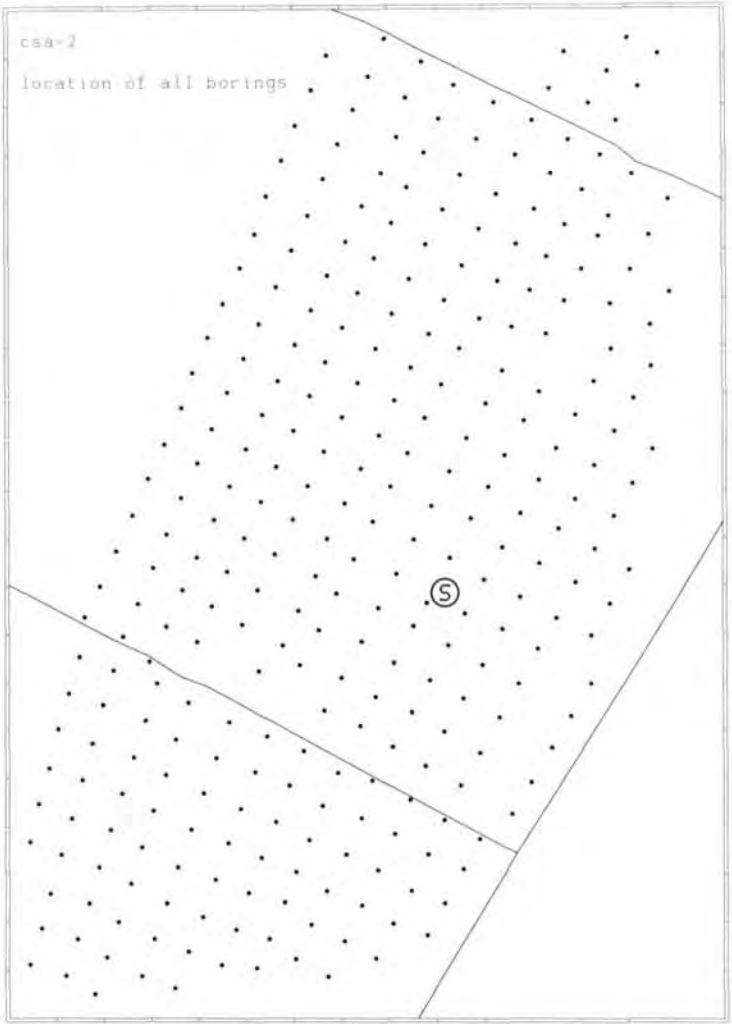


Fig. 34. Location of borings, Leerdam.
See Fig. 4 for topographic details.

of the *loam* and the river dunes were given. For additional paleoecological aspects connected with this and for the description of the vegetational development in the Preboreal and Boreal, see Chs. IIIe, -f and -g.

The topography of the river dunes and to a lesser extent also of the *loam* has exerted an important influence on the paleoenvironmental evolution during the Atlantic and Subboreal, as will be shown in detail in the following chapters. Figs. 36 and 38 show the depth of both (topmost) parts of the Kreftenheye Formation.

The irregular topography of the landscape of a braided river is manifested in the irregular thickness and depth of the *loam* (Figs. 36, 37 and 38). The occurrence of river dunes is limited in both areas to a strip amidst this weakly undulating *loam*-surface. In the Molenaarsgraaf area this strip has a W-E orientation, in the Leerdam area a SW-NE orientation. These may be connected to the direction of the channel floors from which the dune sand was deflated. ALLEN (1965, p. 163) cites a study

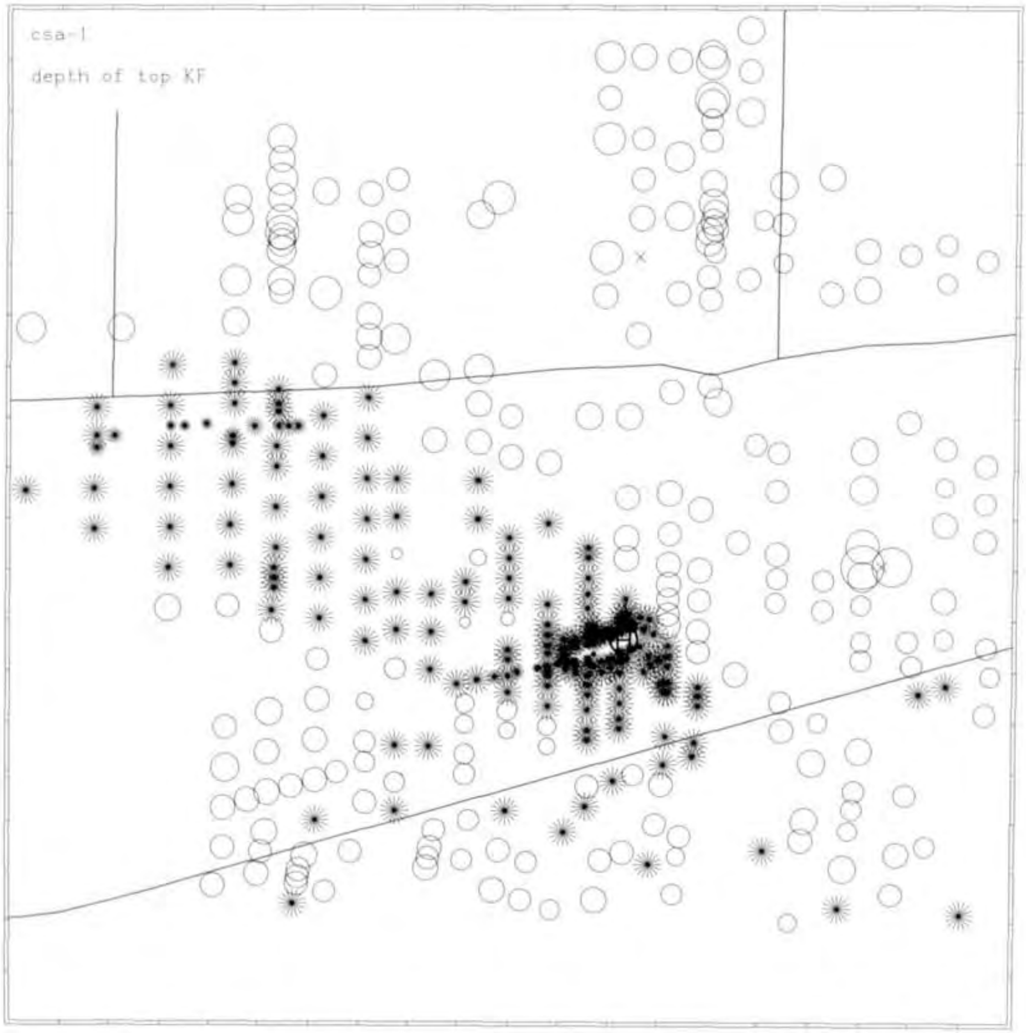


Fig. 36. Depth of the top of Kreftenheye Formation, Molenaarsgraaf. For legend, see Fig. *35; black stars: river-dune sand.

of an area with several series of river dunes, each series showing an orientation parallel to the former channel floor. A similar connection is shown by the river-dune pattern in the fossil northern IJssel valley (ENTE 1971, fig. 1). It was not possible to trace channel floors in the study areas; possibly these were ultimately filled with *loam* and dune sand.

Within the strips of river dunes some high, elongated dunes are situated (see Figs. 36 and 38); their tops outcrop in some places. The orientation of these high dunes is in both areas SW-NE and consequently in the Molenaarsgraaf area not the same as the direction of the whole strip. Possibly the orientation of the high dunes is related to a prevailing wind direction. This might be the same prevailing SW wind ascribed by VERBRAECK (1974, p. 3) to the formation of most river-dune outcrops ('donken') in this region (the Alblasserwaard), although generally these concern not elongated dunes but dunes with sickle and parabolic shapes (ibid.).

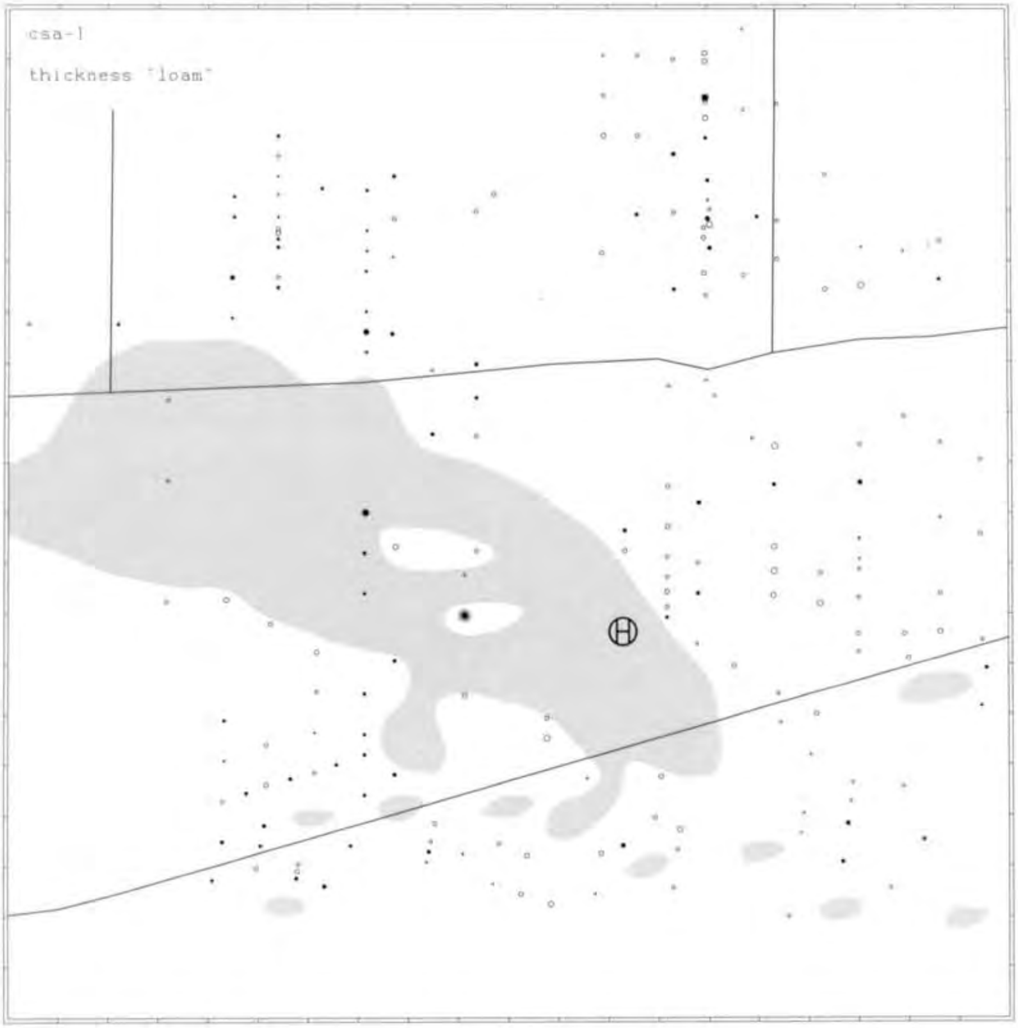


Fig. 37. Thickness of the *loam*, Molenaarsgraaf. For legend, see Fig. *35. Grey: river dunes.

Vb THE MIDDLE-ATLANTIC PERIOD (c. 7400-6100 BP) — THE FLUVIO-LAGOONAL PALEOENVIRONMENT

The period from c. 7400 to c. 6450 BP in the Molenaarsgraaf area.

In the landscape of *loam* and river dunes widespread accumulation of organic and clastic material (Westland Formation) began in the Molenaarsgraaf area around 7400 BP. This was made possible by the rise of the local water level (groundwater-surface and river level) under the influence of the Holocene sea-level rise; perhaps increased river discharge also played a role.

On the rather flat, but irregular relief of the *loam*-surface, small lakes developed about 7400 BP in which fragmented plant- and animal remains were deposited as gyttja (cf. App., Fig. a). Previously, gyttja accumulation had taken place in small depressions, but it was not until about 7400 BP that the rise of the water level had an influence over the whole *loam*-surface. At shallow places and along

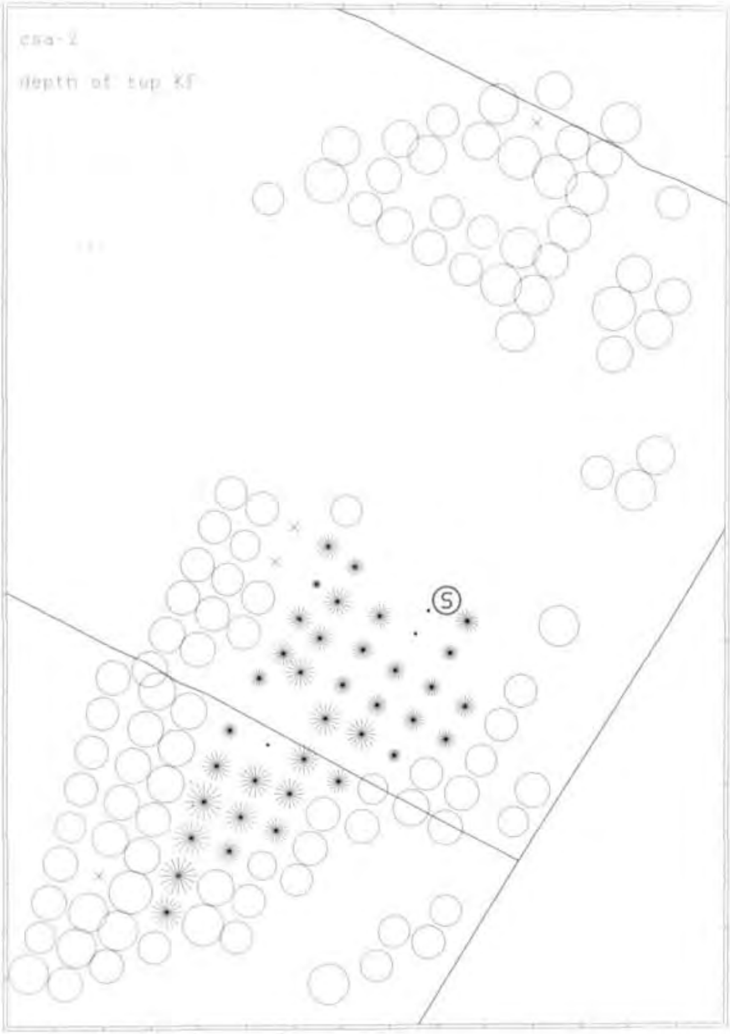


Fig. 38. Depth of the top of Kreftenheye Formation, Leerdam.
For legend, see Fig. *35.

the shores of the lakes stood *Typha angustifolia*, *Sparganium*, Cyperaceae and Cruciferae (probably *Rorippa* and/or *Nasturtium*), while in the water itself *Batrachium*, *Nymphaea* and *Nuphar* grew. *Alnus* and *Phragmites* were present on the shores of the lakes and in general on the somewhat higher parts of the *loam*-surface. On the river dunes, *Quercus* was dominant, but with *Tilia* also occurring locally there. *Corylus* would have been important as undergrowth in the *Quercus* forest, and may also have occurred along the somewhat moist edges of the dunes, together with *Ulmus* and presumably *Fraxinus*. As a consequence of some eolian activity and/or slope processes on the dunes a small quantity of dune sand became incorporated into the basal organic accumulation (see App., Fig. a). Because of the time-transgressive nature of this basal peat, the sand admixture also occurred in later periods, namely where the basal peat is situated at a higher level, especially on the river-dune slopes.

About 7300 BP the small lakes became partly infilled and were enclosed by among others *Phragmites*, ferns (probably *Thelypteris*) and *Alisma plantago-aquatica*. Locally this vegetation developed as floating mats. On the river dunes — of which not just the larger but also several scattered smaller ones still rose prominently above the marsh-surface — there was a local and temporary decrease of

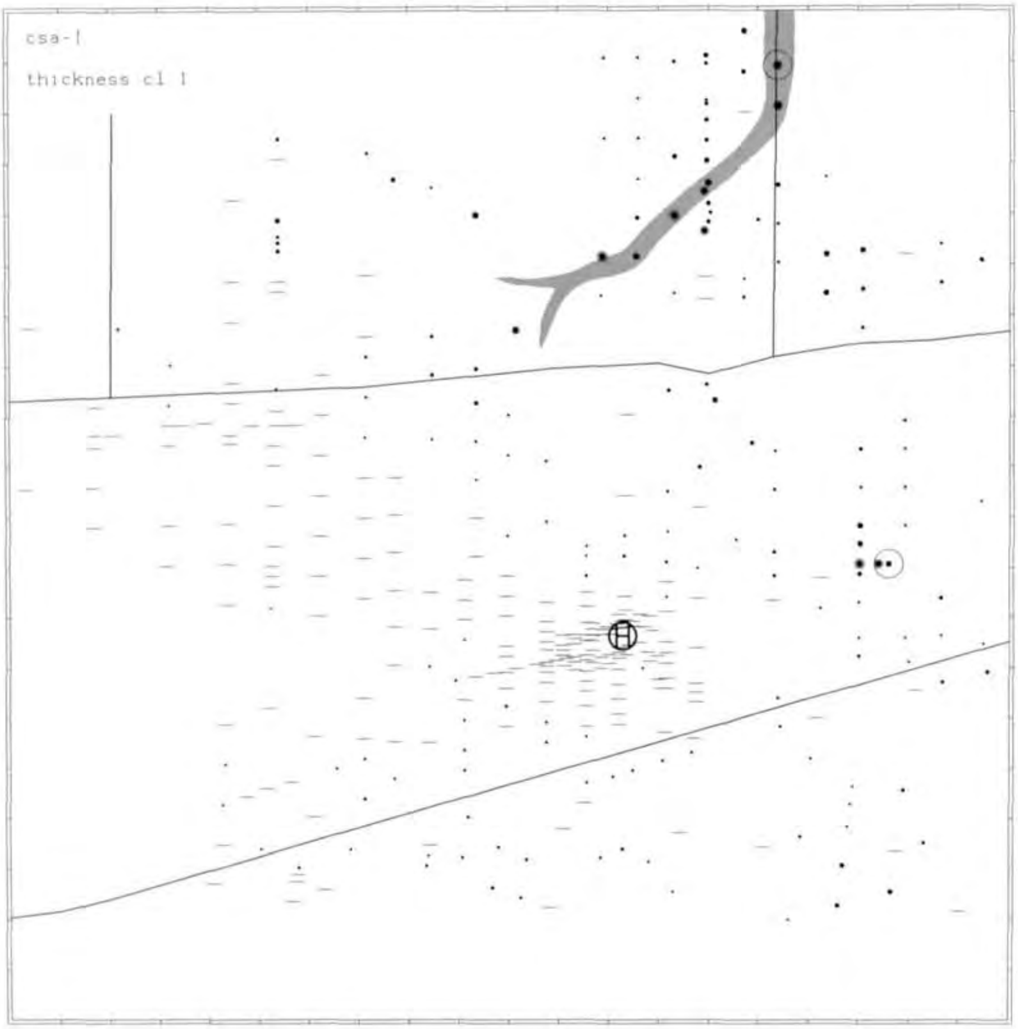


Fig. 39. Thickness of clastic bed cl 1, Molenaarsgraaf. For legend, see Fig. *35. Grey: stream ridge.

the vegetation of *Quercus* in favour of *Corylus*. The cause of this is uncertain. Prehistoric human influence on the vegetation can not be ruled out (although this would be the earliest human trace here): in the standard boring, in the peaty gyttja bed concerned, a small piece of obsidian was found (identification by drs. A. Elink Schuurman). Although it is only a very tiny fragment (longest diameter 5 mm), its sharp edges and the sedimentary matrix make natural supply and deposition unlikely.
The partial filling up of the small lakes brought to an end the first period of extensive organic accumulation in the area. Subsequently, in nearly the whole area outside the river dunes, fluvial inundation took place. In the northern part of the area, there was a small offshoot of the channel system feeding this inundation (see Figs. 39 and 40). In an environment of probably permanent open water, a thin clay bed was deposited during a relatively long period, from c. 7300 to c. 6700 BP. (The arguments for the permanently open-water nature of the depositional environment are given below in the section on the fluviatile expansion from c. 6450-6100 BP.) This water-surface was broken up in many places by stretches of *Phragmites*, *Typha*, etc., with *Salix* and *Alnus* on the some-

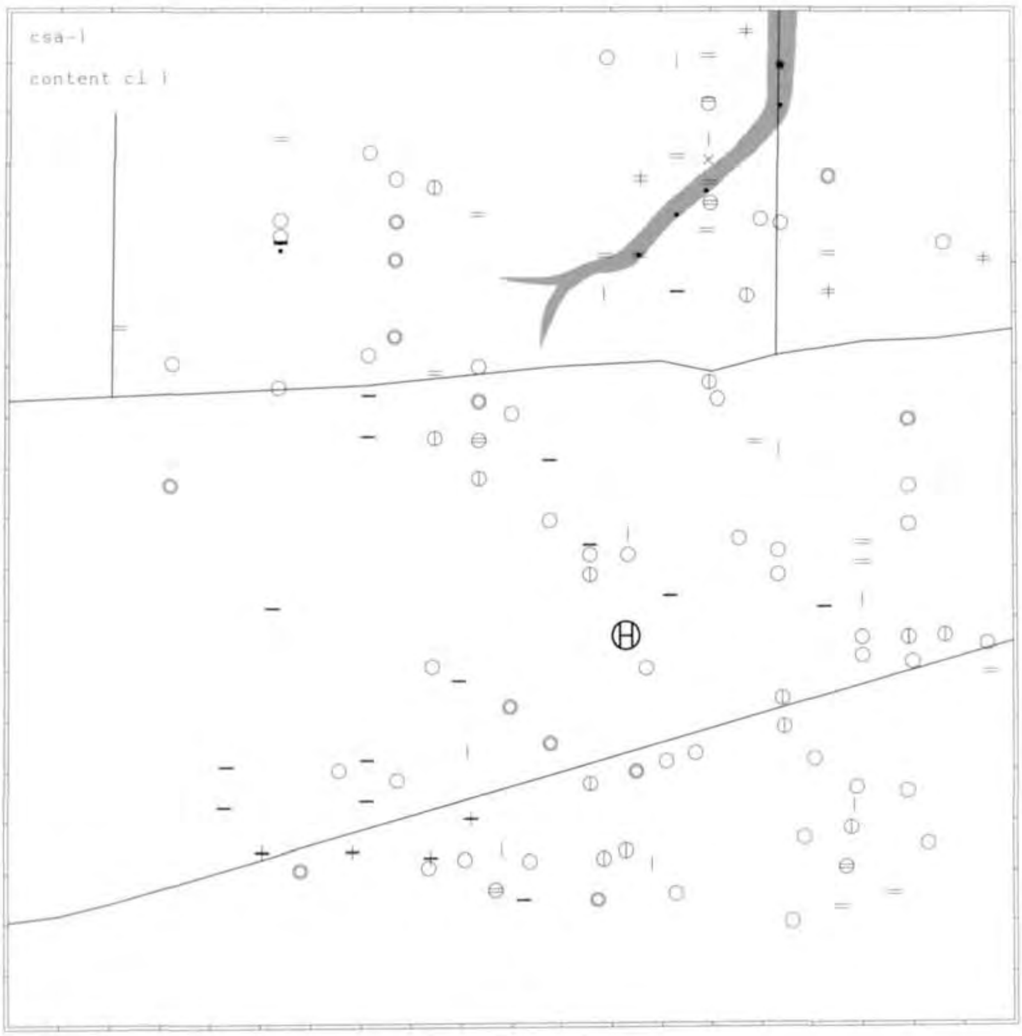


Fig. 40. Lithological content of clastic bed cl 1, Molenaarsgraaf. For legend, see Fig. *35. Grey: stream ridge.

what drier parts. The dunes were mainly colonised by *Quercus*, *Corylus*, *Ulmus* and some *Tilia*. The river dunes still widespread outcropping, formed a hindrance to an even deposition of clay in the area. This is apparent from the variable thickness of the clay bed concerned (see Fig. 39). Well before the proper end of this phase of fluviatile clastic deposition (at 6700 BP) the *Phragmites* fields had already extended into the open-water bodies and thus had initiated their infilling by plant growth.

From c. 6700 to c. 6500 BP little clastic sedimentation occurred, the larger part of the area outside the dunes being transformed to *Phragmites* marsh. Locally small lakes were present with gyttja deposition (cf. App., Fig. b). *Alisma*, Umbelliferae and *Typha angustifolia* would have grown at shallow spots and along the shores of these lakes, and also in somewhat open places in the *Phragmites* marsh. On sandy, somewhat drier localities in this marsh (the sandy filling and levees of the small channel from the previous period of clastic deposition; places where scattered small river dunes just reached the marsh-surface), *Alnus*, *Corylus* and presumably also *Ulmus* would have grown. On the river dunes possibly a local decrease of the *Quercus* vegetation occurred because of prehistoric cutting activities, *Corylus* remaining from the undergrowth of the *Quercus* forest or quickly regenerating again. The discovery of charcoal from 6900 BP at the foot of the Hazendonk river dune (see Ch. IIIi) provides an indication of Mesolithic prehistoric activity in the area. In this connection reference may also be made to the discovery of a Mesolithic wooden statuette dating from 6400 ± 85 BP near Willemstad, c. 35 km SW of Molenaarsgraaf (VAN ES & CASPARIE 1968).

About 6500 BP the marsh became open once more: the *Phragmites* fields gave way partly to an environment of shallow, quiet water with many Umbelliferae (mainly the species *Sium erectum* and S. *latifolium*), ferns, *Alisma plantago-aquatica* and *Typha* angustifolia. Clay deposition occurred from some indistinct small channels (App., Fig. c: the sandy patches in clay bed cl 2a).
The *Quercus* forest on the dunes had been partly restored; some *Betula* probably also occurred in it temporarily, which may be connected to the regeneration of the forest. At the low edges of the dunes and possibly on natural levees stood *Ulmus* and *Alnus*.
This period of clay deposition lasted only a short time and ended about 6450 BP with a partial filling up of the open-water bodies and extension of the *Phragmites* fields; in many places however some clay deposition still occurred (cf. App., Fig. d).

Fluviatile expansion from c. 6450 to c. 6100 BP (Molenaarsgraaf)

Shortly after c. 6450 BP a densely branching pattern of small river channels developed in the Molenaarsgraaf area (see Figs. 41 and 42). Some gullies in this system may have functioned previously in the short period of clay deposition at about 6500 BP.
Because of the continuing Holocene water-level rise, the dry river-dune area was gradually shrinking and by this time even had become split up: the Hazendonk river dune proper was separated from the western river dune complex. A tributary flowed through the gap between both (see Fig. 41). Here, as well as at the border of the river-dune areas in general, and at places where small isolated river dunes still occurred at shallow depth, slight fluvial erosion and redeposition of dune sand took place.
Fig.*43 is a tentative attempt, but one based on considerable evidence, to depict the scenery of the Molenaarsgraaf study area during this period of intensive fluviatile clastic sedimentation. In this pictorial reconstruction the following landscape components can be discerned:

1. The river channels.
Despite the many bifurcations, main gullies can be discerned which flowed through the whole area. Gullies ending in the basins may have originated as breaches of the natural levees; these crevasses may have served not only as inlets for water into the basins, but also at times as outlets (cf. FISK 1944, p. 28; 1947, p. 45). In the channels mainly sand was deposited. Point-bars are not traceable; in small river channels point-bars may pass imperceptibly into natural levees (REINECK & SINGH 1975, p. 244).

2. The natural levees.
Along most channels natural levees of clayey sand and sandy clay would have been formed. The many spurs of sandy clay basinward of the levees (see Fig. 42) point to the existence of crevasses. On the natural levees stood mainly *Ulmus* and *Corylus*, with *Alnus* along the wetter edges. On some very narrow, low levees along the smallest channels probably mainly *Phragmites* grew. The tree vegetation of the levees is dealt with in more detail in Ch. Vd, partly because regional data on this subject have been published for the period described there.

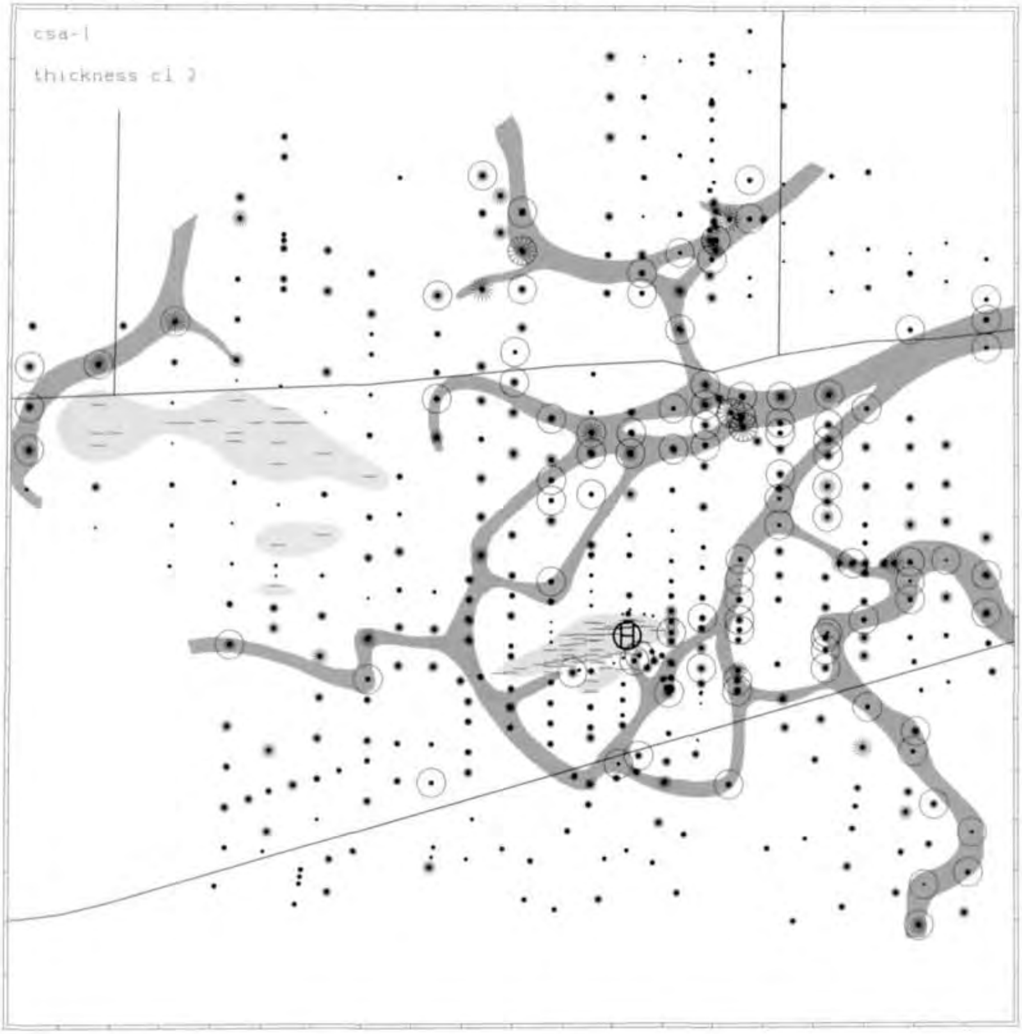


Fig. 41. Thickness of clastic bed cl 2, Molenaarsgraaf. For legend, see Fig. *35. Dark grey: stream ridges; light grey: river-dune outcrop.

3. The basins.

The physiognomy of the whole scenery was strongly fashioned by the basins, being large, permanently open-water bodies. In fact these basins (floodbasins: the lowest parts of the fluvial plain, ALLEN 1965, p. 123) occupied the whole area between the river channels and the still outcropping river dunes. Only in some places, such as at shallow spots along the western river-dune complex, small *Phragmites* fields occurred with little fluviatile deposition.

This open-water aspect of the paleoenvironment in the perimarine fluviatile coastal plain must be strongly stressed. Up till now the physiognomy of the basins has been hardly discussed in the literature; now and then the view is expressed that the basins were densely wooded (see Ch. Vd for references). Below we list our main arguments for a permanently open-water nature of the basins during the middle-Atlantic as well as the middle- and late-Subboreal fluviatile depositional phases. The special nature of the scenery during the intervening late-Atlantic/early-Subboreal depositional phase is

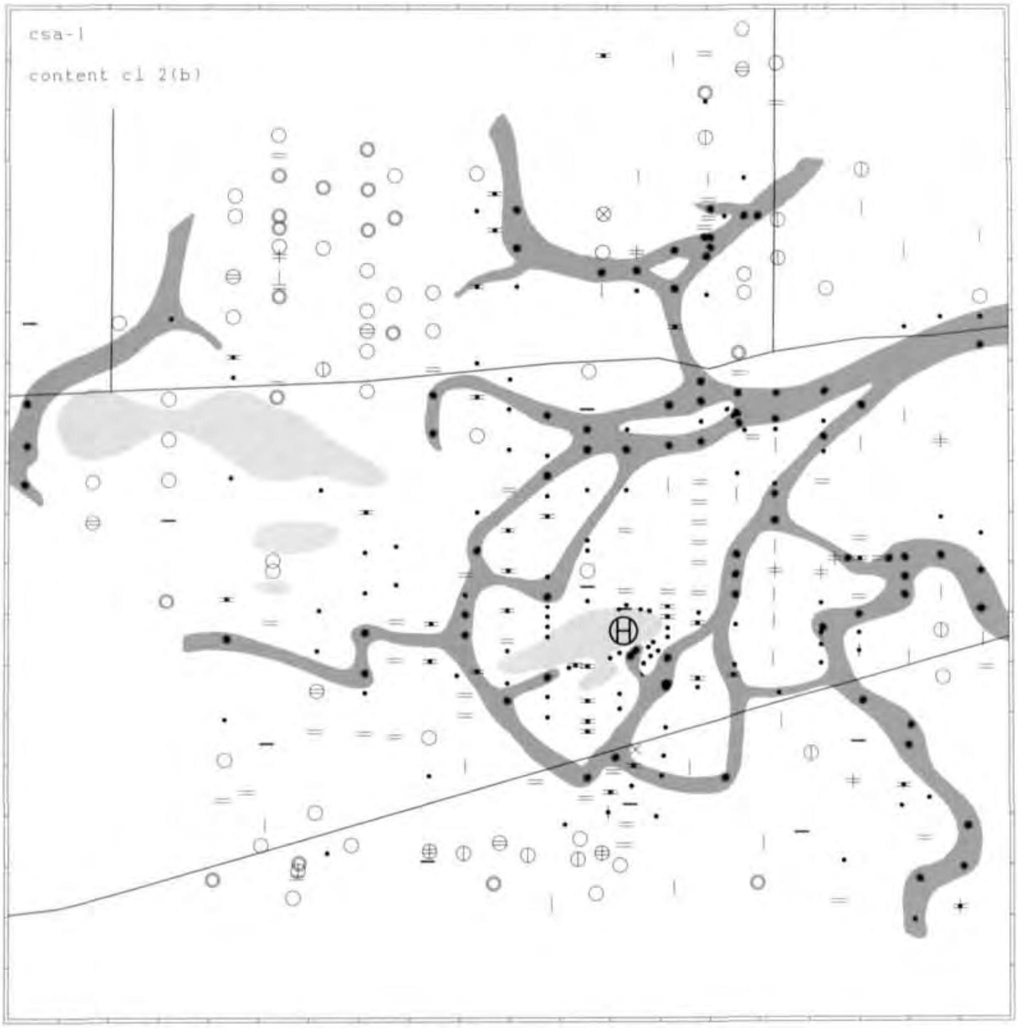


Fig. 42. Lithological content of clastic bed cl 2b, Molenaarsgraaf. For legend, see Fig. *35. Dark grey: stream ridges; light grey: river-dune outcrop.

discussed in Ch. Vc — but then as well the main aspect of the scenery was that of open-water bodies.

a. The basin clays are remarkably soft — this just results in rather easy hand boring over many meters depth. Although this softness has not been quantified by laboratory methods, it is reasonable to conclude that the basin clays were not dried out (Dutch 'ongerijpt'). An exception to this is provided by the late-Subboreal basin-clay deposit in the upstream Leerdam area; this clay is locally tougher (see Ch. Vd).

b. Exposure of the basin clays to the air would have caused not only irreversible drying out (see *a*) but also oxidation phenomena like concretions. These are virtually absent. Moreover, the perfect state of preservation of the plant material found in the basin clays also denies exposure and oxidation.

c. The basin clays are predominantly calcareous. According to PONS (1957) the river Rhine at least always transported calcareous sediment. During deposition in the perimarine fluviatile coastal plain synsedimentary decalcification of the basin clays would take place if sufficient organic acids were present, as would be the case in a densely vegetated basin environment. The fact that decalcification of the clays did not take place except in very shallow localities, and at the end of or after the depositional period (causing the upper few cm or dm to be decalcified) denies a dense vegetation in the basins.

d. Drying up of the basins (or even an important reduction of the water level) during the summer season would have lead to strong expansion of the herb vegetation during that season. However, the pollen diagrams show very low herb values in the basin clays. Absence of herb pollen due to oxidation in exposed basins is unlikely in view of the good state of preservation of most of the pollen.

Recent examples of such permanently water-logged large fluvial basins will not be found easily in the temperate climatic zones because of human interference. In the tropics they do occur, e.g. along the Magdalena river in Colombia. Comparison of the situation there — an aerial view of it much inspired the author — with the paleoenvironment discussed here will be useful, but great care is necessary in view of the differences in climate and geology.

COLEMAN (1966) classified fluviatile paleoenvironments in the Atchafalaya basin, situated in the deltaic plain of the Mississippi river. The permanently water-logged basins discussed here perhaps correspond most closely with the 'poorly drained swamp' and the 'freshwater lacustrine' environments distinguished there. Sediments of the former show however clear oxidation phenomena, whereas the latter might relate more to the 'fluvio-lacustrine' paleoenvironment discussed in Ch. Vc.

The water depth in the basins and the thickness of the clay deposit depended among others on the compaction of the subsoil (sand, clay or peat). Also the distance to the channels influenced the thickness of clay deposition: the basin clay deposits are thicker and sandier near the natural levees.

In the neighbourhood of the channels a rhythmic bedding with humic laminae some mm thick was often found in the basin clays. These laminae locally contain tiny fragments of wood, leaves and snail-shells; according to FISK (1947, p. 57) the latter two are often encountered in floodbasin deposits. The laminae possibly indicate seasonal fluctuations in sedimentation.

The vegetation in the basins — so far as visible above the water level — was restricted mainly to the edges of the natural levees (see Fig.*43). *Phragmites* and other hygrophilous grasses (e.g. possibly *Glyceria*), Umbelliferae (*Sium*, *Oenanthe*), *Alisma*, etc. grew there; in this marsh-herb vegetation probably also *Salix* occurred locally. At shallow points in the basins farther away from the natural levees, a similar vegetation occurred locally, although it consisted mainly of *Oenanthe* and *Alisma*. Consequently, the clay deposited at these shallow spots is more humic (cf. Figs. 41 and 42). In some parts of the larger basins, as in the NW and SW corners of the study area, clay deposition was accompanied by organic accumulation (deposition of clayey gyttja, see Fig. 42).

At only a few places in the basins, *Alnus* swamp forest would have occurred, namely on small offshoots from natural levees (filled up crevasses?), and along the river dunes, where these occurred at shallow depths in the subsoil of the basins, as was the case especially along the western dune area.

4. The river dunes.

The still emerging river dunes would have been visible in the landscape especially because of the tall vegetation mainly of *Quercus*. Locally *Tilia* also occurred in the oak forest, and especially along its wetter flanks *Ulmus* and *Corylus* would also have grown; the latter would also have occurred as undergrowth and in open localities.

Viewing the whole landscape (Fig.*43), the entire area outside the river dunes may be regarded as one large basin intersected by narrow channels with their levees. Looked at in this way, and in view of the permanently open-water nature of the basins, the physiognomy of the scenery may be com-

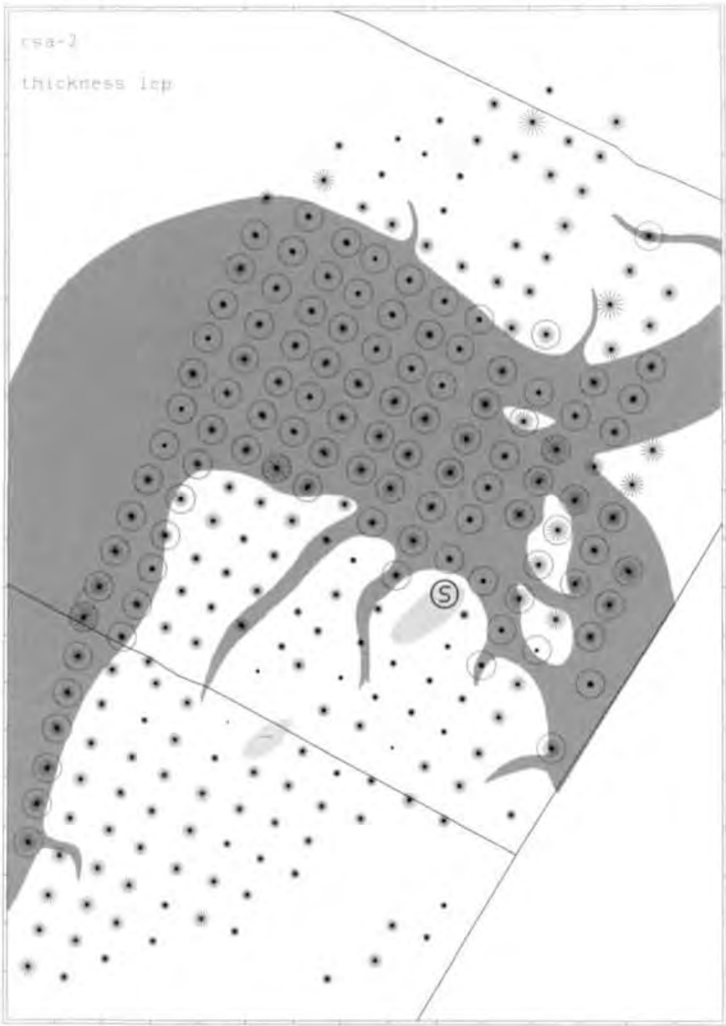


Fig. 44. Thickness of clastic bed lcp, Leerdam. For legend, see Fig. *35. Dark grey: stream ridge; light grey: river-dune outcrop.

pared to that of a lagoon. For this reason we propose to use the term **fluvio-lagoonal** for the paleoenvironment discussed here. It is not certain whether this fluvio-lagoonal region passed seaward into the lagoon proper — if any — of the marine section of the coastal plain. In that case the fluvio-lagoonal region might be regarded as the landward part of the lagoon, and the term would be more or less synonymous to HAGEMAN's (1963) 'para-lagoonal'.

Comparison with the Leerdam study area

In the middle-Atlantic period extensive fluviatile clastic deposition also took place in the Leerdam study area 20 km upstream. Here the alternation with phases of mainly organic accumulation was less pronounced in this period than at Molenaarsgraaf. In the Leerdam area there was no question, as at Molenaarsgraaf, of the formation of new channel patterns in the subsequent subphases of renewed clastic sedimentation. Instead deposition probably occurred repetitively from the same river. This is the so-called Middelkoop stream (see Ch. IIb.3), which was much broader than the contemporaneous channels at Molenaarsgraaf and formed the most important aspect of the paleoenvironment of the Leerdam area at that time (cf. Figs. 44 and 45). The river flowed in a meander

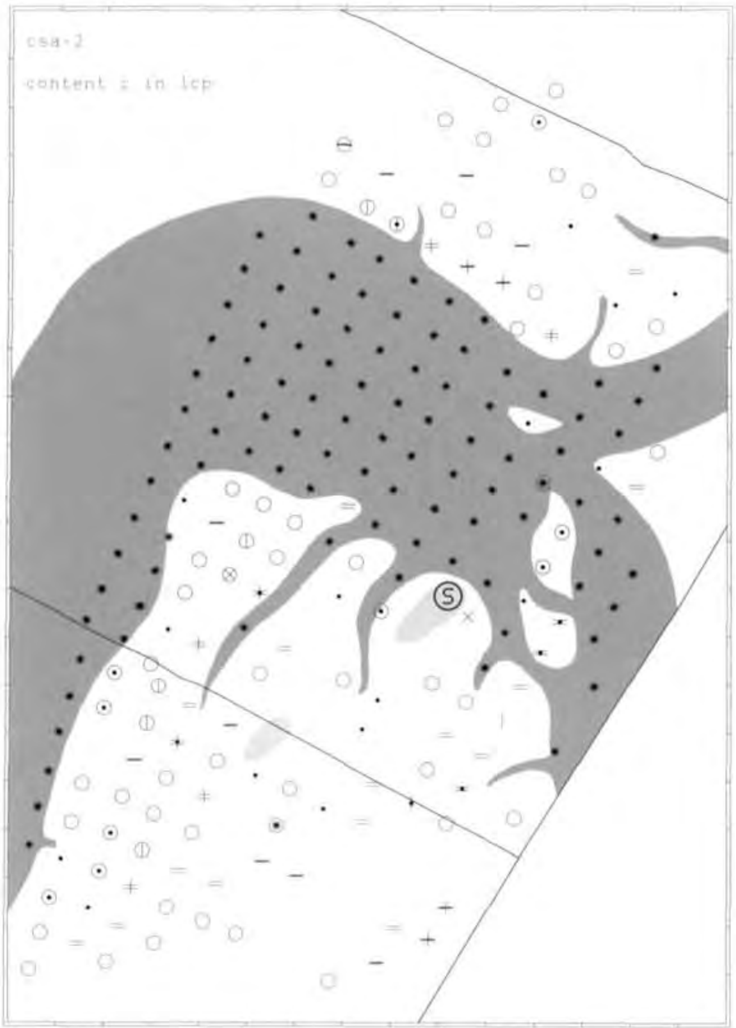


Fig. 45. Lithological content of clastic bed lcp, Leerdam. For legend, see Fig. *35. Dark grey: stream ridge; light grey: river-dune outcrop.

around the northern end of the river dune and partly eroded it. Moreover migration of the meander in a northerly direction presumably occurred, making the stretch of sandy channel deposits (the stream ridge) broader there, and higher along the northern edge (cf. App., Fig. e).

On the natural levees of this stream *Ulmus*, *Quercus* and *Corylus* occurred, with mainly *Alnus* and *Salix* at the transition to the basins. Crevasse channels would have formed many gaps in the levees. During phases of increased clastic deposition, large open-water bodies characterised the basins; non- or weakly sandy clay was deposited there. As at Molenaarsgraaf, locally at shallow points in the basins a marsh-herb vegetation occurred, consisting of *Phragmites*, ferns, Cyperaceae, *Alisma*, *Typha angustifolia*, *T. latifolia*, etc. During phases of decreased clastic deposition, this vegetation expanded over large parts of the basins; at these times more *Sparganium* and Cruciferae (presumably *Rorippa* and/or *Nasturtium*) also grew there.

The elongate river dune in the Leerdam study area became increasingly submerged because of the Holocene water-level rise, and it split up into two parts, just like the river-dune complex at Molenaarsgraaf. The vegetation of the dunes would have been similar to that at Molenaarsgraaf.

The paleoenvironment of the Leerdam study area during the middle-Atlantic may also be outlined as fluvio-lagoonal, as at Molenaarsgraaf. There are however important differences with regard to the latter, downstream study area. The many small channels at Molenaarsgraaf (see e.g. Fig.*43) were probably the downstream branches of the broad Middelkoop stream at Leerdam (cf. Ch. IIb.3). At Molenaarsgraaf the subphases of decreased fluviatile activity and expansion of the marsh-herb vegetation (there mainly consisting of *Phragmites*) are much more distinct than at Leerdam. The more continuous clastic sedimentation at Leerdam may have been due to the nearness of the broad, persistent Middelkoop stream.

Vc THE LATE-ATLANTIC/EARLY-SUBBOREAL PERIOD (c. 6100-4100 BP) — THE FLUVIO-LACUSTRINE PALEOENVIRONMENT AMIDST THE SWAMP FORESTS

The important change in the landscape at c. 6100 BP

At about 6100 BP an important change took place in the paleoenvironment of both study areas. The fluvio-lagoonal environment of the preceding period gave way to an environment of extensive swamp forests with numerous lakes. These lakes expanded gradually but ultimately (about 4700 BP) filled up and gave way to renewed expansion of the swamp forests. In the period described here (comprising c. 2000 years) deposition of clastic and organic material always occurred in very quiet conditions. The local persistence of swamp forest during this period might be related to the slowing down of the Holocene water-level rise. It is also the period in which the most important prehistoric occupation phases on the Hazendonk river dune took place.

Already some time before 6100 BP the filling up of the fluvio-lagoonal area was announced by sand-free clay deposition in the basins as well as the channels. At Molenaarsgraaf this still took place in an environment of open water, but at Leerdam by the time of this clay deposition a marsh-herb vegetation consisting of Cyperaceae, *Alisma*, ferns and *Typha latifolia* had expanded. The end of the fluviatile sedimentation, at about 6100 BP, was followed by extensive *Phragmites* growth at Molenaarsgraaf and by the development of *Salix* bushes at Leerdam. In both areas *Alnus* growth started too. In the Molenaarsgraaf area lakes locally persisted in those parts of the basins where already in the preceding period mainly organic accumulation occurred. Along the shores of these lakes *Urtica dioeca*, *Solanum dulcamara* and *Filipendula ulmaria* probably grew on the nutritious subsoil of wasted plant material drifted ashore. At shallow spots in these lakes and also at open places in the *Phragmites* marsh Umbelliferae and *Typha angustifolia* grew. Locally, *Salix* and *Alnus* would have occurred at drier sites in the *Phragmites* marsh. More closed *Alnus* swamp forests developed along the stream ridges left from the preceding depositional period, and along the borders of the river dunes. On the higher parts of the stream ridges *Quercus*, *Ulmus* and *Corylus* would have occurred. On the river dunes the *Quercus* forest was maintained, including *Ulmus* and *Corylus*.

The change from an environment with a lot of open water (existing in the preceding period) to a marsh of *Phragmites* and *Alnus* probably took place during a temporary fall of the local water level. The increase in plant decomposition resulting from this may have favoured the growth of *Urtica*.

At about 6000 BP this presumed water-level fall may have lead to local, temporary decline of *Alnus* stands along the borders of the stream ridges and the river dunes. At the same time the *Phragmites* fields in the lower parts of the area expanded maximally. Their evapotranspiration may have contributed to the compaction of the underlying sediment and so to the inversion of relief, that had already caused the stream ridges to emerge above the marsh surface.

Although subsequent to c. 6000 BP the *Phragmites* fields did not entirely disappear, *Alnus* swamp forest expanded over a large part of the area. In the *Phragmites* fields remaining more ferns and Cyperaceae than before probably occurred.

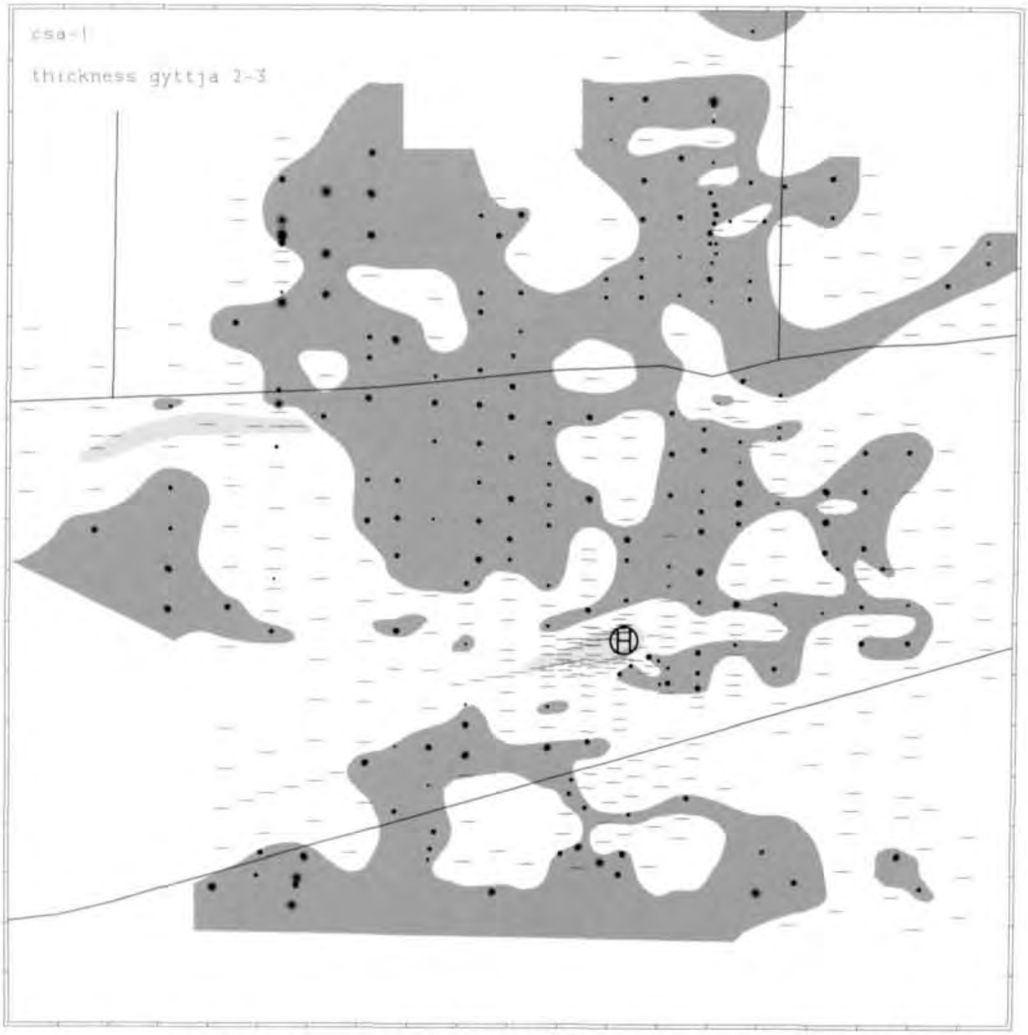


Fig. 46. Thickness of gyttja bed in organic bed ol 2-3, Molenaarsgraaf. For legend, see Fig. *35. Dark grey: extension of gyttja; light grey: river-dune outcrop.

The expansion of the lakes at Molenaarsgraaf

Some centuries after 6000 BP the lakes already in existence started to expand gradually and at several places new ones were formed by an increased rise of the local water level. The lakes expanded at the cost of the *Phragmites* fields as well as the *Alnus* swamp forests. Nevertheless, the latter two still made up the larger part of the area. (cf. App., Fig. f).

The fact that wood-peat accumulation occurred points to water-level rise (cf. OVERBECK 1975, p. 96). The acceleration of this rise in connection with the lake expansion already mentioned may relate to increased compaction of the clay- and peat-subsoil. Such a relationship is also mentioned in connection with the origin and expansion of lakes in the swampy fluviatile coastal plains of Louisiana, USA (FRAZIER & OSANIK 1969, p. 68 f.; COLEMAN 1966, p. 166). In a treatise on the ecology of the Carboniferous coal deposits in Northern Britain, SCOTT (1979, p. 104, 106) likewise ascribes the formation of small lakes in a river-plain swamp to local compaction of the underlying peat.

It might be expected that the expansion of the lakes would also take place by means of wave action.

However, no indication of this has been found in the lake sediment.
The greatest expansion of the lakes took place from c. 5600 BP. Presumably this was caused by an increasing eustatic component in the local water-level rise. In connection with this, the higher parts of the stream ridges would have become too wet to sustain the *Quercus* stands; *Ulmus* and *Corylus* would have remained there.
In the lakes, organic material accumulated in greatly varying thicknesses (see Fig. 46). At most places this gyttja also contains clay; this would have been deposited from forerunners of channels that developed mainly after c. 5300 BP (albeit in a way quite different from those in the preceding middle-Atlantic period; see below).

The landscape reconstruction for c. 5300 BP (Fig.*47) relates to the period in which the lakes had already expanded considerably but were not yet involved in fluviatile clastic deposition; channels were absent. The original river-dune topography (cf. Fig. 36) still exerted an influence on landscape evolution such that the lakes could not yet expand over this dune-surface, even where it had previously disappeared below the marsh-surface. Thus, the area between the Hazendonk and the western dune complex was covered mainly by *Alnus* swamp forest.
At many other places the swamp forest maintained itself beside the expanding lakes. Moreover, on the highest parts of the stream ridges dating from the middle-Atlantic period, *Ulmus* and *Corylus* would still have been growing. Both these tree species would also have occurred on the (flanks of the) river dunes that otherwise still supported an oak forest. This *Quercus* vegetation of the dunes has been presented in Fig.*47 as a closed forest. Probably however there were cleared sites in this forest, since the time to which this reconstruction refers is also the time of the prehistoric Hazendonk-1 culture (see Ch. IVb.2). The position of the lakes (reconstructed on the basis of Fig. 46) is such that these Hazendonk-1 people could have taken the water from the southeastern edge of the Hazendonk river dune, to go from there in many directions over the interconnected lakes. Thus they could have gone to the western river dune, bordered at its NE face by a large lake. Just there a Hazendonk-1 occupation influence may be presumed, as witness charcoal discoveries (in boring cores) at the corresponding stratigraphical position.
The discovery of this western river-dune complex and its charcoal (STEENBEEK 1979) signify a partial denial of the exclusiveness of the Hazendonk river dune as 'the only dry place of the peat landscape within many kilometers' (LOUWE KOOIJMANS 1976a, p. 153). Precisely this exclusiveness has been used to explain the high concentrations of Neolithic material on the Hazendonk. Nevertheless, the total surface of habitable terrain was undoubtedly still very small in the study area, as stated by LOUWE KOOIJMANS (1976c, p. 233) in connection with the very modest grain culture on the Hazendonk.
At many spots along the shores of the lakes, at the transition to the swamp forest, a bordering vegetation of *Phragmites*, *Scirpus* (*lacustris*), Umbelliferae, *Sparganium* and *Typha angustifolia* occurred. Some *Salix* would have bordered the *Alnus* swamp forest proper. At shallow places in the lakes several of the before-mentioned shore plants were growing too, albeit less densely. In the lakes *Nymphaea*, *Nuphar* and *Batrachium* grew.

Comparison with the Leerdam study area

After c. 6000 BP *Alnus* swamp forest spread over the Leerdam area too. A subsequent relative rise of the local water level was not expressed here in the formation of lakes with organic accumulation, but only in an increase of *Salix*. Otherwise, here too, the swamp forest was never entirely closed. At the more open places in this forest (especially in the western part of the area) Umbelliferae and Cyperaceae were growing and some clay deposition took place (cf. App., Fig. g).
The middle-Atlantic Middelkoop stream had been filled up with sand and sandy clay to a considerable altitude and now emerged as a stream ridge above the swamp. The presumed water-level fall around 6100 BP can be assumed to have partly caused this emergence. On this broad stream ridge

stood an oak forest, probably especially including *Corylus*, *Ulmus* and *Fraxinus* at the moist flanks. A similar vegetation would have grown on the river dunes, but their surface was negligible with respect to that of the stream ridge (see e.g. Fig. 45).
The existence of wetter conditions at Molenaarsgraaf compared to Leerdam (resulting in the formation of lakes in the former area, see above) was connected with a larger compaction of the subsoil on the one hand; the underlying clay- and peat beds reach a larger thickness at Molenaarsgraaf than at Leerdam. On the other hand, the so-called gradient effect will have played a role too: the eustatic rise of the local water level was stronger downstream than upstream. The slower rise of the local water level was expressed in the Leerdam area not only in the absence of lakes but also in the stronger humification of the peat bed formed (see App., Figs. f and g).

The lacustrine paleoenvironment described for the Molenaarsgraaf area, would have occurred simultaneously in other parts of the Western Netherlands coastal plain as well. Mention should be made especially of the IJsselmeer area: the oldest precursors of this lake, apparent from extensive gyttja occurrences (WIGGERS' (1955) 'old detritus gyttja'; ENTE 1971), probably also date from the late-Atlantic.

Increasing clastic deposition

Without bringing about important changes in the landscape, clay deposition increased after c. 5300 BP in both areas. This date is not sharp and has been derived mainly from interpolated other dates and from correlation with the Hazendonk-1 culture level (see Ch. IV). In the Leerdam area the increasing clay deposition occurred mainly in the South; there a basin with probably permanent open water developed. The same applies to a very narrow stretch in the northern part of the area. At the transition from these basins to the swamp forest of *Alnus* and *Salix* a shore vegetation existed, comprising among others *Typha angustifolia*, *Phragmites* (and other grasses), *Solanum dulcamara* and Iris. Presumably after some centuries the swamp forest had expanded over these shallow basins and gradually also over the Middelkoop stream ridge. This broad, high ridge became fully covered by swamp forest only at c. 4800 BP. Until that time the ridge carried a rather dry forest (mainly oak, see above). It may have been of importance for prehistoric occupation of the region, namely during one or more of the Hazendonk cultures.
In the Molenaarsgraaf area the lacustrine environment did not essentially change at the increase of clay deposition after c. 5300 BP. The lakes gradually expanded still further at the cost of the swamp forests. Because of the continuing rise of the water level and the related peat accumulation in the swamp forests, the highest parts of the stream ridges dating from the middle-Atlantic period also became submerged and consequently could no longer sustain *Ulmus* and *Corylus*.
The resultant landscape of the Molenaarsgraaf study area has been reconstructed in the drawing in Fig.*50. The time, 4800 BP, has been chosen as a moment during this period in which the lakes had their maximal extension. Presumably the situation shown in the drawing applies to a rather long period, perhaps from c. 5000 to c. 4700 BP.
In this lake area some vague stretches can be discerned where thicker and sandier clay deposition occurred than outside (cf. Figs. 48 and 49). These stretches may be regarded as subaquatic channels; natural levees — if any — would have remained submerged and would have been visible only very locally by a sparse herb vegetation. On the bottom of the lakes clay was deposited, mixed with much organic material (cf. Fig. 49) and consequently non-calcareous in many places. In the channel stretches alternate deposition of clayey and sandy material occurred; the sandy material contains coarser organic remains too (wood- and leaf fragments). This alternate bedding points to periodically somewhat increased stream velocities. The local occurrence of humic laminae in the non-sandy clay also points to this (cf. Fig. 49; see also Ch. Vb). In general however, the environment was as quiet as at c. 5300 BP (see Fig.*47), with a rich vegetation locally at the water-surface and along the shores. Because of the larger size of the lakes and the occurrence of channel stretches, the area

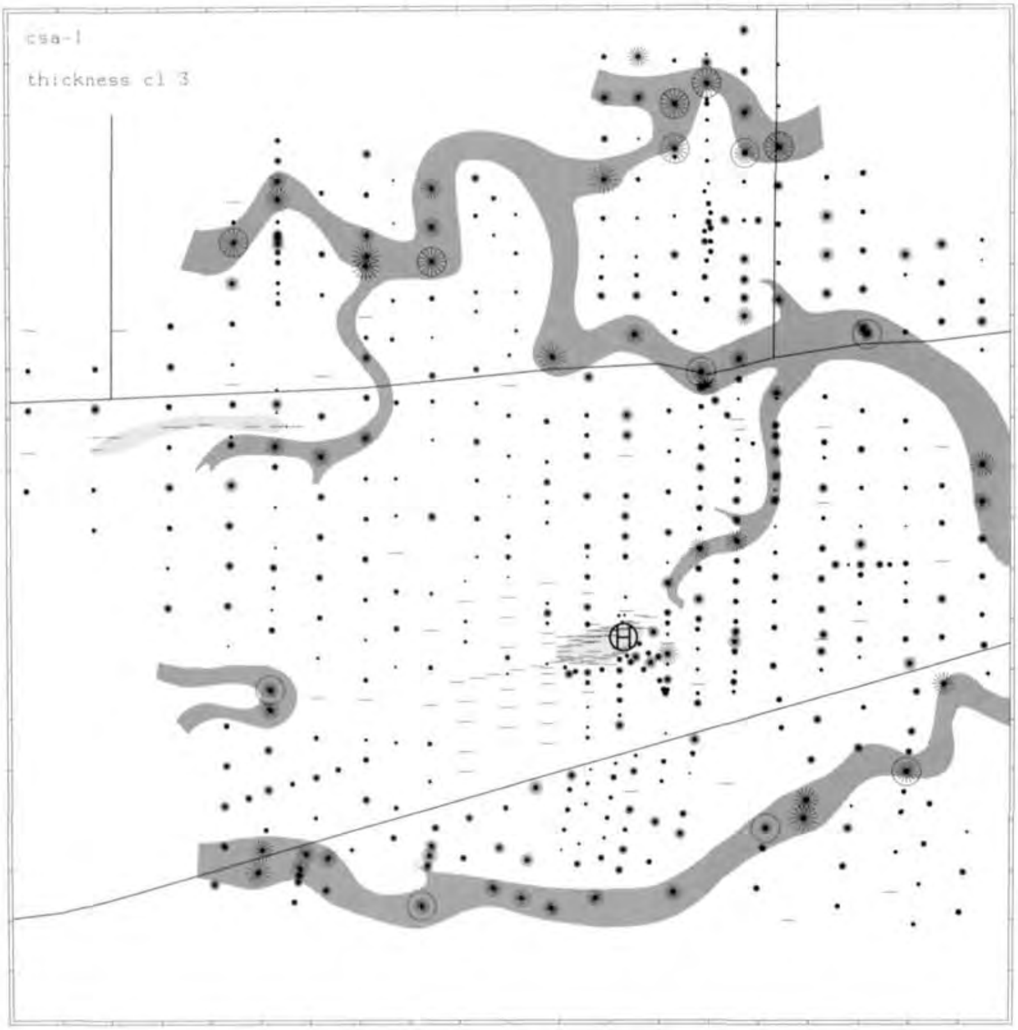


Fig. 48. Thickness of clastic bed cl 3, Molenaarsgraaf. For legend, see Fig. *35. Dark grey: sandy channel deposits; light grey: river-dune outcrop.

must have been somewhat more accessible for prehistoric inhabitants of the region during this later phase (c. 4800 BP; this coincides with the time of the important Hazendonk-3 culture, see Ch. IVb.2) than during the earlier phase around 5300 BP.

The lake environment described here may be called **fluvio-lacustrine.** The term has been taken from DALEY (1973), from his description of Oligocene cyclothems. The term is used there mainly to indicate the transition from a fluviatile to a lacustrine environment. The depositional environment midway through such a cyclothem probably corresponds well with the paleoenvironment described here for the Molenaarsgraaf area: lakes through which small rivers were streaming, with a 'periodic incorporation of the shallow lakes into the flowing water of the river system' (op. cit., p. 239). The sedimentological situation resembles that of the 'lacustrine delta fill', distinguished by COLEMAN (1966; see also Ch. Vb) for the case of a river diverting itself and streaming into a lake.
The term fluvio-lacustrine is used also by GEYS (1978, p. 41) in a description of the depositional

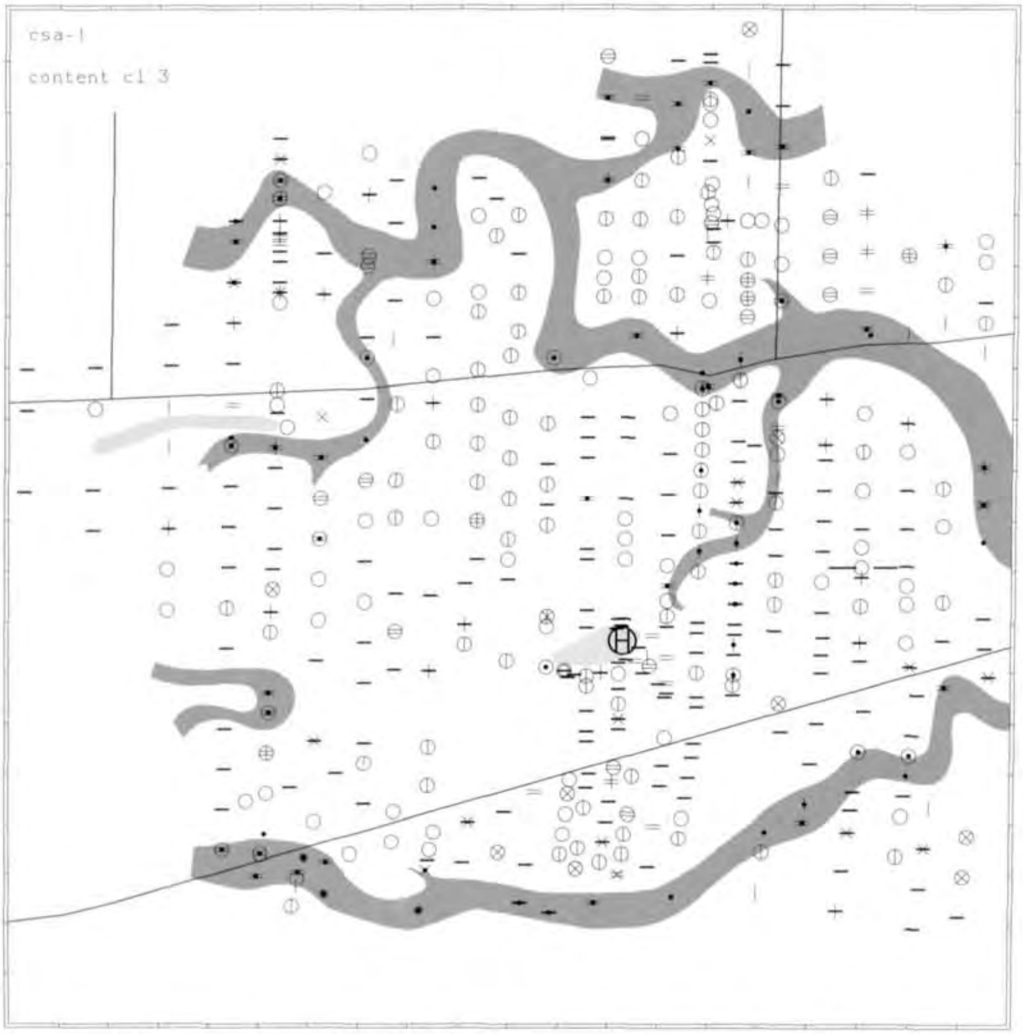


Fig. 49. Lithological content of clastic bed cl 3, Molenaarsgraaf. For legend, see Fig. *35. Dark grey: sandy channel deposits; light grey: river-dune outcrop.

environment of early-Quaternary clay beds in Northern Belgium. However, this probably concerns an environment corresponding more with the fluvio-lagoonal paleoenvironment described in Ch. Vb for the middle-Atlantic period, than with the lake landscape described here. We would reserve the term fluvio-lacustrine for an environment like the latter. The difference between the paleoenvironments (cf. Figs. *43 and *50) is mainly apparent from the weaker relationship between water bodies and river channels in the fluvio-lacustrine environment, and is expressed in the much greater admixture of organic material in the deposition of clastic material there. However, a sharp separation between both terms will not always be possible; at some places in the middle-Atlantic fluvio-lagoonal area at Molenaarsgraaf, lacustrine gyttja deposition also occurred (see Ch. Vb).

The landscape outlined in Fig. *50 besides being characterised by the fluvio-lacustrine environment, is typified by the *Alnus* swamp forests. At their edges besides *Phragmites* etc. presumably locally some *Salix* also grew. Occasionally some clay was deposited in the swamp forests (cf. Figs. 48 and 49). At some higher sites in these swamp forests, e.g. where dunes and stream ridges occurred in the subsoil, *Fraxinus* and *Corylus* may also have grown. On the river dunes the oak forest described before was maintained. There must have been clearings, made by cutting activities of the prehistoric Hazendonk-3 culture. Both river dunes locally bordered open water.

The period from c. 4600 to c. 4100 BP

About 4600 BP, possibly somewhat earlier, the water depth decreased in the fluvio-lacustrine environment at Molenaarsgraaf, and at many places the shore vegetation expanded. At first this involved Umbelliferae and Cyperaceae in particular, but at lower water depths *Sparganium* and *Phragmites*, and probably other grasses, like *Glyceria fluitans* (cf. Ch. IIIc.5, zone 15). Fruits of the latter, which were sought for food in historical times (ROSE 1974, p. 23), might have served as a grain crop for prehistoric inhabitants belonging to one of the early Vlaardingen cultures. A considerable cutting activity in the oak forests on the river dunes is deduced from the pollen record (see Ch. IIIc.5) for this time.

Ultimately the marsh-herb vegetation spread over the former lakes entirely, and subsequently the swamp forest expanded over practically the whole area outside the river-dune outcrops. In the undergrowth of this swamp forest ferns initially formed an important component.

Around this time (4500-4600 BP) the prolonged existence of the swamp forest covering the Leerdam study area came to an end. Two small river branches started flowing through the area towards the West, the Schoonrewoerd stream in the North and the Schaik stream in the South. From these rivers clay was deposited in an environment of shallow water with a probably dense herb vegetation at this time (deduced from the lithological content of the clay bed concerned, bed uc a). Around 4300 BP this vegetation became denser (in several places a *Phragmites* marsh developed) and at most places clay deposition temporarily almost stopped. A relative fall of the local water level may be presumed.

At this time (c. 4300 BP) prehistoric occupation occurred on the Schaikse donk river dune. This can be concluded from the numerous charcoal finds (in the borings) at the stratigraphical level of the C-14 dates around 4300 BP (see Ch. IVb.1). One or more of the Vlaardingen culture phases is probably involved here (cf. LOUWE KOOIJMANS 1974, fig. 18, discovery point 92). At about the same time blackening of the clay-surface occurred in the basin bordering the river dune (see Ch. IIb.2). This black colour might be ascribed to prehistoric burning activities; such is suggested by HAVINGA (1969, p. 38) to explain the dark colour of vegetation horizons in certain parts of the upstream, central-Netherlands river-clay area.

In the Molenaarsgraaf area, the *Alnus* swamp forest, that had spread over the whole area outside the river dunes around 4600 BP, was maintained at most places. Locally however openings originated, where, in shallow water, Umbelliferae, *Alisma*, Cruciferae (presumably *Rorippa*/ *Nasturtium*), *Lythrum*, *Rumex hydrolapathum* and grasses were growing, with perhaps some *Salix* here and there too. A similar herbaceous vegetation occurred in this period in the basin bordering the type locality of the Vlaardingen culture (VAN REGTEREN ALTENA et al. 1963, p. 53 and 106).

The fact that the swamp forest at Molenaarsgraaf became locally more open, probably corresponds with the fluviatile activity described above for the Leerdam area. Presumably some forerunners of the Schoonrewoerd stream (active here after 4100 BP) were formed in the still densely forested Molenaarsgraaf area. Some clay may have been deposited too at the open places in the swamp forest. Parts of any channels remaining from the foregoing depositional phase may have functioned as such forerunners of the Schoonrewoerd stream (DE FRETES 1979; compare Fig. 48 with Fig. 51; see also Fig. 3 for the position of the Schoonrewoerd stream ridge).

Nevertheless, up to c. 4100 BP the Molenaarsgraaf area was still mainly covered by swamp forest (cf. App., Fig. j). On the emerging parts of the river dunes an important part of the oak forest seems to have been cut once more by inhabitants belonging to the Vlaardingen culture (this time

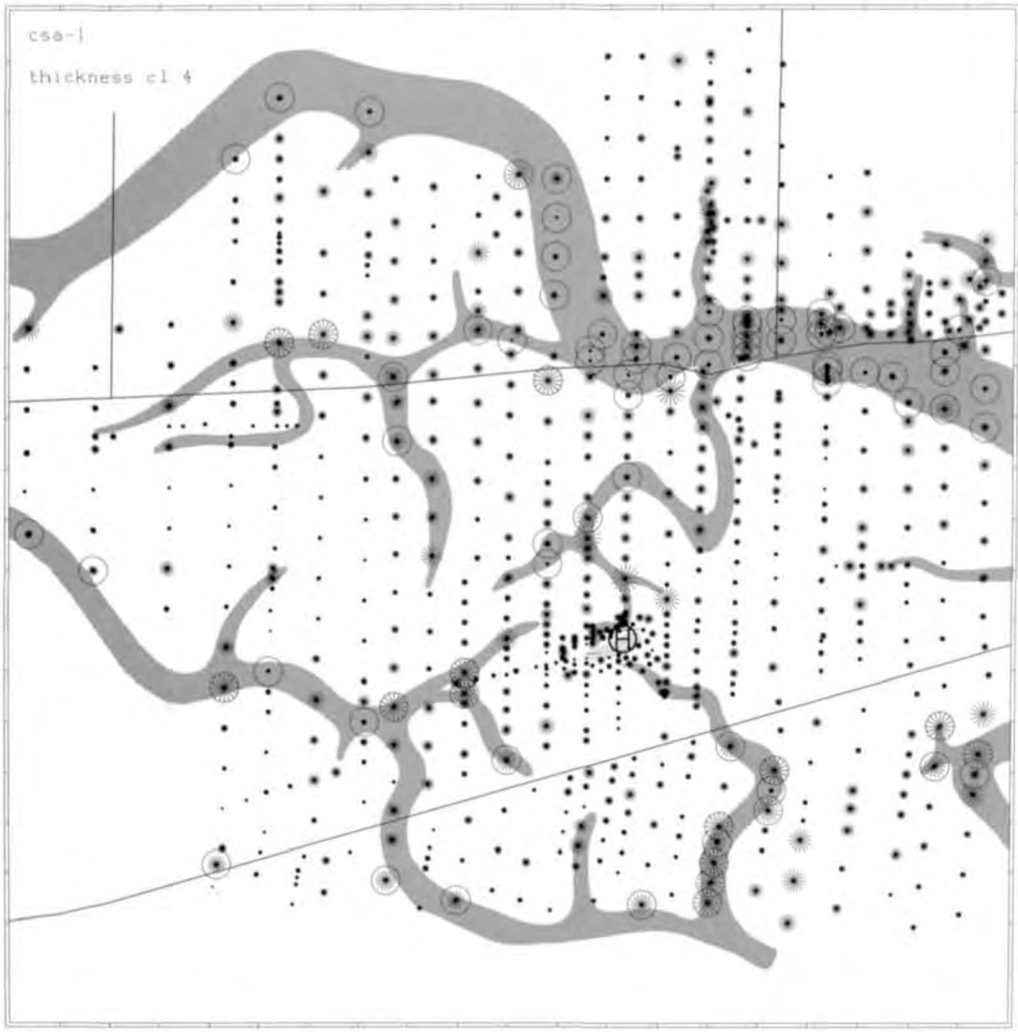


Fig. 51. Thickness of clastic bed cl 4, Molenaarsgraaf. For legend, see Fig. *35. Dark grey: stream ridges; light grey: river-dune outcrop.

apparently Late Vlaardingen). After the cutting of oak, *Corylus* apparently remained from the undergrowth of the forest and/or, as at Voorschoten (GROENMAN-VAN WAATERINGE et al. 1968, p. 108; also in relation to the Vlaardingen culture), functioned in the regeneration of the forest.

Vd THE PERIOD AFTER THE EARLY-SUBBOREAL (after c. 4100 BP) — THE RETURN TO FLUVIO-LAGOONAL CONDITIONS AND THE SUBSEQUENT COMPLETE COVERING BY SWAMP FOREST

Intensive fluviatile deposition

About 4100 BP the environment changed considerably in both study areas. In the preceding period (from c. 6100 BP) large parts of both areas had been covered by swamp forest and *Phragmites* marsh (in degrees varying with time). Moreover the fluviatile depositional activity was rather lim-

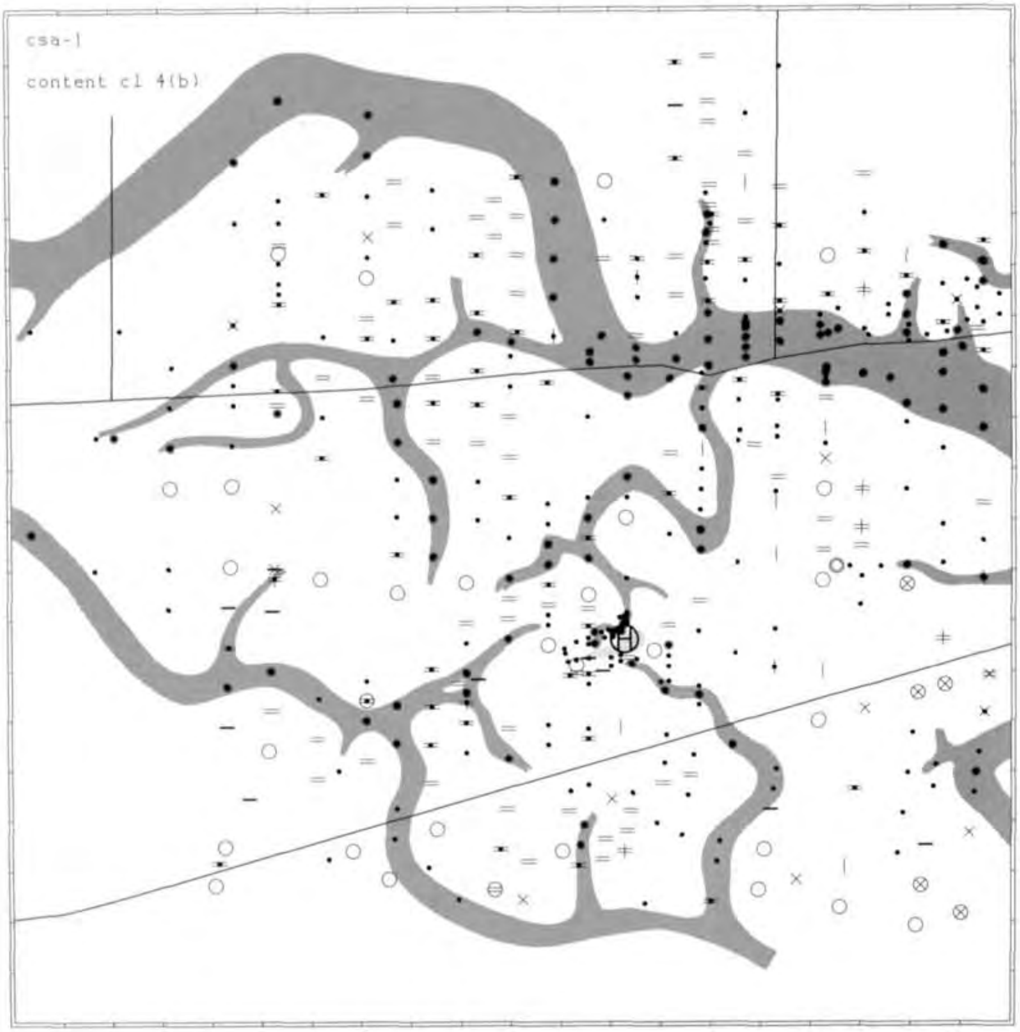


Fig. 52. Lithological content of clastic bed cl 4, Molenaarsgraaf. For legend, see Fig. *35. Dark grey: stream ridges; light grey: river-dune outcrop.

ited. At c. 4100 BP the latter strongly increased again. A landscape came into being that showed a strong resemblance to the fluvio-lagoonal environment described for the middle-Atlantic period (Ch. Vb): a branching river pattern with wooded natural levees and permanent open-water surfaces in the basins. By now, only very small parts of the river dunes emerged yet above the surrounding wet area.

In both areas practically everywhere clastic sedimentation took place, mainly from the Schoonrewoerd stream. In both areas this flowed through the northern part (for location see Figs. 3 and 4; see also lithological maps Figs. 51-54). Approximately parallel to it a smaller tributary (with less intensive sedimentation) flowed through the southern part of both areas. In the Leerdam area this is known as the Schaik stream (see Ch. IIb.3) but it is not certain that the southern river branch in the Molenaarsgraaf area was a direct continuation of the Schaik stream.

Although precursors of these river channels had already been formed some centuries before 4100 BP (at least in the Leerdam area, see Ch. Vc), they attained their greatest importance in the

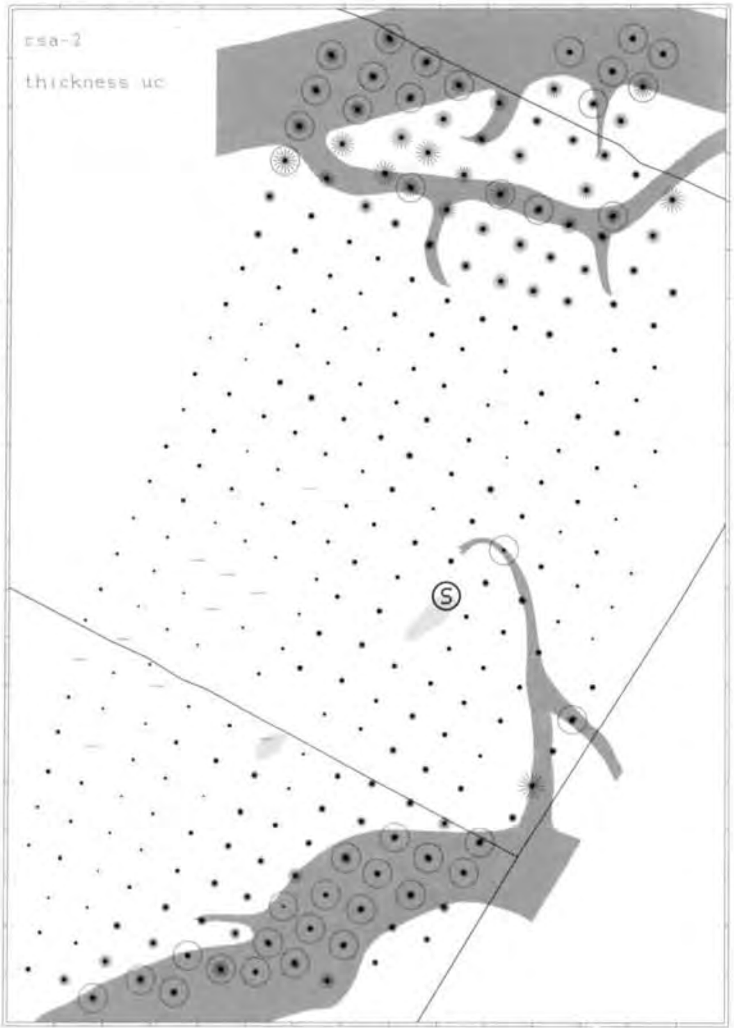


Fig. 53. Thickness of clastic bed uc, Leerdam. For legend, see Fig. *35. Dark grey: stream ridges; light grey: river-dune outcrop.

depositional history of both areas only in the centuries immediately after 4100 BP. Locally the beginning of the intensive sedimentation may have been about a century later than the 4100 BP mentioned.

Fig.*55 illustrates the scenery of the Molenaarsgraaf study area during this period of intensive sedimentation. The point of time c. 3800-3900 BP has been indicated for the reconstruction because it may be assumed that the channel system with the natural levees was fully developed towards the end of the period concerned. In Ch. IVd it was shown that around 3800 BP (or shortly after it) the main channels in the area were filled up with sand.
As in the preceding periods, the river-dune topography in the subsoil still exerted some influence on landscape evolution, especially on the channel pattern, which did not expand over the former dune area. The larger channels, at least the Schoonrewoerd stream, became incised down to the Kreftenheye Formation. The incised clay- and peat beds formed in the preceding periods reached a thickness of at least 6-7 m. Some redeposition of material eroded from these beds seems to have occurred in the area (see Ch. IVb.1).

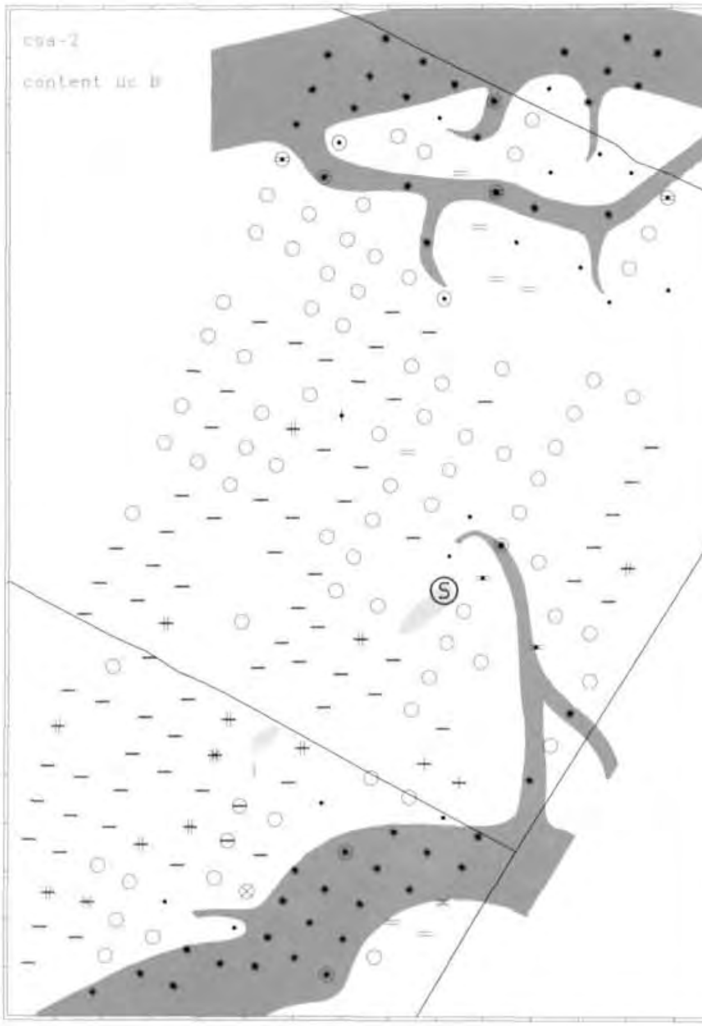


Fig. 54. Lithological content of clastic bed uc, Leerdam. For legend, see Fig. *35. Dark grey: stream ridges; light grey: river-dune outcrop.

The scenery in Fig.*55 is mainly characterised by large open water bodies in the basins and by tree growth on the natural levees. In the channels mainly sand was deposited, in alternation with some clay in the smaller ones. The natural levees consisted of clayey sand and sandy clay. Along the Schoonrewoerd stream sand bodies formed by infilling of crevasses presumably occurred in the natural levees. The many side-channels finishing in the basins may have developed by enlargement of crevasses. Possibly these side-gullies might even be regarded as crevasses running through into the basins (FISK 1960, p. 189; ALLEN 1965, p. 122 f.; COLEMAN 1969, p. 155 f.). On the natural levees *Quercus*, *Ulmus*, *Fraxinus*, *Corylus* and, at the lowest parts only, *Alnus* would have grown. Several authors mention an *Ulmus-Fraxinus* forest as the natural-levee forest of near-coastal Subboreal rivers (VAN REGTEREN ALTENA et al. 1962, p. 23 f.; 1963, p. 105; VOORRIPS 1964; BEHRE 1970, p. 45). In these cases levees are associated with localities closer to the coast and a more clayey development than at Molenaarsgraaf. On the sandier (and higher) levees at Molenaarsgraaf, *Ulmus* and *Fraxinus* as well as *Quercus* may have occurred.
At many points at the transition from levee to basin a *Phragmites* border with some local *Salix* would have occurred. In the fluvio-lagoonal basin environment there was a rather open vegetation of

marsh herbs like *Typha angustifolia* and certain Umbelliferae at the more shallow spots. At these shallow sites some *Salix* shrubs may also have occurred. In general however, the basins were characterised by open water with only a sparse vegetation in some places. The notion that the Schoonrewoerd stream would have flowed through a densely vegetated, even densely wooded landscape (see among others LOUWE KOOIJMANS 1974, p. 99 f.; see also Ch. Ve) is incorrect. For a comprehensive discussion of the fluvio-lagoonal paleoenvironment, see Ch. Vb.

Basin-clay deposition was lowest at some distance from the largest channel (the Schoonrewoerd stream), at the before-mentioned shallow places with sparse vegetation (cf. Fig. 51). Comparison with Figs. 53 and 54 (lithology in the Leerdam area for this period) shows that also in this upstream area clay deposition was lower and vegetation denser with increasing distance from the channel. This vegetation in the shallow border of the basin was however much denser there than at Molenaarsgraaf, and the zone of basin-clay deposition in the open water along the river was rather narrow in comparison with the extensive water bodies in the Molenaarsgraaf area. It is conceivable that the scenery in this period was more open and had more water bodies downstream and was characterised by more frequent branching-off of the main channels into side-channels. The more marshy landscape evolution along the Schoonrewoerd stream at Leerdam might also be explained by shallowness of the basins due to the elevated position of the broad Middelkoop stream ridge. On top of a stream ridge corresponding with the latter, near Zijderveld, N of the Schoonrewoerd stream, the basin clay is likewise mainly peaty (DE JONG 1970-71, see also Ch. IVd).

The Schoonrewoerd stream ridge and its inundated surroundings

The period of intensive sedimentation described above ended at about 3800 to 3700 BP. The (main) channels had been filled with sand and the water depth in the basins decreased considerably. The latter may have been caused by filling with sediment and/or a real fall in water-level (see also Ch. Ve). The basins retained a sufficient water depth for the open-water nature to be maintained and no important expansion of the vegetation took place there. The complexes consisting of natural levees with the filled channels in between, stood as wooded stream ridges above the surroundings.

Thus, the paleoenvironmental situation for a few hundred years after 3800 BP still strongly resembled that of the period from c. 4100 to 3800 BP (shown in Fig.*55). The main difference was that the forest cover of the natural levees had expanded over the filled channels in between. It is possible that some of the smaller channels shown in Fig.*55 were not visible as pronounced stream ridges, because they might not have become incised into the resistant sand-subsoil (Kreftenheye Formation) and so might have been subject to subsidence just as the basin clays were. At any rate, the broad Schoonrewoerd stream ridge remained standing above the wet surroundings, at Molenaarsgraaf as well as at Leerdam. The same is true of the Schaik stream ridge, situated in the south of the Leerdam study area. The situation resembles somewhat that in the lower valley of the Mississippi river: in this river plain (with active sedimentation) some abandoned river courses occur as dry 'alluvial ridges' (FISK 1944, p. 21).

At several places in the *Quercus* stands on the broad Schoonrewoerd stream ridge there may have been clearings, created by prehistoric inhabitants. Just east of the Molenaarsgraaf study area, settlements dating from c. 3700 BP have been found on this stream ridge (LOUWE KOOIJMANS 1974, p. 169 f. and fig. 121). Besides, it is among others on the basis of the dating of these settlements, that it has been concluded in Ch. IVd that the filling of the Schoonrewoerd stream and its inversion into a stream ridge probably took place around 3800 BP. Mention should be made here too of LOUWE KOOIJMANS' description of the rich fauna in the stream-ridge forest (op. cit., p. 274). Inundation and clay deposition in the basins continued, but apparently no longer locally from the Schoonrewoerd stream, but from one or more distant, possibly larger river channels, e.g. precursors of the later large Rhine branches. In connection with this, the open-water environment of the basins had

become even less turbulent compared with the period before 3800 BP. The sedimentation that occurred was less extensive and the deposited material more clayey. Local breaches through the stream ridges may have caused the deposition of sandier material, as found near the so-called break-through channels by LOUWE KOOIJMANS (1974, p. 100 f.; see also Ch. IVd). Such break-through channels, that presumably correspond with the 'overflow gullies' distinguished by HAVINGA (1969, p. 36) in an upstream area (the Betuwe), connected basins, that were separated from each other by stream ridges. PANNEKOEK VAN RHEDEN (1942, p. 669) supposes that in this way 'a drainage system from each basin to the next western one' may have developed.
The above-mentioned prehistoric settlements are found next to the break-through channels (LOUWE KOOIJMANS 1974, ibid.); POORTMAN (1980) made the interesting suggestion of a partly artificial creation of these breaches.
In the Molenaarsgraaf area, the slow clay deposition stopped completely around 3300 BP. In the more upstream Leerdam area however, it continued up to c. 2700 BP. It is possible that in this upstream area the Schoonrewoerd stream remained active after 3800 BP, a view that is supported by the distribution of the archeological discoveries over the whole Schoonrewoerd stream ridge (LOUWE KOOIJMANS 1974, fig. 18). This would mean that the clay deposition in the Leerdam area may also have been fed after 3800 BP by the Schoonrewoerd stream. This leads furthermore to the presumption that the same may hold for the Molenaarsgraaf area, albeit that deposition did not occur directly from this river, but via branches (and/or break-through channels) upstream of the area.

The complete covering by swamp forest

In the Molenaarsgraaf area, the final clay deposition, some time before the above-mentioned 3300 BP, occurred in an environment with decreasing water depth, in which stretches of Cyperaceae and possibly also *Rorippa/ Nasturtium* and *Thelypteris* ferns were formed. The *Alnus* swamp stands along the borders of the stream ridges would have expanded somewhat into the basins. Probably, human interference with the vegetation on the stream ridges was temporarily more intense at that time (see Ch. IIIc.5, zone 22). This would correspond with occupation phase 4 (Middle Bronze Age) in LOUWE KOOIJMANS' (1974) scheme in fig. 120.
At the end of clay deposition, swamp forest (mainly consisting of *Alnus*) spread over the whole study area, except over the Schoonrewoerd stream ridge, on which a *Quercus* forest was maintained, with presumably *Fraxinus* at the lower edges. In and around little ponds in the swamp forest Cyperaceae, Umbelliferae and *Phragmites* among others occurred. After some centuries, these openings in the swamp forest enlarged temporarily, probably because of a temporary increase of the local water-level rise. These wetter conditions might be connected with the possibly simultaneous clay deposition in the Leerdam area (namely in the last centuries before 2700 BP, see above). At the open sites more *Salix* than before grew in the more closed swamp forest. In and around the (shallow) water, Umbelliferae, *Alisma* and Cruciferae (*Rorippa/ Nasturtium*) occurred in particular.
The extensive wood-peat accumulation stopped presumably no earlier than 2000 BP. Its termination would have been due to the end of the Holocene water-level rise.
Afterwards, in the whole region in which the study areas are situated a normally thin clay bed ('cover') has been deposited by inundation from the large rivers (Rhine and Meuse branches). This clay cover occurs in both study areas on both the peat and the Schoonrewoerd stream ridge.
In recent times, artificial drainage contributed to compaction of the exposed clay-and peat-soils. Because of this, the higher position (with regard to the peat area) of both the Schoonrewoerd stream ridge and the river dunes increased somewhat (cf. App., Figs. l and m).

Ve SOME ADDITIONAL REMARKS ON THE REGIONAL PALEOHYDROLOGY IN ATLANTIC AND SUBBOREAL

The central and Western Netherlands area of the so-called large rivers (Rhine- and Meuse branches) has been denoted as the Rhine/Meuse estuary (VAN REGTEREN ALTENA et al. 1963, p. 97) and as Rhine/Meuse delta (LOUWE KOOIJMANS 1974). The former term should indicate only the tidal river area and therefore comprise only the most downstream part of the latter. KRUIT (1963) objected to the use of the term delta here, mainly because the Atlantic progradation of coastal barriers would not have been fed by fluvial supply, but by supply of marine sands only. Even if true, this argument would neglect the important fluvial sedimentation in the Atlantic coastal plain behind the barriers. The question depends of course largely of the definition of the term delta. Instead of the term delta, *deltaic plain* may also be used for this region, as FISK (1944, p. 33) did for the region of the lower Mississippi river, to indicate the whole plain downstream from where, about 300 km upstream of the present bird-foot delta, the Mississippi starts to split into distributaries. In the Rhine/Meuse deltaic plain, the perimarine fluviatile coastal plain forms the western (downstream) part, whereas the eastern (upstream) part is mostly denoted as the 'river-clay area'.
FISK (1947) and ALLEN (1965, p. 124) stress that in river plains the surface area occupied by floodbasins tends to widen in a downstream direction. For the region of the lower Mississippi river this is visualised by LEBLANC & BERNARD (1954, fig. 5). The fluvio-lagoonal paleoenvironment described in Chs. Vb and Vd may be regarded partly as a result of this downstream increase of the floodbasin surface area, and partly of course also as a result of the Holocene water-level rise. It is conceivable that the fluvio-lagoonal nature of the paleoenvironment (large open-water bodies separated by channels with their levees) will apply, for the relevant periods, to the larger part of the Western Netherlands perimarine fluviatile coastal plain. The permanent open-water nature of the (flood-)basins in this coastal plain has been argued in Chs. Vb and Vd, and contrasts strongly with former notions (PONS et al. 1963; LOUWE KOOIJMANS 1974, p. 99 f.) of a densely vegetated, even wooded paleoenvironment of the floodbasins. The basin environment was too wet for tree growth during the phases of clastic deposition, as also stated by HAVINGA (1969, p. 37) for the upstream 'river-clay area'.
The downstream decrease of river gradient leads to decreasing complexity of meandering patterns (FISK 1944, p. 21). This may be observed especially for the Subboreal Rhine/Meuse deltaic plain by comparing the rather straight course of the so-called Schoonrewoerd stream ridge (stressed by LOUWE KOOIJMANS 1974, p. 99) with the more or less contemporaneous complex patterns in the upstream river-clay area (cf. HAVINGA 1969). Moreover, free meandering of river branches may also have been hindered in a downstream direction by the resistance offered by the downstream thickening of clay beds in the subsoil (cf. FISK 1947, p. 64). Besides, at many places the channel pattern was influenced by the topography of the former, mostly buried river dunes.

The paleoenvironment of both study areas would always have been a freshwater environment. One of the commonly used salt indicators in palynological sections of the Dutch coastal areas is the pollen of Chenopodiaceae. The values of this are always very low in our sections, especially so in comparison with the high values in the sections Alphen aan de Rijn (JELGERSMA 1961, p. 83) and Hillegersberg (VOORRIPS 1964); both these sections are situated more seaward in the Western Netherlands coastal plain. *Phragmites*, one of the most important herbs encountered in this study, can tolerate salt, but should not be regarded conversely as an indicator of brackish influences, as is done sometimes. Although several of the marsh herbs that occurred in both study areas during the larger part of the described history, may grow equally well in freshwater- as in oligohaline environments (cf. DEN HELD & DEN HELD 1976, p. 90 f.), there were several species too, that cannot tolerate salt at all.
No indications have been found for the former existence of tides in the study areas. So far as a com-

parison with the former freshwater tidal area of the 'Biesbosch' (ZONNEVELD 1960) can be justified in the light of its extreme tidal amplitude (2 m), it is striking that several of the plant species mentioned by ZONNEVELD (op. cit., p. 312) as definitely lacking in the tide-influenced parts of the Biesbosch, did occur in our study areas (e.g. *Oenanthe aquatica, Carex pseudocyperus, Valeriana dioeca, Nymphaea* alba). Moreover, during the existence of the large open-water bodies, tides may have disappeared rapidly in landward direction (cf. JELGERSMA 1961, p. 21; VAN DE PLASSCHE 1980).

During the Atlantic and Subboreal periods, phases of fluvio-lagoonal/fluvio-lacustrine clastic deposition alternated with phases of organic accumulation. It has been shown in Ch. V that this alternation was more or less synchronous throughout a large part of the region (the perimarine fluviatile coastal plain). The alternation probably reflects water-level fluctuations: the genesis of stream ridges and the origin of swamp forests (giving rise to wood-peat accumulation) should have been initiated by a temporary relative fall of the water-level, whereas the phases of clastic deposition began with a drowning of the swamps and marshes as a consequence of a temporary increase in the relative water-level rise. The relative fall of the water level may have been caused by heightening, and the temporarily increased rise of the water level by subsidence of the sediment- and peat-surface. However, in view of the emergence of channel fills as stream ridges, there may also have been an absolute component in the relative water-level fall; this applies especially to the times 6100 and 3800 BP (see Chs. Vb and Vd).

The phases of clastic deposition in the perimarine fluviatile coastal plain appeared (see Ch. IV) to show a (partial) synchrony with the marine transgressive phases distinguished by HAGEMAN (1969) only for the early- and middle-Subboreal period. A direct relation between the marine and the perimarine fluviatile area regarding their depositional phases and water-level fluctuations, as supposed by HAGEMAN (ibid., see also Chs. Ia and IVe), is thus very uncertain. A possible impeding of marine influences on the perimarine fluviatile area may have been caused by such important factors as the gradient effect and the floodbasin effect (i.e., the raising effect of the river gradient on the water level, and the effect of storage in the huge floodbasins; see further LOUWE KOOIJMANS 1974 and 1976b, and VAN DE PLASSCHE 1980). On the other hand, periodical increase of the water-level rise in the perimarine fluviatile area cannot be easily linked only to increased fluvial activity in the hinterland: the second of the three main depositional phases distinguished in the perimarine fluviatile area, the late-Atlantic/early-Subboreal phase, shows high water-levels like the other two, but much less intensive fluviatile depositional activity.

The better correlation mentioned above between the marine area and the perimarine fluviatile area for the early- and middle-Subboreal period might indicate a larger impact of sea-level fluctuations on the perimarine area in this period compared with the preceding Atlantic period. This would not be surprising in view of the decrease in the fluvial gradient and the decrease in the general water-level rise during the Holocene. The first is illustrated by the following time/depth data:

		depth below N.A.P. of time-correlative deposit on river-dune flank
Molenaarsgraaf study area	6060 ± 80 BP (see Fig. 27)	6.80 m
Leerdam study area	6090 ± 70 BP (see Fig. 30b)	2.25 m
Molenaarsgraaf study area	4570 ± 75 BP (see Fig. 27)	2.50 m
Leerdam study area	4290 ± 190 BP (see Fig. 31b)	0.75 m

The gradient between both study areas in the perimarine fluviatile coastal plain appears to have been roughly three times higher in the middle-Atlantic than in the early-/middle-Subboreal. This agrees well with data published by LOUWE KOOIJMANS (1974, fig. 23). It is conceivable that the steeper fluvial gradient in the Atlantic period impeded influences of sea-level fluctuations more strongly than in the Subboreal. It is even possible that during the middle-Atlantic, in particular the period from c. 6450 to c. 6100 BP (see Ch. IVb), there was a fluvial dominance over marine influences. Thus, the strong fluviatile expansion in that period might have brought freshwater — fluvio-lagoonal — conditions to a large part of the coastal plain and thereby have contributed to (or even dictated?) the marine withdrawal known as the regression-interval Calais I-II (see also Ch. IVe). This would agree with the idea ventured sometimes (HAGEMAN 1970b; DE JONG 1971, p. 148) that marine regressions may have been stimulated by inflow of river water.
As to the second factor, the decrease of the general Holocene water-level rise, it is noteworthy that some authors (e.g. HAGEMAN 1970b) suppose more pronounced sea-level fluctuations during the Subboreal than during the Atlantic, when such fluctuations would have been overtaken by the fast general sea-level rise. This too might have contributed to the supposedly larger influence of sea-level fluctuations on the perimarine fluviatile area in the Subboreal. On the other hand, especially for the middle-Subboreal, mention should be made again of the supposition (by VAN STRAATEN 1963, p. 156; JELGERSMA 1966, p. 65; ZAGWIJN & VAN STAALDUINEN 1975, p. 111; DE JONG 1971, p. 159; cf. Ch. Ia) that marine transgressive phases might correspond climatically with periods of increased precipitation and cyclonic activity, and hence possibly with periods of increased fluvial discharge. Such a relationship — quite opposite to that in the Atlantic (see above) —, might be effected, but only during the slowing down of the sea-level rise after the Atlantic.

ABSTRACT

In the Western Netherlands, in the region to be denoted in a Holocene-geological perspective as the perimarine fluviatile coastal plain (where the vertical space for fluviatile and related organic accummulation was offered by the local water-level rise induced by the Holocene sea-level rise), two small case-study areas were selected for a reconstruction of the paleoenvironmental evolution. This reconstruction has been based on extensive geological mapping, detailed paleobotanical analyses, and numerous radiocarbon dates from several sections. Apart from showing a much more detailed paleoenvironmental picture of the region than hitherto available, the results provide alternatives for several of the existing notions.

In the study areas fluviatile clastic beds (clay- and sand deposits) alternate with organic beds (*Phragmites* peat and wood peat, partially also detritus gyttja). The loamy top of the braided-river deposits at the base of this clay/peat alternation may have originated as a partly fluvial, partly eolian deposit and thus may be linked genetically with the river dunes that also occur abundantly at the base of the clay/peat alternation and at several places pierce through it (as so-called *donken*). Both the *loam* and the river dunes may be dated probably as Late-Weichselian *cum* early-Holocene. From c. 7400 BP the Holocene (ground-)water-level rise brought constantly moist conditions of a strongly varying nature to the region. After slow initial organic lacustrine deposition, *Phragmites*-peat accumulation, and precursory fluvial clay deposition, extensive fluvial deposition of clay and sand took place in the middle-Atlantic in the whole region, in a so-called **fluvio-lagoonal** environment: permanent open-water surfaces covered the area outside the outcropping river dunes and the wooded natural levees of the many small river branches. An important relative, perhaps partly also absolute water-level fall at c. 6100 BP caused the region to become covered by swamp forest (mainly *Alnus* swamp) and to a lesser degree *Phragmites* marsh. These swamp forests persisted at many places notwithstanding the continuation of the Holocene water-level rise, probably because of its gradual slowing down in the course of the Holocene. In the more seaward of the two study areas, wetter conditions created many lakes amidst the swamp forests. In these lakes organic (gyttja) accumulation took place, and from c. 5300 BP also clay deposition, in very quiet conditions (the so-called **fluvio-lacustrine** paleoenvironment). This late-Atlantic/early-Subboreal depositional phase (ending c. 4600 BP in the downstream study area) was followed during several centuries by an environment of closed swamp forest and *Phragmites* marsh. In the middle-Subboreal (from c. 4100 BP) extensive fluviatile depositional activity returned to the region with an environment much like the middle-Atlantic fluvio-lagoonal one. This phase and the final part of the foregoing phase show some synchrony with the marine depositional (transgressive) phases in the foreland, and this might indicate a temporary marine influence on the perimarine area; this contrasts with the situation in the Atlantic period, when there was no such synchrony. After the slowing down of the main fluviatile depositional activity in the region, around 3800 BP, shallow open-water conditions persisted for several centuries. The ultimate complete covering by swamp forest (mainly *Alnus*) first took place in the downstream study area, around 3300 BP, and only occurred in the upstream study area six centuries later. In the downstream study area, the local and temporary existence of open sites (with *Umbelliferae*) in the swamp forest may possibly be related to a temporary increase of the local Holocene water-level rise. The swamp forest persisted at least up to c. 2000 BP.

During the Atlantic and Subboreal evolution of the region, amidst the generally moist environment dry sites, suitable for prehistoric occupation, were offered by the outcropping Late-Weichselian/early-Holocene river dunes, the natural levees of the many small river branches in the middle-Atlantic and middle-Subboreal, and by the stream ridges (channel fills with levees) originating from these river branches. The arboreal vegetation of these dry sites consisted mainly of *Quercus*, *Ulmus* and *Corylus*, and some *Tilia* on the higher parts of the river dunes. Prehistoric wood cutting, occurring at intervals on these dry sites, seems to have been confined largely to *Quercus*. Marsh herbs occurring along the margins and at shallow places of the wet basins, and at open sites in the swamp forests, were among others *Phragmites* (and other hygrophilous grasses), *Typha angustifolia*, ferns, *Scirpus* (and other Cyperaceae), *Alisma* and *Umbelliferae*.

REFERENCES

Ahlbrandt, Th. S, S. Andrews & D. T. Gwynne 1978. Bioturbation in eolian deposits. J. Sed. Petrol. 48, p. 839-848.

Allen, J. R. L.1965. A review of the origin and characteristics of recent alluvial sediments. Sedimentology 5, p. 89-191.

Becker, B. 1980. Dendrochronology of Holocene oak tree deposits along the Main and Regnitz rivers. In: Schirmer, W. (ed.). Guide-book for the Symposium Franken. Holocene valley development — methods and results. Düsseldorf.

Becker, B. & W. Schirmer 1977. Paleoecological study on the Holocene valley development of the river Main, southern Germany. Boreas 6, p. 303-321.

Behre, K.-E. 1970. Die Entwicklungsgeschichte der natürlichen Vegetation im Gebiet der unteren Ems und ihre Abhängigkeit von den Bewegungen des Meeresspiegels. Probl. d. Küstenforsch. im südl. Nordseegeb. 9, p. 13-47.

Bennema, J.1949. Het oppervlakteveen in West-Nederland. Boor en Spade 3, p. 139-149.

Berendsen, H. J. A. in prep. Thesis, Utrecht.

Bosch, J. H. A. & A. P. Pruissers 1979. De laatste 4500 jaar Rijn bij Leiden. Jaarverslag archeol. begel. cie. Leiden 1978, p. 25-36.

Coleman, J. M.1966. Ecological changes in a massive freshwater clay sequence. Trans. Gulf Coast Ass. Geol. Soc. 16, p. 159-174.

Coleman, J. M.1969. Brahmaputra river: channel processes and sedimentation. Sediment. Geol. 3, p. 129-239.

Daley, B. 1973. Fluvio-lacustrine cyclothems from the Oligocene of Hampshire. Geol. Mag. 110, p. 235-242.

De Bakker, H. & A. W. Edelman-Vlam 1976. De Nederlandse bodem in kleur. Wageningen, 148 p.

De Boer, Th. A. & L. J. Pons 1960. Bodem en grasland in de Vijfheerenlanden. Versl. landbouwk. onderz. 66.6, 72 p.

De Fretes, J. A. 1979. Verslag veldwerk Alblasserwaard Molenaarsgraaf. Internal report Institute of Earth Sciences, Free University Amsterdam.

De Jong, J. 1970-71. Pollen and C14 analysis of Holocene deposits in Zijderveld and environs. Ber. Rijksd. Oudh. Bodemonderz. 20-21, p. 75-88.

De Jong, J.D. 1967. The Quaternary of the Netherlands. In: Rankama, K. (ed.). The Quaternary II. Wiley, New York.

De Jong, J. D. 1971. The scenery of the Netherlands against the background of Holocene geology; a review of the recent literature. Rev. géogr. phys. géol. dyn. (2) 13, p. 143-162.

Den Held, J. J. & A. J. den Held 1976. Het Nieuwkoopse Plassen gebied. Zutphen, 314 p.

Ente, P. J. 1971. Sedimentary geology of the Holocene in Lake IJssel region. Geol. Mijnbouw 50, p. 373-382.

Faegri, K. (& J. Iversen) 1975. Textbook of pollen analysis. 3rd. ed. Blackwell Sc. Publ., 295 p.

Firbas, F. 1949. Spät- und nacheiszeitliche Waldgeschichte Mitteleuropas nordlich der Alpen. I: Allgemeine Waldgeschichte. G. Fischer Verlag, Jena, 480 p.

Fisk, H. N. 1944. Geological investigation of the alluvial valley of the Lower Mississippi River. Miss. River Commission, Vicksburg, Miss., USA, 78 p.

Fisk, H. N. 1947. Fine-grained alluvial deposits and their effects on Mississippi River activity. Miss. River Commission, Vicksburg, Miss., USA, 82 p.

Fisk, H. N. 1960. Recent Mississippi River sedimentation and peat accumulation. Quatr. congr. p. l'avanc. d. étud. de stratigr. et de géol. du Carbonifère, Heerlen 1958, Compte rendu I, p. 187-199.

Florschütz, F. & F. P. Jonker 1939. A botanical analysis of a late Pleistocene and Holocene profile in the Rhine delta. Rev. trav. bot. néerl., p. 686-696.

Frazier, D. E. & A. Osanik 1969. Recent peat deposits — Louisiana coastal plain. In: Dapples, E. C. & M. E. Hopkins (ed.). Environments of coal deposition. Sympos. Coal Geol. Div., Geol. Soc. Am., Special paper 114, p. 63-83.

Geys, J. F. 1978. The paleoenvironment of the Kempenland clay deposits (Lower Quaternary, N. Belgium). Geol. Mijnbouw 57, p. 33-43.

Griede, J. W. 1978. Het ontstaan van Frieslands Noordhoek. Thesis, Amsterdam, 186 p.

Groenman-van Waateringe, W, A. Voorrips & L. H. van Wijngaarden-Bakker 1968. Settlements of the Vlaardingen culture at Voorschoten and Leidschendam (ecology). Helinium 8, p. 105-130.

Grosse-Brauckmann, G. 1961. Zur Terminologie organogener Sedimente. Geol. Jahrb., p. 117-143.

Hageman, B. P. 1963. De profieltype-legenda van de nieuwe geologische kaart voor het zeeklei- en rivierkleigebied. Tijdschr. Aardr. Gen. 80, p. 217-229.

Hageman, B. P. 1969. Development of the western part of the Netherlands during the Holocene. Geol. Mijnbouw 48, p. 373-388.

Hageman, B. P. 1970a. Klimaatverbetering en zeespiegelrijzing, Intermediair 49.

Hageman, B. P. 1970b. De geologische ontwikkeling in ons kustgebied. Intermediair 51.

Hartman, A. A. 1968. A study on pollen dispersal and sedimentation in the western part of the Netherlands. Thesis, Amsterdam, 48 p. Also published in Acta Bot. Neerl. 17.

Havinga, A. J. 1969. A physiographic analysis of a part of the Betuwe, a Dutch river clay area. Meded. Landbouwhogeschool Wageningen 69-3, p. 1-47.

Havinga, A. J. 1974. Problems in the interpretation of pollen diagrams of mineral soils. Geol. Mijnbouw 53, p. 449-453.

Hedberg, H. D. (ed.) 1976. International stratigraphic guide. Wiley, New York.

Heukels, H. & S. J. van Ooststroom 1968. Flora van Nederland. Groningen, 892 p.

Janssen, C. R. 1959. Alnus as a disturbing factor in pollen diagrams. Acta Bot. Neerl. 8, p. 55.

Jelgersma, S. 1961. Holocene sea level changes in the Netherlands. Thesis, Leiden, 101 p.

Jelgersma, S. 1966. Sea level changes during the last 10.000 years. Royal Met. Soc., Proc. Intern. Sympos. on world climate from 8000-0 BC, p. 54-71.

Jelgersma, S., J. de Jong, W. H. Zagwijn & J. F. van Regteren Altena 1970. The coastal dunes of the western Netherlands: geology, vegetational history and archeology. Meded. Rijks Geol. Dienst, N. S. 21, p. 93-167.

Kruit, C. 1963. Is the Rhine delta a delta? Verhand. Kon. Ned. Geol. Mijnb. Gen., Geol. serie 21-2, p. 259-266.

Leblanc, R. J. & H. A. Bernard 1954. Résumé of late Recent geological history of the Gulf coast. Geol. Mijnbouw N.S. 16, p. 185-194.

Louwe Kooijmans, L. P. 1974. The Rhine/Meuse delta. Thesis Leiden. Also in: Oudh. Meded. Leiden 53-54, 421 p.

Louwe Kooijmans, L. P. 1976a. The Neolithic at the Lower Rhine. Diss. Arch. Gand. 16, p. 150-173.

Louwe Kooijmans, L. P. 1976b. Prähistorische Besiedlung im Rhein-Maas-Deltagebiet und die Bestimmung ehemaliger Wasserhöhen. Probl. d. Küstenforsch. im südl. Nordseegeb. 11, p. 119-143.

Louwe Kooijmans, L. P. 1976c. Local developments in a borderland. A survey of the Neolithic at the Lower Rhine. Oudh. Meded. Leiden 57, p. 227-297.

Louwe Kooijmans, L. P. 1978. Hazendonk, Molenaarsgraaf. Arch. Nieuws, Bull. Kon. Ned. Oudh. Bond 77, p. 202-203.

Louwe Kooijmans, L. P. 1979. De Lage Landen toen. Prehistorische bewoning van onze kuststreken. Intermediair 42.

Modderman, P. J. R. 1955. De bewoonbaarheid van het rivierkleigebied in de loop der eeuwen. Tijdschr. Aardr. Gen. 72, p. 30-38.

Nap, J. 1979. Geogenese van de omgeving van de Schaikse donk bij Leerdam. Internal report Institute of Earth Sciences, Free University Amsterdam.

Overbeck, F. 1975. Botanisch-geologische Moorkunde. Neumünster.

Pals, J. P., B. van Geel & A. Delfos 1980. Paleoecological studies in the Klokkeweel bog near Hoogkarspel (prov. of Noord-Holland). Rev. Paleobot. Palynol. 30, p. 371-418.

Pannekoek van Rheden, J. J. 1942. Over de reconstructie van voormalige rivierlopen. Tijdschr. Kon. Ned. Aardr. Gen., 2e reeks, 59, p. 661-689, 849-878.

Pons, L. J. 1957. De geologie, de bodemvorming en de waterstaatkundige ontwikkeling van het Land van Maas en Waal en een gedeelte van het Rijk van Nijmegen. Meded. Sticht. v. bodemk., Bodemk. Studies 3, Wageningen, 156 p.

Pons, L. J. & J. Bennema 1958. De morfologie van het Pleistocene oppervlak in westelijk Nederland, voorzover gelegen beneden gemiddeld zeeniveau (N.A.P.). Tijdschr. Kon. Ned. Aardr. Gen. 75, p. 120-139.

Pons, L. J., S. Jelgersma, A. J. Wiggers & J. D. de Jong 1963. Evolution of the Netherlands coastal area during the Holocene. Verhand. Kon. Ned. Geol. Mijnb. Gen., Geol. serie 21-2, p. 197-208.

Pons, L. J. & M. F. van Oosten 1974. De bodem van Noord-Holland. Wageningen.

Pons, L. J. & A. J. Wiggers 1959-60. De Holocene wordingsgeschiedenis van Noord-Holland en het Zuiderzeegebied. Tijdschr. Kon. Ned. Aardr. Gen. 76, p. 104-152; 77, p. 3-57.

Poortman, H. H. 1980. Verslag doktoraal veldwerk Alblasserwaard. Internal report Institute of Earth Sciences, Free University Amsterdam.

Reineck, H.-E. & I. B. Singh 1973. Depositional sedimentary environments. Springer Verlag, 439 p.

Riezebos, P. A. & A. du Saar 1969. Een dwarsdoorsnede door de mariene Holocene afzettingen tussen Vijfhuizen en Vinkeveen. Meded. Rijks Geol. Dienst, N.S. 20, p. 85-92.

Roeleveld, W. 1974. The Groningen coastal area. A study in Holocene geology and low-land physical geography. Thesis, Amsterdam, 252 p.

Rose, F. 1974. The observer's book of grasses, sedges and rushes. Fred. Warne & Co., London, 192 p.

Schelling, J. 1951. Een bodemkartering van Noord-Limburg. Versl. Landbouwk. Onderz. 57.17, 139 p.

Scott, A. C. 1979. The ecology of Coal Measure floras from northern Britain. Proc. Geol. Ass. 90, p. 97-116.

Selley, R. C. 1978. Ancient sedimentary environments. Sec. ed., London, 287 p.

Soil Survey Manual 1962. U.S. Dept. of Agriculture, Washington.

Steenbeek, R. 1979. Enkele geologische onderzoekingen bij de Hazendonk. Internal report Institute of Earth Sciences, Free University Amsterdam.

Stichting voor bodemkartering 1965. De bodem van Nederland. Toelichting bij de Bodemkaart van Nederland 1:200000. Wageningen.

Streif, H. 1971. Stratigraphie und Faziesentwicklung im Küstengebiet von Woltzeten in Ostfriesland. Beih. d. Geol. Jahrb. 119, Hannover.

Tauber, H. 1977. Investigations of aerial pollen transport in a forested area. Dansk Botanisk Arkiv 32, p. 1-121.

Tinsley, H. M. & T. R. Smith 1974. Surface pollen studies across a woodland/heath transition and their application to the interpretation of pollen diagrams. New Phytol. 73, p. 547-565.

Traverse, A. & R. N. Ginsburg 1966. Palynology of the surface sediments of Great Bahama Bank, as related to water movement and sedimentation. Marine Geol. 4, p. 417-459.

Van de Meene, E. A. 1980. Geology and geomorphology of a fossil aeolian landscape in the Liemers (Eastern Netherlands). Geol. Mijnbouw 59, p. 113-120.

Van de Plassche, O. 1979-80. Reducing the effect of root contamination of peat samples. Oceanis 5, p. 215-218.

Van de Plassche, O. 1980. Holocene water-level changes in the Rhine-Meuse delta as a function of changes in relative sea level, local tidal range, and river gradient. Geol. Mijnbouw 59, p. 343-351.

Van der Voo, E. E. & V. Westhoff 1961. An autecological study of some lymnophytes and helophytes in the area of the large rivers. Wentia 5, p. 163-258.

Van der Wiel, A. M., in prep. A palaeoecological study of a section taken next to the Hazendonk (Zuid-Holland, The Netherlands). Rev. Palaeobot. 38, 1982, p. 35-90.

Van der Woude, J. D. 1979. Chronology of the perimarine fluviatile depositional phases at Molenaarsgraaf. Geol. Mijnbouw 58, p. 381-382.

Van Dijk, G. J., R. M. van Heeringen & M. Verbruggen 1976. De Hazendonk. Internal report Institute of Earth Sciences, Free University Amsterdam.

Van Donselaar, J. 1961. On the vegetation of the former river beds in the Netherlands. Wentia 5-6, p. 1-85.

Van Es, W. A. & W. A. Casparie 1968. Mesolithic wooden statuette from the Volkerak, near Willemstad, North Brabant. Ber. Oudh. Bodemonderz. 18, p. 111-116.

Van Regteren Altena, J. F., J. A. Bakker, A. T. Clason, W. Glasbergen, W. Groenman- van Waateringe & L. J. Pons 1962, 1963. The Vlaardingen culture. Helinium 2, p. 3-35, 97-103, 215-243; 3, p. 39-54, 97-120.

Van Rummelen, F. F. F. E. 1970. Toelichting bij de geologische kaart van Nederland 1:50000, blad Schouwen-Duiveland. Rijks Geol. Dienst, Haarlem.

Van Staalduinen, C. J. 1979. Toelichting bij de geologische kaart van Nederland 1:50000, blad Rotterdam-West (37W). Rijks Geol. Dienst, Haarlem.

Van Straaten, L. M. J. U. 1963. Aspects of Holocene sedimentation in the Netherlands. Verh. Kon. Ned. Geol. Mijnb. Gen., Geol. serie 21-1, p. 149-172.

Veldkamp, A. C., T. Hagen & J. D. van der Woude 1981. Laser plotting of pollen diagrams. Rev. Palaeobot. Palynol. 32, p. 441-443.

Verbraeck, A. 1970. Toelichting bij de geologische kaart van Nederland 1:50000, blad Gorkum-Oost (38 O). Rijks Geol. Dienst, Haarlem, 140 p.

Verbraeck, A. 1974. The genesis and age of the river dunes (donken) in the Alblasserwaard. Meded. Rijks Geol. Dienst, N.S. 25, p. 1-8.

Verbraeck, A. & J. H. Bisschops 1971. Toelichting bij de geologische kaart van Nederland 1:50000, blad Willemstad Oost (43 O). Rijks Geol. Dienst, Haarlem, 112 p.

Vink, T. 1954. De rivierstreek. Baarn, 840 p.

Voorrips, A. 1964. A pollenanalytical investigation of a boring made near a river dune in South-Holland. Acta Bot. Neerl. 13, p. 237-245.

Westhoff, V., P. A. Bakker, C. G. van Leeuwen & E. E. van der Voo 1971. Wilde planten. Deel 2: het lage land. Amsterdam, 303 p.

Westhoff, V. & A. J. den Held 1975. Plantengemeenschappen in Nederland. 2nd ed. Zutphen, 324 p.

Wiggers, A. J. 1955. De wording van het Noordoostpoldergebied. Thesis, Zwolle, 214 p.

Zagwijn, W. H. 1965. Pollenanalytic correlations in the coastal barrier deposits near The Hague (The Netherlands). Meded. Geol. Sticht., N.S. 17, p. 83-88.

Zagwijn, W.H. 1974. Palaeogeographic evolution of the Netherlands during the Quaternary. Geol. Mijnbouw 53, p. 369-385.

Zagwijn, W. H. & C. J. van Staalduinen (eds.) 1975. Toelichting bij de geologische overzichtskaarten van Nederland. Rijks Geol. Dienst, Haarlem, 134 p.

Zonneveld, I. S. 1960. De Brabantse Biesbosch. Thesis, Wageningen, 396 p.

APPENDIX

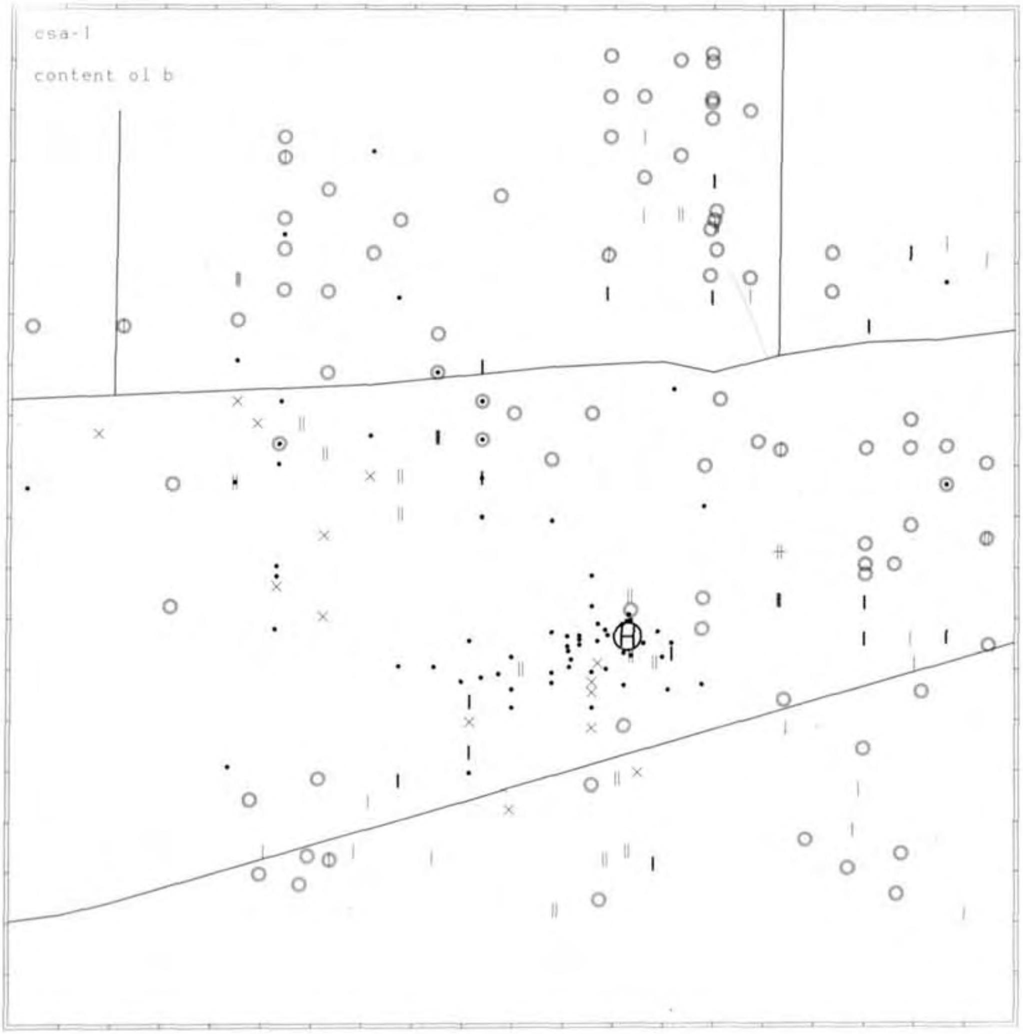


Fig. a. Lithological content of organic bed ol b, Molenaarsgraaf. For legend, see Fig. *35.

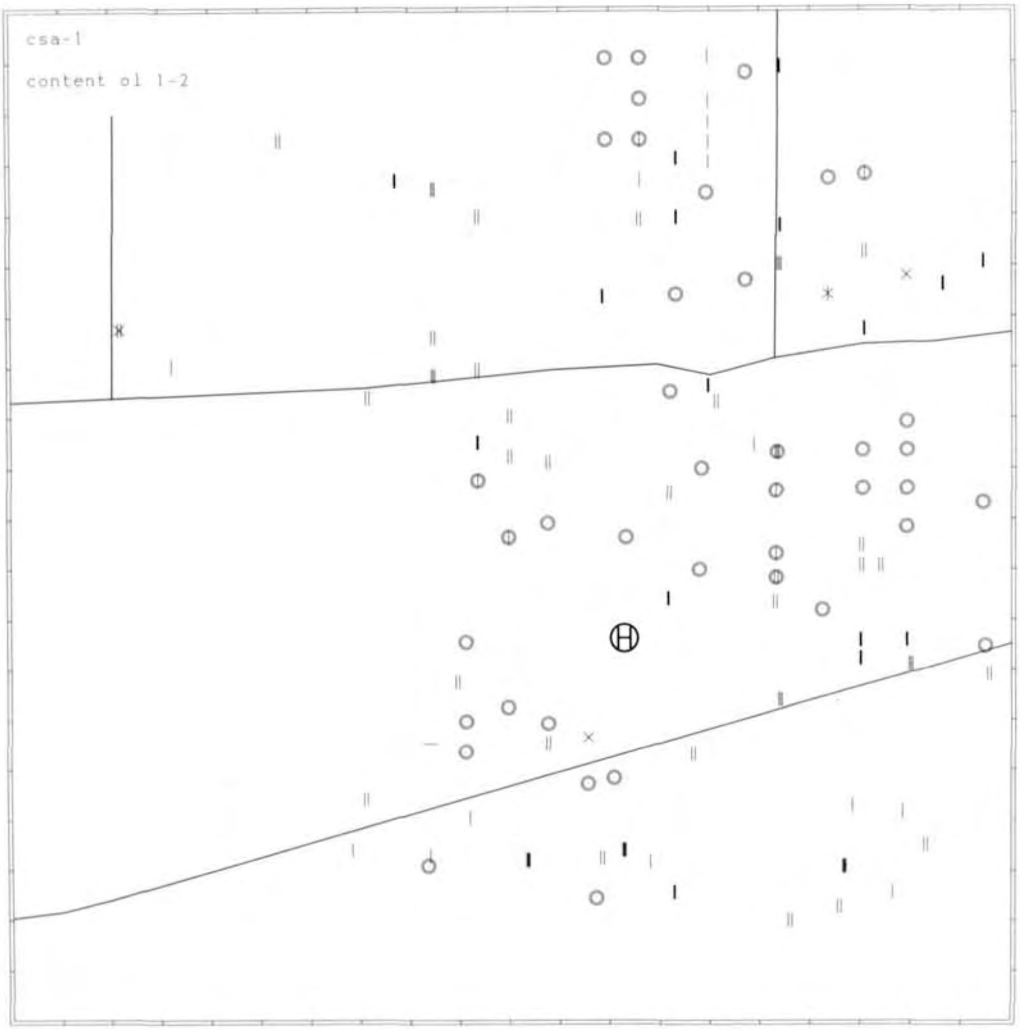


Fig. b. Lithological content of organic bed ol 1-2, Molenaarsgraaf. For legend, see Fig. *35.

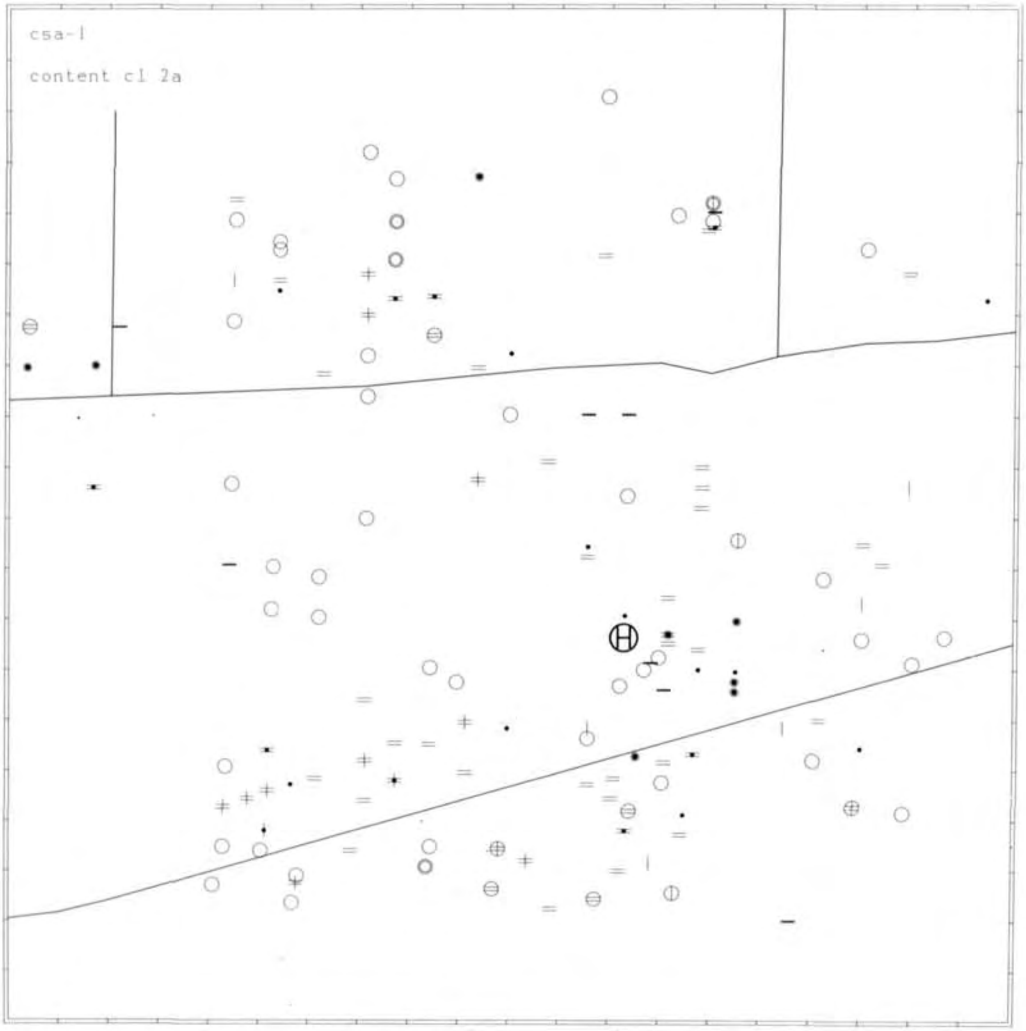


Fig. c. Lithological content of clastic bed cl 2a, Molenaarsgraaf. For legend, see Fig. *35.

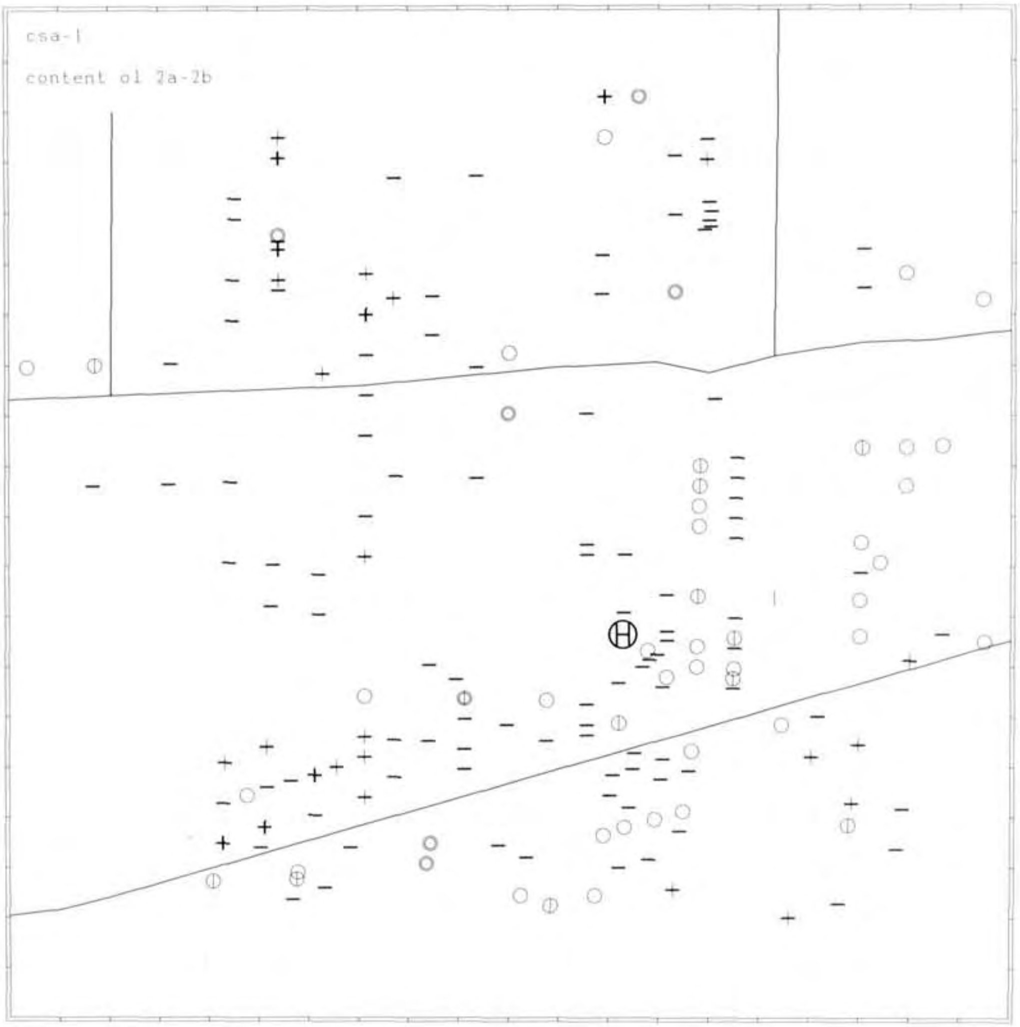


Fig. d. Lithological content of organic bed ol 2a-2b, Molenaarsgraaf. For legend, see Fig. *35.

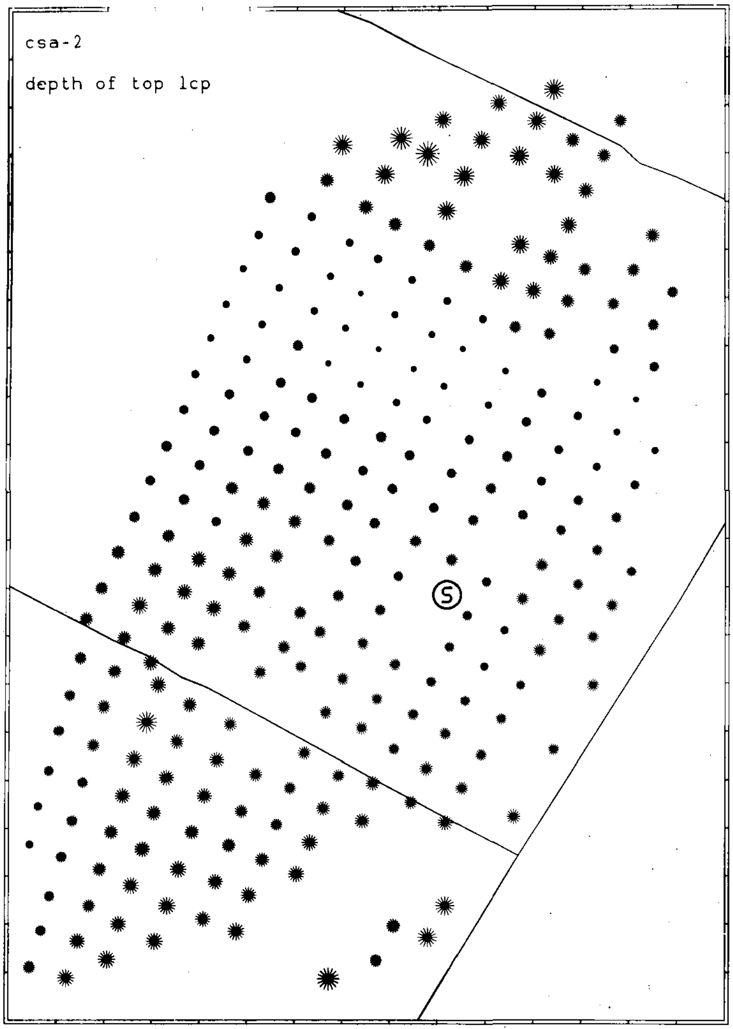


Fig. e. Depth of the top of clastic bed lcp, Leerdam. For legend, see Fig. *35.

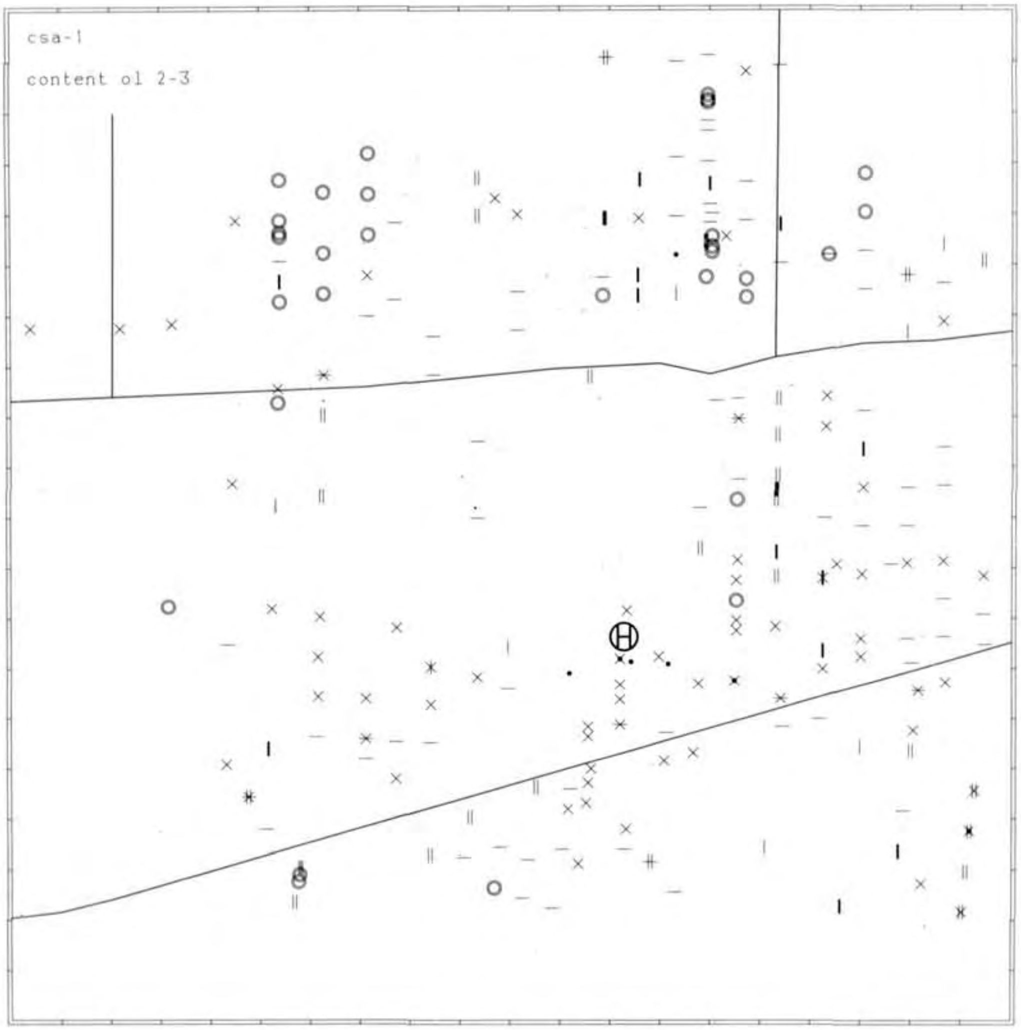


Fig. f. Lithological content of organic bed ol 2-3, Molenaarsgraaf. For legend, see Fig. *35.

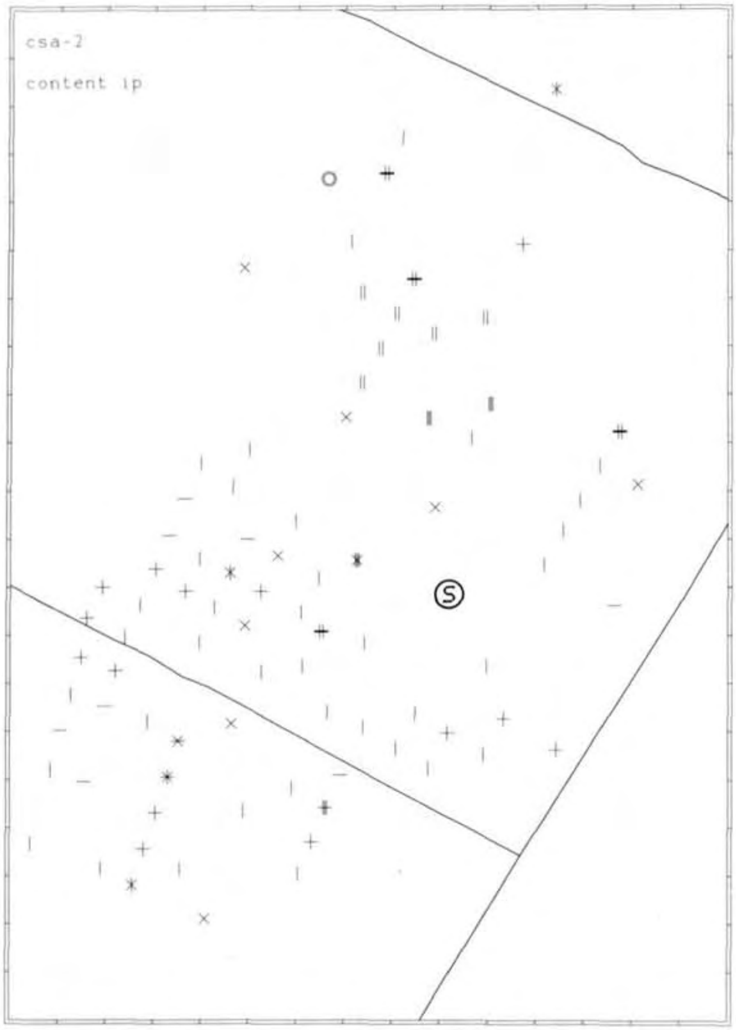


Fig. g. Lithological content of peat bed ip, Leerdam. For legend, see Fig. *35.

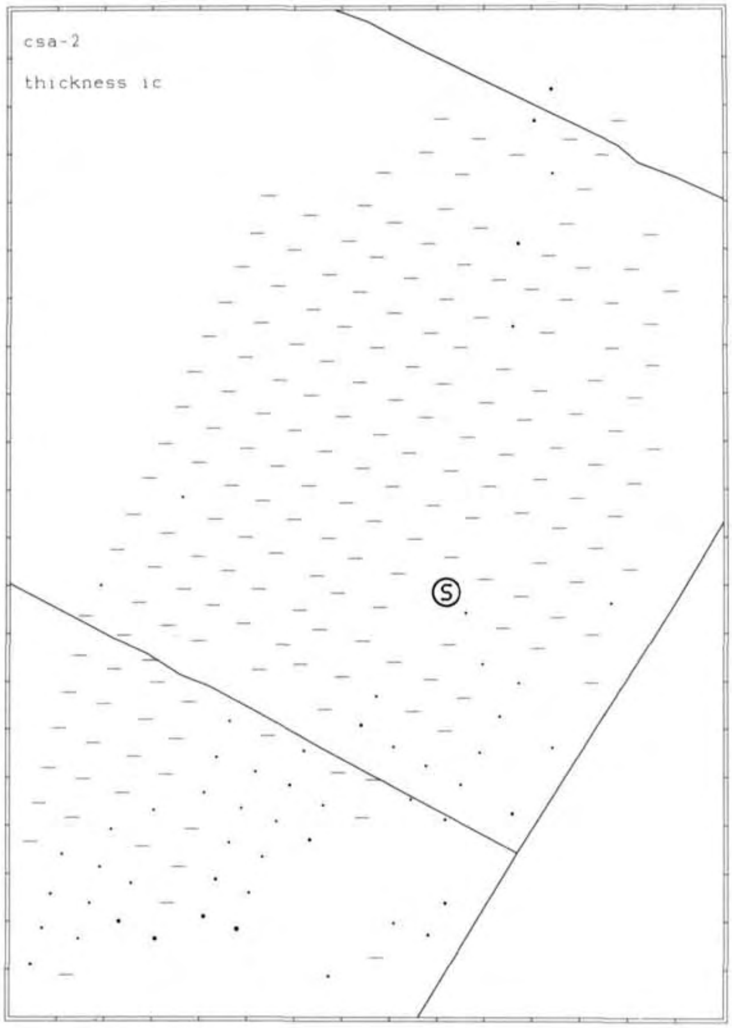


Fig. h. Thickness of clastic bed ic, Leerdam. For legend, see Fig. *35.

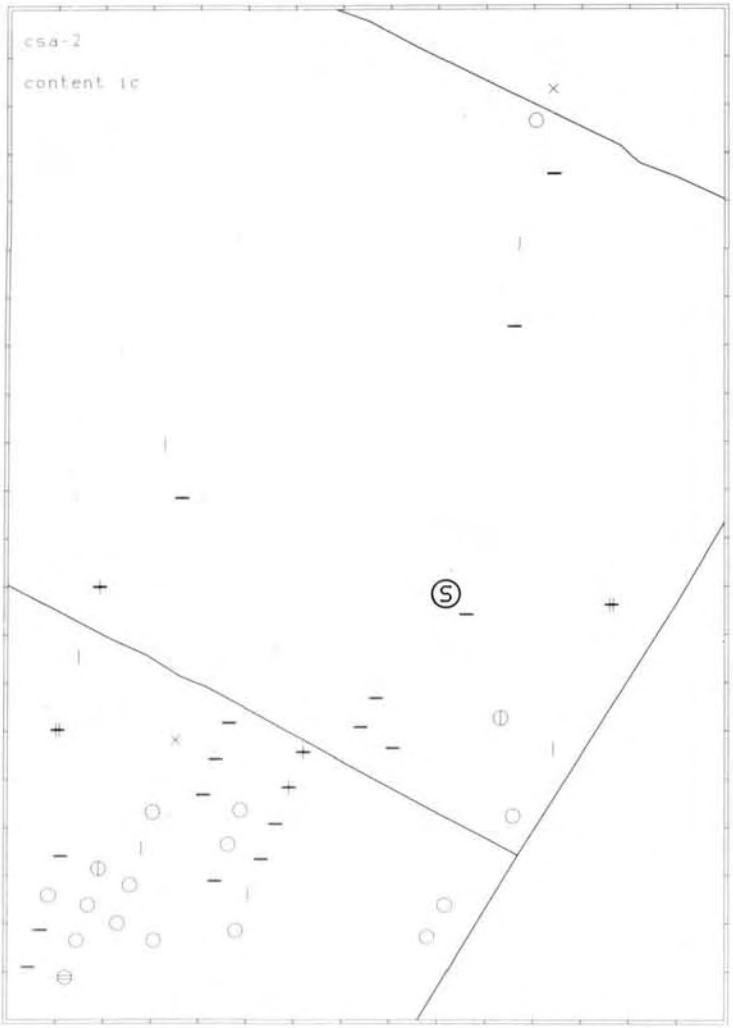


Fig. i. Lithological content of clastic bed ic, Leerdam. For legend, see Fig. *35.

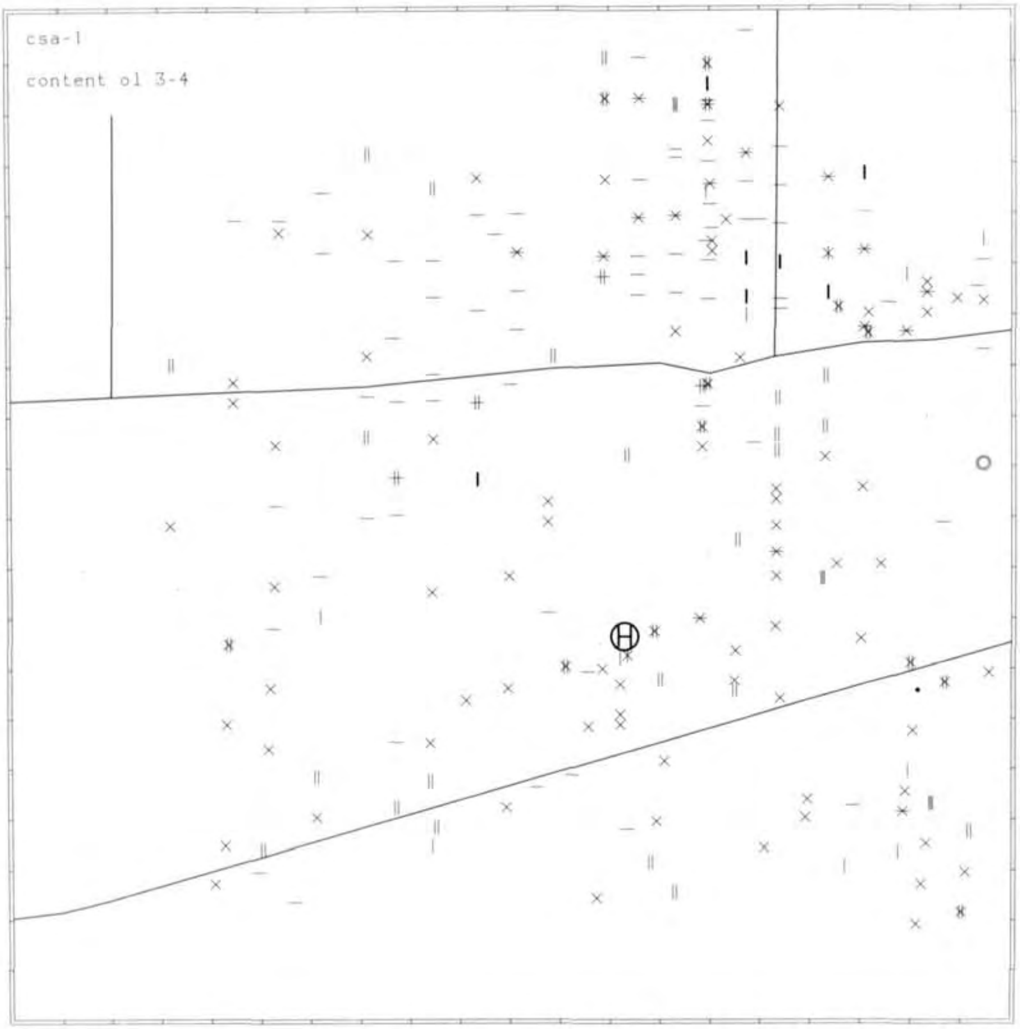


Fig. j. Lithological content of organic bed ol 3-4, Molenaarsgraaf. For legend, see Fig. *35.

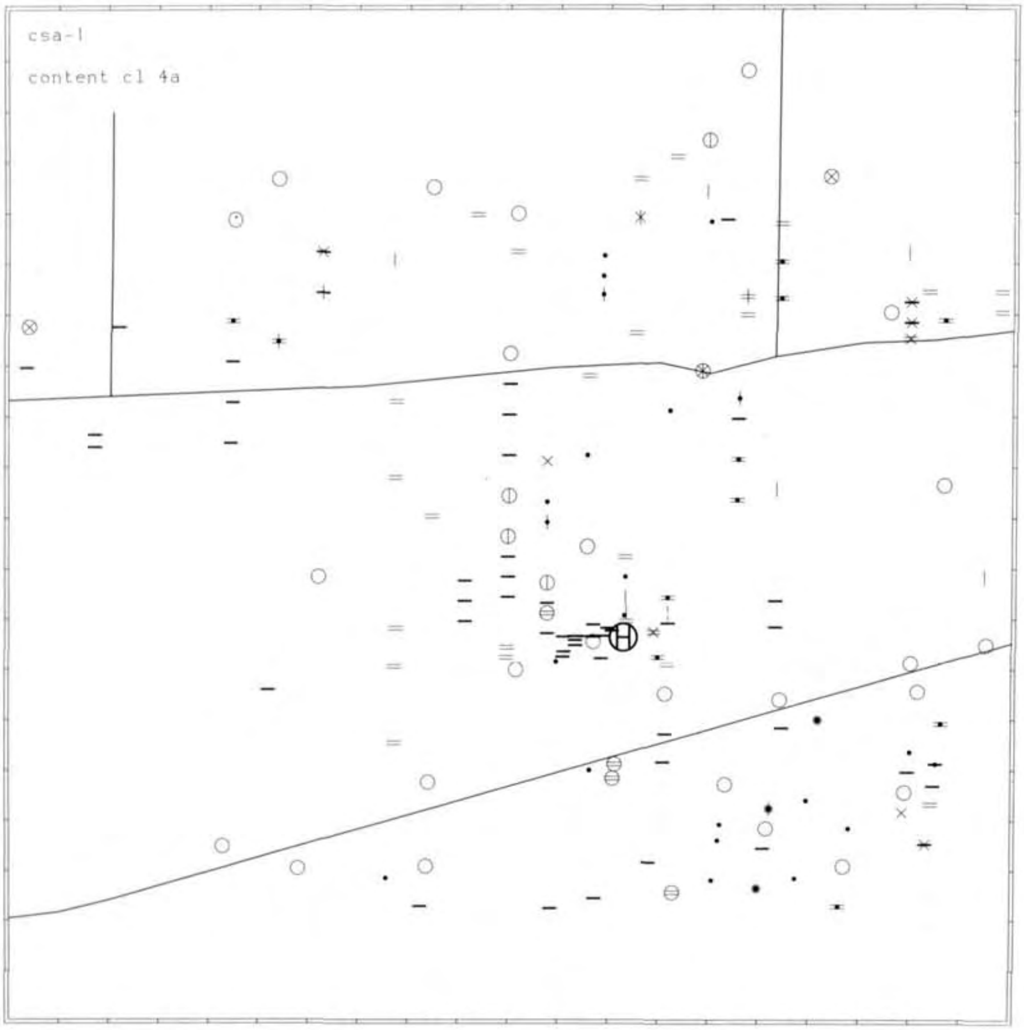


Fig. k. Lithological content of clastic bed cl 4a, Molenaarsgraaf. For legend, see Fig. *35.

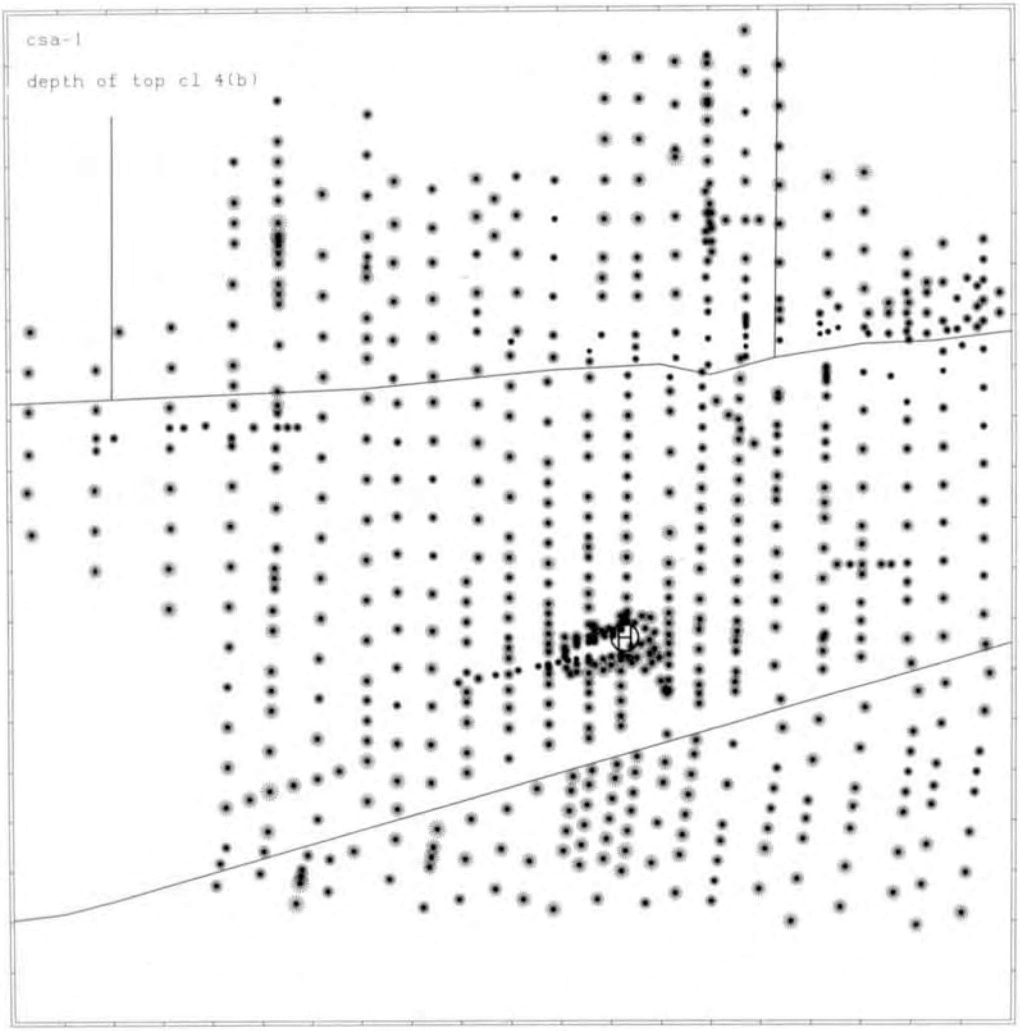


Fig. 1. Depth of the top of clastic bed cl 4b, Molenaarsgraaf. For legend, see Fig. *35.

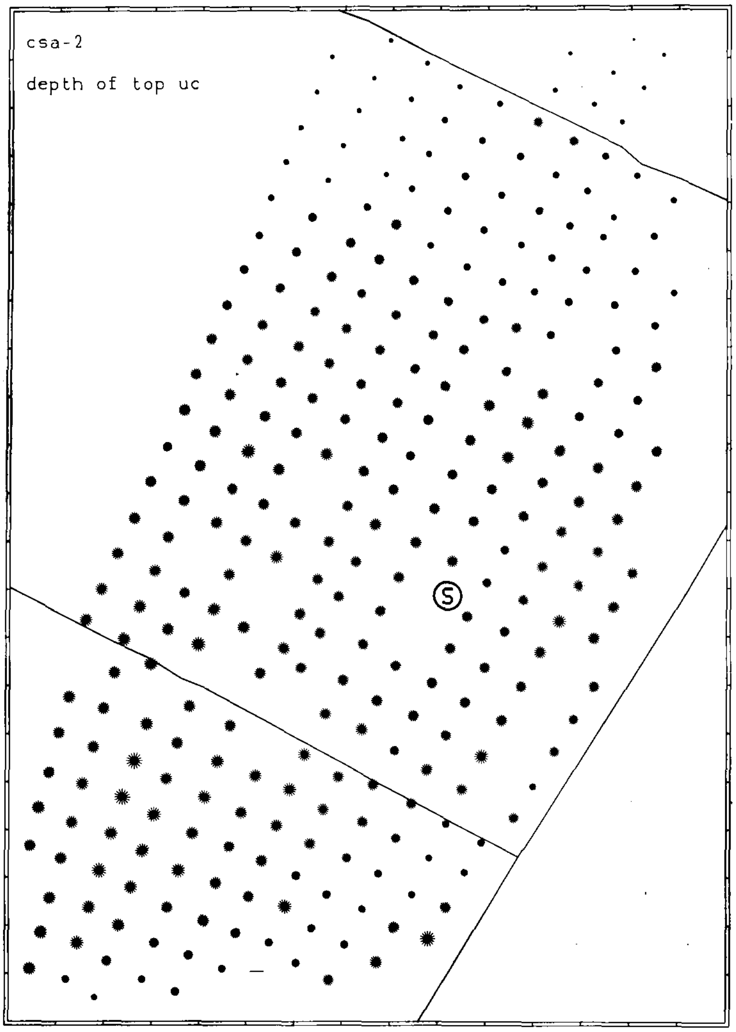


Fig. m. Depth of the top of clastic bed uc, Leerdam. For legend, see Fig. *35.

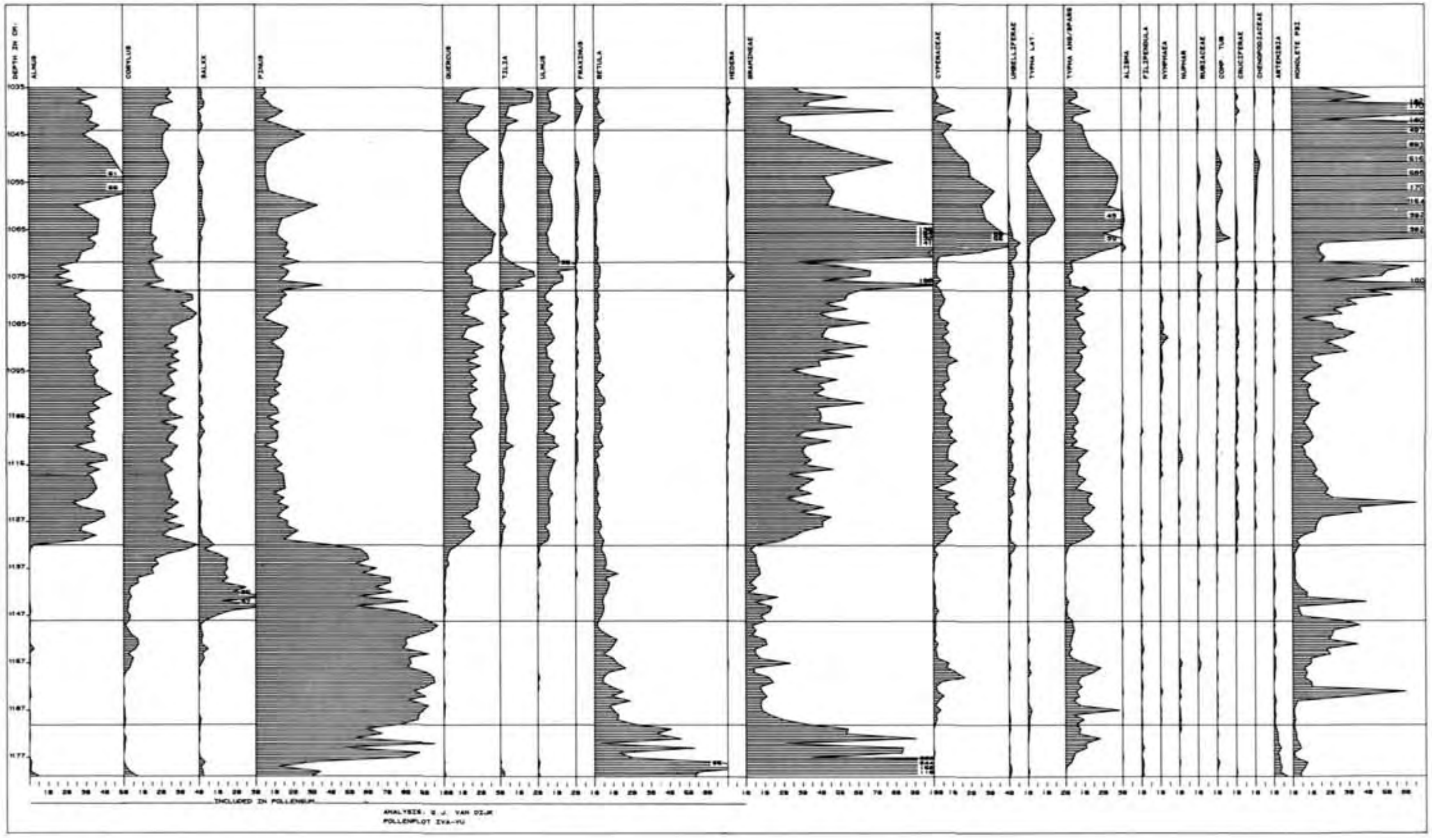


Fig. n. Pollen diagram of boring Molenaarsgraaf H1530 (selected curves). For lithology and zones, see Fig. 18.

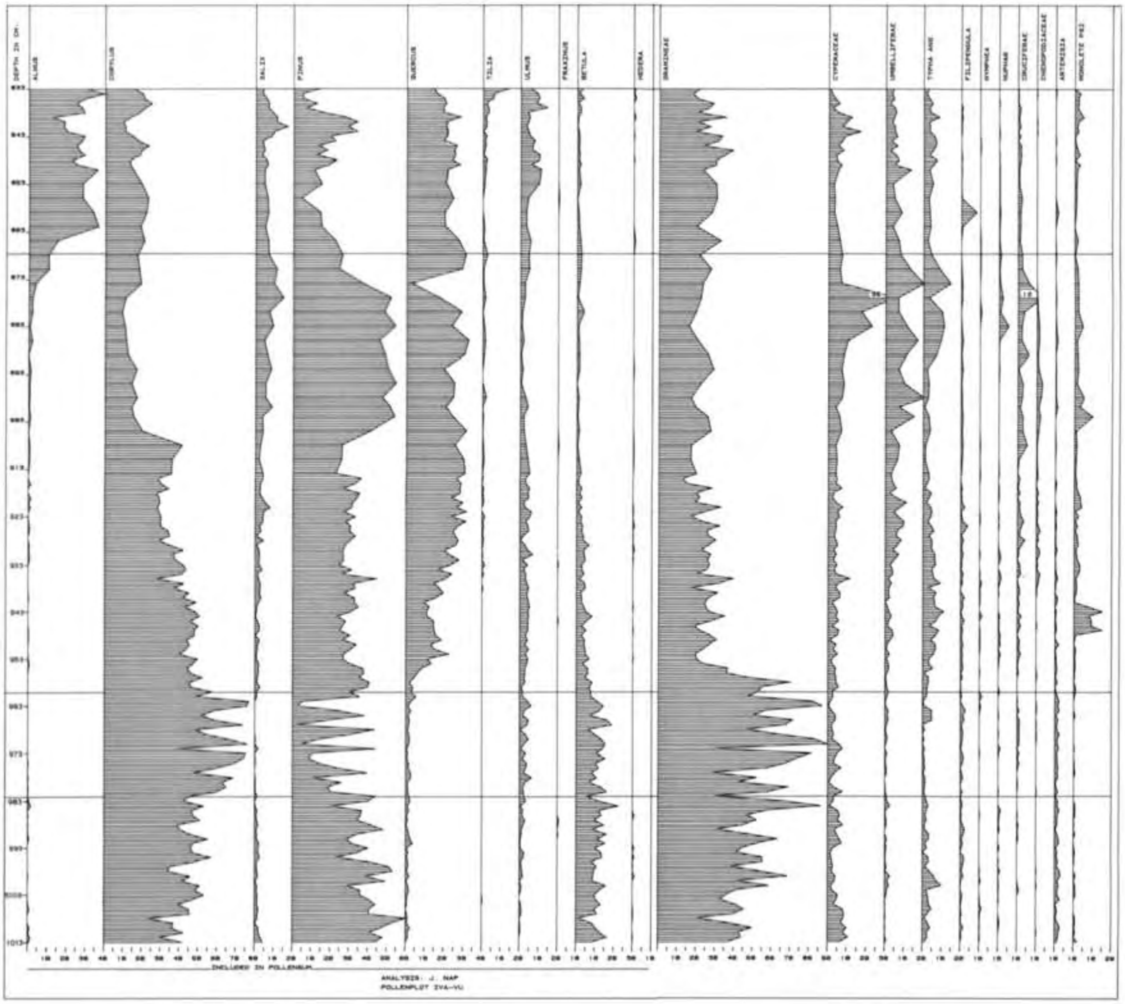


Fig. o. Pollen diagram of boring Leerdam S322 II (selected curves). For lithology and zones, see Fig. 19.

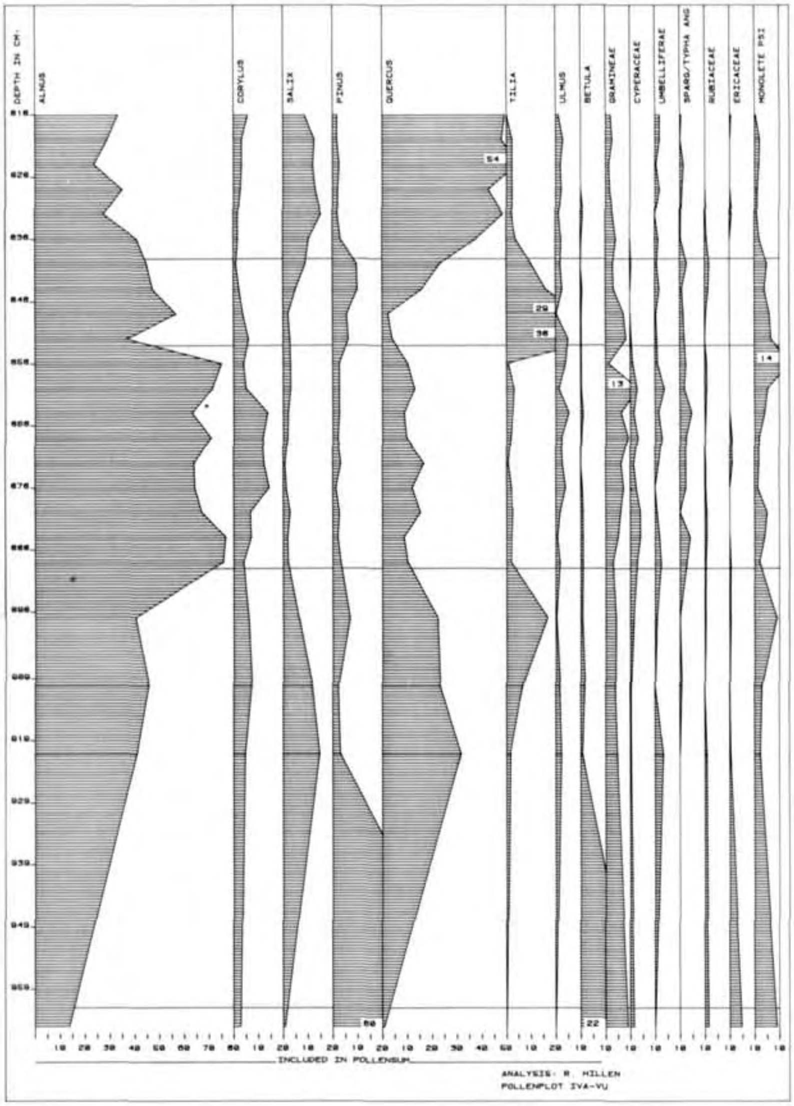


Fig. p. Pollen diagram of boring Molenaarsgraaf H2178 (selected curves). For lithology and zones, see Fig. 21.

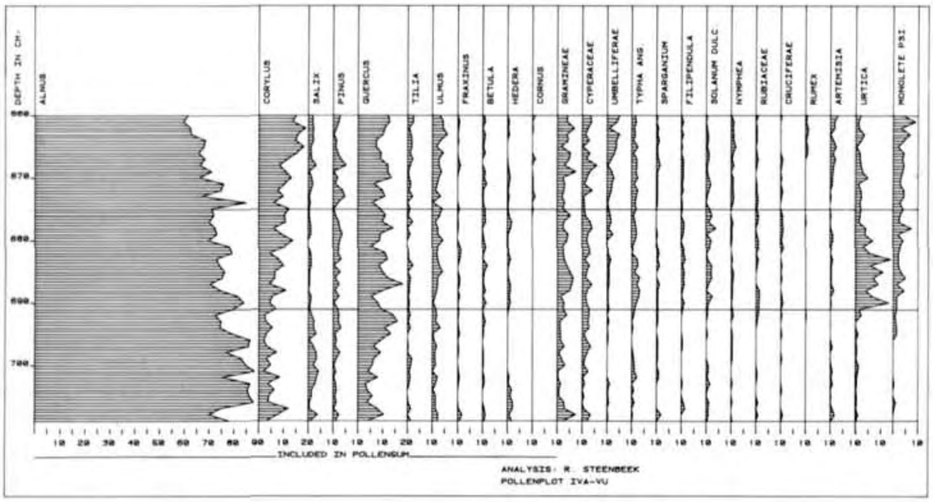


Fig. q. Pollen diagram of boring Molenaarsgraaf H2114 (selected curves). For lithology and zones, see Fig. 25.

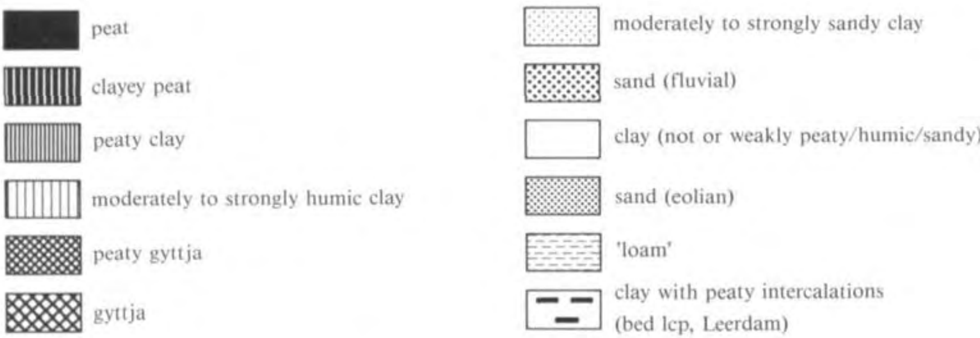


Fig. 9. Legend for lithology in all profiles.

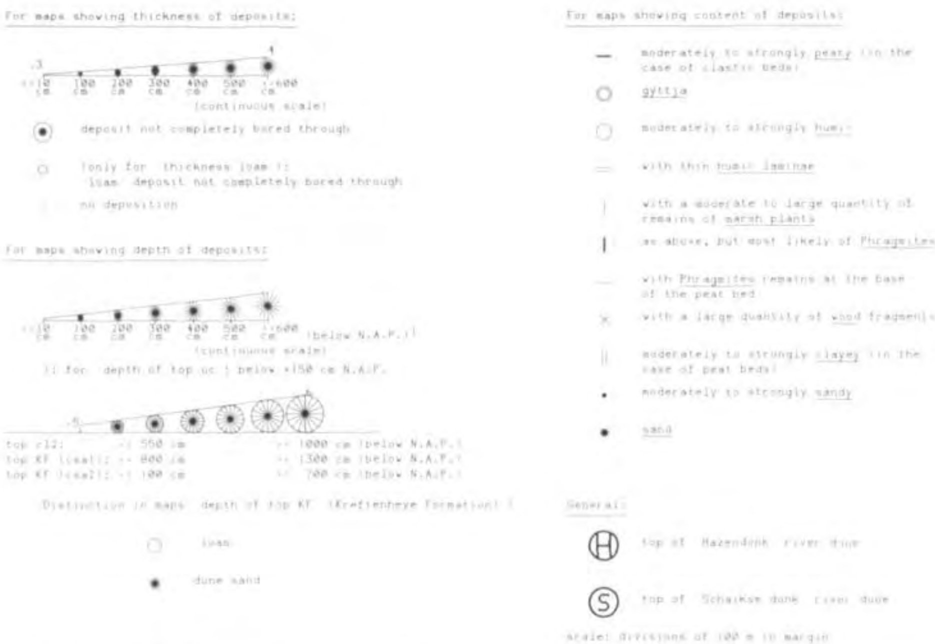
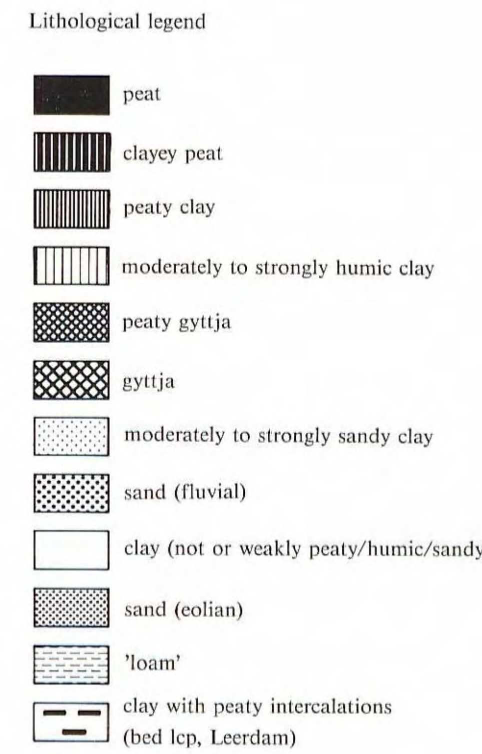


Fig. 35. Legend for all computer-symbol maps.



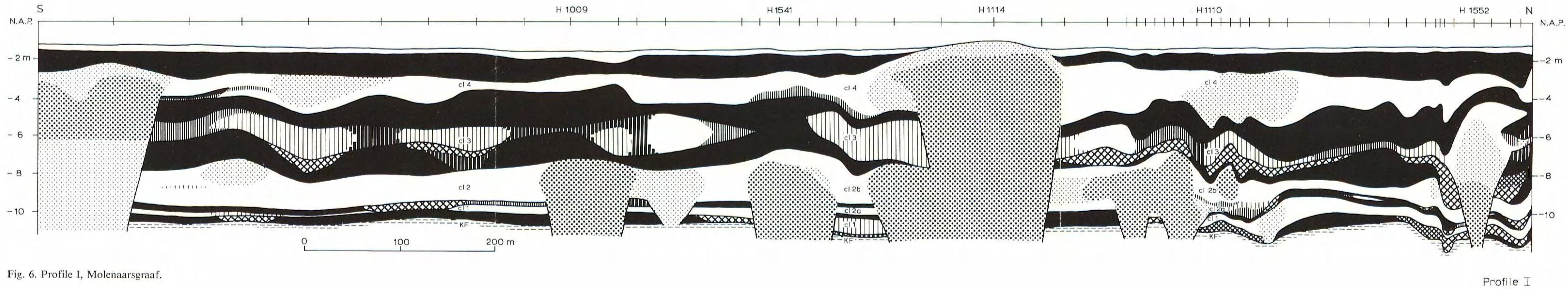


Fig. 6. Profile I, Molenaarsgraaf.

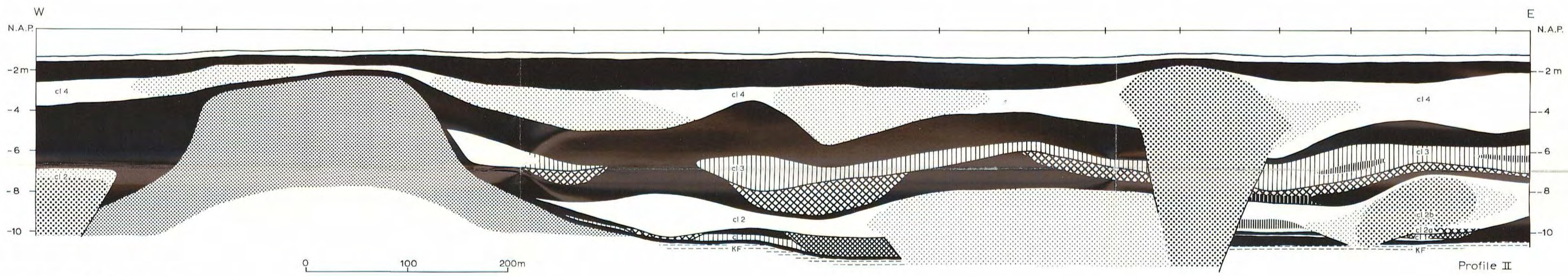


Fig. 7. Profile II, Molenaarsgraaf.

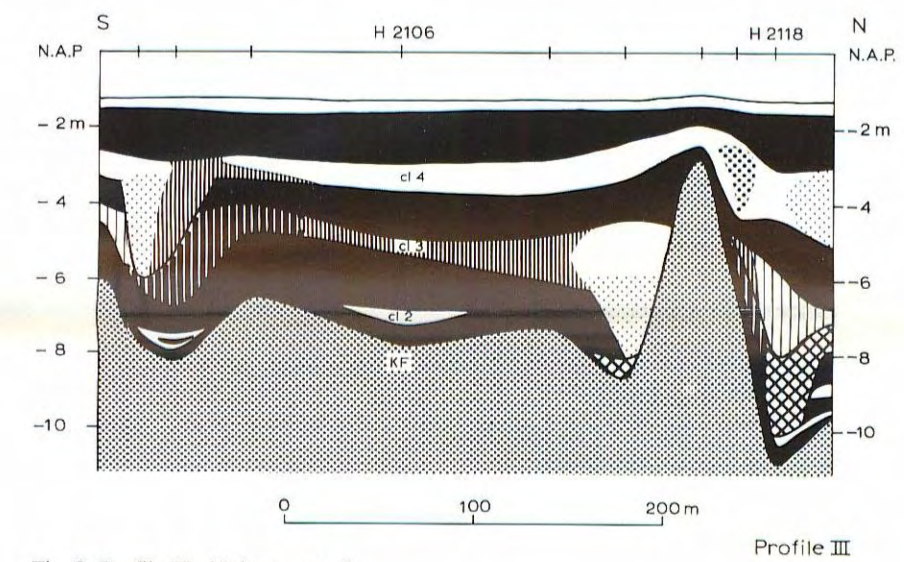


Fig. 8. Profile III, Molenaarsgraaf.

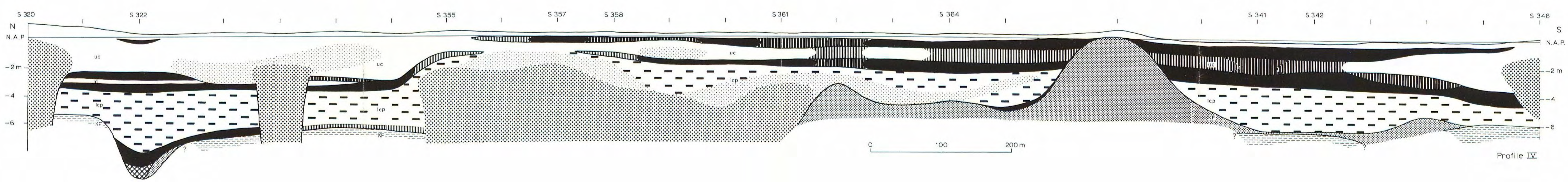


Fig. 10. Profile IV, Leerdam.

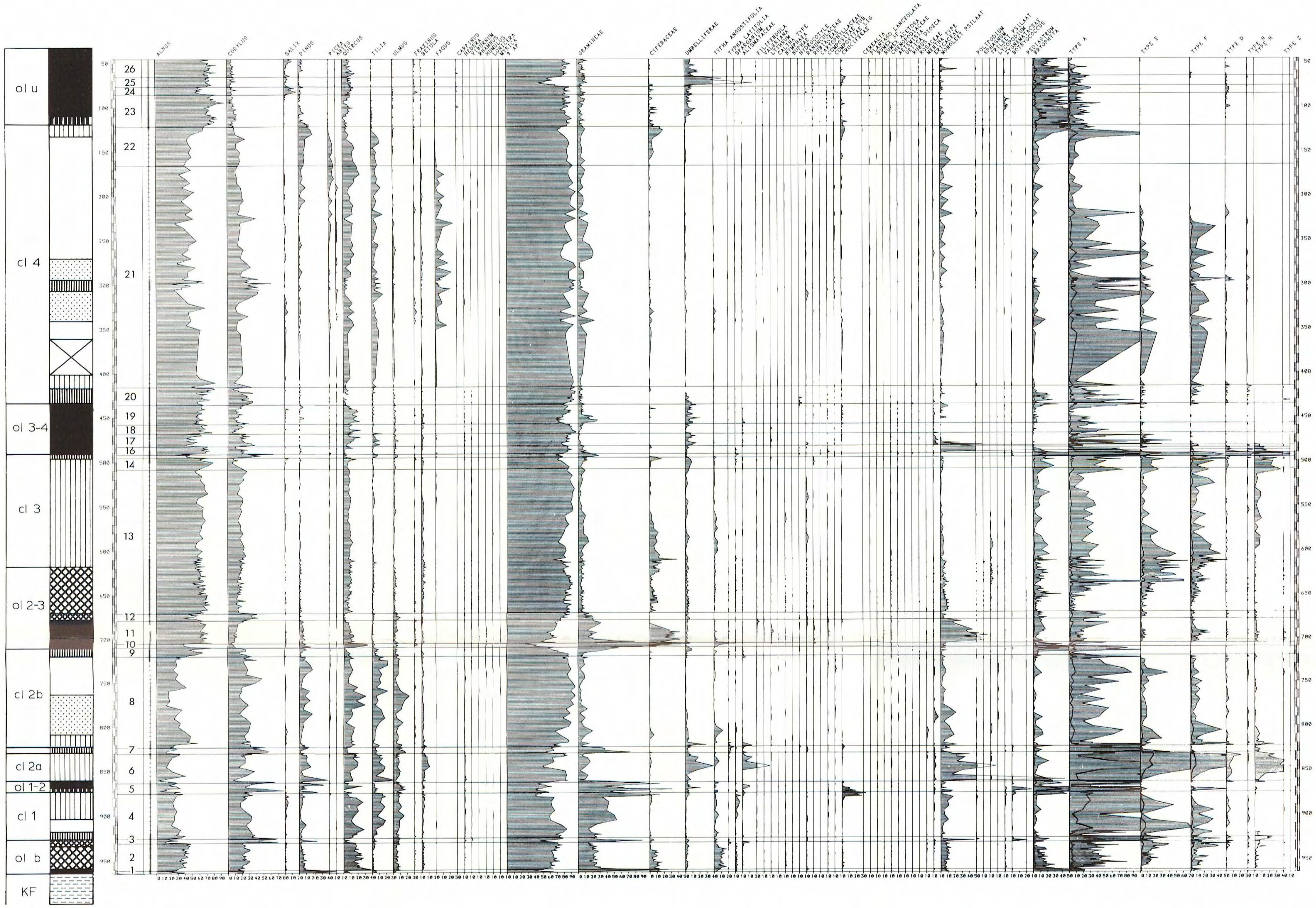


Fig. 12. Pollen diagram of boring Molenaarsgraaf H1110 (standard boring).

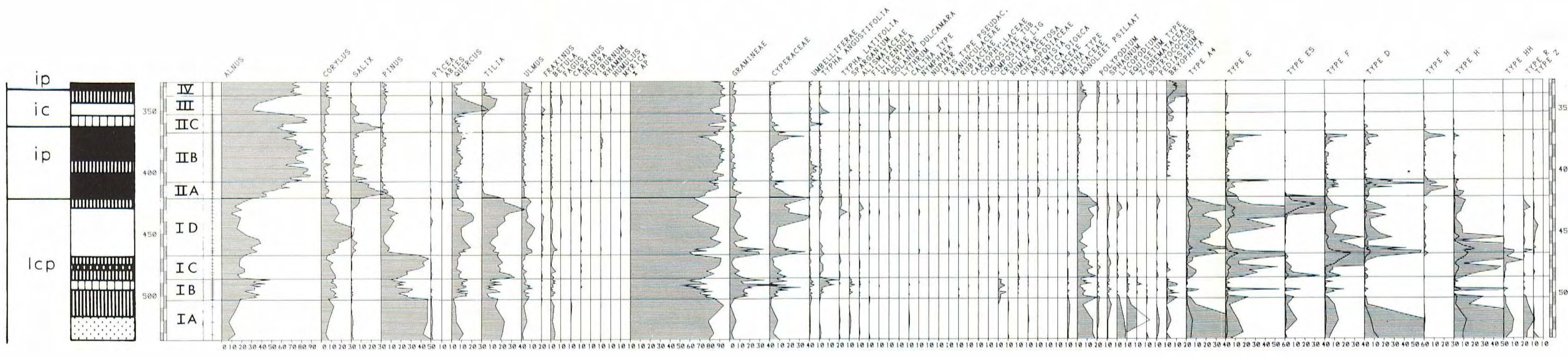


Fig. 15. Pollen diagram of boring Leerdam S322 I.

Lithological legend

- peat
- clayey peat
- peaty clay
- moderately to strongly humic clay
- peaty gyttja
- gyttja
- moderately to strongly sandy clay
- sand (fluvial)
- clay (not or weakly peaty/humic/sandy)
- sand (eolian)
- 'loam'
- clay with peaty intercalations (bed lcp, Leerdam)

Fig. 43. Molenaarsgraaf, the period around 6300 BP.

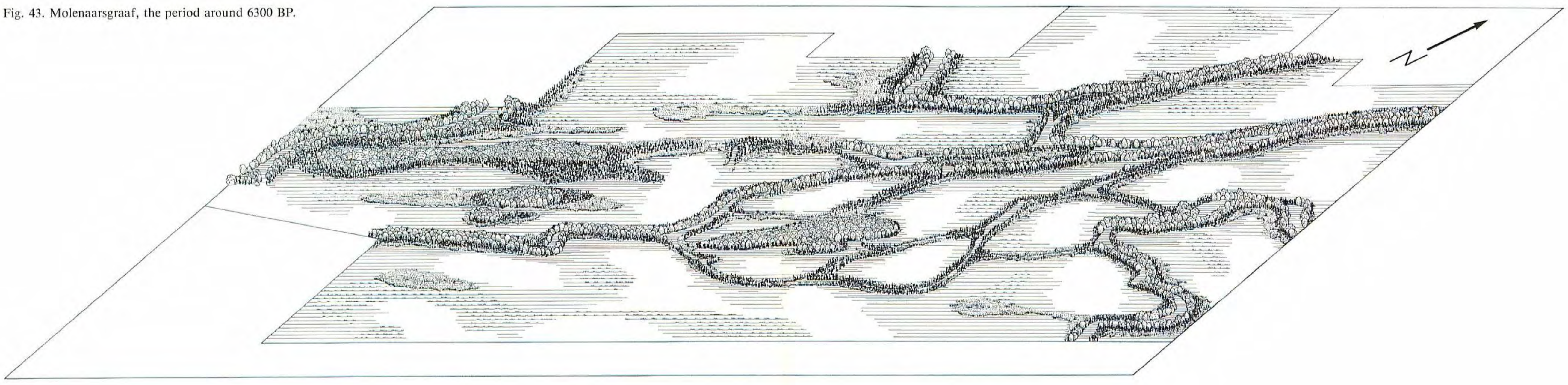


Fig. 47. Molenaarsgraaf, the period around 5300 BP.

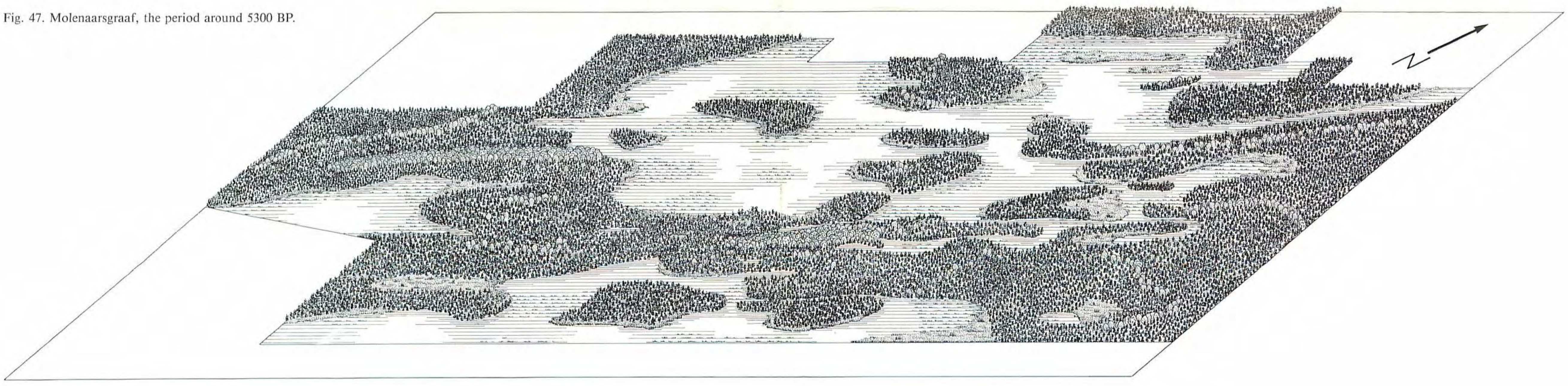


Fig. 50. Molenaarsgraaf, the period around 4800 to 4900 BP.

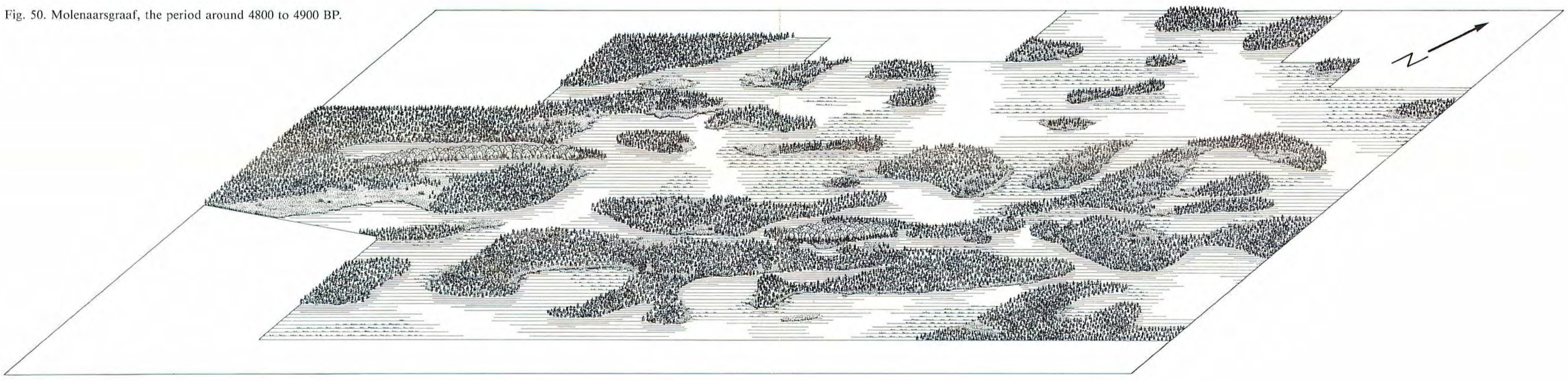
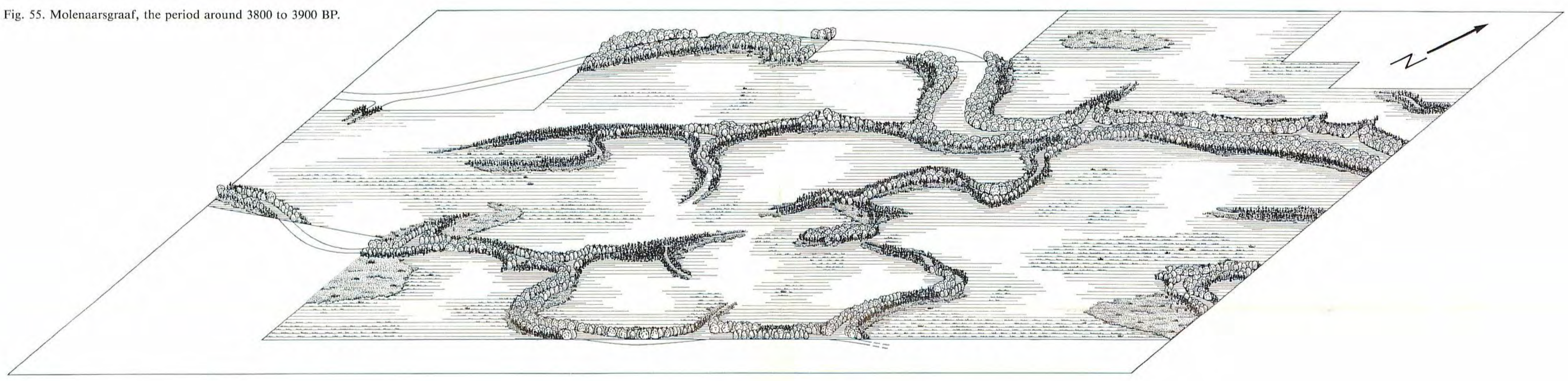
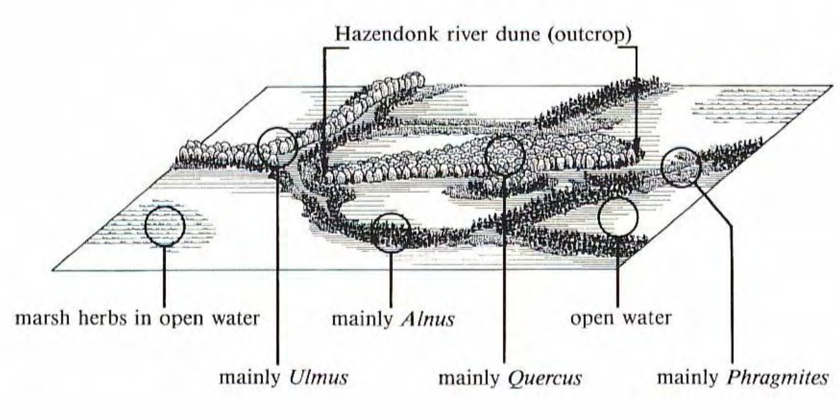


Fig. 55. Molenaarsgraaf, the period around 3800 to 3900 BP.





Enclosure 4. Molenaarsgraaf, landscape reconstructions. Drawing by D.P. Ooijevaar.