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

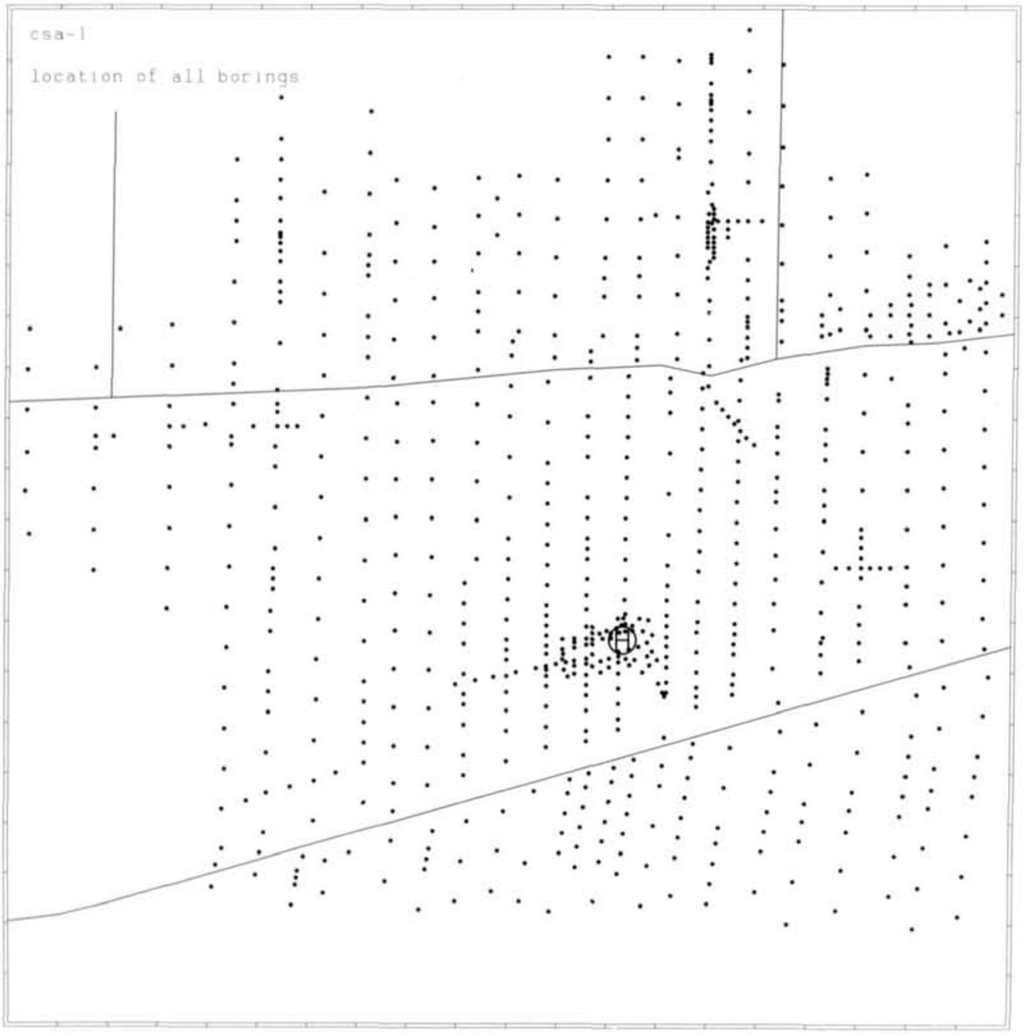

Fig. 33. Location of borings, Molenaarsgraaf. Many borings omitted at flank of Hazendonk river dune. See Fig. 3 for topographic details.

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

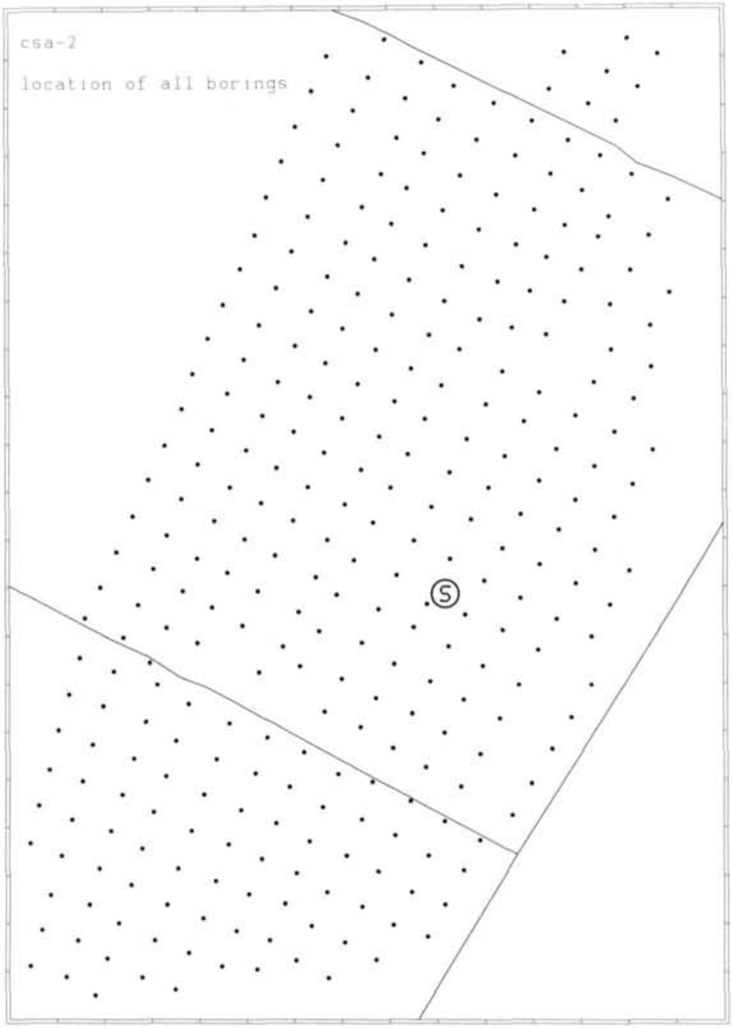

Fig. 34. Location of borings, Leerdam.
See Fig. 4 for topographic details.

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

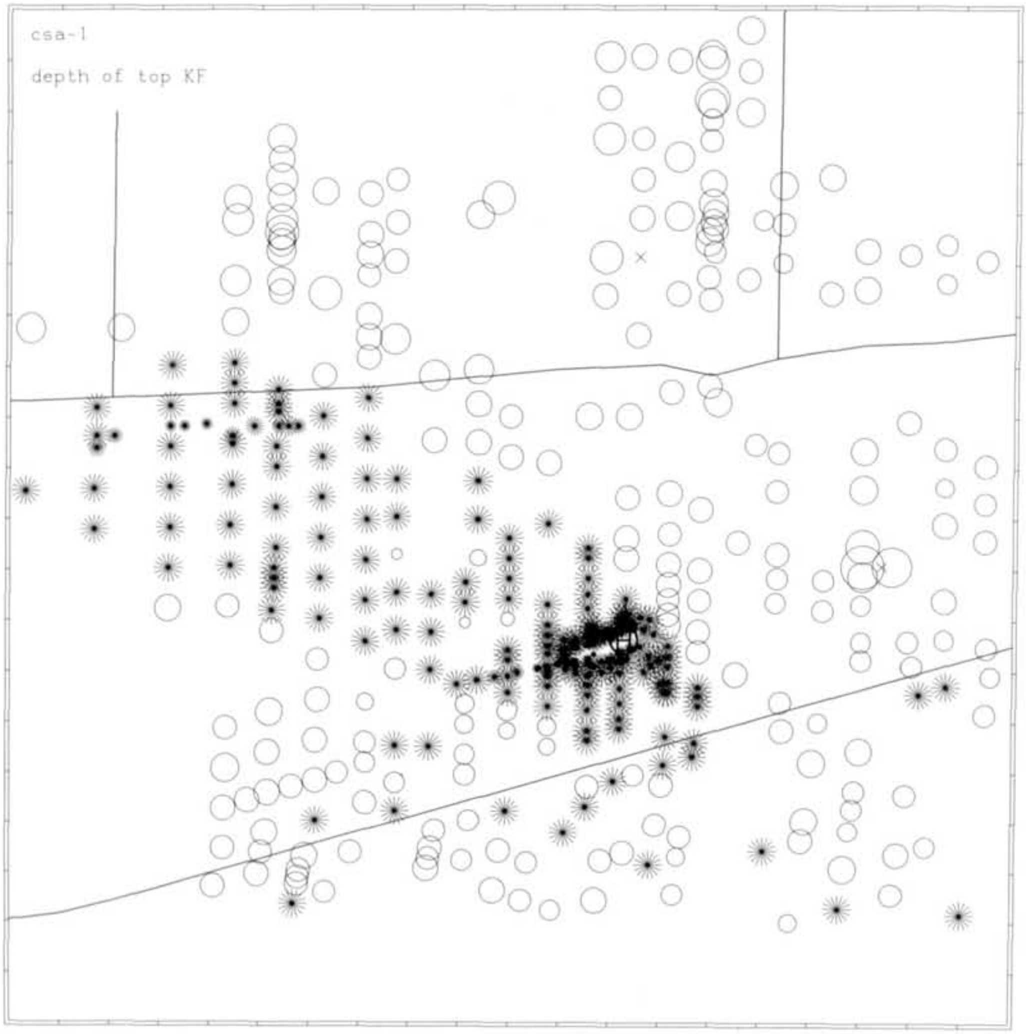

Fig. 36. Depth of the top of Kreftenheye Formation, Molenaarsgraaf. For legend, see Fig. *35; black stars: river-dune sand.

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.).

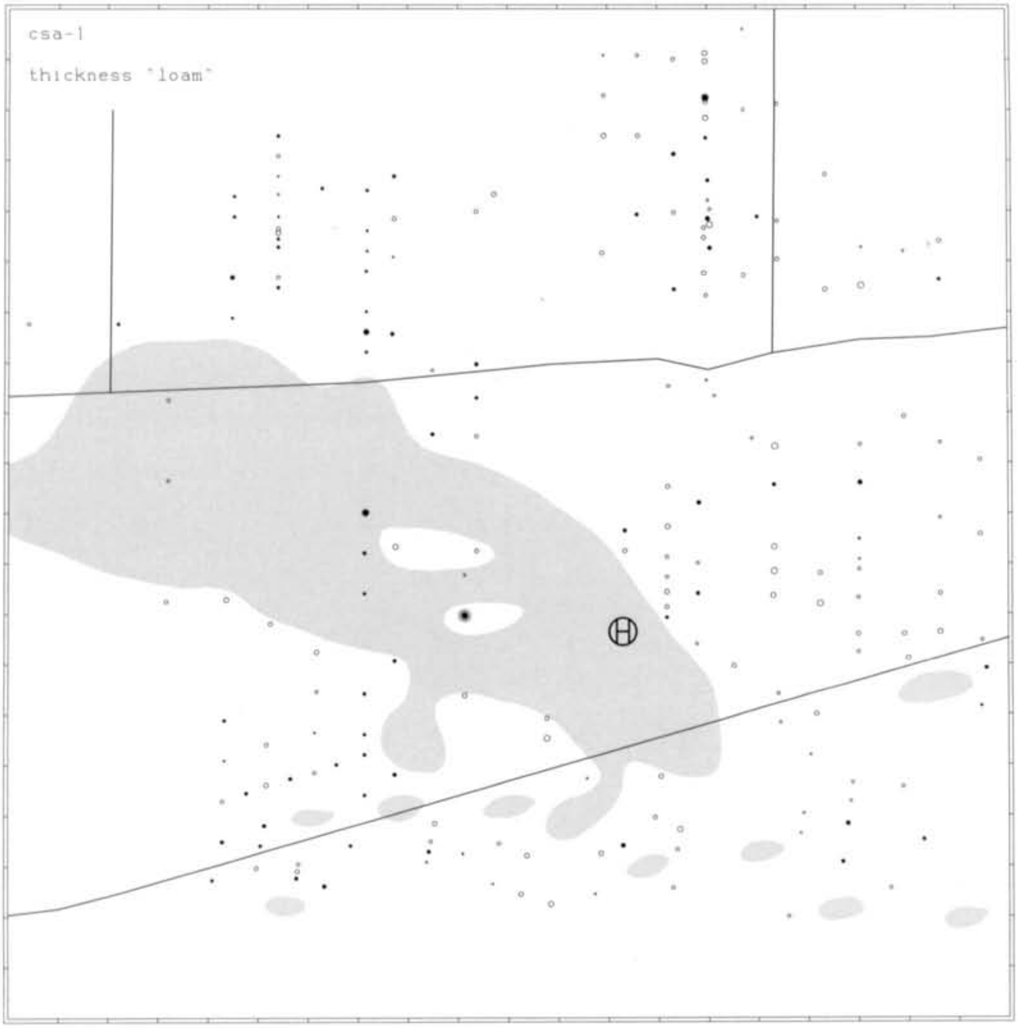

Fig. 37. Thickness of the *loam*, Molenaarsgraaf. For legend, see Fig. *35. Grey: river dunes.

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

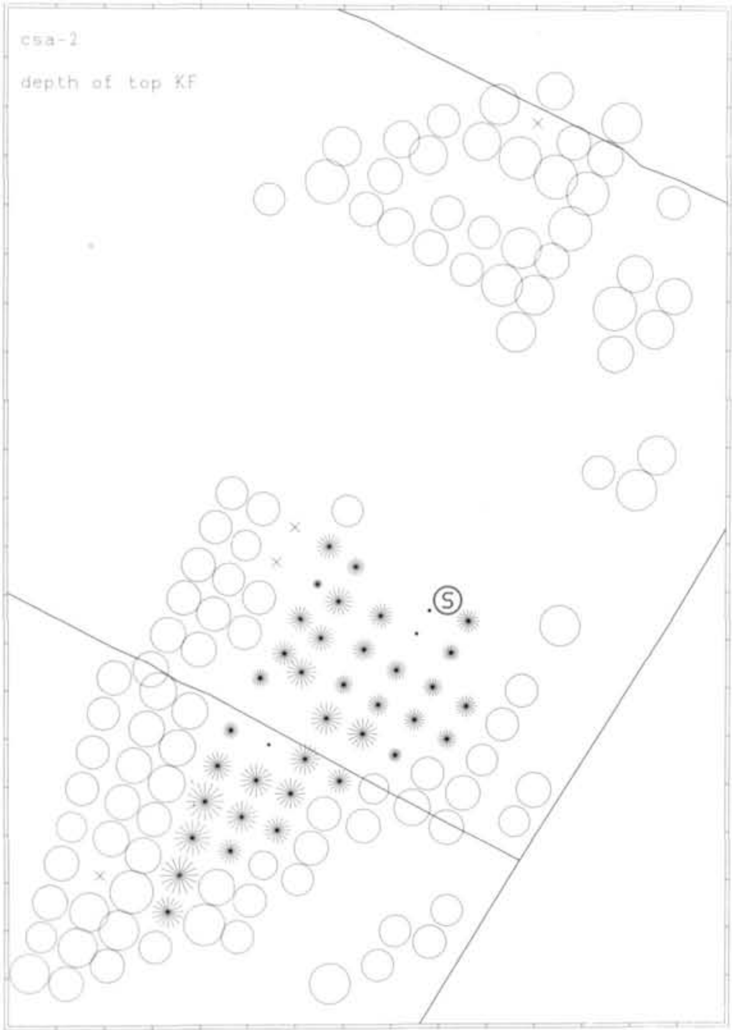

Fig. 38. Depth of the top of Kreftenheye Formation, Leerdam.
For legend, see Fig. *35.

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

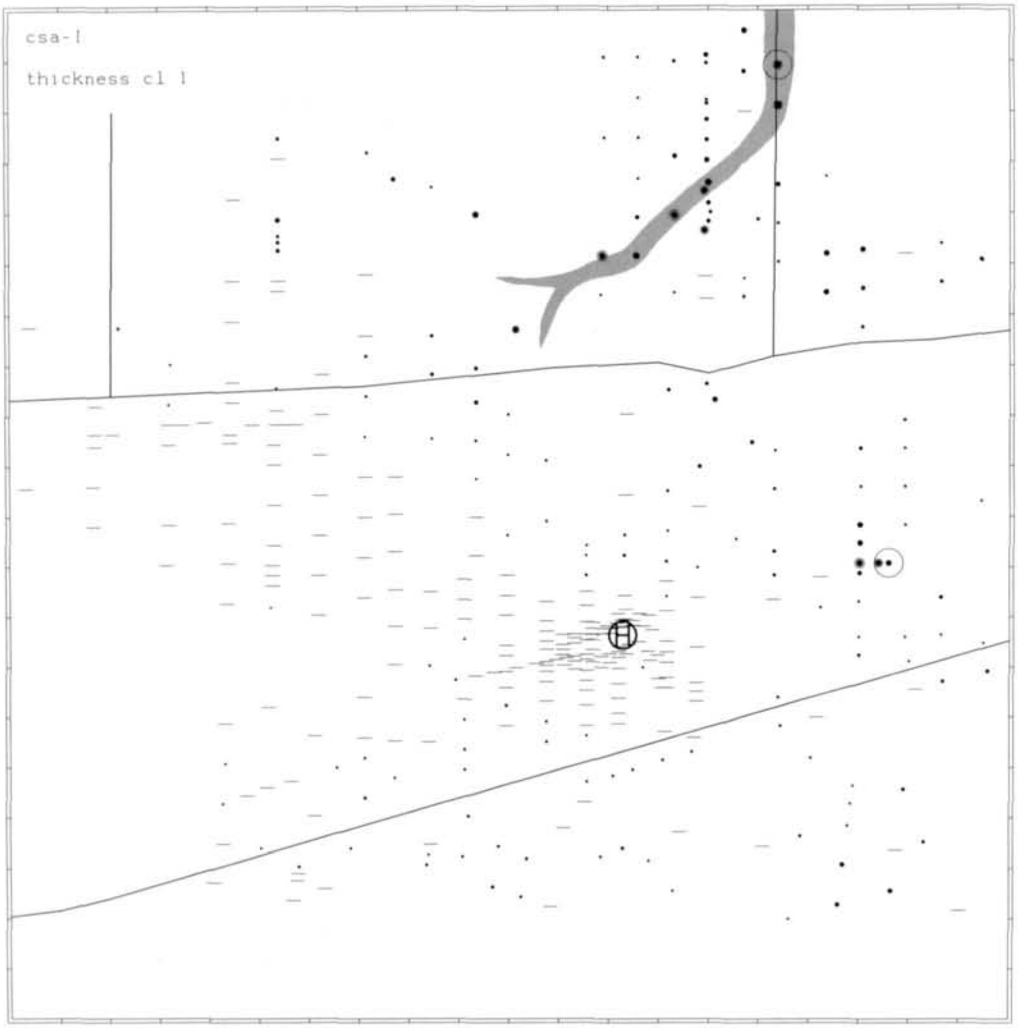

Fig. 39. Thickness of clastic bed cl 1, Molenaarsgraaf. For legend, see Fig. *35. Grey: stream ridge.

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-

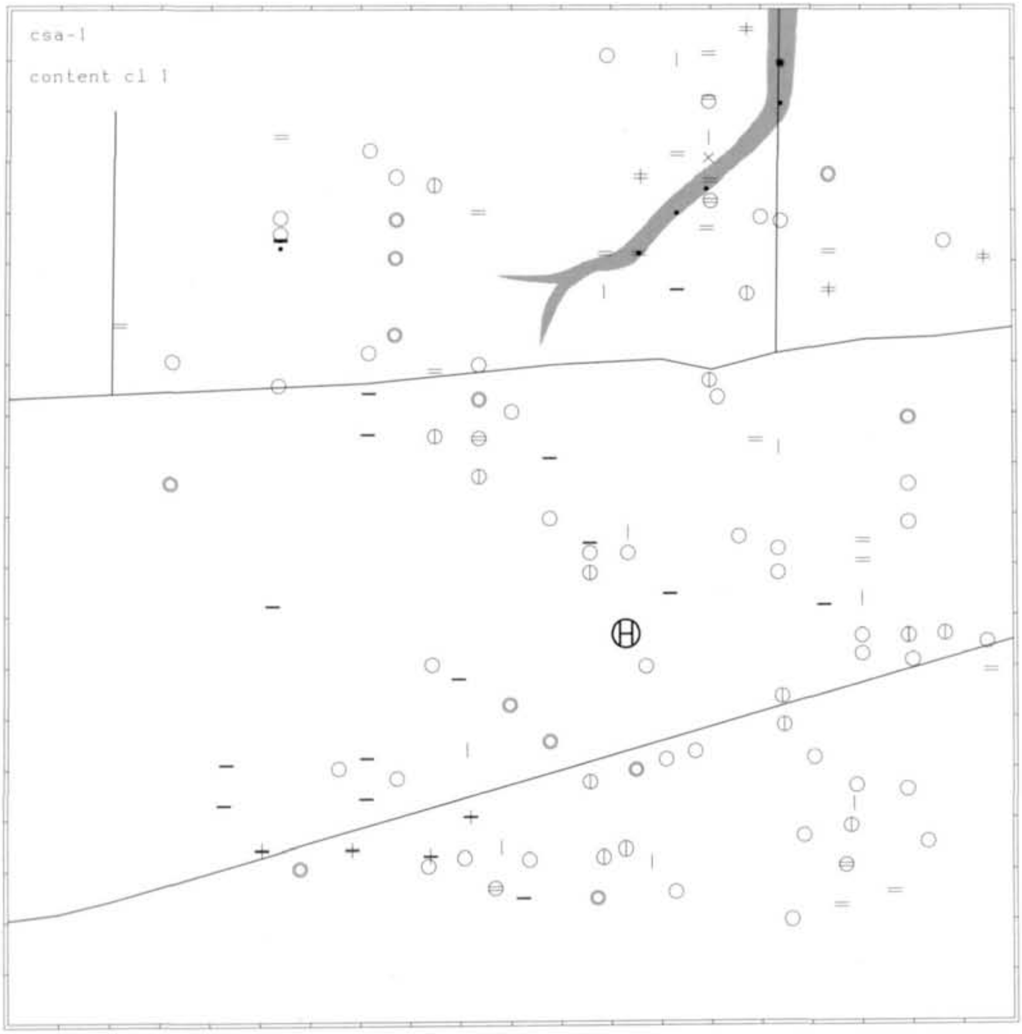

Fig. 40. Lithological content of clastic bed cl 1, Molenaarsgraaf. For legend, see Fig. *35. Grey: stream ridge.

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.

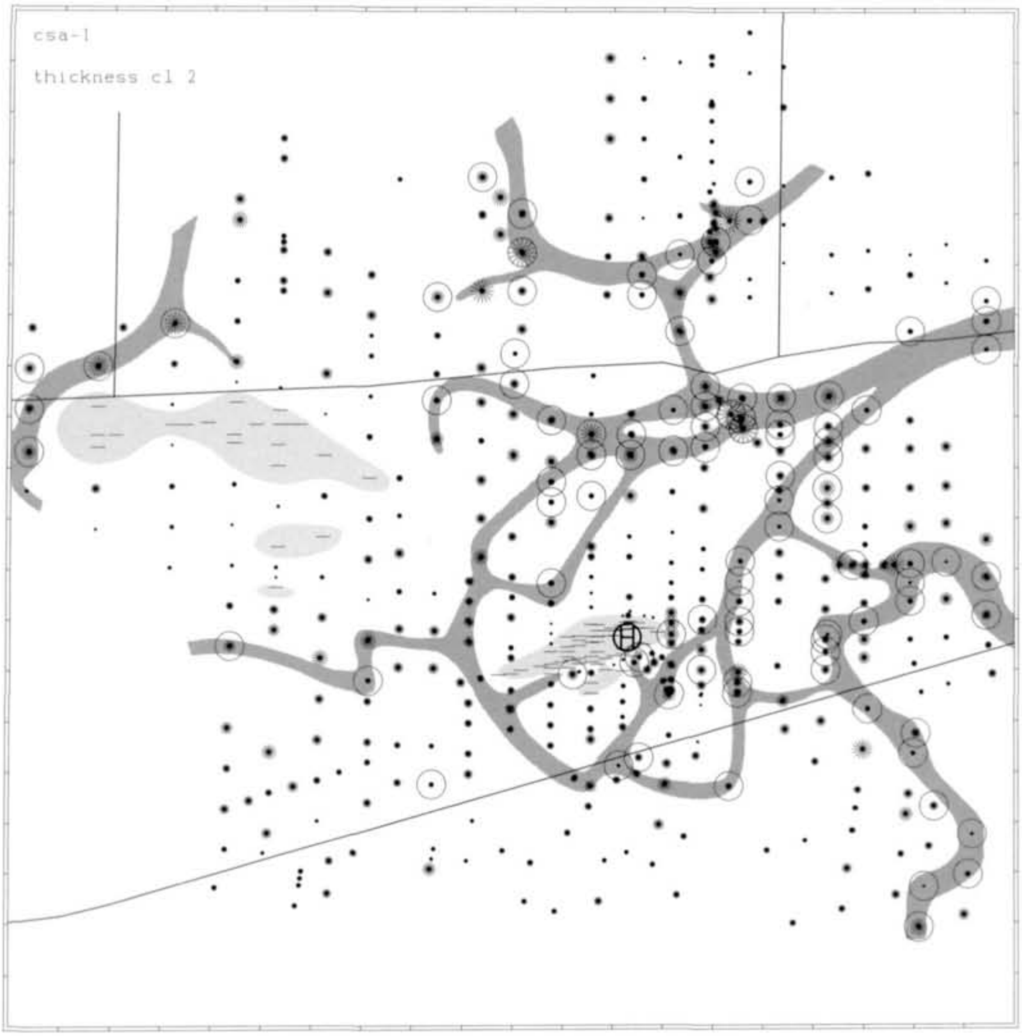

Fig. 41. Thickness of clastic bed cl 2, Molenaarsgraaf. For legend, see Fig. *35. Dark grey: stream ridges; light grey: river-dune outcrop.

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

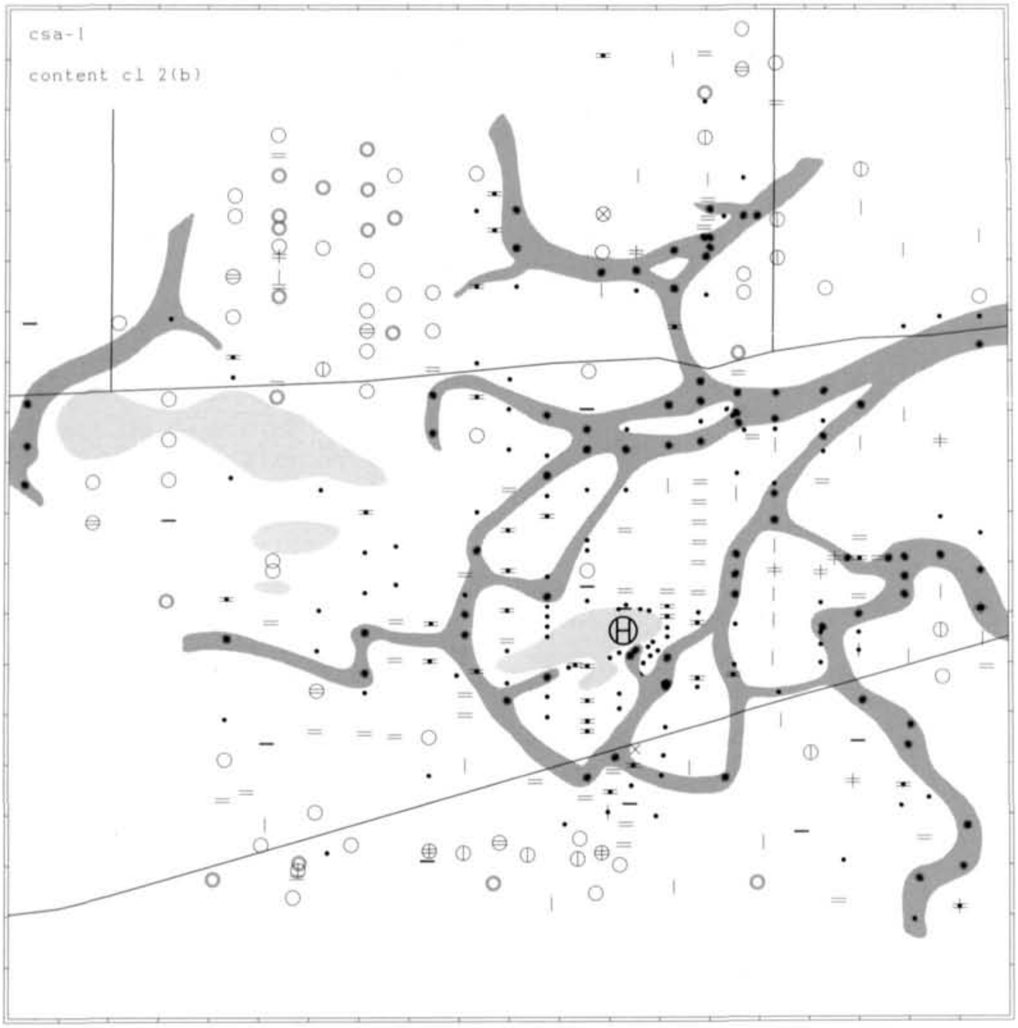

Fig. 42. Lithological content of clastic bed cl 2b, Molenaarsgraaf. For legend, see Fig. *35. Dark grey: stream ridges; light grey: river-dune outcrop.

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-

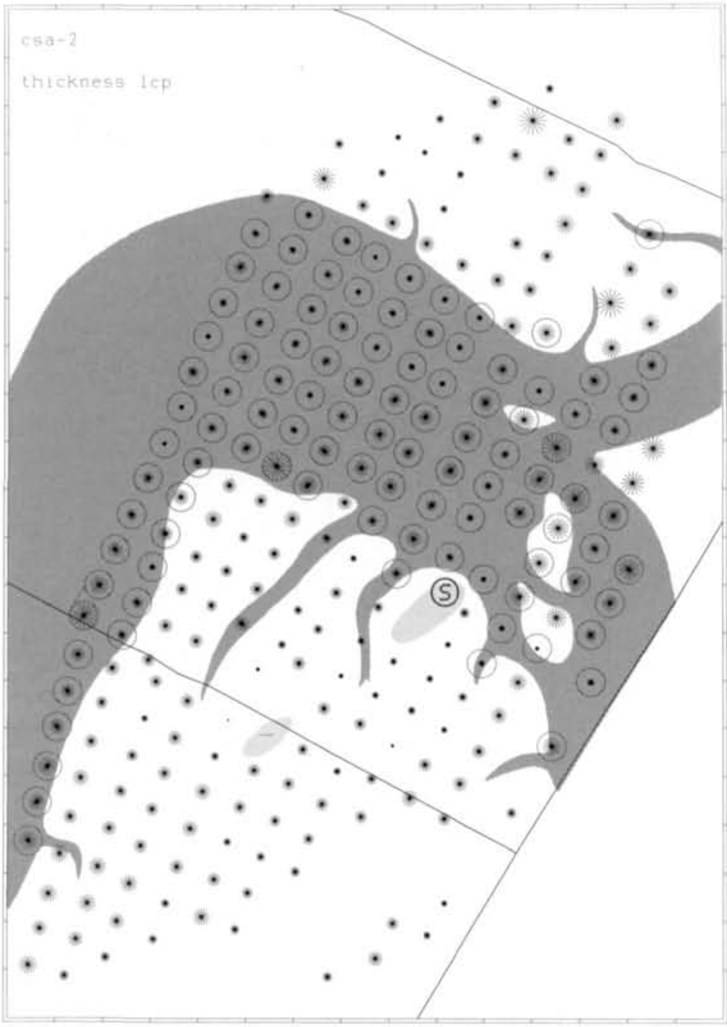

Fig. 44. Thickness of clastic bed lcp, Leerdam. For legend, see Fig. *35. Dark grey: stream ridge; light grey: river-dune outcrop.

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

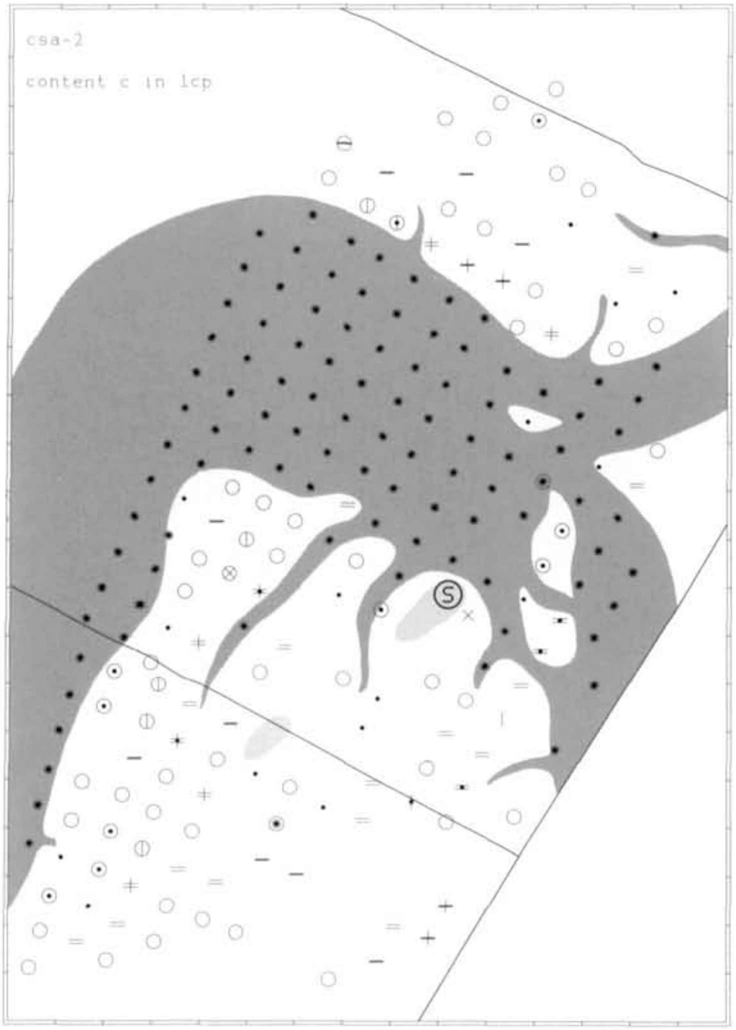

Fig. 45. Lithological content of clastic bed lcp, Leerdam. For legend, see Fig. *35. Dark grey: stream ridge; light grey: river-dune outcrop.

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.

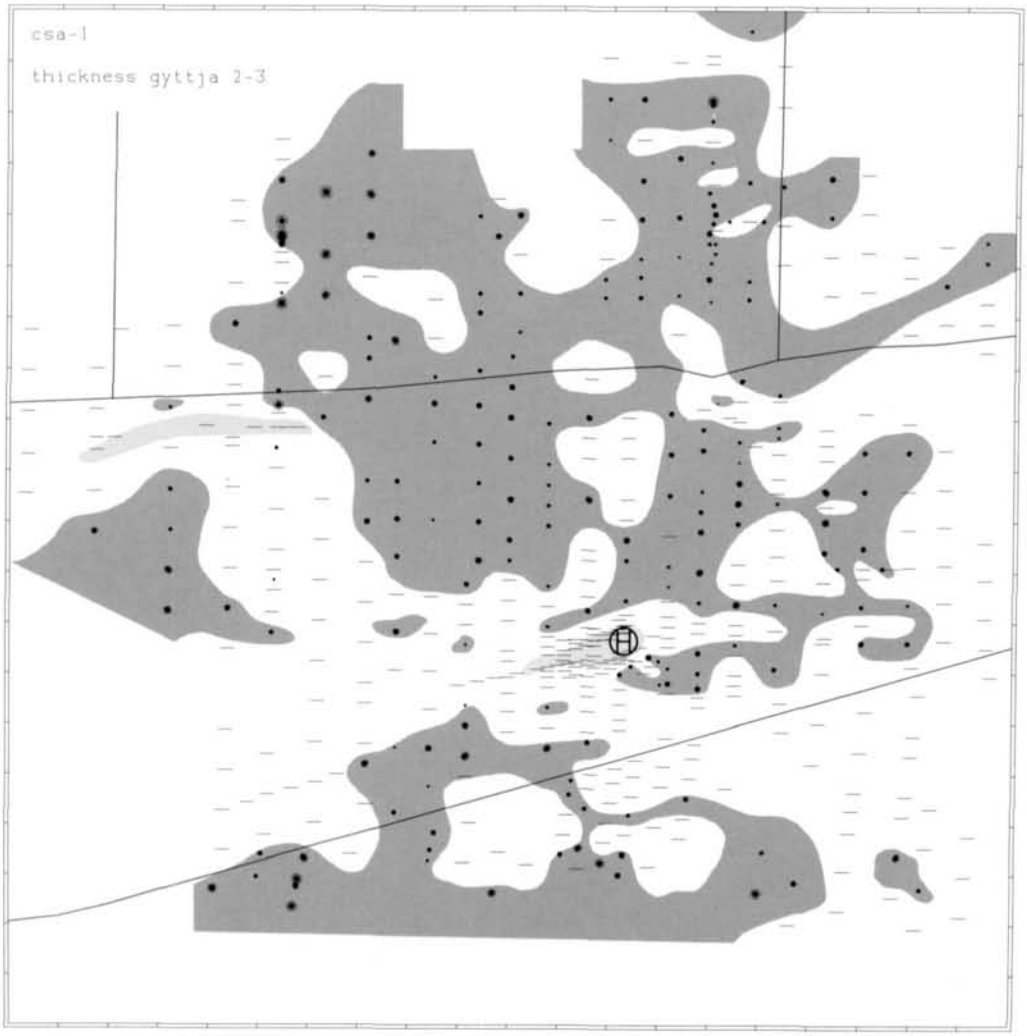

Fig. 46. Thickness of gyttja bed in organic bed ol 2-3, Molenaarsgraaf. For legend, see Fig. *35. Dark grey: extension of gyttja; light grey: river-dune outcrop.

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

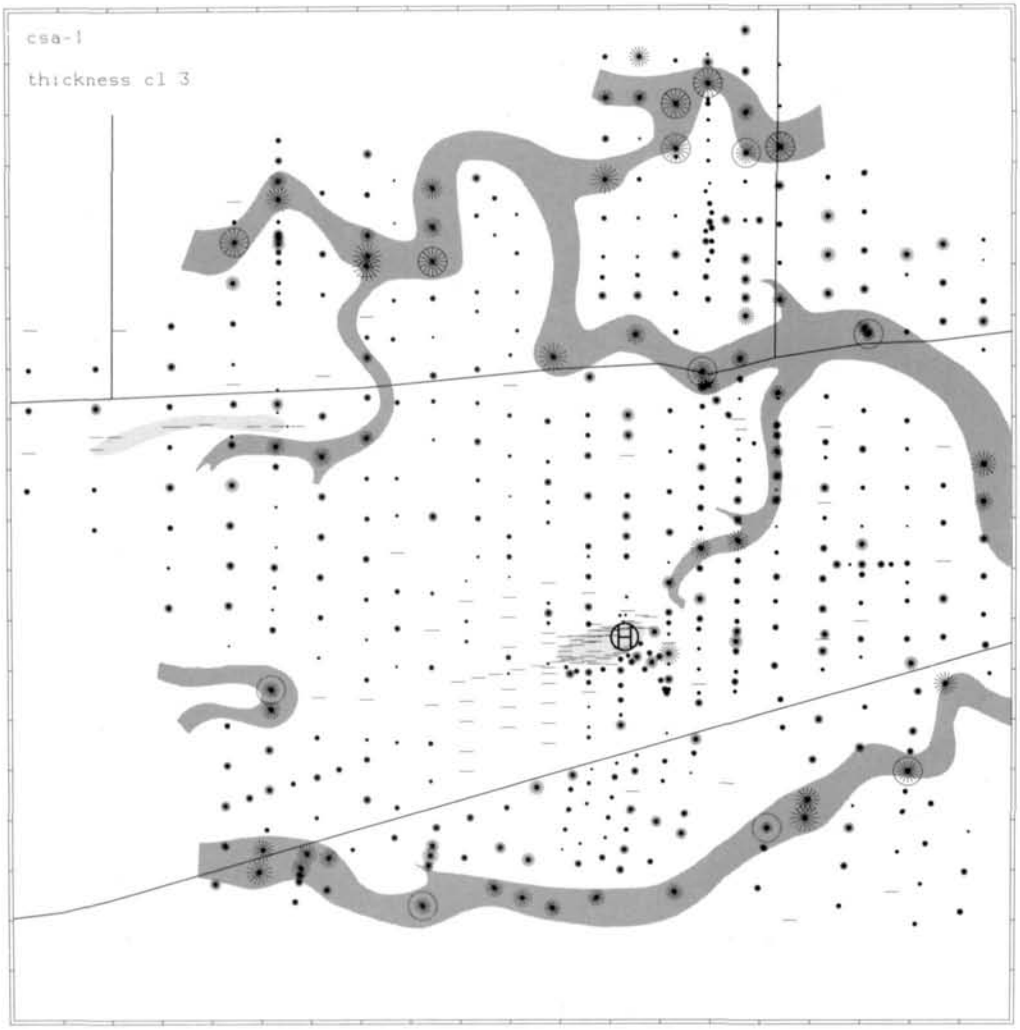

Fig. 48. Thickness of clastic bed cl 3, Molenaarsgraaf. For legend, see Fig. *35. Dark grey: sandy channel deposits; light grey: river-dune outcrop.

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

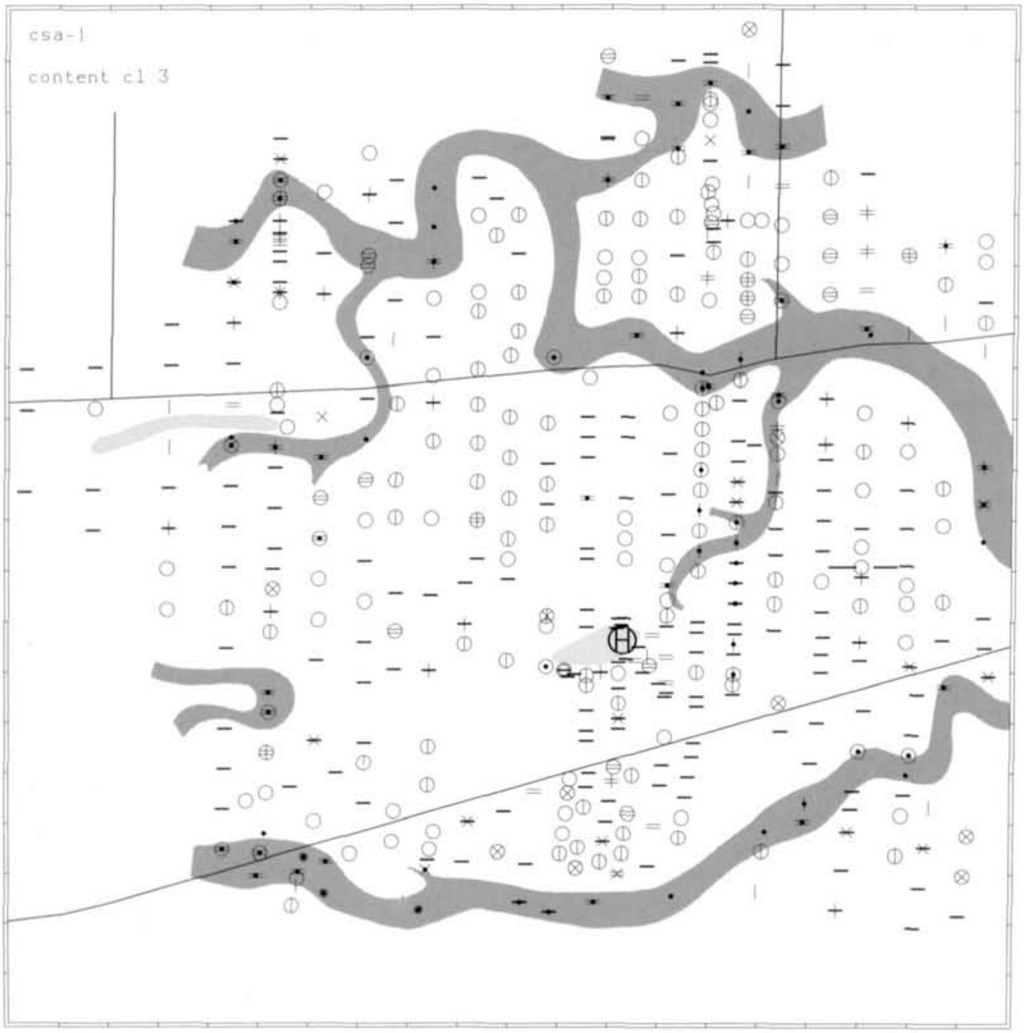

Fig. 49. Lithological content of clastic bed cl 3, Molenaarsgraaf. For legend, see Fig. *35. Dark grey: sandy channel deposits; light grey: river-dune outcrop.

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

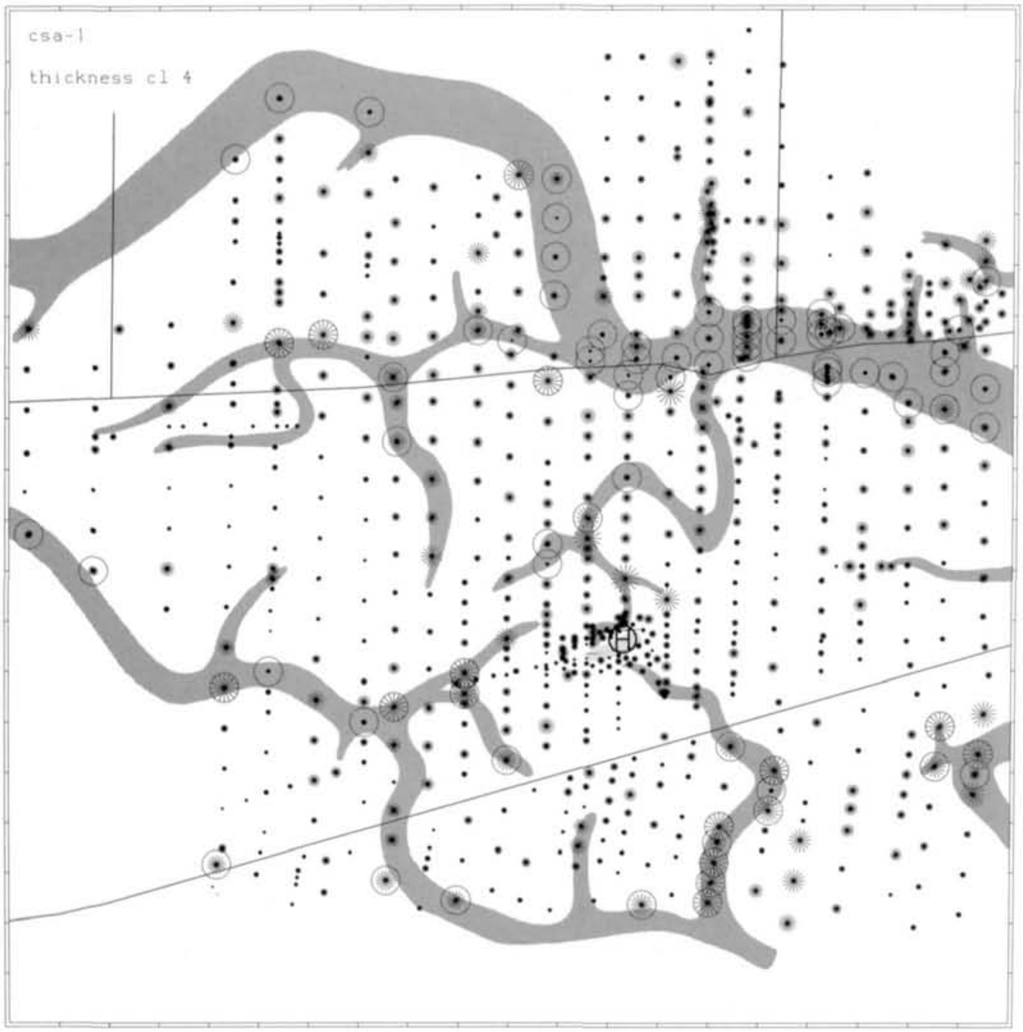

Fig. 51. Thickness of clastic bed cl 4, Molenaarsgraaf. For legend, see Fig. *35. Dark grey: stream ridges; light grey: river-dune outcrop.

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-

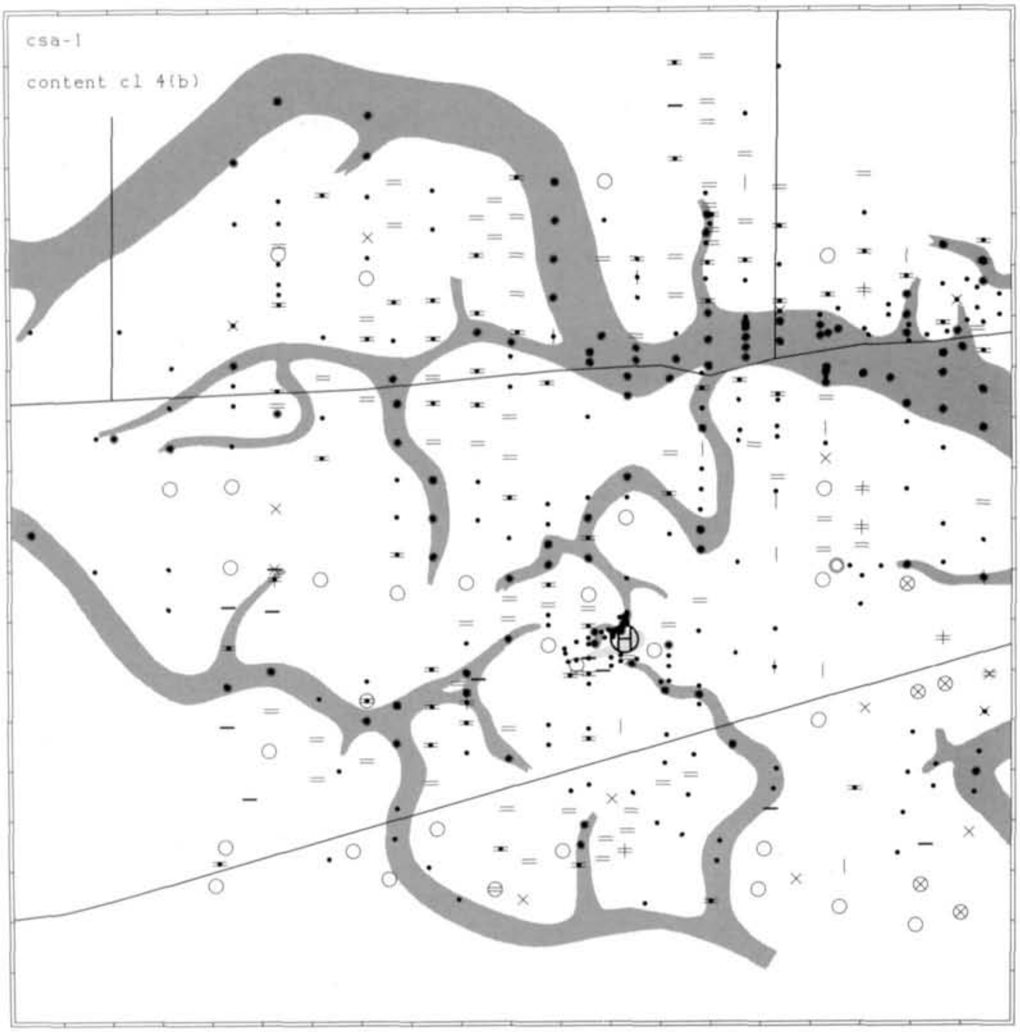

Fig. 52. Lithological content of clastic bed cl 4, Molenaarsgraaf. For legend, see Fig. *35. Dark grey: stream ridges; light grey: river-dune outcrop.

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

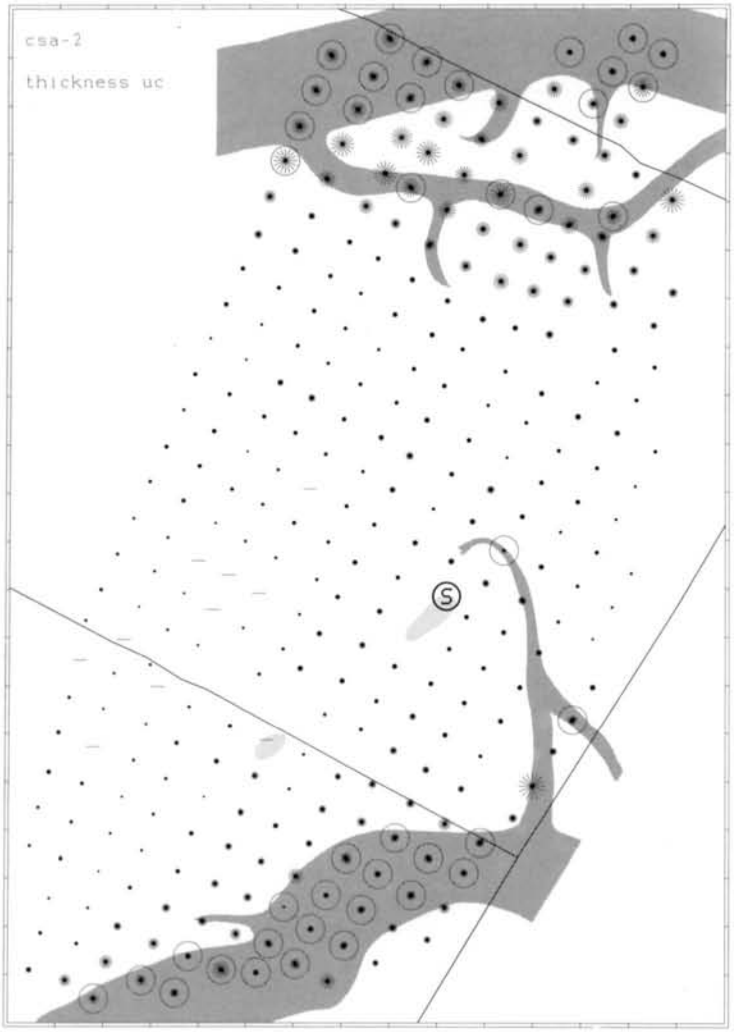

Fig. 53. Thickness of clastic bed uc, Leerdam. For legend, see Fig. *35. Dark grey: stream ridges; light grey: river-dune outcrop.

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).

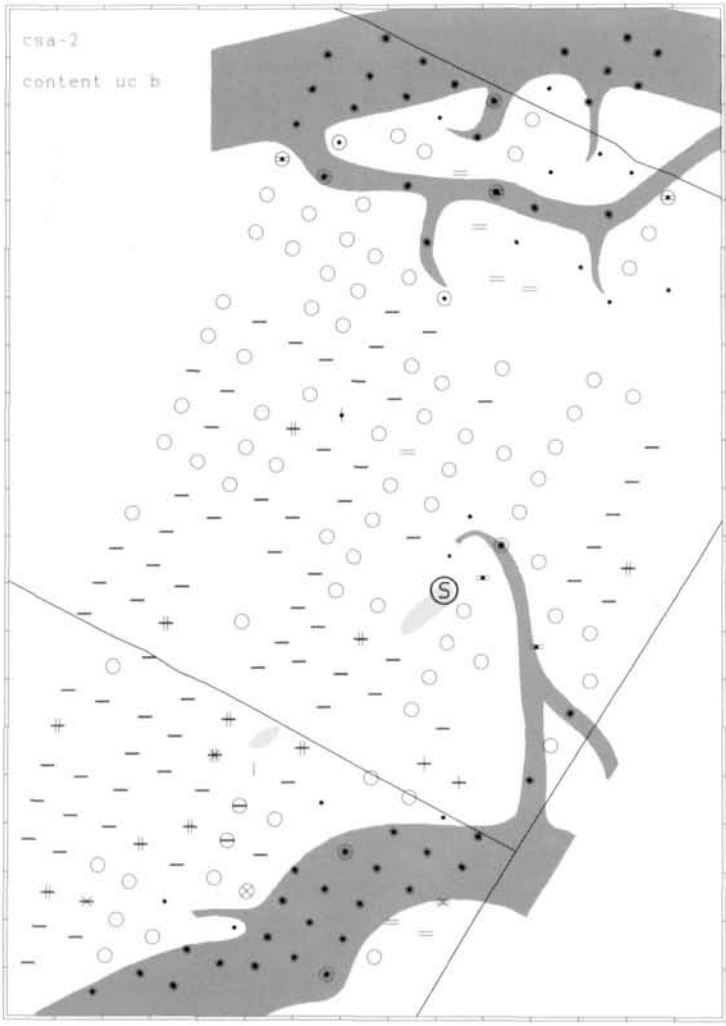

Fig. 54. Lithological content of clastic bed uc, Leerdam. For legend, see Fig. *35. Dark grey: stream ridges; light grey: river-dune outcrop.

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*.

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APPENDIX

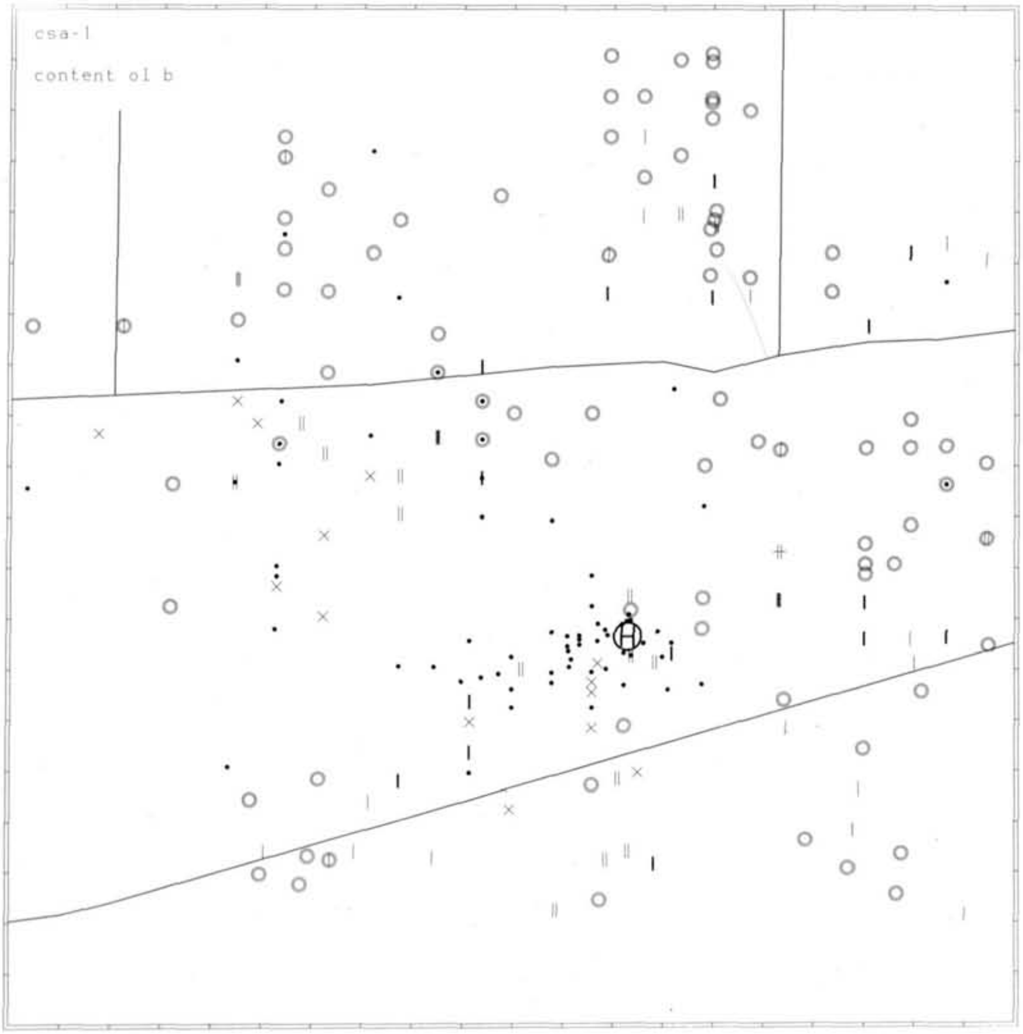


Fig. a. Lithological content of organic bed ol b, Molenaarsgraaf. For legend, see Fig. *35.

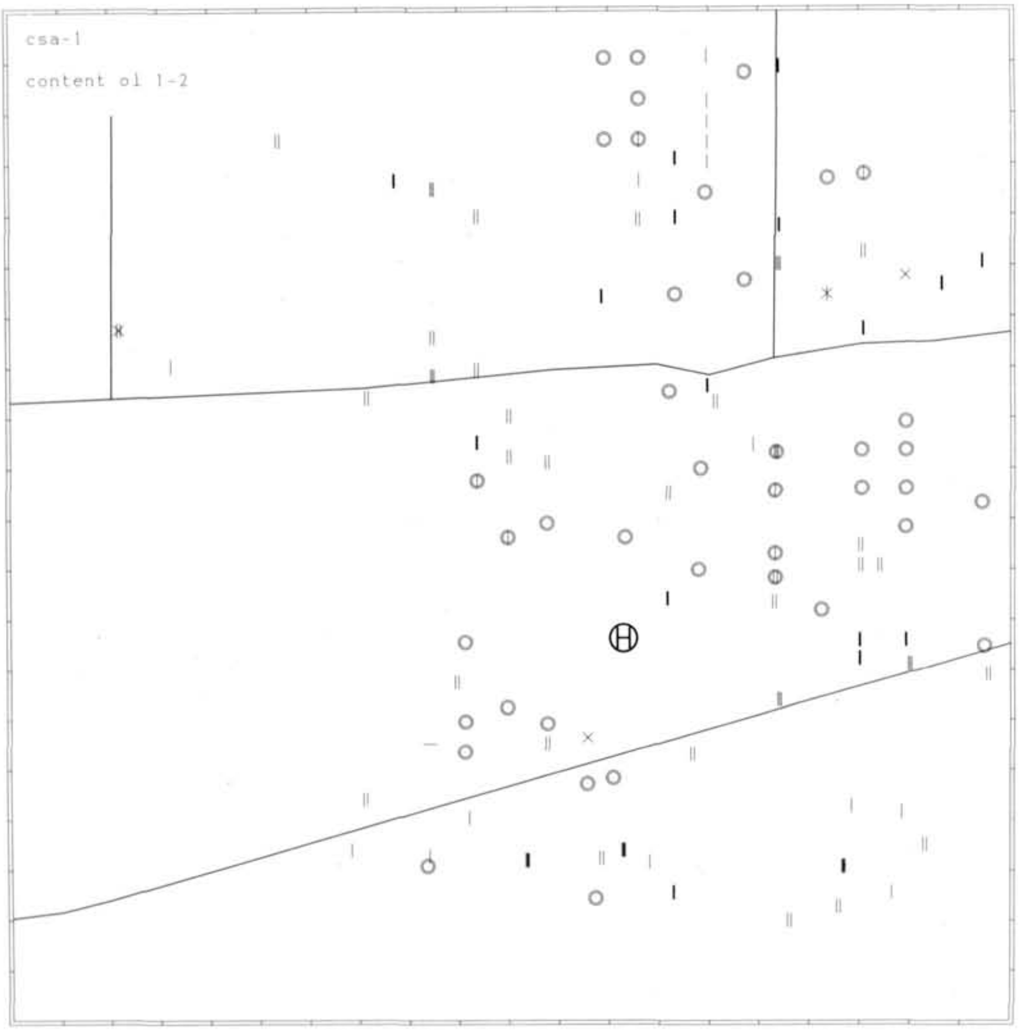


Fig. b. Lithological content of organic bed ol 1-2, Molenaarsgraaf. For legend, see Fig. *35.

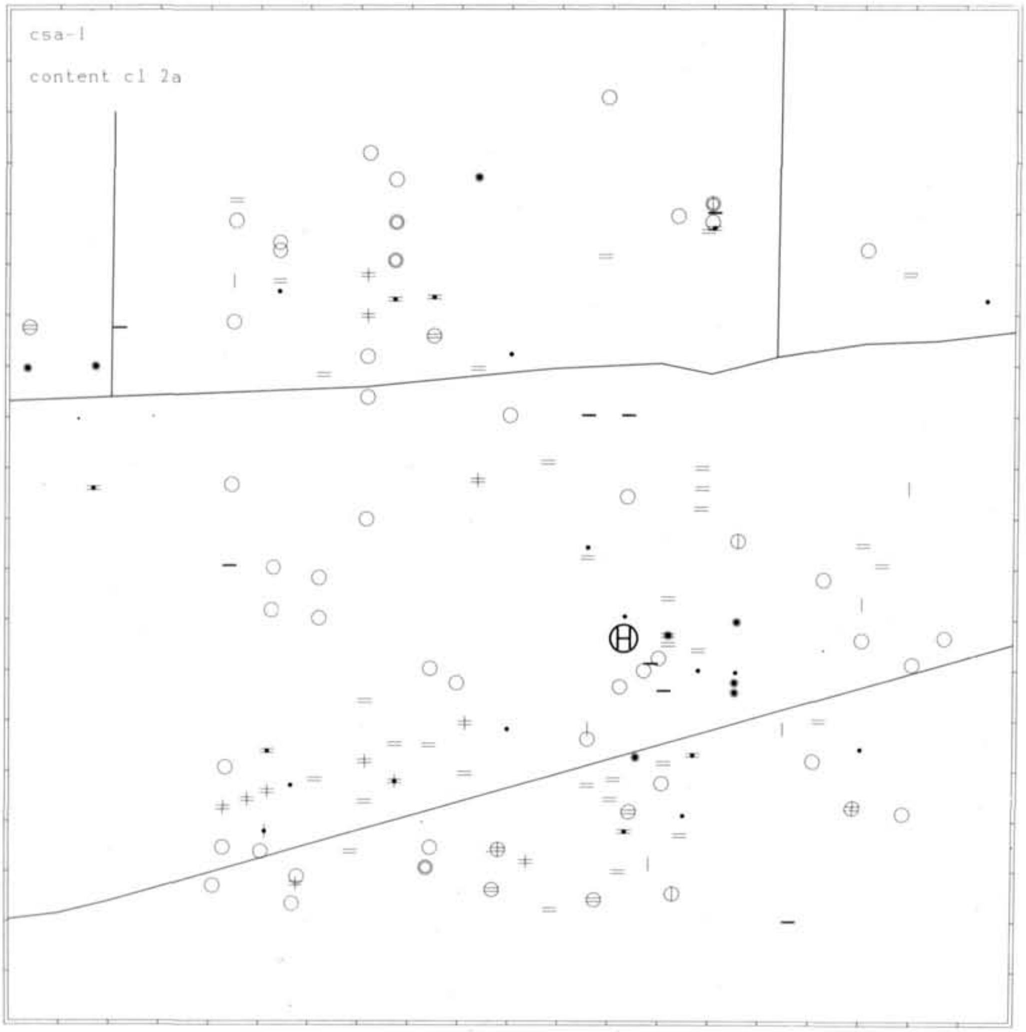


Fig. c. Lithological content of clastic bed cl 2a, Molenaarsgraaf. For legend, see Fig. *35.

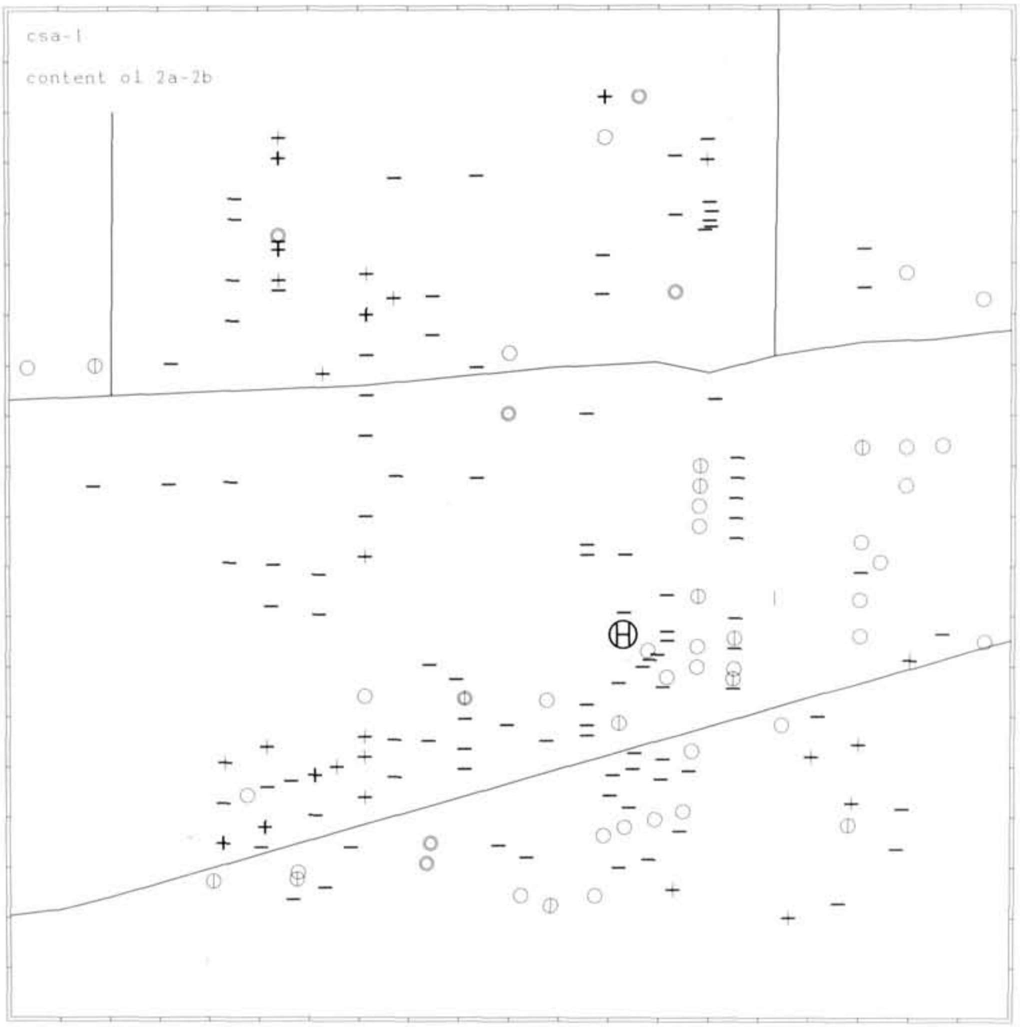


Fig. d. Lithological content of organic bed ol 2a-2b, Molenaarsgraaf. For legend, see Fig. *35.

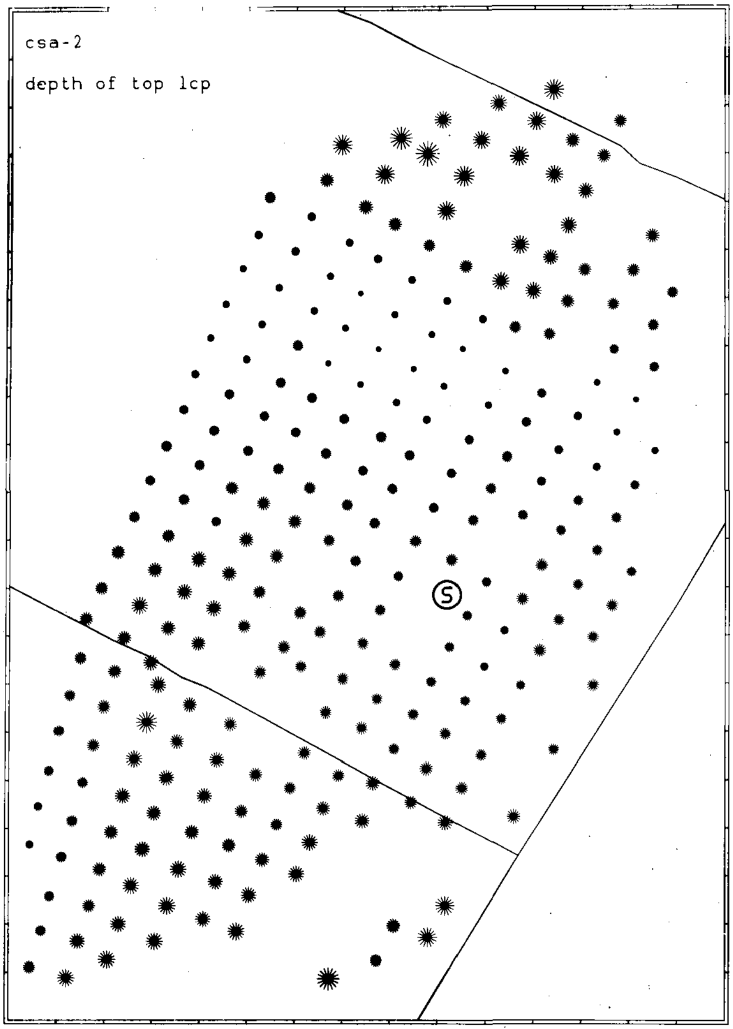


Fig. e. Depth of the top of clastic bed lcp, Leerdam. For legend, see Fig. *35.

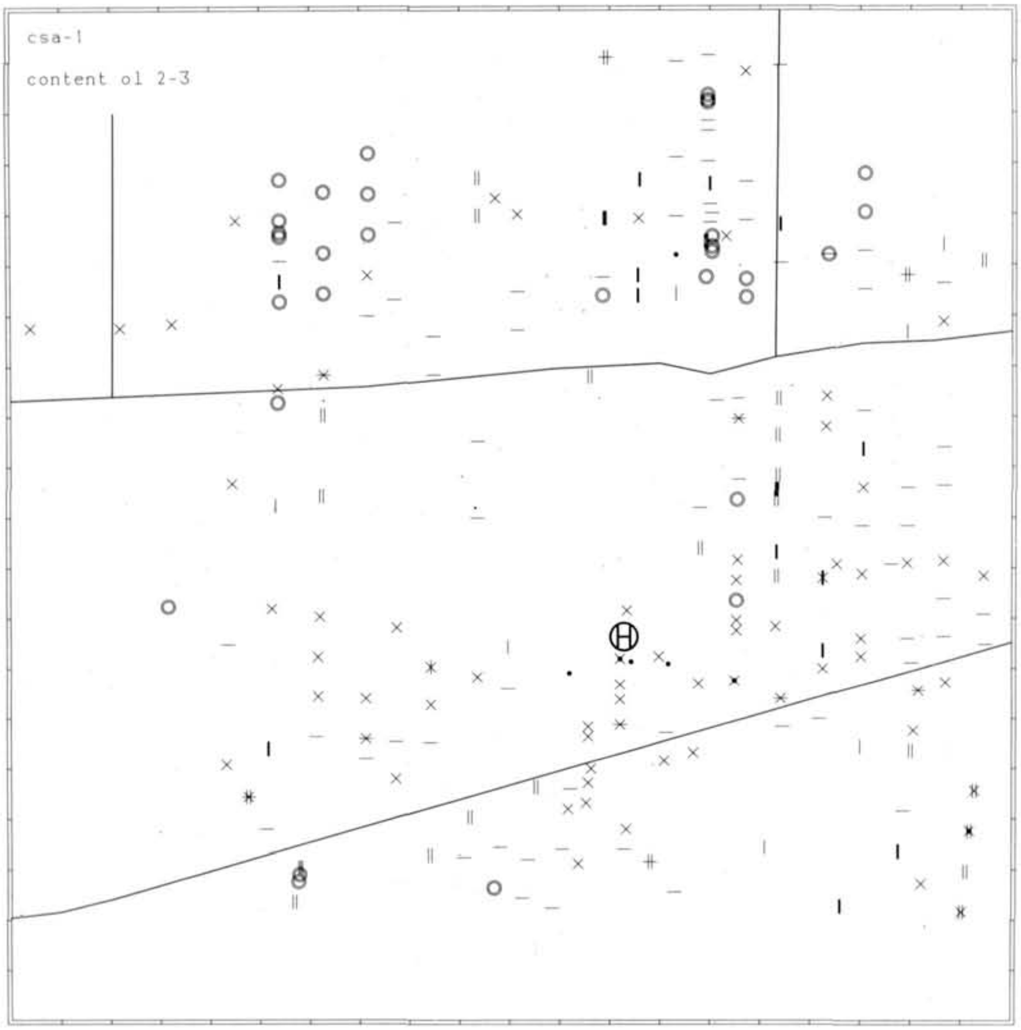


Fig. f. Lithological content of organic bed ol 2-3, Molenaarsgraaf. For legend, see Fig. *35.

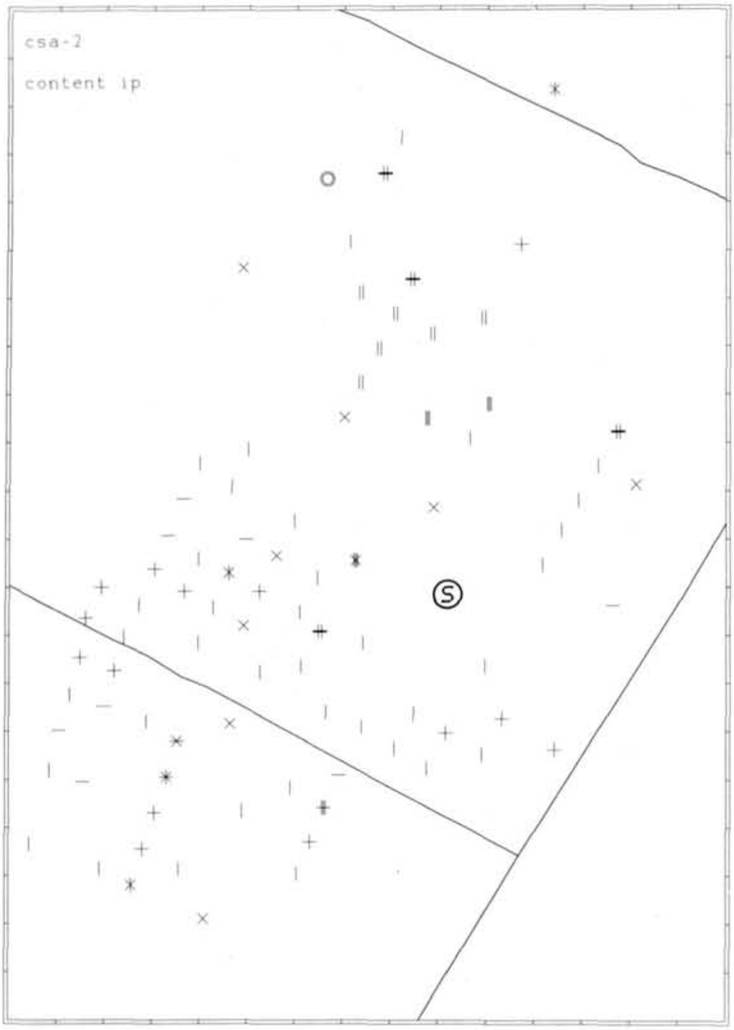


Fig. g. Lithological content of peat bed ip, Leerdam. For legend, see Fig. *35.

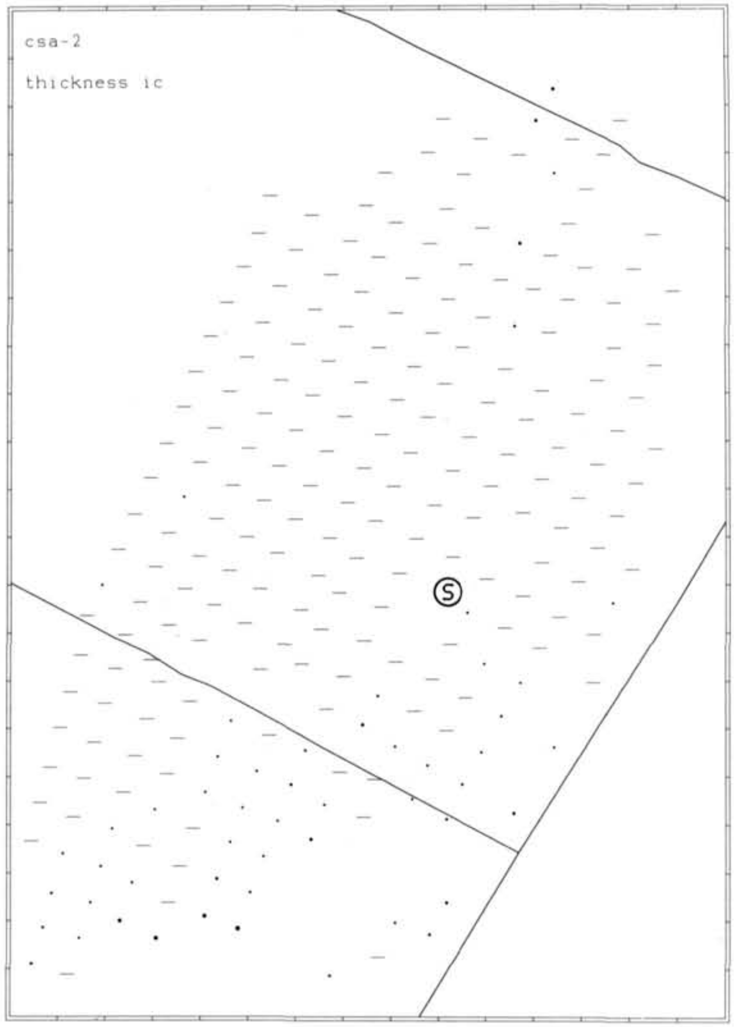


Fig. h. Thickness of clastic bed ic, Leerdam. For legend, see Fig. *35.

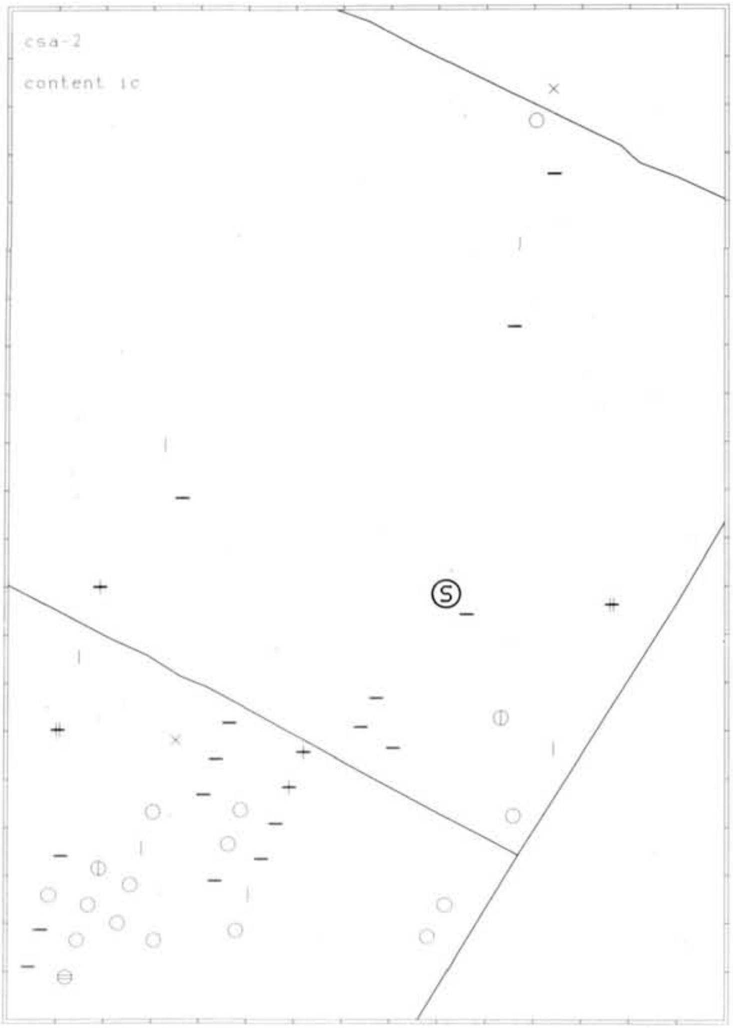


Fig. i. Lithological content of clastic bed ic, Leerdam. For legend, see Fig. *35.

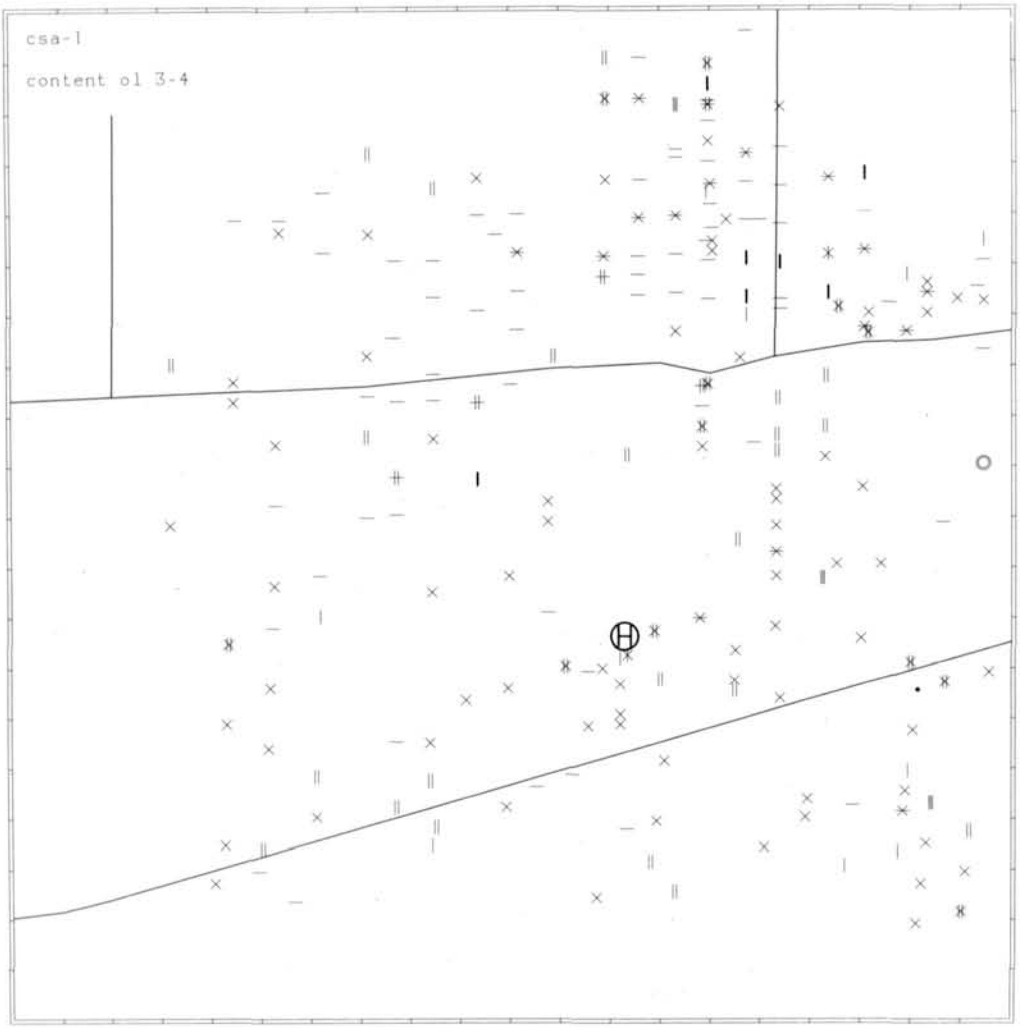


Fig. j. Lithological content of organic bed ol 3-4, Molenaarsgraaf. For legend, see Fig. *35.

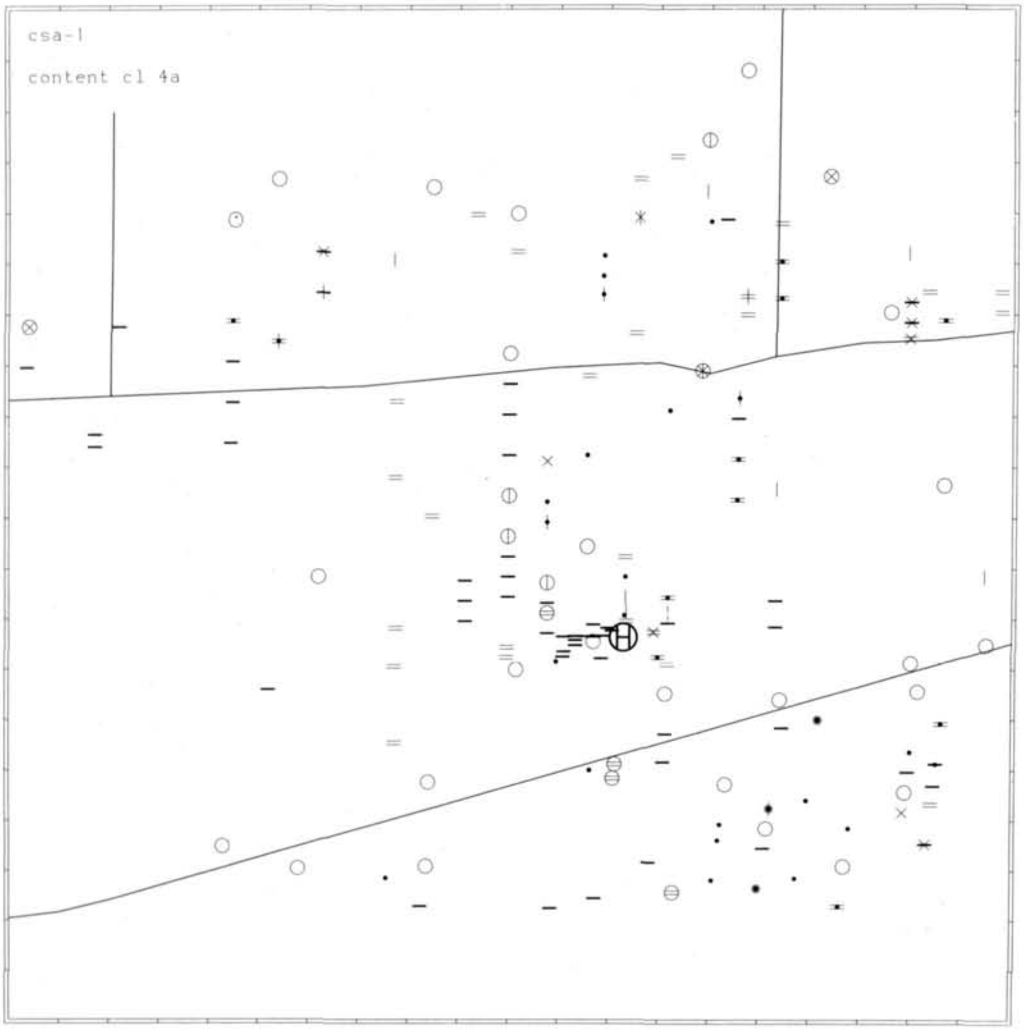


Fig. k. Lithological content of clastic bed cl 4a, Molenaarsgraaf. For legend, see Fig. *35.

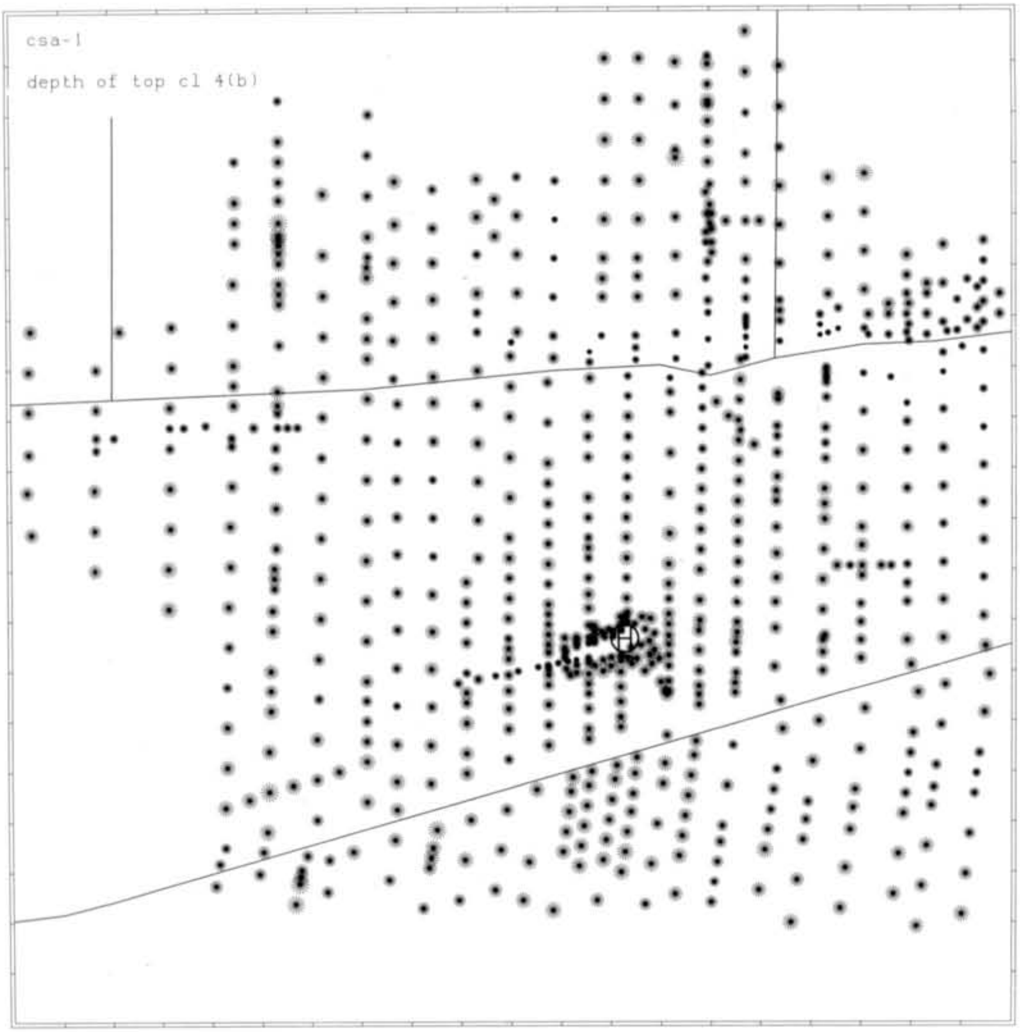


Fig. 1. Depth of the top of clastic bed cl 4b, Molenaarsgraaf. For legend, see Fig. *35.

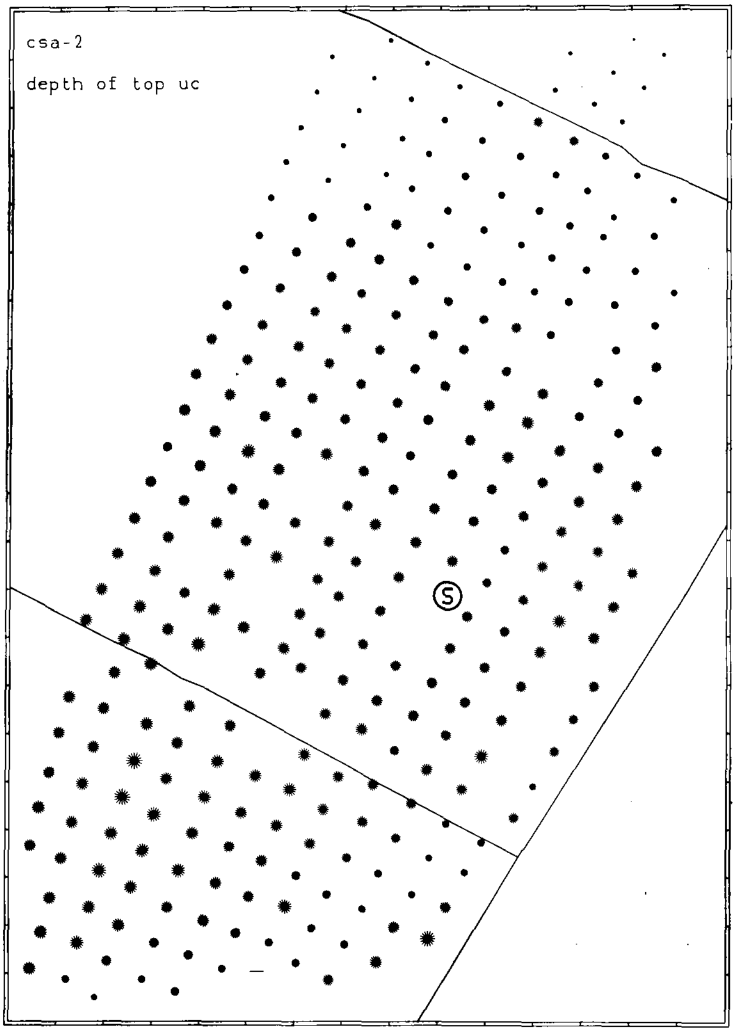


Fig. m. Depth of the top of clastic bed uc, Leerdam. For legend, see Fig. *35.

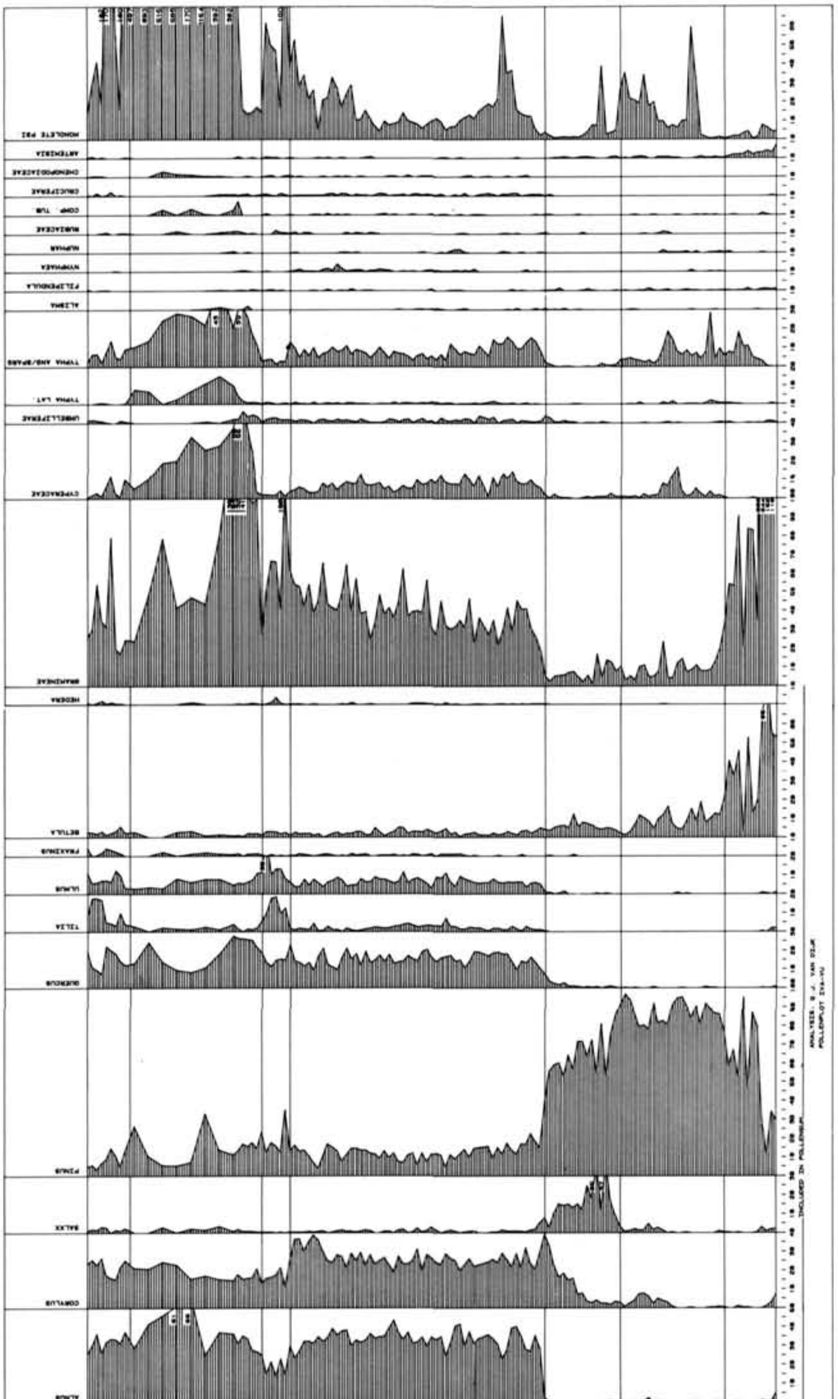


Fig. n. Pollen diagram of boring Molenaarsgraaf HI530 (selected curves). For lithology and zones, see Fig. 18.

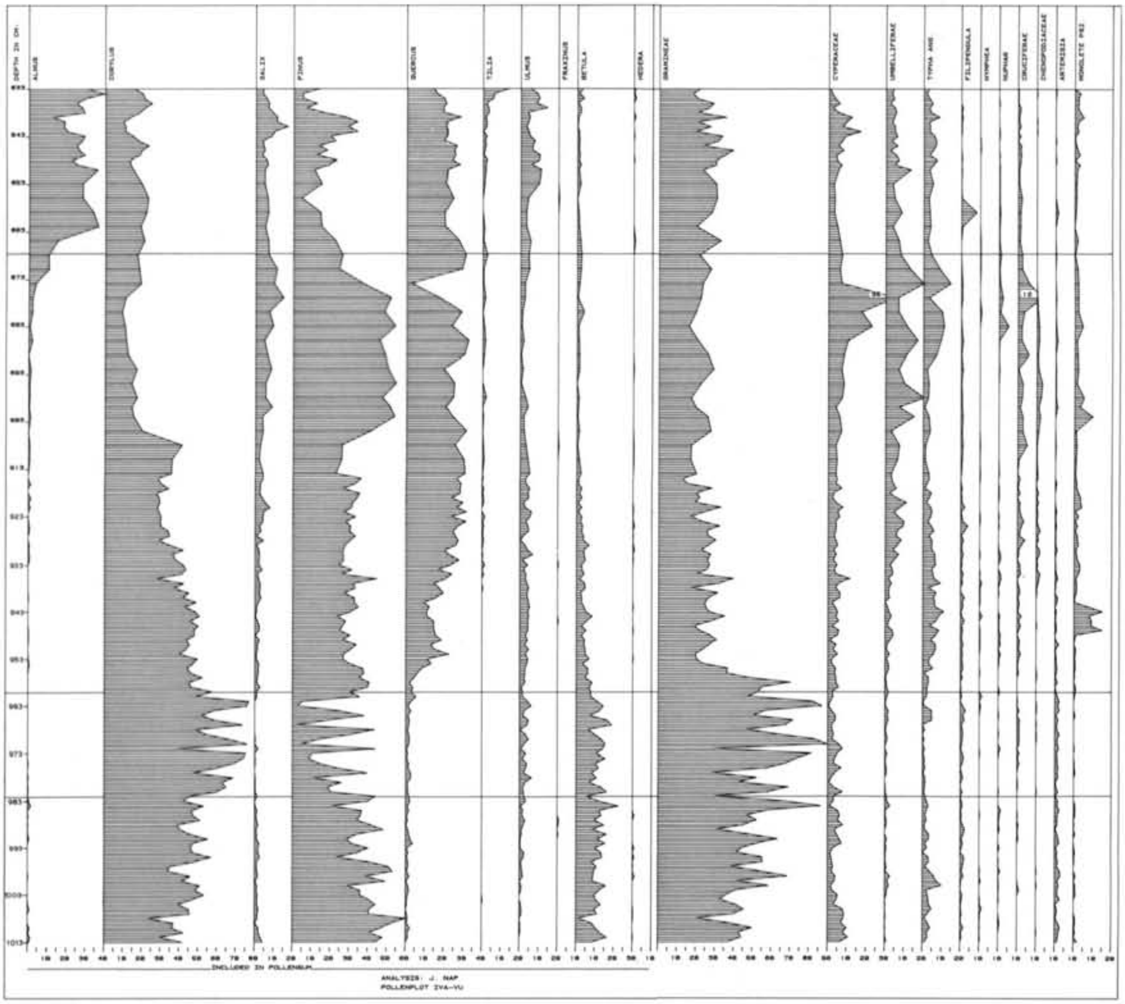


Fig. o. Pollen diagram of boring Leerdam S322 II (selected curves). For lithology and zones, see Fig. 19.

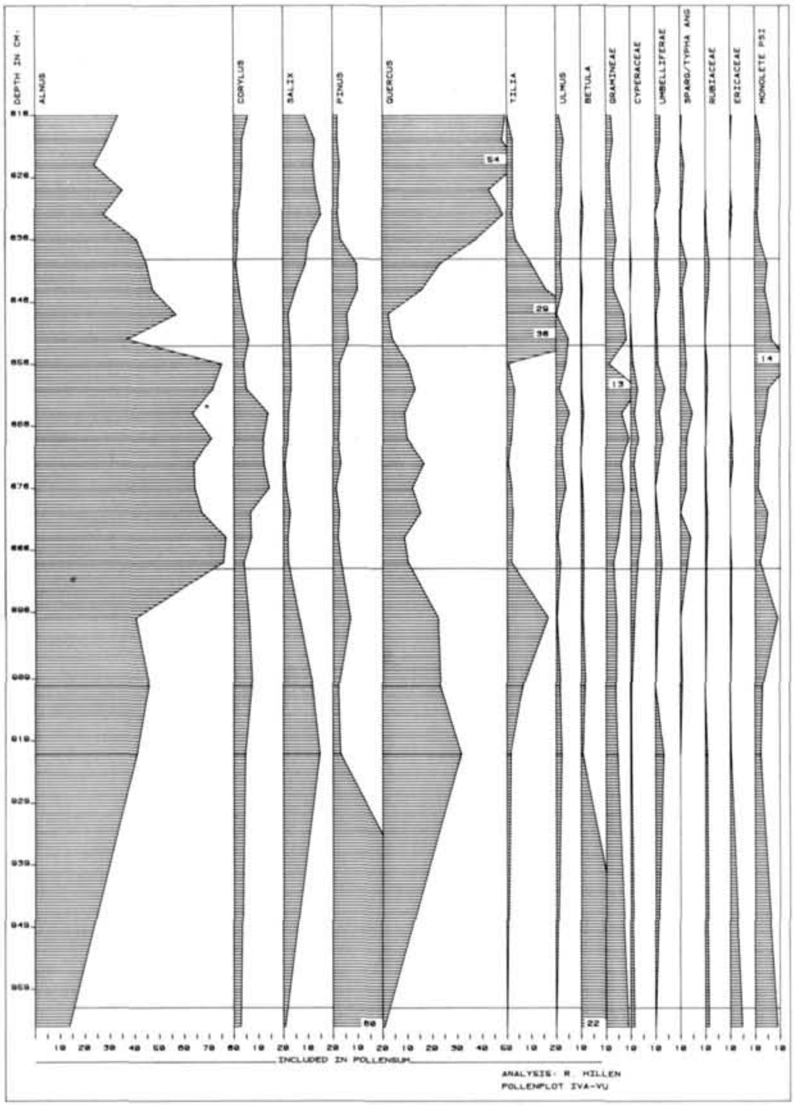


Fig. p. Pollen diagram of boring Molenaarsgraaf H2178 (selected curves). For lithology and zones, see Fig. 21.

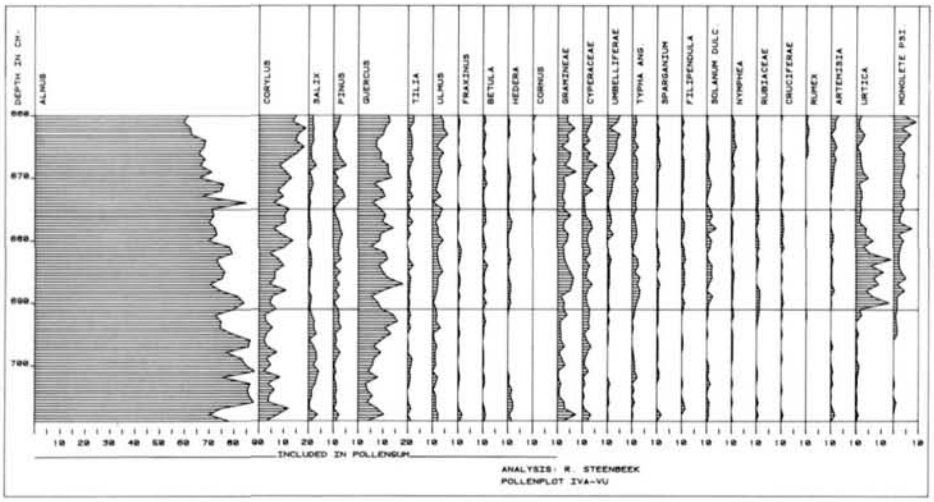


Fig. q. Pollen diagram of boring Molenaarsgraaf H2114 (selected curves). For lithology and zones, see Fig. 25.

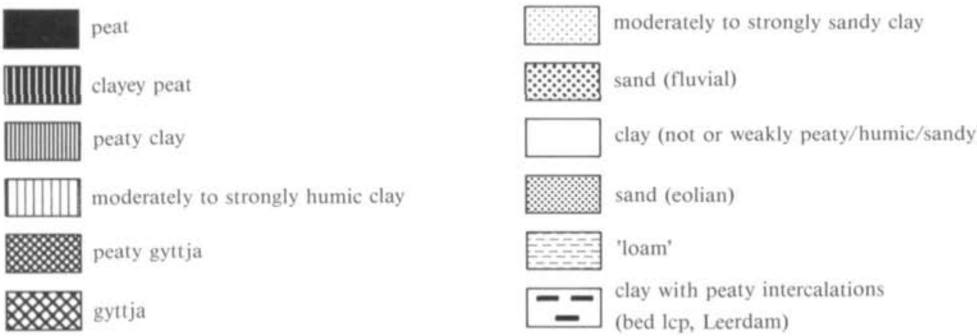


Fig. 9. Legend for lithology in all profiles.

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

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)

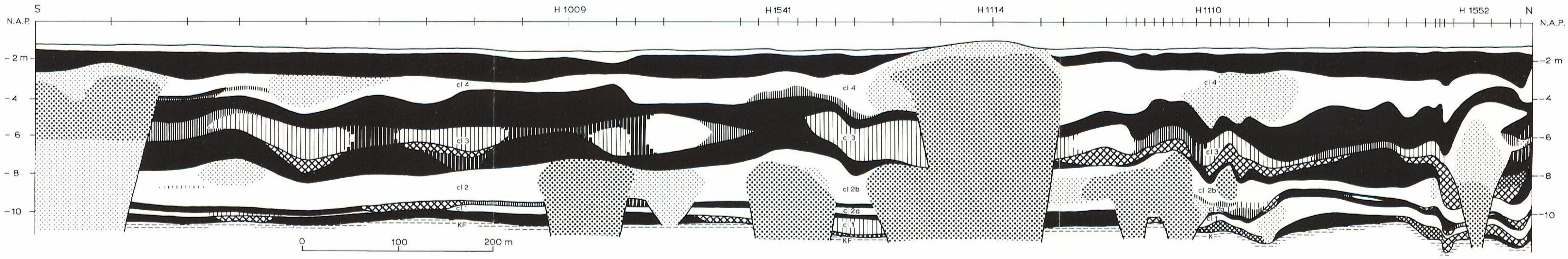


Fig. 6. Profile I, Molenaarsgraaf.

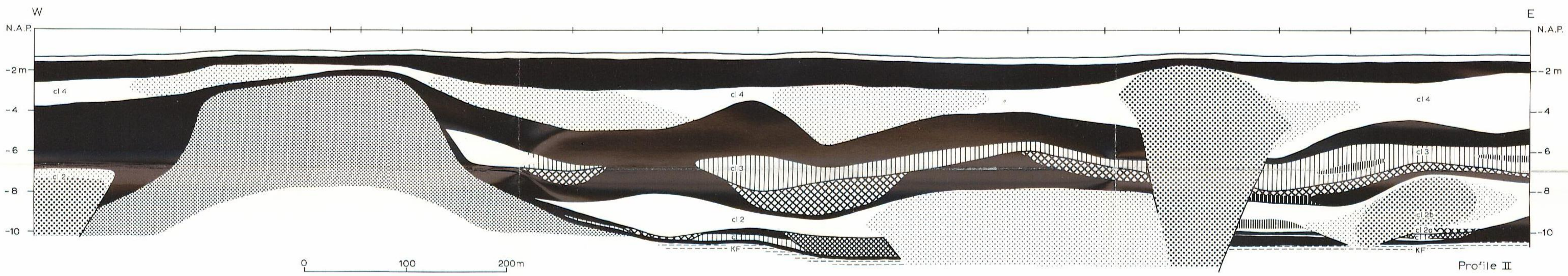


Fig. 7. Profile II, Molenaarsgraaf.

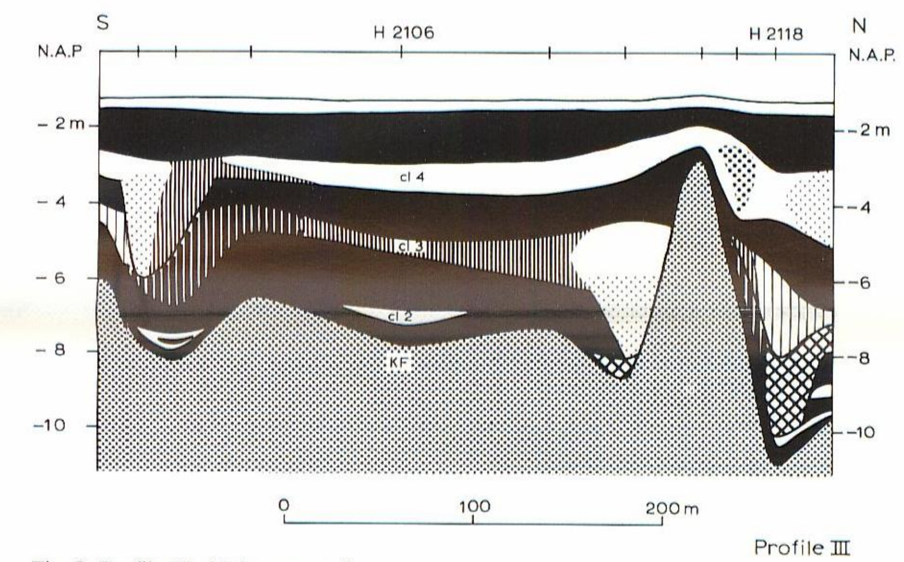


Fig. 8. Profile III, Molenaarsgraaf.

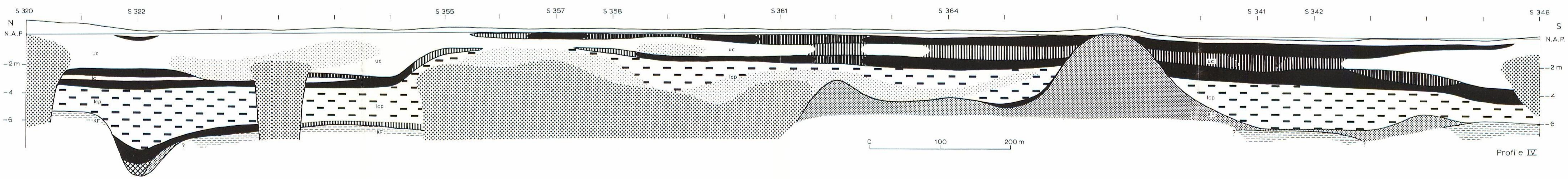


Fig. 10. Profile IV, Leerdam.

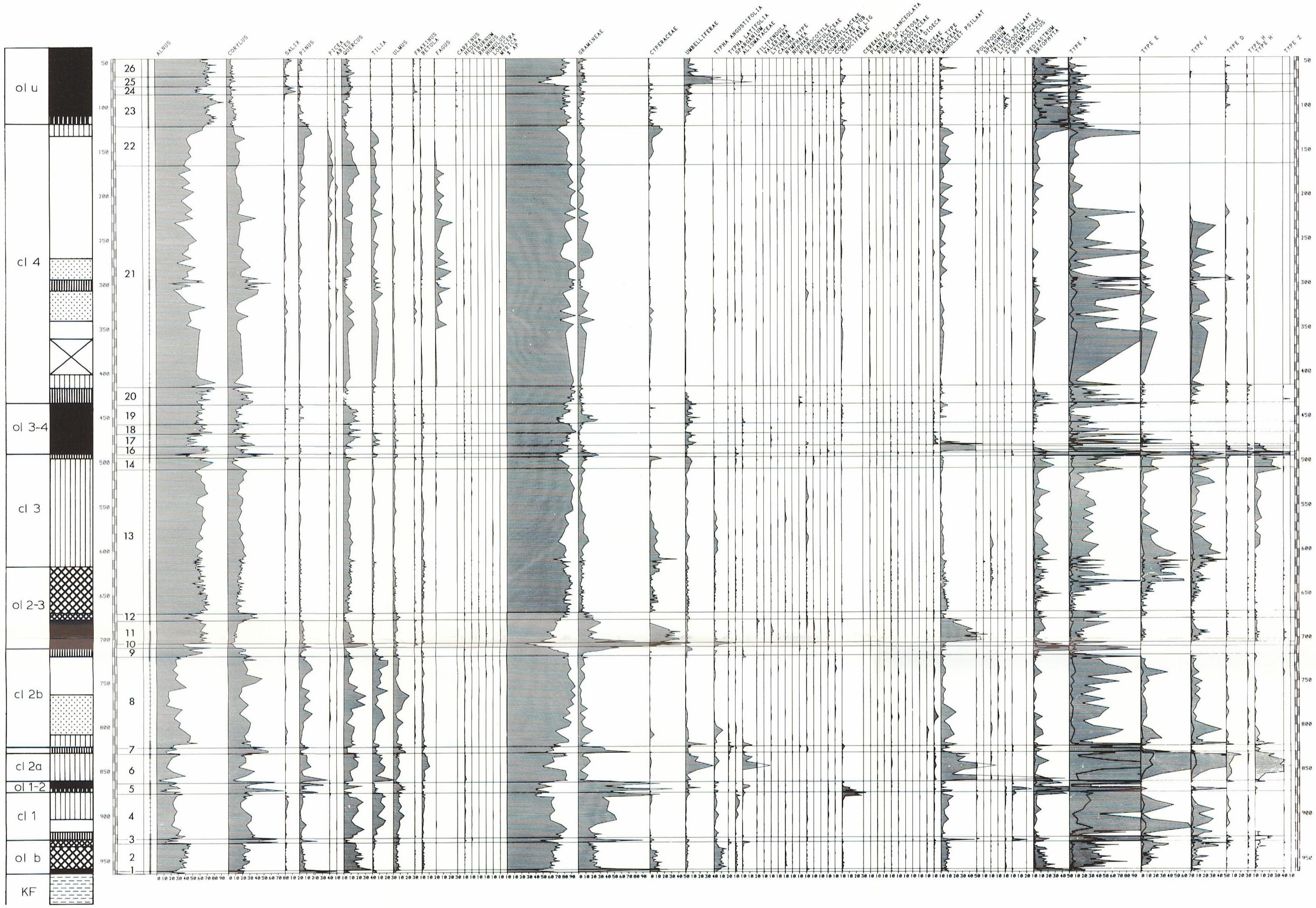


Fig. 12. Pollen diagram of boring Molenaarsgraaf H1110 (standard boring).

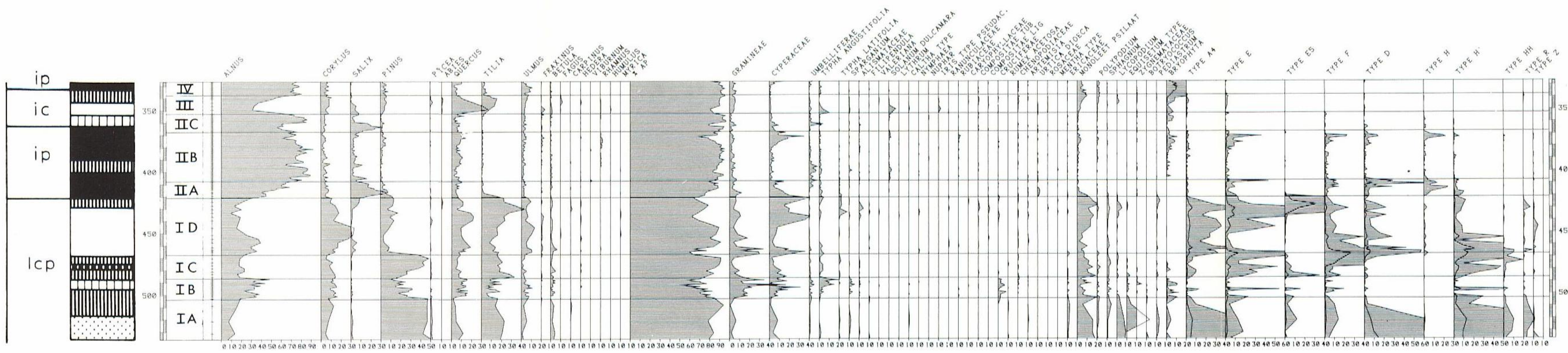


Fig. 15. Pollen diagram of boring Leerdam S322 I.

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.

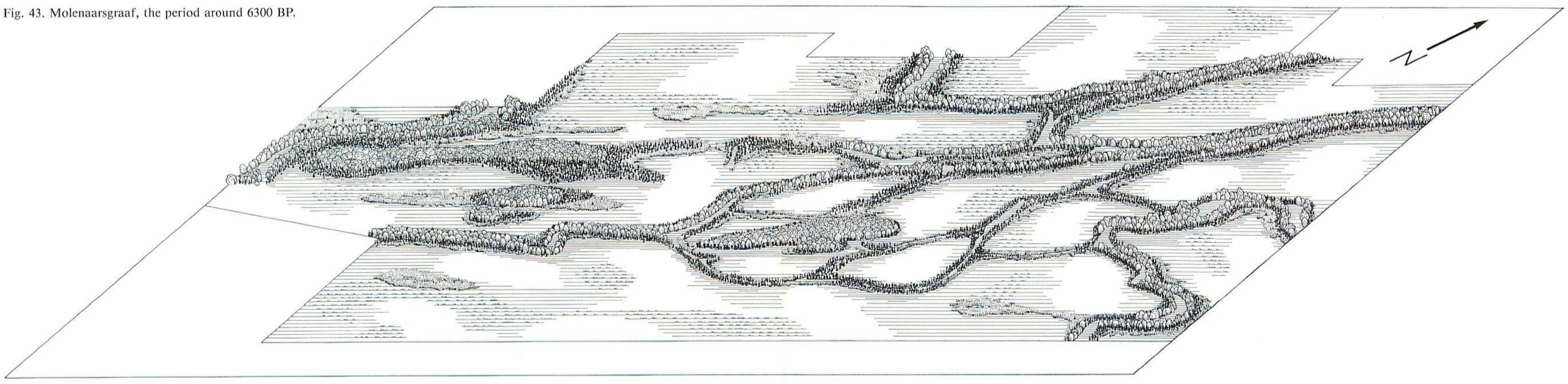


Fig. 47. Molenaarsgraaf, the period around 5300 BP.

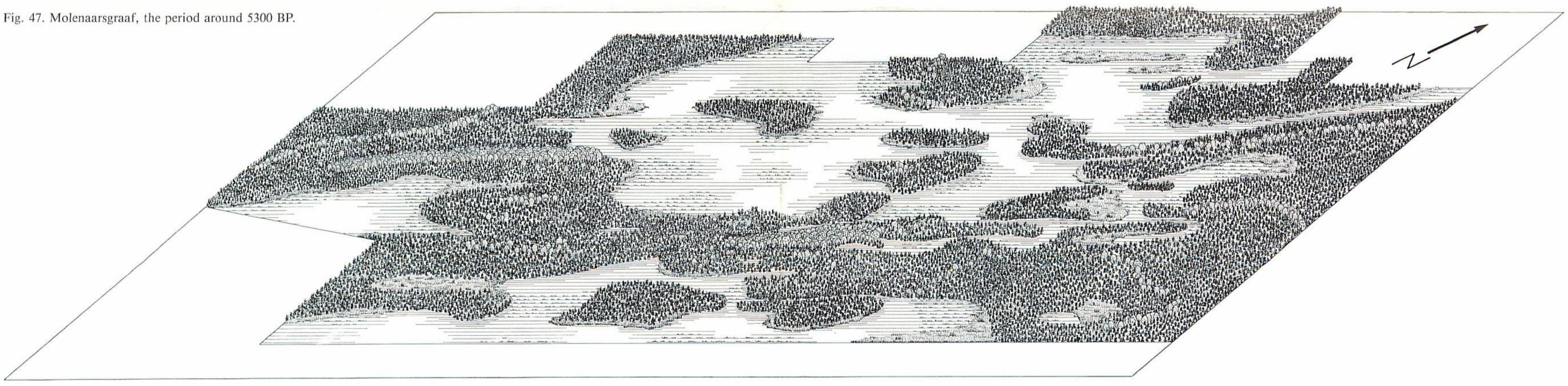


Fig. 50. Molenaarsgraaf, the period around 4800 to 4900 BP.

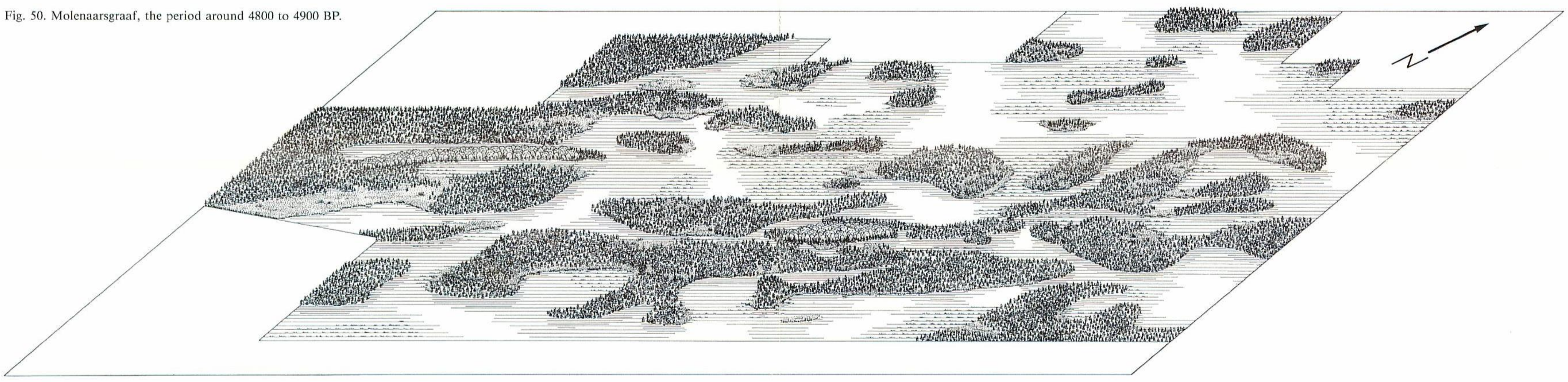
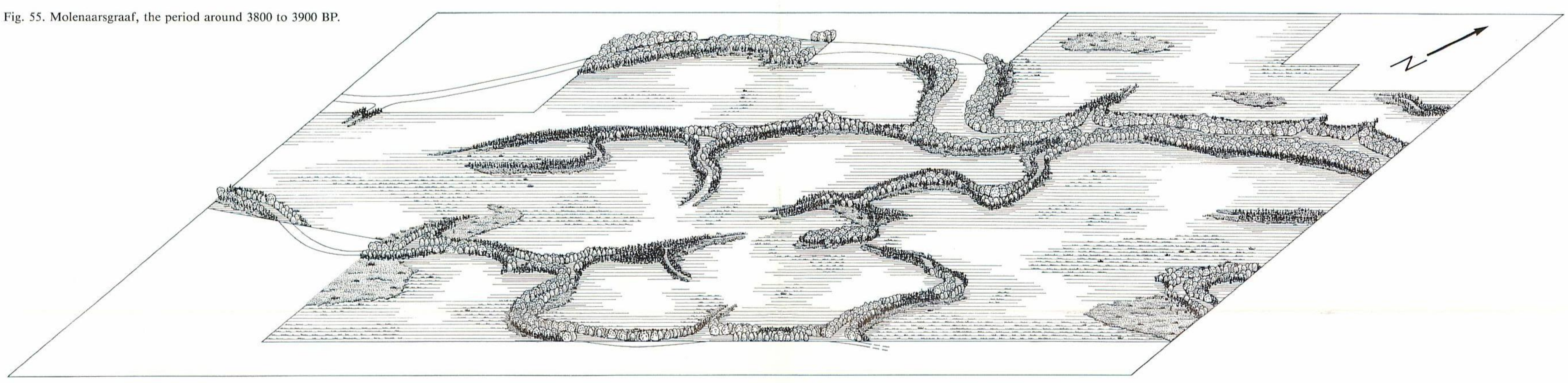
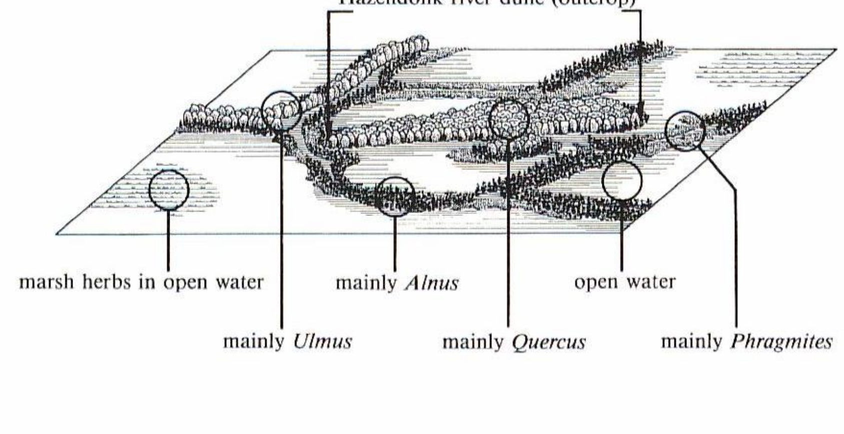


Fig. 55. Molenaarsgraaf, the period around 3800 to 3900 BP.





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