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PHYSIOGRAPHY AND FORMATION OF THE HOLOCENE FLOODPLAIN ALONG THE LOWER COURSE OF THE RHINE IN THE NETHERLANDS

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CONTENTS

ENCLOSURES

1. INTRODUCTION AND METHOD

This study is a continuation of a physiographic survey of a fluvial area adjoining the area under investigation in an upstream, easterly direction (HAVINGA 1969).[1] The main purpose of the previous survey, covering about 1800 ha, was to afford an insight into the physiographic structure of the aggregate Holocene river deposits and the morphology of the physiographic-sedimentological elements forming part of the individual deposits.

The present study covers a fairly extensive area (about 9600 ha) and in addition to providing more information on the above topics it deals in particular with the problems of the genesis of the aggregate Holocene river deposits, the formation of the elements referred to, and the relationship between the sedimentary history of the mapped area and remote upstream and downstream fluvial areas.

As previously, the survey is partly based on data obtained during a soil survey practice for students of the Agricultural University of Wageningen. It mainly covered the levee soils of the river area, where a network of ten borings per ha were made to a depth of 1.20 m. As the soil classification of this survey was particularly concerned with agriculture, so that the relevant soil map was only partly suitable for our purpose, another survey was undertaken applying physiographical criteria. The density of the network of observations varies extensively. At many points, particularly in the levee areas, the borings were closer together than stated above, for instance where fossil gullies could not be traced in soil topography.

Usually, however, a much less detailed network of borings was applied, viz. 1/ha. The borings of the physiographical survey are 2.20 m deep, which is sufficient to provide a clear insight into the complex geological structure of the later section of the aggregate Holocene sediments. Below this depth the geological structure is quite simple, for which reason only a few borings were made below 2.20 m up to the Pleistocene subsoil. These were plotted in a number of rows across the various basins of the mapped area in order to construct the sections shown in enclosure 3.

The mapped area has been subject to two previous soil surveys of 1:80.000 and 1:50.000 by EGBERTS[2] (1950) and the 'Stichting voor Bodemkartering'[2] (1973) for purely agricultural purposes. But these surveys are on far too large a scale for unravelling the intricate sedimentary-geological structure of the floodplain.

[1] Dept. of Soil Science and Geology, Agricultural University, Wageningen, The Netherlands.
[2] Netherlands Soil Survey Institute, Wageningen.

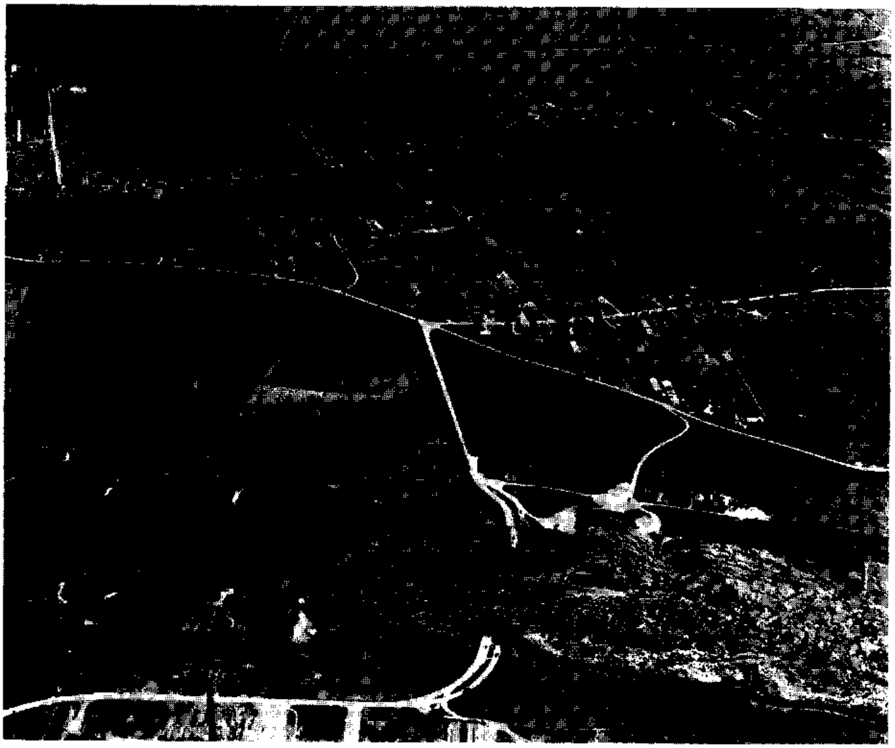

FIG. 1. View of the northern part of the Lower Betuwe near Opheusden (squares 670P).
In the foreground the Lower Rhine. Behind the river-dike a levee with numerous orchards. In the background a basin with pasture land. (Photograph by Aero-Camera).
Gezicht op het noordelijke deel van de Neder-Betuwe in de omgeving van Opheusden (ruiten 670P). Op de voorgrond de Neder-Rijn. Achter de rivierdijk een oeverwal met veel boomgaarden. Op de achtergrond een kom met grasland. (Foto Aero-Camera)

2. LOCATION OF THE MAPPED AREA

The mapped area coincides with the eastern part of the Lower Betuwe (Neder-Betuwe), a floodplain bordered by the Lower Rhine (Neder-Rijn) and the Waal (cf. fig. 1). These river branches bifurcate from the Rhine about 25 km east of the mapped area. The situation is shown in fig. 2. Only the western and eastern section of the northern border of the mapped area run parallel to the Lower Rhine, the central section of this border following the Old Rhine (Oude Rijn), a former southern branch of the Lower Rhine which silted up during the Middle Ages (cf. the maps).

Although the mapped area is located relatively far downstream along the branches of the lower course of the Rhine (the North Sea coast being about

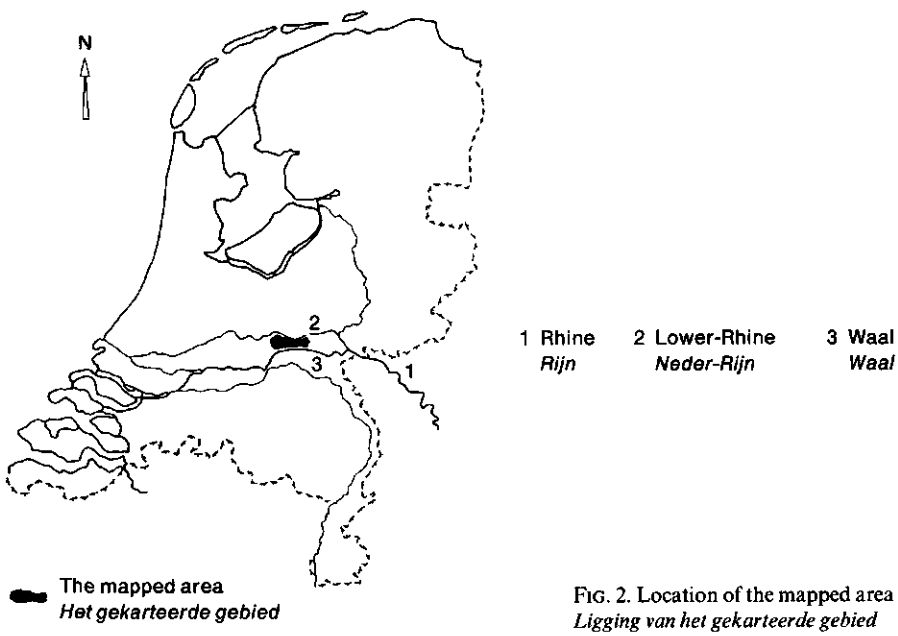

FIG. 2. Location of the mapped area
Ligging van het gekarteerde gebied

100 km away), fluvial sedimentation was in no way subjected to maritime influence. Further downstream, fluvial sedimentation has been indirectly affected by the sea viz. mainly as a consequence of the relative rise of the sea level during the Holocene, which process also led to substantial formation of peat in the there fluvial area.

3. OUTLINE OF THE GEOLOGICAL STRUCTURE AND GENESIS OF THE AGGREGATE HOLOCENE RIVER DEPOSITS IN THE MAPPED AREA

A vertical sequence of heavy clay beds was found in the basins (fig. 3) of the river area studied, each bed representing a period of fluvial activity followed by one of stagnation. During the latter stage a darkgrey vegetation horizon developed at the top of the newly-formed layer of light-grey, heavy basin clay (fig. 4). Usually a vegetation horizon is not evenly distributed over the basin area but has a more or less scattered pattern.

Nearer the meander belt of the fossil river branch which supplied the fluvial sediment, an individual heavy clay bed in a basin merges into a sandy clay bed (levee deposit) (fig. 1). In the meander belt the sandy clay bed is found as a top stratum deposit overlying a body of coarse sand and gravel (fig. 5).

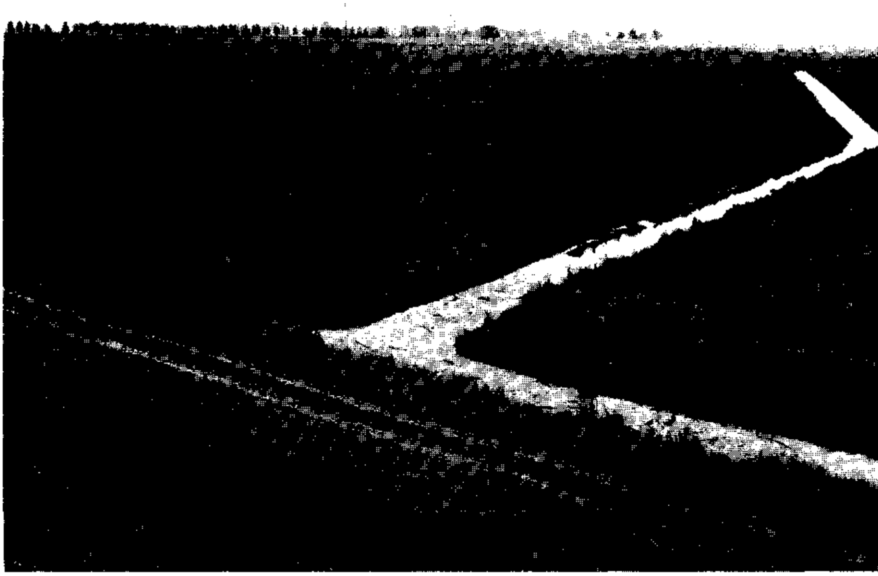

FIG. 3. A typical basin landscape (Photograph by Soil Survey Institute, Wageningen).
Een typisch komlandschap (Foto Stichting voor Bodemkartering, Wageningen).

As a result of a combined process of fluvial erosion and resedimentation the meander belts have been subject to continuous rejuvenation. Very probably this process occurred during stages of fluvial activity and stagnation. This explains why the cyclic nature of the sedimentation process, as shown in the basins, cannot be ascertained at the site of the meander belts. It there alternated between accelerated and retarded rejuvenation during the successive stages of fluvial activity and stagnation, and at the same time between a faster or slower (or even arrested) rise of the top of the meander belt, parallel with the rise of the soil surface in the basins.

In the present publication the time spanning a period of fluvial activity and a subsequent period of fluvial stagnation is designated 'Sedimentation Phase', the clay beds and meander belts, insofar as they were formed during a single Sedimentation Phase, together being designated 'Deposit'.

For a better understanding of these basic ideas reference may be had to the sedimentary picture shown in section A-A′ (enclosure 3). Near A′ the body of coarse sand of the meander belt is shown to contact a layer of sandy clay (levee deposit) extending horizontally towards A. About half-way from A to A′ it merges into a layer of heavy basin clay. The position of the clay bed is clear evidence that it forms part of Deposit 2. This naturally also applies to the contacting body of coarse sand and gravel.

The deeper and older, heavy clay beds, representing Deposits 3 and 4, are cut by the body of coarse sand and gravel. The overlying uppermost clay bed,

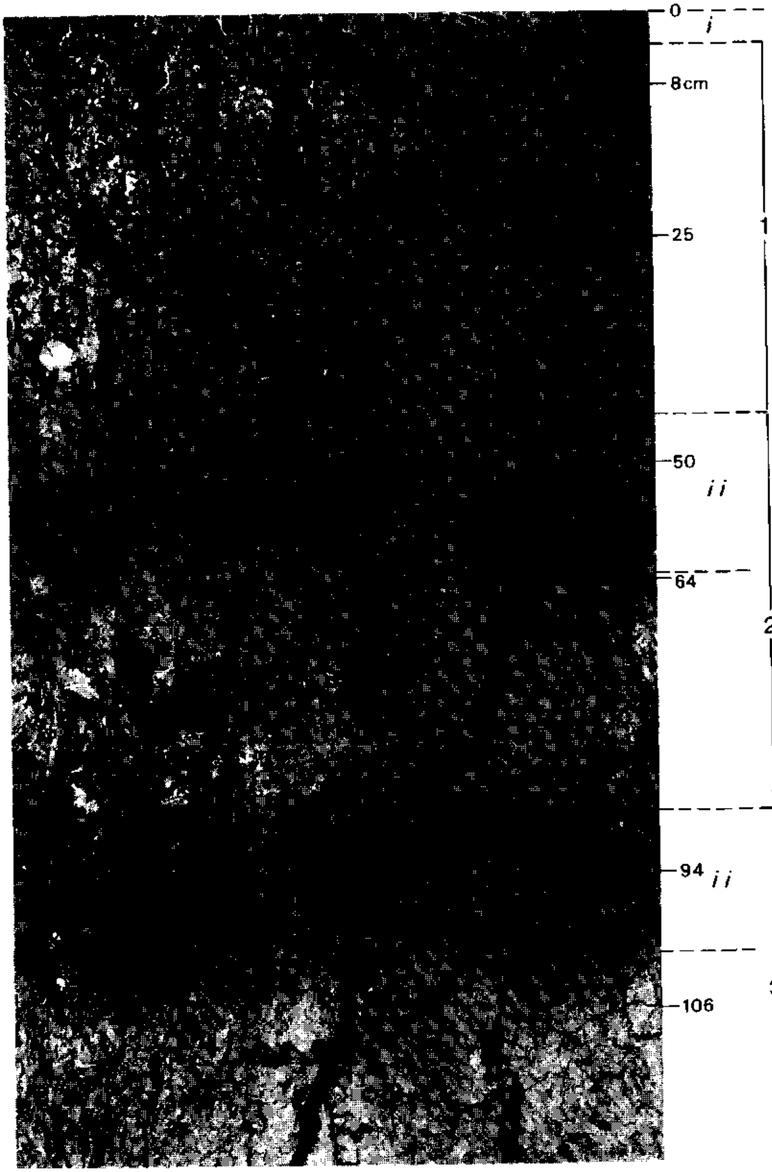

FIG. 4. Soil profile in a basin (Photograph by Soil Survey Institute, Wageningen)
i. Layer of turf; ii. Fossil vegetation horizon.
1. Deposit 1; 2. Deposit 2(a + b); 3. Deposit 3a.

Bodemprofiel in een kom (Foto Stichting voor Bodemkartering, Wageningen).
i. Zodelaag; ii. Fossiele vegetatiehorizont.
1. Afzetting 1; 2. Afzetting 2(a + b); 3. Afzetting 3a.

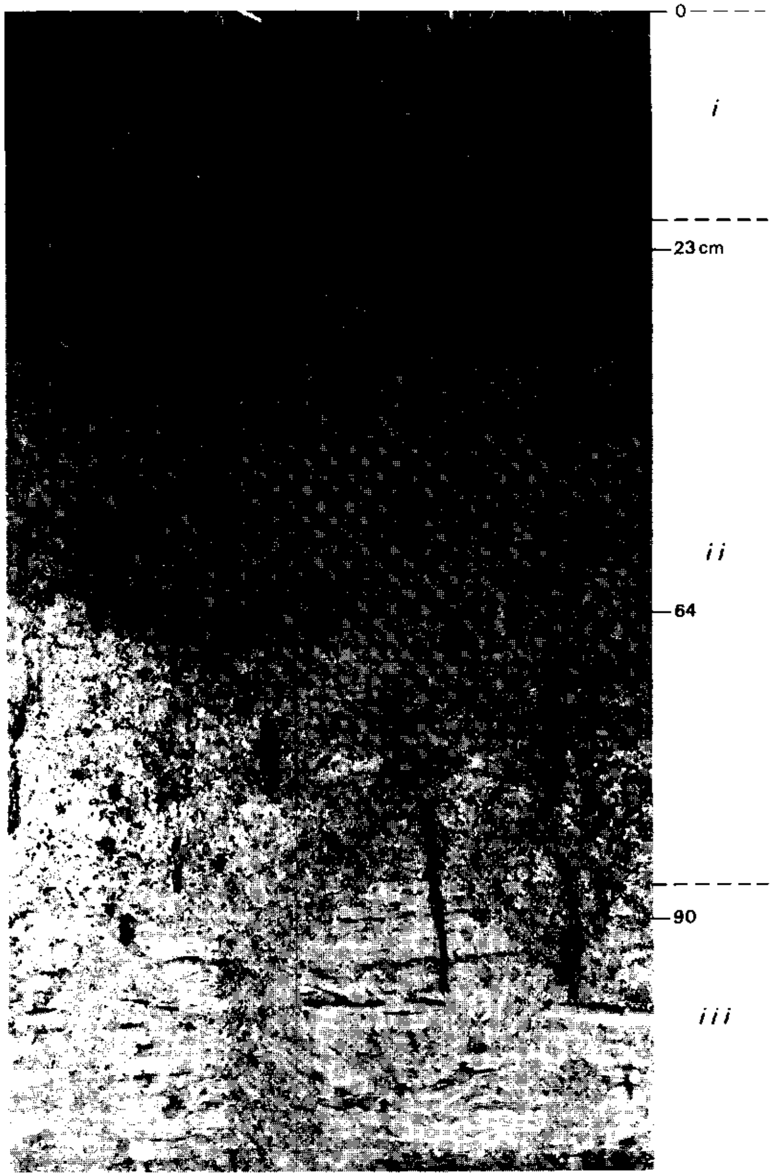

FIG. 5. Soil profile in a levee of Deposit 2(a + b), possibly covered by a levee of Deposit 1, which is very thin at this point (Photograph by Soil Survey Institute, Wageningen)

i. Plough layer in sandy clay; ii. Sandy clay showing decreasing homogenization and humus content from above to below; iii. Stratified fairly sandy subsoil, locally homogenized.

Bodemprofiel in een oeverwal van Afzetting 2(a + b), mogelijk overdekt door een oeverwal van Afzetting 1, die ter plaatse zeer dun is (Foto Stichting voor Bodemkartering, Wageningen)

i. Ploeglaag in zandige klei; ii. Zandige klei welke van boven naar beneden een afnemende homogenisatie en humusgehalte laat zien; iii. Gelaagde vrij zandige ondergrond, plaatselijk gehomogeniseerd.

representing Deposit 1, does not contact the latter deposit as regards the situation shown in the section, but is bound to do so to the right of A′, i.e. to the South of the dike along the Waal (cf. the situation of the section on map 1 + 2) where owing to the activity of the present river Waal, rejuvenation of the meander belt continued up to Sedimentation Phase 1.

Just as the clay beds forming part of Deposits 3 and 4 are cut by the body of coarse sand and gravel forming part of Deposit 2, the clay bed forming part of the latter Deposit is cut by the meander belt section forming part of Deposit 1.

4. MAP COMPILATION

The geographical-topographical background of the maps is a picture in which the actual situation is greatly reduced. The villages are only represented by the mediaeval church. The two maps (enclosures 1 and 2) show the physiographical-sedimentological soil conditions down to 2.20 m below the soil surface. The sections (enclosure 3) illustrate the fairly complex geological structure of the soil to this depth and give an impression of the type and thickness of the underlying Holocene sediments. To facilitate reading the intricate map pattern, small-scale maps are added showing the position of the sections (enclosure 4A), the fossil watercourses referred to in the text (enclosure 4A), the extension of the levees of the successive Deposits (enclosure 4B), and the compartments into which the two large meander belts are subdivided (enclosure 4A).

Within the depth of 2.20 m 6 Deposits could be distinguished in the basins. They are designated by reference numerals 1, 2a, 2b, 3a, 3b and 4 from late to early or from above to below. Numerals 2a, 2b and 3a, 3b are employed for two reasons. Firstly this notation stresses the fact that the 2a or 3a and 2b or 3b Deposits have a very similar soil pattern and cannot often be differentiated. Secondly, it facilitates comparison with the soil patterns of the Betuwe river area studied previously (Havinga 1969). In the latter area the indications for a bipartition of Deposits 2 or 3 were too vague to permit further subdivision of these Deposits[1].

The symbols 2(a+b) and 3(a+b) denote aggregate sub-Deposits a and b. They are also applied in case the extension of either of the sub-Deposits cannot exactly be traced, as inside a meander belt representing an association of a deposit of sandy clay on sand (sub-Deposit 2a) and a sandy clay bed covering a deposit of sandy clay on sand (sub-Deposits 2a and 2b respectively).

As far as possible the individual Deposits are shown as separate physiographical units. Deposits 1 and 2 (a, b) are very similar in the contours of their levees

[1] The order of numbering from above to below is rather unconventional, but had the advantage that the sequence could easily be extended to enclose older (deeper) Deposits too, when we started the present study.

(sandy clay beds in top-stratum position). Deposits 3(a, b) and 4 also exhibit a great deal of conformity in this respect, whereas the two groups show considerable divergency. For the sake of clarity the various Deposits are therefore combined in two separate maps (1 + 2 and 3 + 4) (enclosures 1 and 2). But the meander belts of Deposit 2 (a + b) are also shown on map 3 + 4 where they represent the limits of the sandy or heavy clay beds of Deposits 3(a, b) and 4.

Each Deposit essentially consists of a meander belt of coarse sand and gravel covered by a sandy clay bed several dm thick as top stratum deposit; this deposit of sandy clay (levee) extends beyond the meander belt, where it covers an older Deposit and merges into a bed of heavy clay in the basin. The picture is completed by levee splays (lateral protrusions of a levee of variable morphology, cf. HAVINGA 1969, p. 18), meander belt splays (do. of a meander belt), fossil river channels, fossil overflow gullies and ancient culture soils. All these constituents are shown on the maps for each separate Deposit. To enhance map legibility, various physiographic elements (meander belts, levees) are only shown by hatching in Deposits 2(a, b) and 3(a,b). The simpler soil patterns of Deposits 1 and 4 are marked by placing the numeral referring to the Deposit in question next to the soil boundary to which the sandy clay (levee) deposit extends. The heavy basin clay is found on the opposite side of this line.

Humic matter is always shown in the sections where it accounts for a relatively high percentage of the soil. Where not indicated it is usually found in a relatively low percentage below the oxidized zone in heavy clay (in the basins), this zone usually extends to a fair depth into Deposit 3. Humic matter is not shown on the maps. Peaty matter is shown both on the maps and in the sections. (The maps of the area surveyed previously (HAVINGA 1969) give no information on the occurrence of peaty matter).

It was not always possible to assess or assume the presence or absence of the clay bed representing Deposit 4 within reach of the boring depth of 2.20 m. This is particularly true of places where the aggregate clay beds of later Deposits have or may be supposed to have a relatively great total thickness. Compare, for instance, the two levee splays in squares 8 MN. Both belong to Deposit 3 (a, b). As no textural change or fossil vegetation horizon delimits the sandy clay of the splays in a downward direction, it is a matter of speculation as to whether the splays are very thick or merge imperceptibly into an underlying levee splay of Deposit 4 consisting of sandy clay of the same textural composition as in Deposit 3. In these cases we opted for the first alternative inasmuch as sandy clay was nowhere traced just outside the contour of these splays at a depth corresponding to Deposit 4.

The fossil vegetation horizons are often very discontinuous. As the stratigraphy of the river clay area is largely based on these horizons, even minor occurrences are shown on the maps where this illustrates the stratigraphy. The picture is more or less simplified where gaps in a fossil vegetation horizon only occupy a small space.

Occasionally, when fossil vegetation horizons were absent, we had to rely on certain morphological characteristics (colour, humus or peat percentage) of the basin clay beds for their identification, but this method could only be applied to the deeper clay beds (older Deposits) in a few, relatively small sections of the mapped area. Inside the aggregate levee deposits of Deposits 1 and 2, soil texture and soil consistency were often reliable identification criteria, the sandy clay bed of Deposit 2 having a somewhat heavier texture and firmer consistency than that of Deposit 1.

The representation of the fossil vegetation horizons on the maps takes no account of the extent of development of the horizons in the soil profile. At many points one or more of the successive vegetation horizons are so poorly developed as to exhibit only somewhat darker stains among the lightgrey, heavy basin clay. Extensive field experience is needed to distinguish such an occurrence.

But even where all successive fossil vegetation horizons have a fairly continuous spread it may be difficult to unravel the geological-sedimentological structure. This is owing to the fact that an individual clay bed may vary in thickness, whereas the fossil vegetation horizons limiting the successive clay beds may have unexpected gaps. For this reason we were sometimes obliged to fall back on a subjective interpretation.

For the sake of clarity, only three texture classes are distinguished, viz. heavy clay ($>35\%$ clay) (soil particles with a diameter less than 2μ), sandy clay (35-8% clay) and sand ($<8\%$ clay), but some sections (cf. the legend) show a more elaborate particle size distribution, viz. heavy clay ($>35\%$ clay), light clay (35-30% clay), somewhat sandy clay (30-25% clay) and sandy clay (25-8% clay). 'Sand' in the subsoil of the meander belts usually contains a great deal of gravel (soil particles with a diameter of more than 2 mm).

5. MEANDER BELTS

Except for parts of the circular meander belt in the western part of the mapped area, the meander belt system forms part of Deposit 2. Most of the circular belt represents Deposit 3; it largely escaped rejuvenation after the end of sedimentation Phase 3, which affected the other meander belts to the end of sedimentation Phase 2. By that time practically all river channels in the mapped area had silted up and their activity was taken over by the Lower Rhine and Waal found outside the river dykes respectively north and south of the mapped area. The meander belts of these rivers, forming part of Deposit 1, are situated on the river side of the dykes.

The layers of sandy clay (levee deposits) and heavy clay (basin deposits) genetically related to the meander belts of the present rivers, form a single continuous top stratum of Deposit 1 covering the levee and basin deposits forming part of Deposit 2. In the following description of the meander belts (and this applies equally to the levee deposits forming part of Deposit 2), the covering clay beds mentioned above are usually ignored.

The meander belts are divided into two types, viz. a complex and a plain sedimentary structure. The complex type is represented by the very wide meander belt found between the villages of Lienden and Maurik and the circular one south of the wide meander belt which both consist of earlier and later fragments ('compartments') caused by incomplete rejuvenation. The first differs in that the compartments vary in age within sedimentation Phase 2, whereas the various compartments of the circular meander belt represent the two successive sedimentation Phases 3 and 2.

Most of the meander belts represent a rejuvenated version of an older meander belt occupying about the same space, existing as early as sedimentation Phase 3 (or a still earlier sedimentation Phase). Soil material of the previous stage or stages is often preserved at varying depths in the subsoil of the body of coarse sand and gravel of the present meander belts. Only one meander belt of the plain type was formed as late as sedimentation Phase 2.

As pointed out in the article on the Betuwe area mapped previously (HAVINGA 1969), the meander belts often formed because a relatively wide river channel became filled with coarse sandy material as it deteriorated. The narrowing river channel followed a sinuous course within the developing meander belt. This mode of formation is certainly true of the narrow meander belts in the mapped area. Within these meander belts it is only here and there that the soil pattern vaguely indicates the presence of a point bar, for instance in squares 89E and square 6C (near square 5C), but a clear accretion topography showing a lateral sequence of arcuate elevations (bar sediments) and swales (between the bar sediments) cannot be observed. Only the wide meander belt between Lienden and Maurik partly consists of point bars with a very clear accretion topography (in compartments II and VI).

5.1. STRUCTURE OF THE INDIVIDUAL MEANDER BELTS

5.1.1. *The wide meander belt between Lienden and Maurik*

The very wide meander belt between Lienden and Maurik is divided into 8 sections indicated on the map (enclosure 4A) by compartments Ia, Ib, II, III, VI, VII, VIII and IX. They are distinguished according to their varying soil pattern. Compartments IV and V only partly coincide with a meander belt section: they contain a splay-like extension of the meander belt alongside an area of heavy basin clay.

The various compartments (sections) represent stages of varying age within Sedimentation Phase 2. Two adjoining compartments are usually separated by a fossil river gully, the latter being genetically related to the later compartment. On the side of the fossil gully where the later compartment is found, the soil surface near the gully is somewhat more elevated than in the older opposite compartment. The soil pattern of the latter is mostly cut by the gully genetically related to the later compartment, or where a well-developed fossil gully is absent, by the soil pattern in that compartment (the soil pattern usually has a configuration more or less parallel to the fossil gully). This is clearly shown, for example, in compartment VII and compartments VI and VIII adjoining compartment VII at the eastern and western side respectively. The soil pattern of compartment VII, with an east-west orientation, is cut by the soil pattern, or fossil river gully bordering the soil pattern, with a somewhat south-north orientation of the adjoining compartments and is therefore the oldest of the three. On the southern side compartment VII is also adjoined by a later compartment (Ib). But in this case the above criterion does not apply and may be replaced by the following. In compartment Ib the soil surface is usually slightly more elevated than in compartment VII; the fossil river gullies connected to compartment Ib continue past compartment VI, from which it may be inferred that compartment Ib is even later than compartment VI. Finally, compartment Ib, unlike compartment VII, does not locally contain a layer of heavy clay covering the meander belt deposit. The occurrence of the heavy clay bed suggests that compartment VII was completed at a relatively early date.

5.1.1.1. The individual compartments of the wide meander belt

Compartment I (a and b) represents the latest section of the wide meander belt between Lienden and Maurik. It consists of a long, narrow strip beside or between the other compartments and covering the entire length of the meander belt. The soil surface is relatively elevated (cf. above) and characterized by a very level topography.

Compartment I is divided into two sections Ia and Ib joining at square 3G. Unlike compartment Ia the fossil river gullies (clay plugs) in compartment Ib are very poorly developed.

Compartment Ia has a narrowing end in square 3G where its soil pattern is in a line with that of compartment II (adjoining compartment Ia to the north and east). Compartment II has a very marked accretion topography consisting

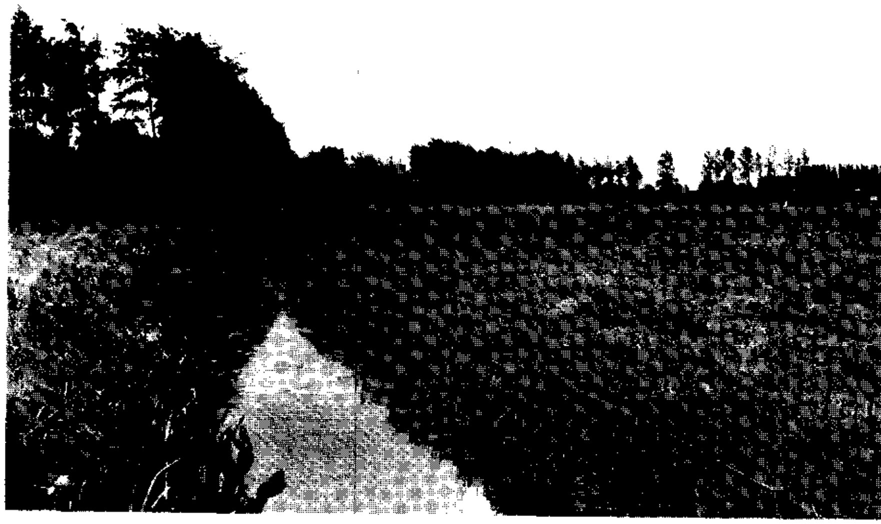

FIG. 6. Swale (with dug ditch) and scroll bar in the point bar in compartment II of the wide meander belt between Lienden and Maurik.

Geul (met gegraven sloot) en rug in de kronkelwaard in kompartiment II van de brede meandergordel tussen Lienden en Maurik.

of many wide and deep and some narrow and shallow swales between marked scroll bars (fig. 6). The soil in the swales partly consists of heavy clay. The heavy clay fills the minor fossil gully in the central part of the swales (clay plug) and often forms a wedge-shaped, thinner clay bed alongside the clay plug.

The soil pattern described shows that compartments Ia and II actually represent a later and earlier stage of the same point bar; its formation was a fairly continuous process. During the earlier stage of its formation, the river channel supplying the sediment of the point bar shifted its bend far to the west, and broke through its bank in a north-eastern direction at the point of contact between compartments Ia and Ib, thus intersecting the meander belt.

Soil profiles inside and outside the fossil gullies in compartment II.

In the central part of a marked swale II, where a clay plug is found genetically related to Deposit 2: 0-6 dm, brown sandy clay (Deposit 1); 7-12 dm, grey, sticky humic heavy clay with a dense concentration of rust-coloured iron compounds and shell fragments; 12-15 dm, dark grey, sticky humic heavy clay; 15-20 dm, idem with many plant remains; 20-22 dm, yellowish sand (Deposit 2).

In a very marked swale where Deposit 1 also exhibits features characteristic of a gully fill: 0-5 dm, grey sandy clay, relatively heavily textured; 5-7 dm, grey, sticky, somewhat humic clay the texture of which is intermediate between sandy and heavy clay (Deposit 1); 7-10 dm, grey, sticky humic heavy clay with a dense concentration of rust-coloured iron compounds; 13-17 dm, dark grey, very humic sandy clay with many plant remains; 17-22 dm sand (Deposit 2).

In a swale at the point of a relatively thin heavy clay bed along the clay plug in Deposit 2. As usually found in such position the profile does not show all the features characteristic of gully fill material: 0-6 dm, brown sandy clay (Deposit 1); 6-7 dm, weakly developed, somewhat dark-grey fossil vegetation horizon in relatively light heavy clay; 7-10 dm grey heavy clay with rust-coloured iron stains; 10-12 dm, sandy clay; 12-15 dm, sand (Deposit 2).

On the scroll bars Deposit 1 is usually thinner than in the swales. Here the sandy clay bed representing Deposit 1 can often be identified above the sandy clay of the top stratum deposit of the meander belt of Deposit 2, its soil texture being somewhat lighter. This is demonstrated in the following soil profile: 0-3 dm, brown sandy clay (Deposit 1); 3-4 dm, yellowish-brown, relatively heavy sandy clay; 4-11 dm, yellowish-brown sandy clay; 11-14 dm, yellowish sand (Deposit 2).

Compartment VIII constituting the north-west end of the meander belt has an even more marked accretion topography than compartment II. This is particularly true of the soil relief, a very wide and deep swale being found in the centre of this compartment. This swale developed as early as Sedimentation Phase 2b, as may be inferred from the fact that a fossil vegetation horizon is found at a relatively great depth in the heavy clay in the swale. This position is considerably deeper than that of a neighbouring layer of ancient culture soil of the Roman era, at the top of Deposit 2a.

Fossil river gully 13 delimiting compartment VIII towards the adjoining compartment VII occupies a much higher position in the landscape than the abovementioned swale. Apparently the river channel functioned up to a fairly late stage of Sedimentation Phase 2a, so that compartment VIII covers a long period of sedimentation.

Profile in the centre of the swale: 0-5 dm, brown sandy clay (Deposit 1); 5-9 dm, grey sticky humic, heavy clay with a dense concentration of rustcoloured iron oxide accumulations (Deposit 2a); 9-10 dm, dark grey fossil vegetation horizon; 10-20 dm, fairly dark grey humic, heavy clay; 20-21 dm, grey sandy clay; 21-22 grey sand (Deposit 2b).

Profile at the site of the ancient culture soil (see above): 0-5 dm, brown sandy clay (Deposit 1); 5-7 dm, ancient culture soil (Roman era); 7-11 dm, brownish-grey sandy clay (Deposit 2a); 11-13 dm, grey, relatively heavy sandy clay; 13-16 dm, grey, very light sandy clay; 16-19 dm, grey sand (Deposit 2b).

Compartments III and VII are much alike as regards their soil pattern and other soil conditions. Both compartments have a fairly level soil topography, the sandier sections rising only a few dm above the heavy clay sections. Instead of a distinct point bar configuration, the compartments have an alternation of the contrasting soil types in a more or less parallel configuration. Gully fill material is usually absent from the faint depressions with the heavy clay soil. Only one long narrow rectilinear depression, in compartment III, has a genuine fossil gully (No. 10). But it is not genetically related to the meander belt as it is a secondary formation which arose during a later stage of sedimentation Phase 2 (cf. p. 48).

The fairly level aspect of the soil surface is due to protracted sedimentation of heavy clay between the light textured ridges. In compartment VII a fossil vegetation horizon is found locally at such a depth in the relatively thick, heavy clay deposit that we must assume it to have been formed at the end of Sedimentation Phase 2b. During Sedimentation Phase 2a renewed deposition of heavy clay largely levelled up the hollows of the meander belt sections in compartments III and VII. The soil pattern in the two compartments is cut by that in the adjoining compartments VI and VIII, and Ia and Ib representing later sections of the same meander belt.

A well-developed accretion topography, although less marked than in II and VIII, is found in compartment VI. Unlike compartments II and VIII it is not an integral part of the core of the meander belt; it is not bordered by a fossil river channel and the concave side of the scroll bars and swales is open towards the exterior of the meander belt instead of the interior. It is in the shape of a wedge in the point of which the swales join to form a fairly wide strip of heavy clay. This sedimentary structure is best described as a form intermediate between a point bar and a meander belt splay (cf. p 8).

A rather similar structure is found in compartment V, but here it has much more the character of a meander belt splay. The deposit has an elongated shape and is without the varied soil pattern characteristic of a point bar.

On the western side of compartment IV a genuine meander belt splay is found along a fossil gully. It differs from the deposit just described in that it projects into the basin like a spear.

On the eastern side of the same compartment a series of three small meander belt splays are located adjacent to a fossil river gully which is not genetically related to these splays but to the Ib meander belt section.

All the meander belt splays of both the genuine and intermediate type have normal meander belt soil profiles. Just outside the splays, in compartments IV and V, the body of coarse sand below the top stratum deposit of sandy clay in the meander belt splays often extends slightly into the basins, below the bed of heavy basin clay which also forms part of Deposit 2. In compartment V the entire spur-shaped southern section of the small basin, enclosed between the meander belt splays, also shows this situation.

As the basin soil in compartments IV and V occupies a very low position with respect to the soil surface at the point of the meander belt splays, the soil pattern is clearly reflected in the soil topography. The pedogenetic morphology of the basin soil indicates very wet conditions in the environment during Sedimentation Phase 2. These conditions must have been conducive to the splay formation (cf. Chapter 6.10).

Compartment IX encloses a meander belt splay having a close affinity to the sections of the meander belt in compartments III and VII, as inferred from its soil pattern. Apparently it also dates from an earlier stage of Sedimentation Phase 2. Its western side is bordered by a minor basin in the same compartment. Here the sandy subsoil of the splay extends below the heavy basin clay bed forming part of Deposit 2 in the same way as in compartments IV and V.

Originally the meander belt splay was genetically related to a river divide coinciding with fossil gully 12 in square 3C which probably had a dead end at the edge of the minor basin. At its other end it continued in square 3D towards the north-east to join a main river course outside the splay. Here it filled up with sand and sandy clay, making it unidentifiable in the terrain. The gully was situated just along the edge of the sandy subsoil of the meander belt splay.

The sandy subsoil of the wide meander belt between Lienden and Maurik locally consists of intensely brown, very coarse sand, instead of the yellowish calcareous, finer sand commonly found below the top stratum deposit of sandy clay in meander belts of Deposit 2. The brown sand was 'inherited' from the stage of the meander belt existing during the previous Sedimentation Phase 3 (cf. below) and was obviously spared during later rejuvenation. But some of the brown sand may occur in a secondary position as it was translocated over a short distance by the eroding river. In such cases it now forms part of Deposit 2 instead of Deposit 3. In this connection it is important to note that the brown sand is sometimes intermixed with the sandy clay of the top stratum deposit of the meander belt (biological mixing may also have been a factor).

5.1.2. *The old circular meander belt*

The complex meander belt described cuts another complex meander belt which forms a wide circular curve from Ommeren (square 5G) towards the south to Blauwe Kamp-farm, where it touches the Linge 'river' (square 7E), and thence towards the north-west and north to terminate south of Eck en Wiel (square 3D).

Within this meander belt only a few compartments are observable. They date from the two successive Sedimentation Phases 3 and 2. The later Sedimentation Phase is represented by two compartments XIb and XIc. XIb forms a lateral strip over the entire length of the western half of the circular meander belt and separates the three compartments dating from the older Sedimentation Phase, viz. Xb and Xc in the same part of the meander belt, and Xa occupying practically the entire eastern half of the meander belt. This is the only large meander belt fragment in the Betuwe known to us which escaped the rejuvenation process subsequent to Sedimentation Phase 3 (with the exception of the small compartment XIc).

The compartments comprising Deposits 2 and 3 respectively have an entirely different pedogenesis and soil texture, particularly in the subsoil below the top stratum deposit. In the compartments with the later Deposit the subsoil consists of calcareous sand of a moderately coarse texture, its yellowish colour indicating little or no pedogenesis at that depth, whereas in the compartments occupied by the older Deposit 3, the subsoil mostly consists of very coarse sand mixed with gravel. Where the soil surface is relatively elevated, an intensely brown colour developed indicating intense pedogenesis (cf. p. 32). The material is free of lime. Where the soil surface occupies a relatively low position, so that the water table occurred at a fairly shallow depth before being artificially lowered, soil formation (in the pedogenetic sense) affected the soil profile to a less extent or in a different way. Here it is of a more yellowish or grey colour.

The eastern half of the circular meander belt is about twice as wide as the western half. West of Blauwe Kamp farm, where the meander belt divides, the eastern half also has a continuation in compartment XIa (in squares 7DC). Like XIb and XIc this compartment represents a rejuvenated stage (Deposit 2) of Deposit 3. A remnant of the latter is still found in the form of a thin layer of sandy clay overlying a layer of gravel, forming a short lateral section (in square 7C) of the meander belt below the clay bed of Deposit 2. Deposit 3 can also be traced from the finds of remnants of two urns from the Middle Bronze Age, at some depth below the soil surface in the more central part of XIa (in the same square)(R.S. Hulst[1], priv. comm. 1980).

The structure of the meander belt is best explained by assuming a clockwise flow of the former river branch along the circular meander belt during Sedimentation Phase 3. The river branch bifurcated near Blauwe Kamp farm. Towards the end of this Phase the river branch ceased functioning in the eastern half of the circular meander belt and filled up, leaving clay plug 22 as a reminder of its former existence. The two branches along the western half of the circular meander belt and the meander belt in compartment XIa respectively, represented by the fossil river gullies 17 and 18, remained intact to form the channel of a new river branch flowing from the west, via Blauwe Kamp farm to the north, during the subsequent Sedimentation Phase 2. During this Phase compartment XIa was rejuvenated over its entire width and the western half of the circular meander belt over part of its width, coinciding with compartment XIb.

The new river branch had an acute angle near Blauwe Kamp farm. At that point a short branch (No. 20), coinciding with a former continuation of No. 22, split off to the east. It is genetically related to the small wedgeshaped rejuvenated compartment XIc.

A series of close borings extending to a few dm below the top of the sandy subsoil, across the eastern half of the meander belt in square 7F, revealed a varying morphology of the top of the sandy subsoil. In the more western borings the material was very coarsely sandy and gravelly and free of lime, as is commonly found in a meander belt forming part of Deposit 3; in the more eastern borings it had a coarse sandy, calcareous aspect. This disparity possibly occurs along the entire eastern half of the circular meander belt, but the matter was not investigated.

The above finding may be taken to indicate that an eastern outward section of the eastern half of the circular meander belt occupies an intermediate position between the old meander belt of the normal type and a rejuvenated one forming part of Deposit 2. However, the occurrence of culture sites dating from the Middle Bronze Age in square 7G, near the edge of the meander belt pleads against a fairly young age.

At the end of Sedimentation Phase 3 the circular meander belt had a fairly pronounced undulating soil topography. Where the belt was not rejuvenated after this Sedimentation Phase, the topography was largely levelled down by

[1] State Service for Archeological Investigation in the Netherlands.

the deposition of the sandy or heavy clay beds of Deposits 2 and 1, the highest elevations remaining as outcrops of the meander belt proper among the later clay deposits. In addition to these outcrops the map (1 + 2) shows lower elevations of the top of the meander belt, which only penetrate the clay bed of Deposit 2 but are covered by the uppermost clay bed (Deposit 1).

This structure is revealed by the very complex soil pattern particularly above the more western longitudinal section of the eastern half of the circular meander belt. The longitudinal arrangement of the small elevations and hollows at the top of this section is distinctly shown by the tangle of soil boundaries on map 1+2.

The western half of the circular meander belt shows a highly contrasting picture. The non-rejuvenated compartments Xb and Xc have only two, fairly large, areas in which the clay bed of Deposit 2 or the two aggregate clay beds of Deposits 2 and 1 are absent.

Map 3+4 shows a fairly large number of clay plugs (fossil gullies) in the old circular meander belt. They date from the end of Sedimentation Phase 3 and occupy a central position in the more or less protracted hollows where the covering clay beds of Deposits 2 and 1 reach their greatest total thickness. At such places the soil surface was often lowered to some extent during the deposition of these clay beds. Apparently a few protracted hollows retained a certain function with respect to the flow of the flood water during Sedimentation Phases 2 and 1. The occurrence of coarsely textured material (coarse sand and gravel) above the meander belt among the heavy basin clay soil, along these hollows (in squares 7E – 6EF and 67G respectively) is connected with this factor (cf. chapter 6.3).

It was stated on p. 16 that the river branch originally found on the site of the circular meander belt had a clock-wise flow. This is supported by the fact that the top of the body of coarse sand and gravel of the meander belt descends in the same direction. The fall along the meander belt could be roughly calculated from a limited number of borings levelled to NAP (Amsterdam Ordnance Level).

From the point of contact of the eastern half of the circular meander belt with the wide meander belt between Lienden and Maurik (in square 5G) to a point 0.4 km to the south, the fall is 7 dm; from here to a point 0.1 km to the south of the point of contact of the western half with the wide meander belt (in square 3D) it is 10 dm over a distance of 7 km. Over the 0.1 km stretch at the end of the circular meander belt it rises abruptly to bridge the difference in height (10 dm) from the top of the sandy subsoil in the wide meander belt representing Deposit 2. The fall is thus + 17 dm, + 1.4 dm and – 100 dm per km over the three subsequent stretches.

Between the above points of contact, the later, wide meander belt (Deposit 2) shows that the top of the sandy subsoil falls 7 dm over a distance of 4 km, or 1.7 dm per km.

In the rejuvenated section of the western half of the meander belt (compartment XIb) the top of the sandy subsoil is about level with that in the non-rejuvenated section (compartment Xc). But north of fossil gully 14 (see map 1 + 2), in squares 43D, a disparity appears. Over this 1400 m long northern stretch the top of the sandy subsoil shows a gradual rise instead of a continuous fall. This rise is about 4 dm up to the point of contact with the wide meander belt between Lienden and Maurik and runs parallel with a rise of the present soil surface over the same stretch. The latter rise is also found above the adjoining part of the non-rejuvenated section (in compartment Xc also to the north of the fossil gully 14). Here the disparity between the level of the present soil surface and the level of the top of the sandy subsoil is overcome by a proportionate increase in the thickness of the covering clay beds of Deposits 2 and 1.

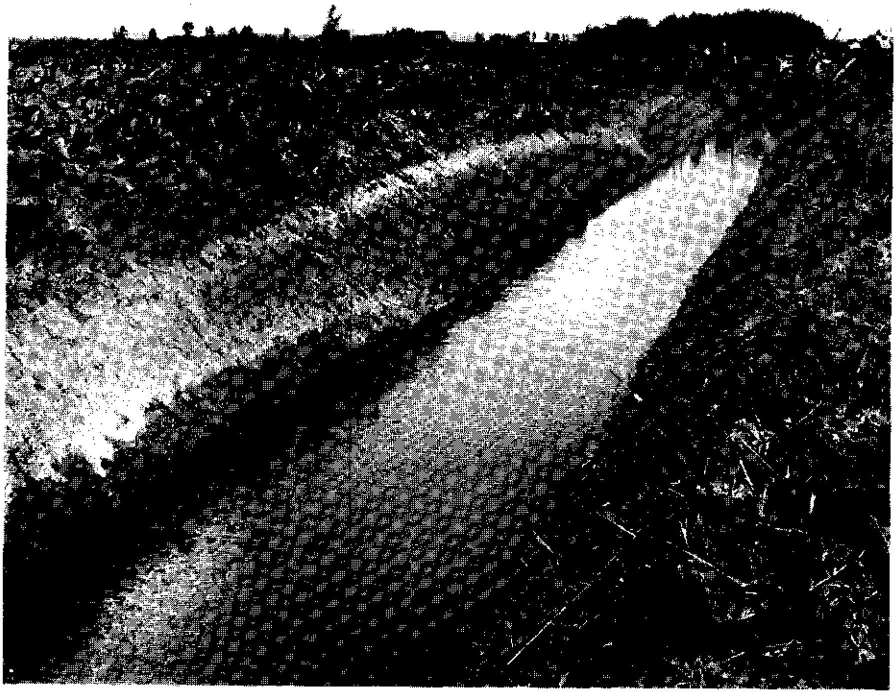

FIG. 7. Section through the fossil river gully No. 28 in square 8H (Photograph by J.A.M. van Schaik and W.G. Sombroek)

Doorsnede door de fossiele riviergeul No. 28 in ruit 8H (Foto J. A. M. van Schaik en W. G. Sombroek)

Soil profiles in the non-rejuvenated compartment Xa of the circular meander belt.

Where Deposit 3 is overlain by a sandy clay bed of Deposit 1 only, in square 6F: 0-5 dm, greyish brown, relatively heavily textured sandy clay (Deposit 1); 5-8 dm, brown sandy clay; 8-9 dm, do. and showing a textural stratification; 9-12 dm, intensely brown, very coarse sand, mixed with gravel (Deposit 3).

Where it is overlain by the two aggregate heavy basin clay beds of Deposits 1 and 2 (in square 7F): 0-5 dm, brownish-grey, heavy basin clay (Deposit 1); 5-6 dm, dark-grey fossil vegetation horizon; 6-8 dm, grey, heavy basin clay (Deposit 2); 8-9 dm, dark-grey fossil vegetation horizon; 9-11 dm, brownish-grey sandy clay; 11-14 dm, fairly intensely brown, very coarse sand mixed with gravel (Deposit 3).

The above two profiles are entirely free of lime.

Soil profile in the rejuvenated section XIc (in square 5C) of the circular meander belt: 0-3 dm, brown sandy clay (Deposit 1); 3-4 dm, greyish-brown, relatively heavy sandy clay; 4-9 dm, brown sandy clay, calcareous below 8 dm; 9-12 dm, calcareous, yellowish-brown, light sandy clay; 12-18 dm, calcareous, yellowish coarse sand (Deposit 2).

5.1.3. *Other meander belts*

All the meander belts not mentioned above have a plain sedimentary structure. With the exception of the meander belt with fossil gully 41 they all represent a rejuvenated version of a meander belt already existing before Sedimentation Phase 2. This may be inferred from the position of levees (or splays) forming part of Deposit 3 with respect to the present (late) meander belts. Sometimes it was also shown by the material bored from the sandy subsoil in the meander belts, viz. where this had the intensely brown colour and very coarse texture characteristic of the old material.

The wall of a newly dug ditch, in square 8H, offered a unique opportunity for observing the twofold sedimentary structure of the body of coarse material of the meander belt with the fossil river gully 28, below and a little on the side of the gully fill (Fig. 7 and section E-E′). With the exception of a relatively thin discontinuous top layer, it was all found to represent Deposit 3 at this point. Apparently the shallow river branch only had a slight erosive capacity during Sedimentation Phase 2.

6. LEVEES, LEVEE SPLAYS AND CREVASSE DEPOSITS OF THE SEPARATE DEPOSITS 1-8

The two sides of a meander belt are usually flanked by a sandy clay bed forming part of the same Deposit. These two clay beds which join above the body of coarse sand and gravel of a meander belt, are known as levee.

For the sake of convenience the term levee (deposit) will also be used to denote the section of a levee running alongside one or both sides of a meander belt.

6.1. Levees and levee splays of Deposit 2

The width of the levees of Deposit 2 is rather variable in the mapped area but fairly uniform in the same levee. The levees generally have a smooth border; levee splays are rather sparse and usually insignificant.

Here and there a meander belt section is flanked by a levee on one side only, for instance that representing the rejuvenated section of the western half of the old circular meander belt (in compartment XIb). The absence of a levee on its eastern side must be due to the presence of the protracted, fairly elevated section of compartment Xc (Deposit 3) east of the former river branch along the rejuvenated compartment XIb, now forming an outcrop in the midst of the clay beds of Deposits 2 and 1. At the points of the lower sections of compartment Xc, the flow into the basin enclosed by the circular meander belt was impeded by the flood water in this basin, which accumulated at its downstream, western side. In this respect it is noteworthy that a similar sedimentary situation as in Deposit 2 is suggested by the soil pattern of Deposit 3 along the western half of the circular meander belt (cf. map 3 + 4).

A fairly extensive levee splay is found near the eastern border of the map area in squares 6 RS. Like the well-developed meander belt splays in compartments IV and V, it formed in a small, poorly drained basin. Another fairly extensive levee splay is found in and near the north-western section of square 4D. It partly overlies the north-easterly section of compartment Xc of the old circular meander belt (Deposit 3) (cf. p. 18).

Splay formation was insignificant in the large basins. In the large basin north-west of Ochten a minor levee splay is found in squares 87J. Note also the small area of sandy clay near compartment XIa of the old circular meander belt, in square 6E, remote from a levee of Deposit 2. It is probably genetically related to the erosion deposit along fossil gully 21 (cf. p. 24). In square 3C a series of minute splays flank the southern bank of fossil gully 12. They form low, but distinct elevations in the terrain.

As stated in chapter 4, Deposit 2 actually consists of two sub-Deposits 2a and 2b. The separate clay beds can only be distinguished for sure in the basins, viz. where the position is indicated by a fossil vegetation horizon at the top of 2b. This horizon mostly occurs about half-way down aggregate clay beds

2a + 2b, but a different depth is not uncommon. The fossil vegetation horizon at the top of the basin clay bed of Deposit 2b is occasionally in contact with the fossil vegetation horizon at the top of the basin clay bed of Deposit 3a, viz. where the 2b-clay bed is only 1 dm or less (cf. section B-B′ at 5000 m and F-F′ at 1750 m, enclosure 3). In such a case the underlying vegetation horizon has a more bluish tinge, a more intensely rust-coloured staining and a weaker consistency than the upper horizon.

Where both fossil vegetation horizons appear to merge into each other (cf. section B-B′ at 5200-5500 m), the morphological features suggest a continuation of the fossil vegetation horizon at the top of Deposit 3a whereas Deposit 2b shows a gap.

Most of the levees of Deposits 2a and 2b are fairly similar and therefore delimited by the same boundary. Here and there sandy clay of Deposit 2b is overlain by heavy basin clay of Deposit 2a, but in one area the textural succession is exactly the reverse (squares 67P). In all these cases the textural transition is found in the deeper part of the aggregate clay beds of Deposits 2a + 2b, so that it is very doubtful whether it actually tallies with the partition level of the two Deposits as suggested by the map 1 + 2. For the sake of convenience this question is omitted from the legend.

Occasionally a sandy clay bed is found sandwiched between an upper and a lower clay bed both consisting of heavy clay (cf., for instance, section D-D′ at 4000 m).

It is clear from what has been said above that deposition of sandy clay remained constant over most of the map area during the whole of Sedimentation Phase 2(a + b). The vertical variations in the textural composition of the aggregate clay beds of Deposits 2a + 2b do not indicate any possible systematic increase or decrease in the deposition of sandy clay systematically spread over the entire mapped area (cf. Deposit 1, p. 27).

The clay bed of Deposit 2 (a + b) is usually 5-6 dm thick (mostly 6 dm in the large basin enclosed by the circular meander belt). Here and there in the levees the thickness gradually increases to 8 dm nearer the fossil river gullies. A thinner basin clay bed of Deposit 2 is found above the old circular meander belt (often only 2 dm thick), but its thickness abruptly increases (up to 8 dm) above the fossil river gullies of Deposit 3 (cf. map 3 + 4, enclosure 2). A thinner clay bed (3-4 dm) is also found above the very extensive branching levee splay of Deposit 3, north of Dodewaard, where the latter has local elevations (occasionally representing Middle Bronze Age culture sites).

6.2. Crevasse deposits of Deposit 2

Besides meander belt splays or levee splays, more or less extensive deposits of sandy material (often coarse sand mixed with gravel, and occasionally lumps of heavy clay or rounded pieces of wood) are found outside the contours of a meander belt or levee. Such deposits are characterised by a flat structure, their thickness not usually exceeding about 6 dm. Unlike the splays, formed during the major part of a Sedimentation Phase (Havinga 1969, p. 33), they owe their existence to a catastrophic break through a levee. Having regard to their position at the end or along a fossil overflow gully, which actually represents a fossil crevasse, 'crevasse deposit' would seem to be an appropriate descriptive term.

Crevasse deposits are found in squares 4AB, 5B, 6C (all three along the western side of the western half of the old circular meander belt), 4F and 3D. The first has a large extension and a complex structure. It runs to about 1 km, and its distance from the meander belt is 1.1 km. This indicates that the flow in the crevasse (gully 14a-b) was extremely rapid during the formation of the crevasse deposit. As shown by the lobate contour of the deposit and a number of gaps inside it, the flow was in two different directions. There was also a time difference. The narrow, long southern lobe borders a fossil gully which must have been a continuation of gully 14b located east of the crevasse deposit. It obviously represents an earlier stage which silted up with sandy material after the gully had shifted, with a curve, to its present, more northerly position.

The stratigraphical situation is shown in section I-I′: enclosed between the topmost and (the level of) the second topmost fossil vegetation horizon, the crevasse deposit apparently forms part of Deposit 2.

In the basin just north of the crevasse deposit two fossil gully fragments are found which probably once formed part of an overflow gully in contact with river branch 17a along the rejuvenated compartment XIb of the circular meander belt. This overflow gully may be considered a precursor of the crevasse, also active during Sedimentation Phase 2. This would agree with the fact that the lobe representing the earlier stage of the crevasse deposit is separated from the fossil vegetation horizon at the top of Deposit 3a by a layer of heavy basin clay of Deposit 2 (cf. p. 51).

The crevasse deposit in square 5B is weakly developed. It is thin and contains scarcely any coarse sand intermingled with sandy clay. But very coarse sand and gravel is found, locally in a thick layer, as a fill of the two narrow branches at the western end of the fossil gully (crevasse) 15, enclosing the crevasse deposit (cf. section J-J′). Section K-K′ across the crevasse shows that just east of the bifurcation sand is found as a thin layer at the bottom of the fossil gully below 2 m humic, peaty, heavy clay. Apparently the flow in the crevasse was not powerful enough to throw a thicker bed of sand over its bank. This sedimentary structure may be connected with the fact that the surrounding soil surface was relatively high owing to the presence of a thick levee of Deposit 3 (a + b) in the subsoil (cf. map 3 + 4).

Soil profile in the northern divide of the crevasse 15 to the east of section J-J′: 0-3 dm, sandy clay (Deposit 1); 3-5 dm, fairly dark grey, relatively lightly textured heavy clay; 5-11 dm, coarse sand mixed with gravel; 11-12 dm, sand; 12-18 dm, coarse sand mixed with gravel (Deposit 2).

The extensive crevasse deposit south of Ingen in square 4F has a somewhat complex structure. It mainly formed as early as Sedimentation Phase 2b, viz. alongside the overflow gully which near the village of Ommeren branches from the river gully 1. Its southern end formed during Sedimentation Phase 2a, and is related to overflow gully 26. (The difference in age is not represented on the map).

The Dutch landscape is no longer shaped by natural fluvial activity. Fortunately we learned from Mr. S. van der Werf[1] (priv. comm. 1982) that a crevasse deposit had recently formed near the bank of the Ems river in West Germany after it had burst during a very high water level (spring of 1981) (5 km north-west of Rheine). Here a gully four m wide and some m deep had scoured across a well-developed point bar on the inside of a bend of the river channel. It extended 200 m beyond this ridge. At its end a deposit of sand about 4 dm thick, 200 m long and some tenths of metres wide ran in the same direction as the crevasse. The process of scouring, erosion of the sandy subsoil and redeposition of sand had taken place in a wooded area. On the point bar the forest was mainly beech; the lower ground behind was covered by an ash-elm forest. Except for some nettles, the sward had completely vanished below the covering bed of sand.

The above formation is very reminiscent of the much more extensive crevasse deposit in squares 4AB in the mapped area.

6.3. Crevasse deposits and comparable erosion deposits forming part of Deposit 1 or Deposit 2, adjoining or covering the old circular meander belt

Extremely coarse-textured deposits (gravel or a mixture of very coarse sand and gravel) are found in contact with the inner bend of the circular meander belt in square 6D (falling inside the contour of a levee splay of Deposit 1) and above this meander belt in squares 7E-6EF and 67G.

The first is a true crevasse deposit formed by a breach in the bank of the nearby former channel 17a. It consists of gravel mostly mixed with coarse sandy material, and usually occupies the lower part of Deposit 1.

In square 7E a similar formation is found above the circular meander belt. It extends from the same river channel towards the north-east, thus forming a fairly narrow strip over a relatively short stretch. It differs from the above crevasse deposit in that it usually also spans the upper part of Deposit 2 from which, however, the gravelly component is absent.

Some hundreds of metres from the 17a former channel it merges into another erosion deposit extending strip-wise along the western side of fossil gully 21 in the old meander belt (Deposit 3) (map 3+4) and further to the north. This deposit has a variable structure, in the form of a fairly irregular pattern of small

[1] Institute for Nature Management.

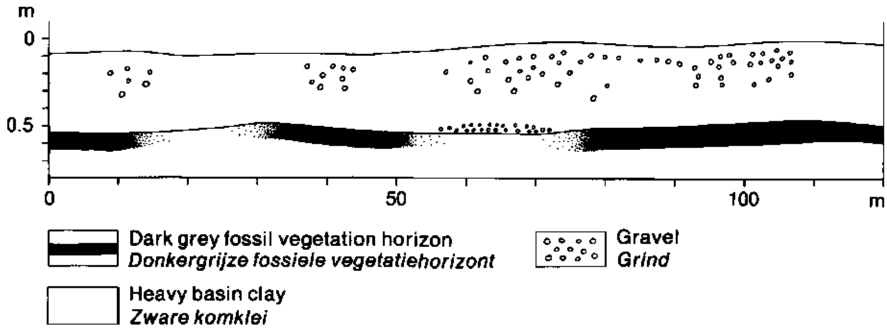

FIG. 8. Section showing the erratic distribution of gravel in heavy basin clay of Deposit 1, in square 7E

Doorsnede door zware komklei van Afzetting 1 met grillige vermenging met grind, in ruit 7E

areas where gravel and coarse sandy material are intensely intermingled, or where pure gravel is interspersed with heavy basin clay, the sandy material being entirely absent. The eroded material is found at varying depths in Deposit 1 as well as over the entire depth of this Deposit.

The section in Fig. 8 illustrates the fairly erratic occurrence of pure gravel as observed from the wall of a newly-dug ditch near the edge of the area where eroded material is found.

It is unlikely that the discontinuous deposit of eroded material also formed by the breach in the bank of the river channel (the eroded material is distributed quite differently in the vertical plane). Most probably the formation of this deposit is connected with the hollow at the surface of the heavy basin clay soil coinciding with the underlying fossil river gully fragment 21 in the old meander belt. The shallow, gully-shaped hollow influenced the direction and velocity of superfluous flood water which drained from the basin to the east of the compartment Xa of the circular meander belt, via this compartment, into the western downstream basin (cf. p. 50). The irregular, discontinuous spread in the horizontal plane suggests that the eroded material was partly derived from neighbouring outcrops of the old meander belt in the middle of the heavy basin clay soil.

The distribution of pebbles in the heavy basin clay, as shown in Fig 8, is not easy to account for. It cannot be assumed that they had sunk in the clay to varying depths since the clayey soil must have had a relatively firm consistency due to the shallow, periodically well-drained, coarse-textured subsoil represented by the underlying meander belt. The peculiar distribution is most probably due to simultaneous superficial erosion of clay and sedimentation of pebbles which occurred at various places, at various times and depths.

A similar, though minor occurrence of gravel is found in the heavy basin clay bed of Deposit 1 above the western half of the old circular meander belt very near the 'opening' in the levee of the rejuvenated section (compartment XIb) of the meander belt. This opening is in the form of a shallow hollow through which flood water drained, at a greater velocity, from the large basin enclosed by the circular meander belt towards overflow gully 15 and via the latter into the basin to the west of this meander belt. The gravel is not shown on the map.

Coarse-textured erosional deposits are also found in Deposit 2. They often differ from similar deposits in Deposit 1 in that they contain rounded lumps of heavy clay. These balls of clay were apparently swept away from the clay plug in the fossil gullies, or the bed of heavy basin clay beside the gullies, by the force of rapidly flowing flood water. The heavy clay beds of Deposits 1 and 2 are often entirely eroded at the point of these erosion deposits.

Deposits of this type have a more local, discontinuous spread, in or alongside the fossil river gully fragments 21 (mentioned above), and 23 (in squares 67G).

The occurrences of the erosional deposits on the circular meander belt described above clearly indicate that the more upstream basins drained into the more downstream western basins partly via the heavy basin soil above the old circular meander belt, where it preferentially flowed through the fairly shallow gully-like hollows. It must be assumed, however, that the great mass of water drained via the intact overflow gullies.

Soil profile containing erosion material in the heavy clay bed of Deposit 1 only, at the point of fossil gully 21 in the old meander belt (Deposit 3): 0-9 dm, heavy clay mixed with gravel and coarse sand, the percentage of the latter increasing in a downward direction (Deposit 1); 9-15 dm, humic sticky heavy clay (gully fill) (Deposit 2); 15-18 dm, very coarse sand mixed with gravel (Deposit 3).

Soil profile containing eroded material in both heavy clay beds of Deposits 1 and 2 near the above gully: 0-3 dm, heavy clay mixed with gravel and coarse sand (Deposit 1); 3-4 dm, weakly developed, somewhat dark grey fossil vegetation horizon; 4-5 dm, sandy clay mixed with coarse sand; 5-8 dm, sandy clay; 8-10 dm, mixture of very coarse sand, gravel and heavy-clay balls (Deposit 2); 16-14 dm, very coarse sand mixed with gravel (Deposit 3).

6.4. Levees of Deposit 1

With the exception of gully 41 on the eastern boundary of the mapped area and of some 'continuous basin drainage channels' (cf. p. 43), the river branches and overflow gullies had completely or largely silted up towards the end of Sedimentation Phase 2. The meander belt system underwent no change after that date. River activity was now largely confined to the river courses of the Lower Rhine – Old Rhine and Waal respectively north and south of the mapped area. This substantially altered the pattern of deposition of the sandy clay and hence the configuration of the levees. During Sedimentation Phase 1 these were mainly formed more or less parallel to the present river – dikes, but the flow of the flood water conveying the sandy clay and heavy basin clay was greatly influenced by the pattern of the silted-up, fossilized, gullies, as well as the few gullies which had remained open. Most of the former consisted (as they still do) of shallow hollows of varying depths and widths in the terrain.

The effect can be seen at several places. Thus the protrusions of the northern and southern levees at their point of contact in squares 8KL, between the large basins respectively east and west of Ochten, was certainly induced by fossil river gullies 36 and 29. It is also obvious south of the western section of No. 29 (via Echteld) where the sandy clay of Deposit 1 has a heavier texture about half-way along this river gully and the dike along the Waal than nearer the gully and dike; locally it even gives way to a deposit of heavy clay, viz. where the miniature basins are found in squares 9FG (cf. section D-D′ at 300-500 m).

The large south-north orientated meander south of Blauwe Kamp farm (squares 89E) of the fossil river gully 29, forms a fairly wide and deep hollow in the terrain. Via this course and the dividing fossil overflow gully 19 (in square 8E), sandy clay was carried far to the north along former river gully 17a (in contact with No. 19 near Blauwe Kamp farm). The river gully 17 had not entirely silted up by the end of Sedimentation Phase 2 as it was inserted in the natural basin drainage system which arose at that period (cf. p. 51). Most of the sandy clay was deposited along the western side of this gully system, which is similar to the situation found in Deposits 3 and 2 along the western half of the circular meander belt (cf. p. 20). But unlike the levee of the latter Deposit, that of Deposit 1 is not genetically related to the rejuvenated section of the circular meander belt.

The vast extension of the levee of Deposit 1 in the north-western part of the mapped area, at the site of the wide meander belt between Lienden and Maurik, was apparently due to the numerous fossil river gullies in this meander belt (Deposit 2). To the south of Ommeren it extends still further as a vast lobate protrusion running south-west above the northern section of the eastern half of the circular meander belt (Deposit 3). The shallow hollows at the point of fossil river gully 22 and fossil river gully fragments west of No. 22 (cf. map 3+4) must have furthered the transport of sandy clay so far to the south-west. The sandy clay only sedimented on the western side of the fossil gully 22. This uneven distribution is caused by the position of the gully parallel to the downstream edge of the basin east of the circular meander belt (cf. the situation in Deposits 1, 2 and 3 along the western half of the circular meander belt.

The levees of Deposit 1 often correspond fairly well to underlying levees of Deposit 2, for instance, along the western half of the circular meander belt, in the small basin east of Opheusden, where a levee splay is found in squares 6RS, and around the two minature basins found east of Maurik in squares 3BC and 34D.

In view of such agreement it might seem likely that the development of the soil pattern of Deposit 1 was greatly affected by biogenetic homogenization. This process might be assumed to have turned a clay bed of Deposit 1, consisting of clay of a heavier texture, into a more lightly textured clay bed where it is underlain by a sandy-clay bed of Deposit 2 (cf. HAVINGA 1969, p. 40). But in many sites the composition of the vertical soil profile is incompatible with this theory, the overlying Deposit 1 having a lighter texture than the underlying Deposit 2. Such situation is found, for instance, in most of the fossil gullies found within the contours of the levees of Deposit 1, and in most of the miniature basin of Deposit 1 in squares 7KL.

Although it is difficult to say precisely how far biogenetic soil homogenization may have affected the contours of the levee deposits forming part of Deposit 1, we may hazard the theory that generally speaking it was only of limited importance.

Crevasse deposits are scarce in Deposit 1. Two crevasse deposits resulting from a breach of a current through the bank of the channel, are found in squares 6D and 7E, respectively adjoining and above the circular old meander belt. They were described above in chapter 6.3.

The levees of Deposit 1 often show a textural bipartition, i.e. a layer of sandy clay covering most of the vertical plane occupied by Deposit 1 rests on a 1 to 2 dm layer of heavy clay, or occasionally a layer of sandy clay of a distinctly heavier texture. The more heavily textured bottom layer is not continuous but covers fairly extensive separate areas, viz. a zone comprising the section of the wide meander belt between Lienden and Maurik north of Compartment I and east of Compartment VIII; a zone south of this meander belt between squares 3C and 7J (cf. section F-F′ at 2400-2900 m and section D-D′ at 4300 m); a zone north of the Waal dike between the Amsterdam-Rhine Canal and squares 89I (cf. section D-D′ at 200-300 m and 2100-2400 m, and section E-E′ at 20-40 m).

Outside these zones the layer has a very scattered distribution.

The level of textural partition does not represent a stage of reduced sedimentation during which a vegetation horizon could develop. A fossil vegetation horizon was nowhere found in the levee or in the basin deposits of Deposit 1. This is why Deposit 1 was not subdivided into 1a and 1b. Apparently sedimentation was a continuous process the character of which changed during Sedimentation Phase 1.

The clay bed of Deposit 1 is usually from 4 to 6 dm thick. A greater thickness is often found in the basins and also in the levees. In the latter it may rise to 8 dm or even more at a fairly short distance from the river dikes. But a layer of such thickness is often partly due to the addition of very coarse sand from the deeper subsoil as a result of a dike break in historic times. In the more central part of the basin enclosed by the circular meander belt the heavy clay bed of Deposit 1 is usually 7-8 dm thick (cf. section F-F′ at 900-2100 m)(cf. p. 40). Such a thick layer is also found in the northern section of the most easterly small basin, particularly beside and at the end of overflow gully 39 which apparently had a certain sedimentation function in this basin during the last Sedimentation Phase (1). A heavy clay bed 7 dm thick is locally found in the north-western section of the large basin to the east of the circular meander belt, and in the basin north-west of Dodewaard in square 8P.

Like Deposit 2, Deposit 1 is relatively thin (3-4 dm) above the unrejuvenated sections (Xa, b, c) of the old circular meander belt and at scattered points above the levees or splays of Deposit 3 (cf. p. 21).

The clay beds of Deposit 1 as observed during the survey must be slightly thicker than shortly after their deposition. During the reclamation of the river clay area in historic times a thin layer of soil material from the newly-dug ditches was evenly spread over the parcels and distributed over the topsoil by ploughing. Such a process can sometimes be inferred from the morphology of the soil profile, viz. where it has a coarse-sandy component in the ploughed layer which is absent below but is well represented in the deeper subsoil into which the ditches have been dug. (This is not true of areas where coarse sand was supplied by flood water as a result of a dike break).

To afford some idea of the increase in the thickness of the clay beds of Deposit 1 we take as an example a parcel 100 m wide and 200 m long, surrounded by ditches 1.2 m deep and 1.5 m wide at a depth of 0.6 m. The raising of this parcel is equal to half the content of the surrounding ditches divided by its area, i.e. $^1/_2$ (600 x 1.5 x 1.2):(100 x 200)m = 0.027 m.

6.5. Levees of deposits 1 and 2 showing distinct hydromorphic characteristics in the soil profile

The levees forming part of Deposits 1 and 2 usually have a soil morphology corresponding an effective external or internal drainage, viz. a brownish colour and spongy structure due to intense biological activity in the soil (cf. fig. 5).

Near the edge of a levee the soil surface gradually descends to the level of the soil surface in the adjoining basin. Here the soil texture closely resembles that found in the basin, and the same is substantially true of the pedogenetic soil profile i.e.: it becomes more greyish, rust-coloured stains appear, and the structure becomes fairly compact.

In some areas the soil profiles in the levees may even show distinct hydromorphic features, viz. where until recently drainage of the levee soils was greatly impeded. Such a situation is found in the levee at the eastern boundary of the mapped area, in square 8S. Here the very wet environment is due to the low position of the top of the levee with respect to the soil surface in the adjoining basin. The various overflow gullies crossing the levee indicate that the flow in the former river channel along the poorly developed levee was greatly impeded (cf. also map 1+2 in Havinga 1969, showing the eastern section of the south-north orientated levee), and this certainly contributed to the wet environment. In this connection it should be noted that the levee is practically without an underlying body of coarse sand.

Soil profiles in a levee showing distinct hydromorphic features are also found around the partly corresponding miniature basins in Deposits 1 and 2 in squares 7KL, south of Kesteren. Here also the soil surface is very flat.

Extreme hydromorphic pedogenesis occurred in the levee of Deposit 1 above the small basins of Deposit 2, north of the wide meander belt between Lienden and Maurik, in compartments IV and V. Here the sandy clay has a greyish colour densely mixed with rust-coloured stains, together with a fairly high humus content and scattered shell fragments. The very wet environment (obtaining up to some decennia ago) was caused by the low position of the soil with respect to the surrounding meander belts or meander belt splays (cf. p. 14). The soil surface is lowest where very humic/peaty clay or peat is found in the underlying Deposit 3 (particularly in compartment IV, cf. map 3 + 4).

6.6. Levees, splayed levees and levee splays of Deposit 3

Deposit 3 is usually 8-9 dm thick. The minimum thickness is 5 dm, the maximum 12 dm.

Like Deposit 2 it consists of two sub-Deposits, 3a and 3b, which are often indistinguishable. Where a fossil vegetation horizon is found at the top of Deposit 3b (in scattered areas in the basins and sporadically in the levees) it usually occurs about halfway down the clay bed of the aggregate Deposits.

Deposit 3 often shows a bipartite soil texture viz., sandy clay on heavy clay or the reverse. Since the partition level is often also found at about half-way the total depth of Deposit 3, it is assumed that it actually coincides with the top of Deposit 3b (or bottom of Deposit 3a). This is supported by the fact that at various points a fossil vegetation horizon was found just below the textural transition. This situation differs from that in Deposit 2 (cf. p. 21).

Where the combined Deposit 3 (a + b) consists of sandy clay over its entire depth it is usually impossible to distinguish the individual Deposits; occasionally however, the top of Deposit 3b is locally marked by a bed of heavy clay 1 or 2 dm thick.

The assumption that a textural bipartition usually coincides with a stratigraphical bipartition in Deposit 3 was a starting point for drawing soil boundaries, although there is no evidence that this always reflects the real situation.

Deposit 3 differs widely from Deposits 1 and 2 in that it has mainly splayed levees or levee splays instead of levees with smooth contours. The term 'splayed levee' refers to a sandy clay deposit adjoining a meander belt, with a pattern intermediate between a normal levee and a lateral series of levee splays along the meander belt. The most striking feature of the soil pattern of Deposit 3 (as also of Deposit 4) is the complete absence of such formations over fairly long stretches of the various meander belts.

The levee splays have widely varying contours but can be roughly classified as a lobate and a narrow protracted type. North of Dodewaard a levee splay is found having an exceptional, complex structure. It consists of various anastomosing narrow strips of sandy clay, often with wavy contours. Since the strips have various longitudinal and lateral sections, the top of which varies according tot the top of Deposit 3a, 3b or 4, it may be inferred that the complex splay took a long period to form.

Curiously enough, the remote, rather west-east orientated strip of the complex splay in squares 7Q-6RS (supporting a dense concentration of Middle Bronze Age culture sites) has its top level with the top of Deposit 3a, whereas nearer the meander belt from which this splay divides, it only silted up to the lower level coinciding with the top of Deposit 3b. It is only at scattered sites along this part of the splay that the sandy clay occupies the same elevated position as in the remote strip.

There are two more or less valid explanations for this discrepancy. The most plausible is that the soil pattern within the splay as shown on the map is defective, the network of borings being too wide to reveal the precise structure of the splay. If this is so, the small patches of sandy clay representing Deposit 3a would give a fragmentary picture of a continuous, very narrow, elevated strip of sandy clay deposited during Sedimentation Phase 3a.

The second explanation is that the soil pattern is true to nature. This would imply that the separate elevations were formed prior to Sedimentation Phase 3a. The presence of separate elevations on a splay or a more continuous irregular relief of such a formation is known from published evidence (HAVINGA 1969, SOMBROEK and ZONNEVELD 1971, p. 66, fig. 21). In explanation of the elevated position of the top of the remote strip of sandy clay in squares 7Q-6RS it could be argued that deposition of sand or of sandy clay up to a relatively high level, at a relatively large distance from the supply base, is by no means impossible (cf. the crevasse deposits west of the circular meander belt (p. 22). Reference may also be made to the occurrence of isolated patches of sand at the ends of the lobes of some splays (two patches in square 8L and one in square 8N). As in the crevasse deposits, the concentration in all the above splays of material with a coarser texture could have resulted from a more or less catastrophic break in the levee in contact with the splays. The formation of the protracted complex splay could also be thought to result from the activity of a crevasse.

A gully fill inside the splay was only found at one point, in square 7Q, south-east of Opheusden (it is not shown on the map).

The soil pattern shown by Deposit 3 (and also Deposit 4) has been observed in other parts of the world at the present soil surface, for instance in the Rima-Sokoto river basin in north-west Nigeria (surveyed by SOMBROEK and ZONNEVELD (1971)) and in north Dorobougou-Soye in the Republic of Mali (surveyed by BERTRAND (1973)).

The first area is a large river basin with numerous rivers joining in the Niger river flowing south towards the Gulf of Guinea and draining the basin. Along part of the present or former rivers a soil pattern is found consisting of irregularly shaped levees, as well as levee splays comparable with the soil patterns of map 3+4. The basin is locally poorly drained, as shown by the fact that in one part fluvio-lacustrine deposits are found in the back swamps comparable to some extent with the local gyttja deposits found in the basins in the mapped area (cf. p. 39).

The deposits with splay configuration in the Rima-Sokoto river basin have a flat macro-relief but a considerable meso-relief and rather homogeneous and wide (250-500 m), relatively high stretches of a somewhat sinoidal form (former river levees) having locally a fig-leaf shape and containing shallow creeks resembling veins ('crevasses with crevasse splays'). Alternating with the levees are fair-

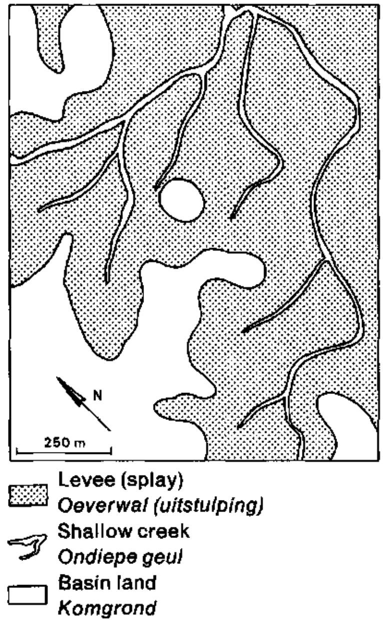

FIG. 9. Erratic levee (splay) configuration in the Rima-Sokoto river basin (N.W. Nigeria) (drawn from Sombroek and Zonneveld 1971, fig. 16)

Grillige configuratie van oeverwal(uitstulpingen) in het bekken van de Rima-Sokoto rivier (N.W. Nigeria) (nagetekend van Sombroek en Zonneveld 1971, fig. 16)

ly extensive regular lower parts (parts of former basin lands).

The aerial photograph (Fig. 16 in SOMBROEK and ZONNEVELD) representing 120 ha (copied in Fig. 9) closely resembles a certain part of the splayed levee of Deposit 3(a+b) west of the circular meander belt, in square 6B (cf. map 3+4).

The latter picture differs from the photograph in that fossil gullies are absent from the splay deposits. A gully fill in a splay was only bored twice during the survey of the mapped area, viz. No. 44 in a narrow protracted splay (in square 8R) near the eastern boundary of the area, and in a similar splay south-east of Opheusden (see above, p. 30). The short strip of sand in square 8I in the subsoil of a narrow protracted splay may also be considered as a deposit in a former gully (No. 43).

Since the relatively few borings in the narrow protracted splays revealed the existence of former gullies, whereas the many borings in the lobate splays or splayed levees gave no such indication, it seems likely that the latter are actually devoid of fossil gullies. Whatever gullies may have existed in these splays they were no doubt shallow and finally silted up with sandy clay indistinguishable from that in the levee deposits.

Meander belt splays are fairly common in Deposit 3, and occur inside the contours of the levees of this Deposit (cf. the situation in Deposit 2, p. 14). The thickness of the layer of coarse sand may vary to a large extent. Thus it is only a few dm thick in the major part of the meander belt splay adjoining compartment XIa to the south, in squares 8CD, which therefore could be considered a coarsely textured levee splay as well.

6.7. PEDOGENETIC CHARACTERISTICS OF DEPOSIT 3

The sandy clay in the levees or levee splays of Deposit 3 has a quite different morphology from that in the levees of Deposits 2 and 1. Instead of a brown colour and spongy soil structure (cf. p. 28) it has a grey colour interspersed with rust-coloured stains, and a relatively compact soil structure above the water table. The higher parts of the levees or levee splays have a lighter grey colour, as well as fewer rust-coloured stains than the lower parts. A very light-grey colour is characteristic of the highest parts, where ancient culture sites occasionally occur (Middle Bronze Age). Sandy clay in a lower position usually contains humic material and sometimes plant remains suggesting deposition of sandy clay in an environment comparable with a back swamp.

Most of the sandy clay contains lime up to the top of the deposit or slightly below. In the highest parts a some dm thick non-calcareous zone is found near the top, but occasionally such a zone is also found where the bed of sandy clay occupies a lower position. Shell fragments occur at varying depths at scattered sites in sandy clay both humic and non-humic.

Lime also commonly occurs in Deposits 1 and 2 only a little way below the top in a deposit of sandy clay. However, this similarity is mostly due to different pedogenesis. In Deposits 1 and 2 the shallow occurrence of lime was maintained because eluviation of this component by internal drainage was counteracted by biological homogenization (bioturbation), whereas in Deposit 3 eluviation was largely checked by a relatively shallow water table and an adjoining full capillary zone. In the higher parts the situation must have been more similar to that in Deposits 1 and 2.

The soil type in the meander belt of Deposit 3 is in sharp contrast with the above picture. Where this meander belt remained intact (compartments Xa, b, c) the soil profile mostly shows a more or less homogeneous, intensely brown colour, both in the thin top stratum deposit consisting of sandy clay and in the very coarse sandy, gravelly subsoil.

Strangely enough this colour, which is reminiscent of the morphology of the calcareous soil profile type in the levees of Deposits 1 and 2, is accompanied by deep decalcification. It may be assumed that the brown, noncalcareous soil profile developed as the result of the fluctuating water table. During the low stages lime could easily eluviate through the very coarsely textured soil and owing to the absence of a rich soil fauna this process was scarcely counteracted by bioturbation. Such a fauna was prevented from developing by the combination of a periodically very high water table (during the flooding stages of the rivers) and a highly porous subsoil at a shallow depth below the thin top stratum, causing rapid and complete drenching of the whole of the profile when the river rose to flood level. Owing to eluviation of the lime in the soil profile, the pH gradually fell to such an extent that free iron oxides were released from the soil minerals and gave the soil matrix its intensely brown hue.

According to a micro-morphological investigation by JONGERIUS and REIJMERINK (1963) of a soil profile in the Utrecht river clay area having the same morphological characteristics as the normal soil profile in the old meander belt, pedogenesis would even have proceeded to the extent of clay eluviation and formation of an argillic horizon (Soil Taxonomy 1975). But this finding was not confirmed by a more recent investigation of R. MIEDEMA[1] (priv. comm. 1982).

As the intensely brown, decalcified soil profile is found both covered by the two more recent clay beds of Deposits 2 and 1 and in the outcrops of the old meander belt, it is clear that the time factor was not of paramount importance for the pedogenesis.

But it is doubtful whether the special soil morphology can be fully explained by the above theory. The morphological characteristics (intensely brown colour and absence of lime) may be partly inherent in the fluvial sediment. It may be taken for certain that it partly consists of reworked, coarsely textured material eroded from Pleistocene ice-pushed ridges or fluvio-glacial deposits upstream of the circular meander belt. In its original position it may already have had some of the features as in its present position in the old meander belt.

The following factors may explain the discrepancy of the pedogenesis in the levees and levee splays on the one hand and in the meander belts on the other.

During Sedimentation Phase 3 the hydrological balance of the Rhine was largely adapted to the original natural environment, the destruction of the natural plant cover by man still being at an early stage. Owing to the uniform regime of the river, as adapted to this situation, periods of exceptionally low and very high river levels were not so frequent and of short duration compared with the regime during the later Sedimentation Phases 2 and 1. As a result an intenser internal drainage usually only reached the coarsely porous meander belt, whereas wet soil conditions continued to prevail in the finely porous, more remote levees and levee splays. This factor becomes increasingly important where the levee splays or (splayed) levees extend far into the basin, particularly if their contours narrow towards the point of contact with the meander belt (as in square 8L or 7M). Another factor is the often relatively high silt percentage in the deposit of sandy clay in the levees and levee splays of Deposit 3 (cf. chapter 6.11). This is conducive to a long capillary fringe above the ground water table thereby somewhat impeding the lateral internal drainage.

Finally, it is conceivable that the pedogenetic characteristics in the sandy clay deposits of Deposit 3 underwent a change after being overlain by the clay beds of Deposits 2 and 1. The hydromorphy may then have increased or developed as a result of the relative rise of the ground water table which prevented air

[1] Micro-morphologist at the Department of Soil Science and Geology, Agricultural University, Wageningen.

from entering the soil to a greater depth. This implies that originally the soil profiles in the higher parts of the levees or splays of Deposit 3 may have been less hydromorphic than at present or may even have resembled a brownish soil profile lacking rust-coloured stains, as commonly found in the levees of Deposits 1 and 2.

6.8. Levees, splayed levees and levee splays of Deposit 4

Deposit 4 spans a thickness of 6-8 dm in the (splayed) levees, levee splays or basins. Its soil pattern is very similar to that of Deposit 3, but the levees and splays occupy a much smaller total area than in the latter Deposit. The map shows only three fairly extensive levees, viz. in squares 6LMNO, 8DEFG and 3CDE, and one large splay, viz. the branched, protracted narrow one north of Dodewaard largely coinciding with the similar splay in Deposit 3 at this point. The remainder is mostly occupied by fairly small splays.

Where such correspondence is found it was usually impossible during the survey to ascertain whether the sandy clay deposit near 2.20 m depth actually forms part of Deposit 4 or of Deposit 3, owing to the similarity of the sandy clay in the successive Deposits at the same place. Fortunately the transition between the two Deposits could be established at scattered points by the presence of a 1-2 dm layer of heavy clay about 1.9 m deep, obviously coinciding with the top of Deposit 4. A fossil vegetation horizon was sporadically found in a similar position.

A meander belt deposit forming part of Deposit 4 was nowhere identified during the survey. But it may be inferred from the points of contact of the levees or levee splays with the present meander belts that the meander belts of Deposit 4 occupied about the same position as the later ones. This is not true of the meander belts along fossil river gullies 36 and 41. These specimens were newly formed during Sedimentation Phases 3 and 2.

It may be concluded from the relative scarcity of levees or levee splays of Deposit 4 that the river activity was lower during Sedimentation Phase 4 than during the subsequent Sedimentation Phase 3. It may therefore be assumed that the meander belts were narrow at this period.

6.9. The clay beds of Deposits 5, 6, 7 and 8

Below Deposit 4 four more Deposits were identified in the basins above the Pleistocene subsoil. As they are found in the subsoil of the river clay area below the boring depth of 2.20 m we can only rely on information obtainable from the sections in enclosure 3, on a section across the basin enclosed by the circular meander belt, perpendicular to section F-F′ and on fifty sections made by the students during their practical work. These are scattered over the mapped area, 500-1000 m in length, and also span the total thickness of the aggregate Holocene

Deposits. The latter sections and the one across the mentioned basin are not dealt with in the present publication.

Deposit 5 roughly varies from 6 to 8 dm thick in the basins or levee splays. The thickness of Deposits 6, 7 and 8 cannot be exactly established owing to the scarcity of fossil vegetation horizons in the sections at the corresponding depths, or because the clay beds are limited downward by the Pleistocene subsoil. It is clear, however, that the thickness of the clay beds of the older Deposits is of the same order of magnitude as that of the later clay beds.

Only a few borings in the sections revealed the presence of a levee or levee splay. This suggests that the total area occupied by these elements in Deposits 5-8 is less than in Deposit 4.

6.10. ENVIRONMENTAL CONDITIONS FAVOURING LEVEE SPLAY DEVELOPMENT

Levee splays and splayed levees are the commonest feature of Deposits 3 and 4. The pedogenetic soil profile, often showing an intense hydromorphy, and the frequent presence of organic material in the sandy clay, shows that the splays were formed under very wet conditions.

Splays are scarce in Deposits 2 and 1. Meander belt splays (Deposit 2) occur in the small isolated basins in compartments IV and V north of the wide meander belt between Lienden and Maurik, and a fairly extensive levee splay in the small basin south-east of Opheusden. In these basins drainage was entirely or substantially obstructed. The former basins had no overflow gully through which flood water could drain into a river branch, and the latter drained into a secondary small river branch via overflow gully 39.

It may therefore be concluded that a very wet environment in a levee as well as in the adjoining basin land was greatly conducive to splay formation. For instance, a there waterlogged, oozy soil which is more or less permanently flooded will only offer slight mechanical resistance to the flow of flood water entering the basin and supplying the sandy-clayey sediment. The flood water moves towards the interior of the basin and has a 'front' (viewed as iso-velocity curves) with an erratic outline, due to minor variations in soil consistency and possible variations in the vegetation cover. The flow is occasionally concentrated in a more or less narrow stream leading to a levee splay of the narrow, protracted type. It may be assumed that such a formation was often induced by an isolated low section in the river bank or a crevasse. The occurrence of a short strip of coarse sand in square 9Q extending from the meander belt at the base of the protracted branched levee splay north of Dodewaard would fit in with this theory.

Here and there a lobate levee splay extends into a narrow protracted type (in squares 5A and 7J-8I on map 3 + 4). In this case it is impossible to tell whether the latter is an extension of the lobate splay or a separate splay traversing a lobate splay.

6.11. Differences between the soil texture of levees of later and older Deposits

It would be logical to assume that the different sedimentary conditions obtaining during Sedimentation Phases 1 and 2 as compared with those during Phases 3 and older, which caused a such marked difference in the general soil pattern, also affected the textural composition of the various Deposits. This theory agrees with the fact that the soil texture of the sandy clay in the levees or levee splays of Deposits 3 and 4 was estimated during the field work to contain a higher relative silt percentage than that of the later Deposits, although the method employed (viz. rubbing some soil material between thumb and forefinger) is far from exact.

Establishing the validity of the above observation would reguire a very time-consuming, statistically reliable investigation into the particle size distribution. We confined ourselves to a tentative investigation of a few soil samples from Deposits 2 and 3, which, according to field estimates, fell within two textural groups, viz. 20-25% and 30-35% clay (<2μ) (cf. tables 1a, b)

The data in Table 1b show that the silt percentages are actually higher in Deposit 3 than in Deposit 2. The higher silt percentages mean lower clay percentages in all cases, and lower sand percentages in all cases but one (sample No. 6).

It seems probable that a difference in the ratios of the three textural classes sand, silt and clay also exists between Deposits 1 and 2, although in this case we must expect that the sand percentage in Deposit 1 will be relatively higher than in Deposit 2. This would agree with the high discharge capacity of the Lower Rhine and Waal during Sedimentation Phase 1, which is also reflected in the vast extension of the levees of Deposit 1.

TABLE 1A. Comparison of the textural composition of some soil samples from Deposits 2 and 3

soil texture field estimate	No.	Dep.	percentages clay <2μ	silt 2-50μ	sand >50μ
	1	2	22.5	43.9	33.6
20-25% clay	2	3	25.2	54.0	20.8
	3	3	24.2	58.7	17.1
	4	2	34.7	57.1	8.2
30-35% clay	5	3	31.0	62.5	6.5
	6	3	29.2	59.5	11.3

TABLE 1B. The silt: clay, silt: sand and silt: clay + sand ratios of the soil samples in Table 1a

No.	Dep.	silt : clay	195 fixed at 100	silt : sand	130 fixed at 100	silt : clay + sand	95 fixed at 100
1	2	195	100	130	100	95	100
2	3	215	110	260	200	117	123
3	3	240	122	340	260	142	150
			165 fixed at 100		702 fixed at 100		133 fixed at 100
4	2	165	100	702	100	133	100
5	3	200	121	970	138	167	126
6	3	205	124	525	74.5	147	116

7. THE BASINS

7.1. Pedogenesis in the basins

The beds of heavy basin clay of Deposits 1 and 2 and the upper part of the bed of heavy basin clay of Deposit 3 are affected by pedogenesis unlike the deeper layers of heavy basin clay. The pedogenesis which led to the formation of the fossil vegetation horizons is ignored in this respect (cf. Havinga 1969, p. 22). This results from artifical drainage of the Betuwe area connected with reclamation of the originally waste back swamps since the Middle Ages. The lowering of the ground water table led to a prismatic or angular blocky soil structure (cf. fig. 4) oxidation of part of the humic material in the heavy basin clay, etc.

The appearance of the heavy basin clay below the upper part of the heavy clay bed of Deposit 3 has not altered much since its deposition. It has no pedogenetically induced soil structure, a very weak, slushy consistency, and contains finely-divided humic or peaty material. (In the sections, the first component is only shown where it occupies a higher percentage in the heavy basin clay). Strangely enough, these features appear immediately below a fossil vegetation horizon which is assumed to represent a stage of stagnating flooding, i.e. drier soil conditions. It is notable that even the levees or levee splays of the older Deposits are often without the soil morphological features corresponding to relatively dry soil conditions (cf. p. 32).

7.2. The occurrence of lime in the basins

Lime is quite common in a basin where sandy clay is found in the subsoil, e.g. in a levee splay of Deposit 3. The heavy basin clay proper is usually free from lime. This is also true of the peaty material in the basins.

The sections B-B′, C-C′, D-D′ and F-F′ give a good idea of the distribution of lime in the basins of the mapped area. Its occurrence was only traced at the site of borings marked with a signature (Δ).

The sections show that calcareous heavy basin clay only occupies short vertical stretches in the soil profile at a few scattered points. A fairly dense concentration of lime is only found where the soil was so wet during clay deposition as to lead to the formation of clayey gyttja (in section F-F′ between 1000 and 1800 m and in section D-D′ between 3800 and 4000 m). But even here the various occurrences are not continuous in an upward direction. Thus the following alternation of soil material and lime is found in section F-F′ at 1350 m: calcareous heavy clay – non-calcareous heavy clay – non-calcareous clayey gyttja – calcareous clayey gyttja – calcareous clayey peat – non-calcareous clayey peat.

This confirms the theory that precipitation of lime in a basin requires a very wet environment (cf. HAVINGA 1969, p. 39). But precipitation obviously depends on subtle chemical variations in the environment.

7.3. FOSSIL VEGETATION HORIZONS (FIG. 4)

As in the mapped area of the previous study, the distinctness of a fossil vegetation horizon varies considerably from place to place. It often shows gaps of varying size or is absent over an extensive area. These variations are not usually related to other visible evidence of varying soil conditions. A well developed fossil vegetation horizon may be found at the top of a peaty clay bed, or even clayey peat bed, as well as at the top of a normal heavy clay bed. But where these layers give way to a deposit of clayey gyttja a fossil vegetation horizon was nowhere found in the mapped area (cf. section F-F′ between 1000-1800 m and D-D′ between 3800-4000 m).

The fossil vegetation horizon at the top of Deposit 2a is the only one with a very extensive continuous spread in all basins. This is thought to be due to the fact that soil conditions at the end of Sedimentation Phase 2a were periodically much drier than at the end of the earlier Sedimentation Phases (cf. p. 64).

It was mentioned in the previous publication (HAVINGA 1969, p. 39) that the number of fossil vegetation horizons sometimes increases near the border of a basin. This applies to the pictures shown in section C-C′ at 100-400 m and in section D-D′ at 2100-2500 m and 3900-4300 m. As a provisional explanation it was stated that the higher concentration of fossil vegetation horizons was due to somewhat drier soil conditions associated with a slightly higher soil topography. But section F-F′ shows that this is not the general rule. In the deepest part of the basin enclosed by the circular meander belt, crossed by this section, the number of fossil vegetation horizons is greater than on the side. We can offer no satisfactory explanation of this discrepancy.

7.4. DEPOSITION OF PEAT AND GYTTJA IN THE BASINS

The extensive spread of peaty material in the basins of Deposits 3 and older and its absence from the basins of Deposits 2 and 1 is a very striking sedimentary feature. Apparently the total mass of sediment brought down by the Rhine increased considerably after Sedimentation Phase 3. The amount of peaty material deposited enabled the individual older Deposits to maintain about the same level soil surface throughout the basin area.

In the central part of the basin enclosed by the circular meander belt clayey gyttja is found in the midst of clayey peat (cf. section F-F′ at 1000-1800 m). Clayey gyttja also occupies a short stretch in section D-D′ (at 3800-4000 m), i.e. in the basin east of the circular meander belt. This material was deposited in a pool which may have been formed by erosion of the unstable peaty soil.

7.5. Wood remnants in the basins

Wood remnants are found in the basins below the permanent water table in the heavy clay and in the top layer of the Pleistocene subsoil. During the survey only 4 of the 81 borings deeper than 2.20 m revealed wood remnants in the heavy basin clay at a greater distance above the Pleistocene subsoil. Near or at the top of the Pleistocene subsoil the frequency is somewhat greater (7 of the 81 borings). One wood remnant was bored in a levee splay having soil features inherent in a very wet environment (humic sandy clay) (at 6200 m in section B-B′). The remnants originated from alder and willow or possibly poplar.

Even taking into account the slight chance of an auger only some cm thick touching a piece of wood if wood remnants are fairly scarce in the basin clay, it may be concluded from the extremely low frequency that wood growth was very scarce in the basins. It was only somewhat commoner prior to and during the initial stage of the heavy basin clay deposition.

7.6. Effects of subsidence on soil topography and thickness of individual clay beds in the basins

Differences in height of the soil surface in a basin are often due to differential subsidence resulting from reclamation and embankment of the river clay area and the accompanying improvement of the soil drainage since the Middle Ages. But differential subsidence also occurred under the natural conditions preceding the period of human impact.

An elevation in the soil surface existing at the beginning of a certain Sedimentation Phase was partly levelled during this or later Phases, a thicker layer of clay being deposited where the soil surface was lower.

Where a heavy clay bed of Deposit 1 has the same thickness at the point of a terrain elevation as beside it, it may be assumed that the relief is due to differential subsidence since the Middle Ages. Such a situation is found, for instance, in squares 8MN. Above the there splay in Deposit 3, the heavy basin clay bed of Deposit 2 is somewhat thinner than usual at scattered sites, viz. where the splay is somewhat elevated above the usual top of Deposit 3. It thus levels the relief existing prior to Sedimentation Phase 2. Deposit 1 does not vary in thickness in the surroundings.

A fairly complex situation is found in the basin enclosed by the circular meander belt. As stated on p. 27, the basin clay bed of Deposit 1 is much thicker than usual in the more central part of this basin (cf. section F-F′ between 900 and 2100 m). But Deposit 2 is of normal thickness throughout this basin. This may be connected with the fact that the soil surface fell in the basin as a result of increased drainage after the continuous basin drainage gully (No. 6-14) had formed during the later part of Sedimentation Phase 2 (cf. p. 50). The more central part of the basin was very liable to subsidence, its subsoil largely consisting of peaty clay, peat and gytja in combination with a deep position of the

Pleistocene. The present relatively low level of the soil surface in the basin results from the artificial drainage.

When interpreting differences in thickness it should be remembered that a local thickening of a bed of heavy basin clay may sometimes be associated with the presence of an overflow gully in the same area. Thus overflow gully 39 is thought to be responsible for a local thickening of the basin clay bed of Deposit 1 (cf. p. 27).

But in many cases it is not possible to trace any relationship to the soil profile or the relief of the present or former soil surfaces. We must therefore assume that deposition of clay was often influenced by 'accidental' factors. This is true, for instance, of the local thickening of the heavy basin clay bed of Deposit 2a in the basin enclosed by the circular meander belt shown in section F-F′ at 1600 m, and of the varying thickness of the heavy basin clay bed of Deposit 2 (a + b) in the large basin south of Opheusden shown in section C-C′ between 1100 and 2300 m. In the latter case the clay bed is very thick even where the Pleistocene subsoil occupies a shallower position.

8. THE PLEISTOCENE SUBSOIL

The Holocene river clay is underlain by a Late-glacial (Weichselian) braided river deposit. It consists of a body of coarse sand and gravel several metres thick with a clayey layer on top up to 1 m thick. In the mapped area the top layer is usually only some dm thick and consists of sandy clay, sandy clay on clayey coarse sand or clayey coarse sand. Locally it is absent, the Holocene river clay (or peat, locally) being in direct contact with the coarse sandy-gravelly Pleistocene subsoil.

The Late-glacial formation includes a few small river dunes. Some specimens are found in square 7Q. These rise to the level of the clay bed of Deposit 3 and made a favourable occupation site for the Middle Bronze Age folk.

Where the sandy clay of a levee splay or levee of a given Deposit is in contact with a layer of sandy clay forming the top of the Pleistocene subsoil, it is difficult to ascertain the level of contact. We employed the following criteria for identifying the individual Deposits: humic (or peaty) clay is assumed not to have been deposited during the Late-glacial (unless found in a fossil river channel in the Pleistocene subsoil); a Late-glacial age is only attributed to the layer of sandy clay at the top of the Pleistocene subsoil where it is intermixed with a relatively high percentage of coarse sand. In a thicker layer this is often only true of the lower part in contact with the underlying coarse sand and gravel.

A similar bipartition of the 'loam layer' at the top of the Pleistocene subsoil is distinguished by VAN DER WOUDE (1981, p. 67) in the fluviatile area of the Alblasserwaard far downstream of the mapped area.

The fluvial Pleistocene-Holocene transition zone is near the present soil surface in the Pleistocene river clay area studied by PONS (1966), roughly 40 km upstream of the mapped area, where the lower sections of the old braided river deposit are covered by a layer only 25-60 cm thick of humic-peaty heavy basin clay of Holocene age. Here the soil occupies the same wet position as may be assumed for the lower sections of the Pleistocene subsoil in the Neder-Betuwe when deposition of the Holocene river clay had just begun. The correspondence is confirmed by the fact that in both areas remains of alder roots are found in the clayey top layer of the Late-glacial fluvial deposit.

9. FOSSIL GULLIES

9.1. Fossil gullies and their contribution to fluvial sedimentation

In the present publication the term 'fossil gully' is applied to all the various types of former watercourses, silted up in the course of time, insofar as they can be distinguished according to present terrain characteristics. For instance, this definition is covered by a narrow clay plug in the middle of a deposit of sandy clay (levee or levee splay) with no hollow in the terrain and a fairly wide, protracted hollow in a similar deposit without a clay plug, but having only very indistinct features in the soil profile below (slightly humic, slightly sticky sandy clay) but still clearly indicating sedimentation in a former watercourse.

The great majority of watercourses which once crossed the mapped area silted up in the course of time. A few partly escaped this process and were nearly all inserted in the drainage system constructed by man in the Middle Ages. The present Linge 'river' is a main water course forming part of this modern drainage system.

The following gully types are distinguished according to their function: river gully, representing a section of a river branch; overflow gully, branching off from a river gully and usually having a dead end in a basin; crevasse gully, very similar to an overflow gully but accompanied by a deposit of sand either adjacent to the gully or at its dead end; junction gully, connecting an overflow gully (or crevasse gully) at a more upstream side of a basin with another at a more downstream side of the same basin. A continuous basin drainage gully consists of a series of junction gullies in more upstream and more downstream basins, interconnected by overflow gullies and river gully sections. Such a continuous gully drained the basins when the river courses had lost their normal function and could no longer carry off superfluous drainage water from the basins. Most of the continuous basin drainage gullies have remained active up to the present day.

The physiographic position of the various fossil and active gullies and their morphological characteristics are discussed below in relation to their function during the successive Sedimentation Phases 3, 2 and 1.

The fossil gullies representing a former river course, silted up as early as Sedimentation Phase 3, locally have a dark-grey fossil vegetation horizon at a relatively great depth below the present soil surface. This may have a more or less continuous or fragmentary spread over the gully. Another fossil vegetation horizon, related to Deposit 2a, is often found above. This old gully type is confined to the unrejuvenated compartments (Xa, b, c) of the old circular meander belt.

Most gullies fossilized during Sedimentation Phase 2a. They locally have only one fossil vegetation horizon at a relatively shallow depth below the present soil surface and/or a bipartition with respect to the textural composition of the gully fill, the partition level coinciding with that of the fossil vegetation horizon. Where the latter situation is found, a layer of sandy clay of Deposit 1 covers a gully fill consisting of heavy clay of Deposit 2(a + b).

The gullies fossilized during the last Sedimentation Phase (1) have no fossil vegetation horizon. In such gullies the soil features inherent in a gully fill (humic material, sticky consistency, dense concentration of rust-coloured iron compounds (only above the water table) and shell fragments) may be found up to the soil surface. In the others these features are almost entirely confined to the part of the soil profile below the lowest fossil vegetation horizon.

After its fossilization a gully may have continued to make a greater or lesser contribution to fluvial sedimentation. This partly depends on whether it consisted a more or less wide and deep hollow in the terrain after fossilization, and on its position with respect to the active river courses Rhine and Waal supplying flood water with the sediment. It can be seen from the soil pattern of Deposit 1 as shown on map 1+2, and the soil conditions referred to below, that the (fossil) gullies or complexes of fossil gullies were often important factors. To assess their influence the following facts must be taken into consideration.

A parallelism of the course of fossil river or overflow gullies with the contours of the levees of Deposit 1 where these extend to the interior of the mapped area, is strong evidence that the gullies made a considerable contribution to the sedimentation pattern in the environment (cf. p. 26).

It can sometimes be inferred from the position of the gullies in the present or former landscape that they must have existed as a watercourse during Sedimentation Phase 1. This is true, for instance, of the continuous basin drainage gullies. The fact that a present fossil gully now marches with a municipal boundary could indicate that it was a watercourse as late as the Mediaeval period.

Valuable information was often in a more direct way obtained from the soil profiles in a fossil gully. To gain a proper insight it is indispensable to have a section across a gully. We were fortunate enough to have such a section, viz. in the form of a wall of a freshly dug ditch across fossil gully 28 in square 8H. (shown in Fig. 7 and in the section E-E'). The other fossil gullies could only be pieced together from data from the scattered borings in the fossil gullies, which only give a fragmentary picture of the actual situation.

The presence of a road or wide ditch at the gully site often made it difficult to obtain an insight into the sedimentary situation in a fossil gully.

In some fossil gullies a chronostratigraphic bipartition was established at scattered sites, although the morphology of the gully fill usually suggested that the gully had silted up as late as Sedimentation Phase 1. This situation is possibly the result of a shift or narrowing of the former watercourse during Sedimentation Phase 2.

Fossil gullies filled up during the latest Sedimentation Phase (1) usually have a marked hollow in the terrain, whereas those silted up during an earlier Sedimentation Phase may differ extensively in their surface topography. Some specimens have no hollow at all. If a fossil vegetation horizon or textural partion level is found at the same depth as that occupied by the top of Deposit 2 beside the fossil gully, this proves beyond doubt that the gully cannot have acted as a watercourse, however shallow, during Sedimentation Phase 1 (cf. p. 53, compartment Ib).

But most specimens have a fossil vegetation horizon or textural bipartition in combination with a more or less marked depression in the terrain. Only occasionally the part of the fill representing Deposit 1 in such a gully has the soil morphology inherent in a gully fill. However, the absence of such evidence does not imply that the fossil gully was not then active to some extent.

This can be clearly seen, for instance, in section E-E′ across fossil gully 28. The top of the clay plug of Deposit 2 has a hollow with an indentation in the centre. Above the clay plug and in the indentation the sandy clay of Deposit 1 has no special features suggesting a gully fill. But the existence of the indentation and the fact that the gully runs parallel with the contour of the levee of Deposit 1 (there extending towards the interior of the mapped area), show that the gully did not altogether lose its function after the end of Sedimentation Phase 2.

It may seem strange that a fossil gully was able to influence the flow of flood water, but it should be remembered that when it was active during Sedimentation Phase 1 its capacity was greater than can be inferred from its present potential wet section. To calculate the wet section for the time in question we must take into consideration the thickness of the clay bed of Deposit 1.

The wet sections of No. 28 are calculated to afford some idea.

At the initial stage of the formation of Deposit 1 the narrow fossil river gully 28 averaged 10 m wide and 0.2 m deep. On completion of this Deposit the depth was 0.4 m, if it is assumed that the deposition of sandy clay had not yet begun in the fossil gully itself. This assumption tallies with the observation that in the fossil river gully 34, near Kesteren, mediaeval potsherds were found in the sandy clay bed of Deposit 1 down to the top of the gully fill of Deposit 2 (priv. comm. R.S. HULST 1977). These data correspond to a wet section of 2 m^2 and 4 m^2 respectively.

For an important fossil river gully we calculated a maximum wet section of about 40 m^2. Apparently the wet sections were but small compared with the wet sections of the intact river channels. Yet the fossil river gullies greatly affected the extension and configuration of the levees of Deposit 1. This is explained by assuming that in the overgrown levee soils the fossil gullies formed tracks with little or no overgrowth for the flood water supplied by the Rhine and Waal during high levels. But they probably affected the flow rather than acting as a river course on their own accord.

Reference must also be made to the erosion sediments of Deposits 1 and 2 above the old circular meander belt, found along a few fossil river gullies (fragments) fossilized as early as Sedimentation Phase 3 (cf. chapter 6.3). These sediments show that the flood water preferentially followed the shallow hollows above these gullies in the covering basin clay bed. The current there obviously reached a high velocity.

Intact river branches were not found in the mapped area during Sedimentation Phase 1, probably with the exception of the small No. 41 at the eastern boundary of the mapped area, which remained more or less intact. This is inferred from the occurrence of a gully fill without a fossil vegetation horizon or textural bipartition and from the fact that it separates the large administrative units of the Upper and Lower Betuwe into which the Betuwe has been divided since mediaeval times (VLAM 1950).

It follows from the vast extension of the levees of Deposit 1 towards the interior of the mapped area and the relatively great thickness and light texture of the levees near the river dikes that the river branches (outside the mapped area) had a much greater flooding and sedimentation capacity during Sedimentation Phase 1 than the river branches (both outside and inside the mapped area) during Sedimentation Phase 2. Although the latest Sedimentation Phase had fewer river branches than the other Phase, this cannot have been the only factor. The greatly increased deforestation and soil erosion in the hinterland must also have played an important part, as well as the deteriorating climate (increased precipitation), during the Sub-atlantic period.

9.2. OVERFLOW GULLIES

In the article on the river clay area mapped previously (Havinga 1969) it was mentioned that overflow gullies branching from a river course and having a dead end in a basin rarely affected the contours of the levees of Deposit 2. In the area now under investigation, only three gullies had such an effect, viz. No. 5, splitting off from the fossil river gully 4 along compartment Ia of the wide meander belt between Lienden and Maurik, and Nos. 14b and 15, originally splitting off from the fossil river gully 17 along compartment XIb of the circular meander belt. All three gullies incidentally acted as a crevasse (No. 5 to a slight extent only).

The other overflow gullies always carried a stream which was not rapid enough to convey sandy clay beyond the smooth contour of a levee. Possibly they partly arose not earlier than the final stage of Sedimentation Phase 2a. This theory is supported by the fact that in the previously mapped area (HAVINGA 1969) two overflow gullies are found slightly on the side of and across a well-developed levee splay, the latter showing no connection with the splay configuration. As stated in the earlier article (p. 34), the formation of the splay must have occupied most of Sedimentation Phase 2. The position of the two gullies would be incompatible with the position and configuration of the splay if it were assumed that the gullies had been active when the splay was formed.

It is noteworthy that the long overflow gully 35, south of Kesteren branching from a former river channel north of the mapped area, crosses a series of three miniature basins inside a levee, and continues in the large basin north-west of Ochten (gully No. 32). This curious situation is apparently connected with the fact that in between these basins the long gully is actually situated at the points of contact between the levees of the fossil river gullies 34 and 36, parallelling No. 35 to the north and south respectively.

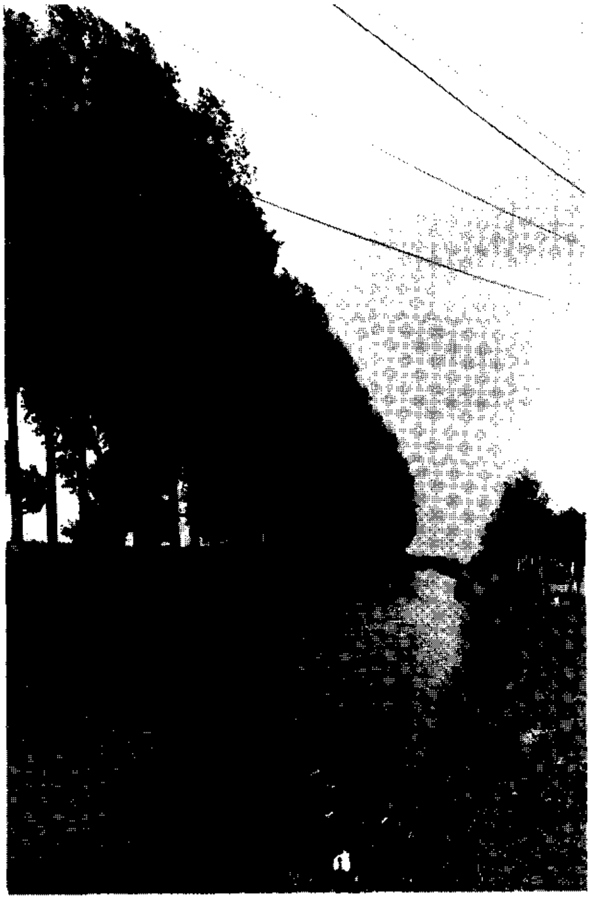

FIG. 10. The Linge 'river' where it follows the course of a practically straight stretch of the former junction gully No. 38 (square 7P)

De Linge, waar deze de loop volgt van een praktisch recht traject van de voormalige, natuurlijke komontwateringsgeul No. 38 (ruit 7P)

9.3. JUNCTION GULLIES

A junction gully connects an overflow gully (or crevasse) on a more upstream side of a basin with an overflow gully (or crevasse) on a more downstream side of the same basin. Most specimens have a fairly straight course (cf. figs. 10 and 11). All the basins in the mapped area are crossed by such a gully. The longest specimen (No. 38), in the large basin north-west of Dodewaard, has a length of no less than c. 6 km.

The development of a junction gully may be assumed as follows: When the river levels rise, the overflow gullies on the upstream and downstream sides begin

FIG. 11. The Linge 'river' where it follows a short sinuous stretch of the former junction gully No. 38, in squares 8NO

De Linge, waar deze de loop volgt van een kort bochtig traject van de voormalige, natuurlijke kom-ontwateringsgeul No. 38, in de ruiten 8NO

to convey the river water into the basin. This continues until the level of flood water in the basin has reached the river level. From then on the gully on the downstream side forms an outlet enabling flood water to run back into the river, the area traversing the basin between the two gullies temporarily acting as a by-pass of the river current. Where the levee and basin only differ slightly in height as was usually the case in the Betuwe river clay area, the layer of flood water is thin and a gully is easily scoured in the slushy basin soil. Conceivably, however, this situation was not essential to the formation of a long fairly straight gully in a basin. Such a type may also be found as a continuation of a single overflow gully only, e.g. No. 37 in the same basin. The weak soil consistency may have been a major factor in the formation of straight watercourses in the basins. In this connection the experiments of SCHUMM (1977) may be referred to, which showed that a straight channel was formed when the gradient was low and no stabilisation of the channel banks or bars was possible.

Although this is an attractive theory it does not fit all occurrences, e.g. it does not explain the straight gully No. 10 in compartment III of the wide meander belt between Lienden and Maurik, where heavy basin clay soils alternate with sandy clay soils.

Generally speaking the junction gullies cross a more central part of the basins and follow the east-west slope of the river clay area. But there are exceptions to this rule, e.g. No. 27, which occurs on the downstream side of the large basin east of the circular meander belt.

Two specimens (Nos. 30 and 33) are found in the position of a shunt of fossil river gully 29. The first crosses a small area of heavy clay soil on the edge of a basin; the other is entirely located inside the sandy clay deposit of the levee beyond the basin and therefore closely resembles a true river branch. But it lacks an accompanying meander belt.

The above agrees with HAVINGA'S (1969) theory that a fossil junction gully is to some extent a transitional form between a fossil overflow gully and a fossil river gully.

9.4. DEVELOPMENT OF THE WATERCOURSE SYSTEM DURING THE SUCCESSIVE SEDIMENTATION PHASES 3, 2 AND 1

Fossil river gullies connected with Deposit 3 (Nos. 42, 21, 22, 23, 24) are found in the unrejuvenated parts of the old circular meander belt.

The fossil river gullies of Deposit 2 represent a fossilized, later stage of river branches which were already active during Sedimentation Phase 3 or an even earlier Phase. This is not true of Nos. 40 and 41 in the eastern part of the mapped area, which arose during Sedimentation Phase 2.

The river branch which formed the wide meander belt between Lienden and Maurik repeatedly changed its course during Sedimentation Phase 2, as may be inferred from the complex structure of the meander belt described in chapter 5.1.1.

The situation around the circular meander belt is very complex. As the various river branches silted up in course of time (cf. p. 16), both the flow of the river water and the flow pattern of the superfluous flood water in the basins changed considerably as time went on.

The following is a tentative reconstruction of what took place. Attention is first paid to the more northerly part of the area around the circular meander belt, and then to the more southerly part, corresponding to the dual route taken by the flood water.

On and parallel to the eastern half of the circular meander belt two long fossil gullies (Nos. 22 and 27) run parallel. The first is a hollow in the present soil surface coinciding with an underlying fossil river gully genetically related to the old circular meander belt (Deposit 3). The other is considered to be a junction gully originally in contact with the river channel at the site of the present fossil river gullies 1, 2 and 3 in compartment Ia, and that represented by the fossil river gully 28, respectively north and south of the eastern half of the circular meander belt.

Near its northern end the first gully has two short branches with a south and east orientation, viz. Nos. 24 and 25. Its position inside the eastern edge of the meander belt would suggest that gully 24 represents a short section of a former branch of No. 22; No. 25 represents an overflow gully. Like No. 22 they both apparently date from Sedimentation Phase 3.

The old river branch represented by fossil gully 22 was cut by a river branch at the site of the present wide meander belt between Lienden and Maurik, still during Sedimentation Phase 3 (cf. p. 16). Its remainder (fossil gully 22) can be traced to the north to a short distance from the latter meander belt. Its end is in contact with overflow gully 26, which is a branch of the junction gully 27.

During Sedimentation Phase 2 flood water from the river branch of the wide meander belt drained via the two gullies 26 and 27. As long as this river branch and river branch 28 in contact with the southern end of 27 continued to function, flood water from the basin east of the old circular meander belt was caught by junction gully 27. To the north, near the northwestern part of the basin, it was also caught by overflow gully 25, and via this gully, the northern junction of fossil river gully 22 and the western section of the overflow gully 26, it drained into the basin enclosed by the old circular meander belt. Owing to their continuous activity since Sedimentation Phase 3, No. 25 and the northern end of 22 remained more or less intact (cf. the profile descriptions of No. 22 on p. 53–54).

After one of the two river branches had silted up in the course of Sedimentation Phase 2, the junction gully largely lost its function and also fossilized. From then on, superfluous flood water in the north-western part of the basin drained via Nos. 25-26 only, which must then have deepened and widened as a result of the stronger current. This caused the formation of part of the crevasse deposit in square 4F (cf. p. 22).

The flood water also followed another, more southerly route. Via the soil surface above the eastern half of the circular meander belt it also flowed westward towards the basin enclosed by the circular meander belt. But there must also have been a south-western flow lengthwise across the meander belt, induced by the narrow hollows above the fossil gullies of Deposit 3 and the micro-relief beside these gullies. Such a flow is demonstrated by the erosion deposits among the layer of heavy basin clay on top of the meander belt, described on p. 24.

The situation outlined above agrees with the finding of FISK (1947) in the alluvial valley of the lower Mississippi, viz. that small channels in a flood basin (most of the eastern half of the circular meander belt underlies such a physiographic element) may be inherited from older and more important drainage systems.

The basin enclosed by the circular meander belt in turn drained into the gully system in the western half of the circular meander belt. As long as river branch 17, genetically related to the rejuvenated compartment XIb, was fully active during Sedimentation Phase 2, the basin mainly drained into this river branch, viz. via overflow gully 14a and the fairly wide hollow representing a break in the levee just opposite overflow gully 15, further south. The hollow contains a normal heavy basin clay soil without the characteristics of a gully fill.

When during Sedimentation Phase 2 the river branch was cut by the river branch of the wide meander belt between Lienden and Maurik, the current was barred, so that all drainage water from the eastern basin was forced towards the western basin. This occurred via overflow gullies 14b and 15 opposite the overflow gully and hollow mentioned above.

Overflow gully 5, beyond the village of Ingen, drained flood water from the river along the wide meander belt into the northern part of the basin enclosed by the circular meander belt. Between this gully and gully 14 across the western half of the circular meander belt, junction gully 6 developed. The stream passing through No. 14 once reached such a velocity as to scour the subsoil of the meander belt to a considerable depth (see section H-H'). This possibly occurred in a fairly catastrophic way, as may be inferred from the great distance between the crevasse deposit in squares 4AB and the meander belt, and from the great mass of coarsely textured erosion material in this deposit (cf. also p. 22).

Junction gully 6 differs from all other large gullies across a basin in that it has a very winding course (not represented on the map). In this respect it resembles a small river channel.

Towards the final stage of Sedimentation Phase 2a the large meander in compartment Ia deteriorated and split up into three separate narrow channels which finally silted up completely (fossil river gullies 1, 2 and 3). The continuous basin drainage gully consisting of gullies 5, 6, 14a and 14b then also deteriorated and partly silted up.

Some distance north of this gully system a long gully is also found consisting of a series of connected gullies or gully fragments. It is entirely located inside the levees of Deposits 1 and 2, and most of it even inside the meander belt of Deposit 2. From east to west, the various gully fragments are: fossil river gully 7, genetically related to compartment Ib, fossil overflow gully 11, splitting up from 7 and cutting through the northern end of the western half of the circular meander belt, and fossil river gully 12. The latter actually consists of two connected, separate gullies, located east and west of Maurik and genetically related to compartments IX and Ib respectively. The joint gullies began to function as a single, very long overflow gully, after the large meander had formed of which fossil gullies 1, 2 and 3 are remnants.

It might be thought strange that the current through this long gully did not lead to the formation of a crevasse deposit west of the cut, south-north orientated, western half of the circular meander belt (as found along the more southern continous basin drainage gully 5-6-14). The discrepancy is due to the entirely different terrain relief. Whereas the meander belt formed a barrier against flood water in the basin in the neighbourhood of the latter gully, it had no elevation in the surrounding levee soil where the other gully is found.

During the final stage of Sedimentation Phase 2, a similar sequence of events as described above for the more north-western part of the mapped area occurred in the more southern and eastern parts. Here also various overflow gullies, junction gullies and fragments of former river branches escaped fossilization to form a continuous basin drainage gully. It largely coincides with the present Linge 'river'. From east to west, the component sections are: river gully fragment 40, junction gully 38, river gully fragment 29 (in square 8K), junction gully 31, river gully fragment 28, overflow gully 20, splitting up from river gully 18-17a near Blauwe Kamp farm (for the development of the system of river and overflow gullies in this neighbourhood during the earlier stage of Sedimentation Phase 2 and the end of Sedimentation Phase 3, cf. p. 16).

West of Blauwe Kamp farm two possible continuations of the continuous basin drainage gully should be envisaged, viz. the former river channel fragment 18 crossing or bordering compartment XIa and extending towards the west, or the former river channel fragment 17a, extending along compartment XIb towards the north. The latter continuation corresponds to the slope of the meander belt (cf. p. 17), whence it may be assumed that the flow mainly followed the northern gully; the other gully silted up.

This theory is supported by the fact that gully 17a runs parallel to a levee formed during Sedimentation Phase 1, showing that the channel fragment had then remained more or less intact (cf. p. 26). It not only drained the flood water carried by the continuous basin drainage gully but, besides, the stream carried by the southern overflow gully 19, via the three overflow gullies 16, 15 and 14b, into the basin west of the circular meander belt. The two latter overflow gullies are accompanied with sandy clay of Deposit 1. Such soil configuration is absent along gully No. 16 but in this case its coincidence with a municipal boundary shows that it was still intact as an open watercourse during the early Middle Ages (this coincidence continues along fossil gully No. 17a).

Apparently its present fossilized state is of more recent date.

It is interesting to note the fairly unique position of fossil gully 16 with respect to the pattern of land parcels, in squares 6BC. In this neighbourhood the fossil gully, and the municipal boundary coinciding with this gully, cross the parcels instead of running between them, as is usually the case. This situation shows that the open watercourse had silted up before the wasteland was reclaimed in the Middle Ages. At the time of reclamation the gully had already silted up to such an extent that it had no hollow in the terrain which was preferentially utilized for the construction of a ditch.

The silting up of the gully 16 is probably connected with a shift in the course of the flood water passing Blauwe Kamp farm in a westerly direction. Instead of bearing north via 17a, the stream was diverted into fossil river gully 18, to continue its westerly course. This change is most probably due to human activity connected with the construction of the Linge 'river' in its modern state.

The drainage system of the entire river clay area was reconstructed in the mediaeval period. The natural, continuous basin drainage gullies were maintained as far as possible (though in a widened and deepened state), but where this could not be done new canals were dug which preferentially followed the hollows of fossil river gullies (cf. p. 57). Where no such possibility existed, a rectilinear canal was dug, as, for instance, in squares 7R-6S, where the Linge traverses a small basin. This stretch was obviously newly constructed, despite the occurrence of a fairly deep and wide hollow in the terrain at the site of fossil river gully 40 bordering this basin at its western and southern edge. Apparently owing to this orientation the gully was unsuitable for incorporation in the new basin drainage system.

In this connection it is interesting to note that a municipal boundary coincides with the part of the Linge 'river' represented on the map by the gully 38, across the large basin north-west of Dodewaard. At the point of contact of this junction gully with fossil river gully 40, instead of continuing to the east along the straight Linge stretch in the small basin, it turns north-west to follow No. 40, and further on, more to the north, overflow gully 39, which runs parallel to the straight Linge stretch.

9.5. Soil profiles in fossil gullies

A soil profile in a fossil gully generally shows one or more of the following features over a greater or lesser part of its depth: sticky consistence of the clay, relatively high humus percentage, occurrence of peaty material, dense concentration of red-brown trivalent iron compounds (not always mentioned below), shell fragments.

Profile in fossil river gully 1 bordering compartment Ia of the wide meander belt between Lienden and Maurik, where it consists of a very shallow hollow in the middle of the ancient culture soil of the village of Lienden: 0-12 dm, ancient culture soil (sandy clay) (Deposit 1); 12-15 dm, sticky humic, very sandy clay (gully fill); 15-18 dm, sand (Deposit 2).

Profile in fossil river gully 2, (north of No. 1) where it has a very shallow hollow just east of the ancient culture soil: 0-6 dm, sandy clay (Deposit 1); 6-12 dm, relatively heavy sandy clay, increasingly humic in a downward direction, shell fragments; 12-14 dm, slightly humic, very sandy clay; 14-16 dm, sand (Deposit 2).

Towards the west the fossil gullies have a deeper and wider hollow. Profile in the fossil river gully 3 in square 4G: 0-4 dm, sandy clay (Deposit 1); 4-12 dm, sandy clay, increasingly humic in a downward direction; 12-14 dm, clayey peat; 14-16 dm, slightly humic sand (Deposit 2).

Fossil river gully 4 representing the continuation of the above separate gullies is very wide and relatively deep (several dm). It has the following soil profile in square 3G: 0-5 dm sticky, somewhat humic sandy clay (like Deposit 2 with the characteristics of a gully fill)(Deposit 1); 5-14 dm, very humic, relatively heavy sandy clay; 14-16 dm, sticky, weakly humic sandy clay; 16-20 dm, sand (Deposit 2).

Fossil overflow gully 5 branching from fossil river gully 4 has a wide and fairly deep hollow near the latter, and becomes shallow when crossing the ancient culture soil of Ingen where it has the following soil profile: 0-7 dm, ancient culture soil (sandy clay) (Deposit 1); 7-12 dm, sticky, humic heavy clay, yellowish phosphate stains; 13-22 dm, bedded sandy clay (Deposit 2).

Near the south-western edge of the ancient culture soil the soil profile has the following pattern: 0-5 dm, sticky, slightly humic sandy clay, shell fragments (Deposit 1); 5-9 dm, sticky, humic heavy clay, shell fragments; 9-13 dm sand with gravel (Deposit 2); 13-22 dm, heavy clay (Deposit 3).

The fossil river gullies in the more central part of compartment Ib can be very vaguely seen in the terrain, and are very narrow (about 10 m wide). But the soil profile may represent a marked gully fill, e.g.: 0-4 dm, sandy clay (Deposit 1); 4-8 dm, heavy clay; 12-15 dm, peaty sandy clay; 15-17 dm, sand (Deposit 2).

The fragment of the former junction gully 10 in compartment III crosses an area of heavy basin clay underlain by a meander belt deposit (both of which were formed during Sedimentation Phase 2), the latter locally outcropping through the bed of heavy basin clay. Where the gully cuts such an outcrop it is very narrow and shallower than beyond this ridge of sandy clay on sand. Soil profile in the gully at the site of the outcrop: 0-2 dm, excavated soil; 2-7 dm, sandy clay (Deposit 1); 7-13 dm, rust-coloured heavy clay, shell fragments; 13-15 dm, peaty heavy clay; 15-18 dm, sand (Deposit 2).

Fossil river gully 22 in compartment Xa of the old circular meander belt (Deposit 3), to which it is genetically related, was preserved during the later Sedimentation Phases except for its northern end which has a southeast-north-west orientation on the map. This section was again scoured during Sedimentation Phase 2 as shown by its soil profiles which differ from those in the more southern, long section.

Soil profile in square 6G, in the old section: 0-3 dm, relatively lightly textured heavy clay (Deposit 1); 3-7 dm, heavy clay (Deposit 2); 7-8 dm, weakly developed fossil vegetation horizon; 8-15 dm, sticky, humic heavy clay; 15-18 dm, slightly sticky humic relatively lightly textured heavy clay; 18-19 dm, sandy clay; 19-22 dm, coarse sand (Deposit 3).

Soil profile in square 7F, also in the old section: 0-3 dm, heavy clay; 3-5 dm, sandy clay (Deposit 1); 5-6 dm, marked fossil vegetation horizon in heavy clay; 6-8 dm, relatively lightly textured heavy clay (Deposit 2a); 8-9 dm, vague fossil vegetation horizon; 9-10 relatively lightly textured heavy clay (Deposit 2b); 10-11 dm, marked fossil vegetation horizon; 11-12 dm, heavy clay; 12-16 dm, sticky humic sandy clay (gully fill); 16-18 dm, coarse sand (Deposit 3).

Soil profile in square 5G in the rejuvenated section: 0-3 dm, sandy clay; 3-4 dm, relatively heavily textured sandy clay (Deposit 1); 4-14 dm, very sticky humic heavy clay with much rust-coloured iron compounds, shell fragments; 14-19 dm, sandy clay mixed with gyttja; 17-19 dm, very sticky, humic relatively heavy sandy clay; 19-21 dm, sticky, very humic heavy clay, shell fragments (Deposit 2). The sandy sub-soil below (Deposit 3) was not bored. This soil profile indicates that al this point the gully was practically filled up at the end of Sedimentation Phase 2.

The fossil river gully 17(a, b) genetically related to the rejuvenated compartment XIb of the circular meander belt formed part of a continuous basin drainage gully during the later part of Sedimentation Phase 2 and the whole of the succeeding latest Sedimentation Phase 1.

Soil profile in square 6D: 0-3 dm, heavy clay; 3-14 dm, sticky humic heavy clay; 14-19 dm, sticky, very humic heavy clay; 19-20 dm, gravelly sandy clay; 20-22 dm, sticky, very humic heavy clay (Deposit 1 and perhaps also Deposit 2). The sandy subsoil (Deposit 2) was not bored.

The levee along the southern edge of the very wide fossil river gully 36 has a very wide break in square 6O. Such a wide opening was not found anywhere else in a levee.

Soil profile just north of the opening, in the fossil river gully: 0-9 dm, sandy clay (Deposit 1); 9-14 dm, heavy clay; 14-17 dm, clayey peat; 17-21 dm, peaty heavy clay; 21-24 dm, peaty sandy clay, shell fragments; 24-26 dm, humic sandy clay, rounded pieces of wood (Deposit 2). The sandy subsoil (Deposit 2) was not bored.

Soil profile in the opening: 0-7 dm, sandy clay (Deposit 1); 7-11 dm, heavy clay; 11-17 dm, peaty heavy clay; 17-19 dm, clayey sand; 19-21 dm, sandy clay; 21-25 dm, sand (Deposit 2).

Soil profile just outside, south of the opening: 0-7 dm, sandy clay (Deposit 1); 7-11 dm, heavy clay (Deposit 2); 11-26 dm, peaty, heavy clay (Deposit 3).

The wide opening was probably made when the river branch was cut by river branch 29. Strangely enough, no sandy clay or sand material from the breached levee could be traced in the adjoining basin area. It must therefore have been dispersed over a very wide area.

Soil profiles in an overflow or junction gully are usually very similar to those in adjoining land in the basin, the only difference being that the former have a somewhat more rusty, sticky and humic appearance.

Soil profile in fossil junction gully 6, near the present 'Leewetering' open watercourse: 0-5 dm, heavy clay (Deposit 1); 5-6 dm, distinct fossil vegetation horizon; 6-12 dm, slightly sticky humic clay (Deposit 2); 12-13 dm, fossil vegetation horizon; 13-19 dm, heavy clay (Deposit 3); 19-20 dm, fossil vegetation horizon; 20-22 dm, heavy clay (Deposit 4).

This profile is apparently found in the outermost lateral section of the gully fill where the silting up had ended during Sedimentation Phase 2. The following soil profile was also found near the 'Leewetering' in a more central section of the gully fill: 0-2 dm, excavated soil; 2-6 dm, heavy clay; 6-16 dm, sticky humic clay (Deposit 1 and possibly also Deposit 2); 16-17 dm, distinct fossil vegetation horizon; 17-22 dm, slightly peaty heavy clay (Deposit 3 and possibly also Deposit 4).

As the Linge 'river' channel has been much widened in recent times, it contains hardly any soil profiles with distinct gully fill characteristics.

Soil profile 1 m south of the concave bank of the wide bend in gully 38 (in square 8N): 0-2 dm, grey, heavy clay with rust-coloured iron compounds; 2-5 dm, brown calcareous humic sandy clay, shell fragments, without rustcoloured iron compounds, a gravel-stone at 45 cm; 5-7 dm, dark-grey calcareous sandy clay, shell fragments; 7-9 dm, do., but very sandy clay; 9-10 do.; wholly intact mussel valves (Deposit 1 and, possibly, also Deposit 2); 10-11 dm, grey heavy clay; 11-15 dm, peaty heavy clay (Deposit 2 (?) and Deposit 3).

Soil profile close to the entirely rectlinear gully 31, in square 8J: 0-3 dm, grey heavy clay; 3-8 dm, sticky, slightly humic heavy clay; 3-8 dm, sticky, slightly humic heavy clay with rust-coloured iron compounds, some shell fragments; 8-13 dm, do. but without rust coloured iron compounds (Deposit 1 and possibly also Deposit 2); 13-15 heavy clay (Deposit 3).

10. ANCIENT SETTLEMENT SITES

A fairly dense concentration of Middle Bronze Age sites is found in the eastern part of the mapped area. They are mainly concentrated in the low ridges which the branching splay north of Dodewaard constituted in the wet basin at the end of Sedimentation Phase 3a.

Archeological remains (mainly potsherds) were not always found in the ancient settlement sites shown on the map. In such case ancient culture soil was identified as such because the top layer of Deposit 3 had a darker colour (indicating a higher humus content) over a larger vertical area than is characteristic of a well-developed dark-grey fossil vegetation horizon. In the previously mapped area, a superficies of c.25 ha is occupied by this type of ancient culture soil near the edge of which are found one or two sharply defined concentrations of cultural remains.

Towards the west Bronze Age settlement sites are only rarely found, viz. near some meander belts forming part of Deposit 2, and on the extreme edge of the eastern half of the old circular meander belt (Deposit 3), in square 7G. The first occurrences are clear evidence that the meander belts in question represent a rejuvenated version of meander belts once forming part of Deposit 3. We should also mention some burial remains of the Middle Bronze Age culture found in the subsoil of the meander belt in compartment XIa, west of Blauwe Kamp farm (R.S. HULST, priv. comm. 1981).

The dense concentration of Bronze Age settlements in the eastern part of the mapped area and in the adjoining area mapped previously must be indirectly connected with the presence of the important meander belt extending south-east to north-west across the Betuwe just east of the latter area. It no doubt formed a connecting route between the high Pleistocene sand soils to the south and north of the Betuwe river clay landscape where the Middle Bronze Age (Hilversum) culture was widely distributed.

Strangely enough the settlements were largely concentrated on levee splays in the middle of the basin soils far distant from a river course. Some even occur on the actual basin soils. This proves that the neighbourhood was not very frequently flooded during the stage of stagnating river activity at the end of Sedimentation Phase 3a, probably because particularly dry climatic conditions then prevailed, as would agree with the generally marked appearance of the fossil vegetation horizon at the top of Deposit 3a. Another factor favouring occupation must have been the still fairly intact forest vegetation in the hinterland, which ensured a regular river flow and relatively little risk of flooding of the basin soils at that time.

The ancient settlement soils in map 1+2 date from the Middle Iron, Late Iron and Roman era and/or the Middle Ages (fig. 12). They nearly all contain Batavian-Roman archeological remains; in about half of them the mediaeval Merovingian or Carlovingian periods are also represented (MODDERMAN, in EGBERTS 1950).

FIG. 12. The 'De Beldert' farm (south-east corner of square 6C). The slight elevation below the farm has ancient settlement soil from the Batavian-Roman era.
Boerderij 'De Beldert' (zuidoosthoek van ruit 6C). De zwakke terreinsverhoging onder de boerderij bevat oude-kultuurgrond uit de Bataafs-Romeinse tijd.

The dense concentration of settlements along the river channels since the Roman era is associated with different environmental conditions in the river area. At that time the levees were well-developed and afforded the best dwelling sites. It should be noted, however, that even the basins were not then always completely uninhabited as appears from the occurrence of two small patches of ancient culture soil in squares 7 OP.

Despite the dense concentration of dwelling sites, no traces of Roman roads were found anywhere in the mapped area. This is even true of the raised military road on the left bank of the Rhine, the construction of which was begun by Drusus and completed by Paulinus Pompeius (TACITUS Annales XIII, quoted by SEBUS 1919, p. 691). Presumably this road went past the present villages of Kesteren, near which the castellum Carvo was probably located, and of Maurik, north of which, beyond the Rhine dike, remains of a castellum (presumably the Mannaricium castellum) were dredged from a sand/gravel pit (cf. VAN ES 1981).

The road was located on the meander belt of the Lower Rhine-Old Rhine which in the Roman era, as at present, ran a little north of the mapped area. The meander belt has only one relatively short stretch extending so far to the south as to coincide with a narrow lateral section inside the mapped area, viz. along the north of fossil river gully 34, which coincides with its southern edge. But no remains of the road or castellum have ever been traced in this section. Probably the meander belt was subject to erosion and redeposition in these surroundings after the flourishing period of Roman occupation. This is certainly true of the area along the north of the river dike where the Old Rhine represents a remnant of a mediaeval river branch.

11. THE PRESENT LANDSCAPE

The present landscape, though greatly influenced by human activity, is in many ways a reflection of the original, natural situation. As in ancient times the basins are extensive, mainly uninhabited, grassy areas (fig. 3). At a distance the levees have a more or less wooded appearance due to the many orchards (fig. 1). The villages on the levees are often found in the same place as a Batavian-Roman settlement.

The roads all date from the period after which the watercourses had silted up, probably the early Middle Ages or later. They usually follow the course of the present fossil river or overflow gullies. But this is not true of the more modern roads. The construction of a road on a fossil gully was more logical than might be imagined, as it saved the more fertile, lighter and more elevated, drier levee soils for farming. It also got over any problems arising out of proprietary rights to farmland. The fact that the soil surface was lower than the surrounding land was clearly not a serious drawback. To improve road drainage, ditches were dug on the sides and the excavated soil used to heighten its position. The ditches were also useful for draining farmland.

A road is usually partly inside and partly alongside a narrow gully, and is entirely located inside a wider gully. Very wide fossil gullies with a road are characterized by a broad shoulder at one or both sides of the road, the ditch bordering the shoulders having a more winding course than the road itself. Such a shoulder may occasionally provide space for one or more small cotter farms, viz. where there is a good deal of room between the road and the ditch.

Like the above roads, ditches with a winding course also follow the track of a fossil river or overflow gully. It cannot usually be ascertained whether they represent a more or less deepened and widened version of a former natural, open residual watercourse or are new excavations in the fossil gully.

The soil topography in the present landscape is mainly related to the soil pattern of Deposit 2, although the relief is less pronounced, than at the time of Sedimentation Phase 2 as it was somewhat levelled when it was covered by the clay bed of Deposit 1.

Generally speaking Deposit 3 has a limited effect on the topography, the only prominent feature being the old circular meander belt. Elsewhere in the basins the levee splays of Deposit 3 can sometimes be seen in the present relief, viz. as a more or less distinct, slight elevation in the middle of the level basin soils.

It cannot be doubted that the differences in height in the soil surface were increased or arose as a result of intense drainage (lowering of the water table) since the Middle Ages.

Thanks to modern soil management, intensive cattle-breeding can be practised on the heavy basin clay soils which formerly were scarcely fit for anything but the production of low-grade hay. But the poor physical qualities of the clay soil (very sticky when wet, very hard when dry) (cf. fig. 4) are still an obstacle to tillage or horticulture. It is significant that the old-fashioned superficial type of land drainage is often preferred to underground tile drainage.

12. TIME-STRATIGRAPHY AND CYCLIC FLUVIAL SEDIMENTATION

12.1. The situation in the Lower Betuwe

The age of the later Deposits can here and there be established from archeological finds. Since Deposit 1 overlies the fossil vegetation horizon at the top of 2a representing the occupation level during the Roman era, it clearly represents a post-Roman deposit.

The position of Deposit 1 with respect to mediaeval chronology is harder to estimate. Hitherto no connection has been established in the mapped area between the occurrence of traces of mediaeval occupation and soil stratigraphy. Hence as regards this area alone, it cannot be said to what extent Deposit 1 was formed before, during or after the Merovingian period (400-650 A.D.).

Fortunately the situation is more favourable in a more upstream part of the fluvial landscape, viz. in the neighbourhood of Elst, Upper Betuwe. It was here during an excursion in 1980 that P. Harbers[1] demonstrated the following soil profile in a levee along a fossil main river branch of the Rhine. A layer of ancient culture soil of the Merovingian period some dm thick, at the top of the river clay deposit, was underlain by a clay bed, several dm thick and uninfluenced by human activity, representing Deposit 1. The latter was in turn underlain by a layer of culture soil of the Roman era. This situation proves that Deposit 1 was mainly formed before the Merovingian period at the site in question.

A more doubtful, indirect proof of this date is afforded by Merovingian graves at two sites in the Upper Betuwe at about the level of Roman occupation (priv. comm. by R.S. Hulst 1980). Unfortunately the Merovingian occupation level could not be observed at the two sites, the upper part of the soil having been previously excavated. But since the graves were found near the present soil surface, it may be assumed that the Merovingian occupation level must have been located at, or not far below the top of a fairly thick Deposit 1 at both sites.

The top of Deposit 2a represents the Batavian-Roman occupation level. The settlement sites often also contain archeological remains from the preceding Middle and Late Iron Age. As a separate layer of ancient culture soil was never found at the top of Deposit 2b in the mapped area, it cannot be definitely stated when the formation of Deposit 2a began. Very likely the latter was contemporaneous with a clay bed in the fluvial area of the Meuse, locally intercalated between two Iron Age refuse layers, and must therefore have been formed between 400 and 100 B.C. (Louwe Kooijmans 1974, p. 44). If this assumption is correct it also gives us a terminus ad quem for Deposit 2b.

The widespread occurrence of culture soil from the Middle Bronze Age (1500-1000 BC) at the top of Deposit 3a shows that this Deposit was complete

[1] Netherlands Soil Survey Institute.

before 1500 BC (or a little later). But the dating is complicated by a find (by R.S. HULST; cf. HAVINGA 1969, p. 27) of Middle Bronze Age and Late Neolithic (1800-1700 B.C.) archeological remains at a site near Dodewaard at exactly the same level in the soil profile. We agree with LOUWE KOOIJMANS (1974, p. 34) that this situation may imply the absence of a river clay bed which would be the fluvial counterpart of a marine clay bed, known as Dunkirk 0, (1500-1000 B.C.), at the top of which Bronze Age culture soil is found in coastal districts of the Netherlands.

But it should not be overlooked that the situation near Dodewaard actually reveals the following local sedimentary structure. The cultural remains are found on a splay which was formed during several Sedimentation Phases, viz. during the successive Phases 4, 3b and 3a. As separate, relatively small elevations often form part of the morphology of a levee splay (cf. HAVINGA 1969, p. 18), it may also be thought that the cultural remains are located at a site with a local levee elevation representing an earlier Sedimentation Phase (3b). After splay formation was over (at the end of Sedimentation Phase 3a) this could have formed an outcrop in the middle of the sediment constituting the later part of the splay. It should be noted that in the area mapped previously (HAVINGA 1969) cultural remains from the Middle Bronze Age were even found among culture soil from the Roman era. At the site in question a levee splay in Deposit 3 had a marked elevation in the form of an outcrop in the middle of the clay bed of Deposit 2 (Loc. cit. p. 19, section T-U.).

No archeological, but two C14 dates are available below the fossil vegetation horizon at the top of Deposit 3a, viz. of the fossil vegetation horizons at the top of Deposit 4 (at the 2800 m point in section B-B'): 4000 $\pm$ 35 B.P. (GrN-9179), i.e.c. 2600 B.C., and at the top of the lowest Deposit, 8: 7120 $\pm$ 70 B.P. (GrN-9180) i.e.c. 5900 B.C.

If the date c. 5900 B.C. is taken as correct and it is assumed that the sedimentation in the Betuwe practically finished 400 A.D. (cf. p. 58), then the total time needed for the formation of Deposits 1, 2a, 2b, 3a, 3b, 4, 5, 6 and 7 can be estimated as 6300 years. This implies an average duration of 700 years for a single Sedimentation Phase, which is $\pm$ 150 years more than estimated by BENNEMA (1954) and PONS (1957) for the duration of a sedimentation cycle.

A cyclic sedimentation comparable with that found in the Lower Betuwe is also found elsewhere in the Dutch river and coastal areas. It was estimated by PONS and MODDERMAN as early as 1951 more upstream along the Rhine, but only comprised the period during and subsequent to the Roman era. More downstream along the Rhine, in the perimarine fluvial area, where the fluvial sedimentation was influenced by the sea, it was demonstrated by VERBRAECK (1970), VAN DER WOUDE (1981) and BERENDSEN (1982), and in the coastal marine area by BENNEMA (1954), JELGERSMA (1961, 1980) and VAN DE PLASSCHE (1982).

PONS and MODDERMAN (1951) were the first to assume a relationship between the fluvial and marine cyclic sedimentation, and BENNEMA was the first to assume a connection between cyclic sedimentation and cyclic changes in a variety of natural processes in various parts in the world, for instance, the periodic withdrawal and return of glaciers. This would be due to regular climatic fluctuations, the true nature of which is quite obscure (BRUNNACKER, 1978).

The above theories have recently come under attack. VAN DER WOUDE (1981, p. 73) states that no connection exists between a cyclic fluvial and a cyclic marine sedimentation as far as concerns the older deposits. According to BERENDSEN (1982, p. 81) the absence of synchronity between the periods of peat formation in the fluvial, perimarine fluvial and marine area (cf. p. 61) is evidence that the sedimentation of clay was not simultaneous in these areas. The time-stratigraphy of the Holocene fluvial deposits should only be considered as locally significant. He also denies that the climate may be a possible mechanism governing the various processes referred to above (loc. cit., p. 84).

12.2. COMPARISON BETWEEN THE SITUATION IN THE LOWER BETUWE AND THE DOWNSTREAM PERIMARINE FLUVIAL AREA

Downstream of the mapped area, viz. between the fluvial area proper and the marine coastal area, an extensive area is found where the stream ridges of the present and former rivers widely diverge, leaving space for extensive peatlands. Here the deposition of river clay and peat growth was indirectly influenced by the sea, for which reason the term 'perimarine' is applied to this area (HAGEMAN 1969, VERBRAECK 1970).

The influence was of a complex kind, being due to the gradual eustatic rise of the sea level during the Holocene, the periodic alternation of transgression and regression phases, and the damming effect of the daily floods on the river level to far inland. The first factor particularly affected the deeper, viz. older part of the geological formation. This comprises the perimarine fluvial 'Gorkum deposits' (loc. cit.), which were formed during the Atlantic and earlier part of the Sub-boreal period. The eustatic rise of the sea level considerably declined towards the end of this period.

Since the eustatic rise interfered with the cyclic fluvial sedimentation, an extensive layer of peat was formed in the perimarine fluvial area whenever river activity was low. Thus a fossil vegetation horizon in the mapped area usually has a peat layer as a counterpart in the other area. This, of course, is only true of the situation at some distance from the meander belts.

Peat layers are usually absent from the perimarine fluvial area between the later 'Tiel deposits', the separate deposits having a dark-grey fossil vegetation horizon at the top, as in the mapped area.

Despite the above similarities in the time-stratigraphic situation, precise synchronisation of the separate deposits of both areas, mainly based on soil stratigraphical knowledge, would seem difficult. This is because the vegetation horizons often have such extensive gaps that a given vegetation horizon cannot be traced in the horizontal plane. The often irregular spread and thickness of a peat layer is another important factor. Thus the sections (enclosure 3) clearly demonstrate that a peat-river clay transition may shift in the vertical plane and this may greatly impede or even prevent its insertion in the chronostratigraphy.

These factors can easily lead to error in a time-stratigraphical interpretation of data obtained from field borings. We believe that this may be a main reason why BERENDSEN (1982, p. 81) assumes the stratigraphy of the Holocene in the fluvial area to have only a local validity, and denies any synchronity between the periods of peat formation or development of a fossil vegetation horizon in the fluvial, perimarine fluvial and marine area. But only a detailed survey covering connected sections of these areas attended with sufficient C14 datings, especially of fossil vegetation horizons, could settle this matter beyond doubt. The boring depth should of course be adapted to the variations in the vertical space occupied by the aggregate Deposits in the various areas.

It is worth noting that the difference in soil pattern between Deposits 1 and 2 on the one hand and Deposits 3 and 4 on the other as established in the mapped area, is also associated with the geological structure of the perimarine fluvial area. This may be inferred from the geological survey by VERBRAECK (1970) (cf. subsidiary map 1). But splay development seems less pronounced in the older deposits in the latter area than in the Lower Betuwe.

12.3. COMPARISON BETWEEN THE SITUATION IN THE LOWER BETUWE AND UPSTREAM FLUVIAL AREAS IN GERMANY

As in the Netherlands, cyclic fluvial sedimentation of the Rhine (and its tributary the Main) has been established in Germany. Several phases of fluvial activity are reflected in the Holocene deposits. These were characterized by the predominance of erosion in the Middle Rhine valley and southern Lower Rhine area, i.e. in regions where the slope is still relatively steep. In the northern Lower Rhine area dispersal fans were formed which correlate with the erosion stages. The river meandered after the periods of dispersal fan formation. It then cut into the newly formed deposits to some depth, resulting in a drier environment along the river, and led to the establishment of prehistoric settlements (BRUNNACKER 1978).

As a result of archeological finds the following two stages in the fluvial sedimentation along the Rhine between Bonn and Emmerich can be correlated with the findings in the Lower Betuwe. From a find of Roman pottery (1-2th century A.D.) in a gravel pit near Rindern and the occurrence of late Roman archeological remains elsewhere in the gravel deposit, BRUNNACKER (loc. cit.) concludes that the gravel body of the dispersal fan was formed during the Roman era (gravel deposition must have ended when the subsequent meandering river stage set in).

We believe, however, that it would be more logical to assume that the pottery (in a sunken ship) was burried by the outward shifting of a meander loop during the period of declined river activity following the formation of the gravel body of the dispersal fan.

From finds of Bronze Age urns in the top section of a dispersal fan and a bronze lance peak in the gully fill of a former meander loop it may be concluded that the Bronze Age was also a period of stagnating river activity.

The above findings show good agreement with that is known about the cyclic sedimentation in the Lower Betuwe. Apparently the light-grey section of a separate bed of heavy clay in the latter area is contemporaneous with the sand/gravel body of a dispersal fan deposit in Germany, and a dark-grey fossil vegetation horizon with the pedogenetic soil profile (e.g. 'Braunerde') at the top of the dispersal fan. This developed in the clay bed (Hochflutlehm) covering the sand/ gravel body proper. It is probable that this clay bed was partly formed during the meandering stage of the river.

Becker and Schirmer (1977) established a cyclic fluvial sedimentation in the valley of the Main, a tributary of the Rhine in southern Germany. Their palaoecological study included a dendro-chronological analysis (tree ring study) of fossil oak trunks in the gravelly subsoil of the river deposits.

In this case two oak trunk accumulations of the Roman era and the Bronze Age can be synchronized with the fossil vegetation horizons at the top of Deposits 2a and 3a in the Lower Betuwe.

The position of oak trunks of varying age (found in a gravel pit) with respect to a former river course, proved byond doubt that the trunks had been burried by lateral undercutting of the oak-covered outer bank of a meander loop and accretion of redeposited gravel over the uprooted trees on the inner bank.

According tot Becker and Schirmer the oak trunk accumulations, and, hence, the intense meandering of the river were due to increased fluvial activity. This would mean that the cyclic sedimentation here is asynchronous with the cyclic sedimentation along the Lower Rhine. But it may also be doubted in this case whether the stages of increased fluvial activity were in fact characterized by a meandering flow of the river. In this respect it is significant that the gravel bodies are covered with a thick flood-loam deposit ('Hochlutlehm'), which followed the gravel deposition, and in which a brown earth developed, as in the area along the Lower Rhine in Germany. This situation suggests that the Main, like the Rhine, had a more or less braided character during the stages of increased fluvial activity, and a meandering course during the intervals of low activity.

13. HUMAN INFLUENCE ON FLUVIAL SEDIMENTATION

In addition to the vertical alternation of dark-grey and light-grey horizons in the basins resulting from cyclic climatic fluctuations various other sedimentary changes were noted above which apply to the later Deposits (2a, 2b and 1) only, and are not attributable to this factor. To recapitulate, these changes are:

1. Increased clay deposition. Compare the absence of peaty material in the basins of Deposits 2 and 1, this material being widespread in the older Deposits.
2. Formation of well-developed levees instead of poorly developed ones with numerous splays.
3. Pedogenesis in the levees under much drier soil conditions than found in the older Deposits.

All these changes, which seem to be interconnected, can only be satisfactory explained by assuming that they were due to human influence.

From the Late Neolithic onward (4400-1650 B.C.) man began farming in N.W. Europe, an activity which gradually increased in course of time. This may readily result in soil erosion, as shown, for instance, by a preliminar palynological study by HAVINGA and V.D. BERG VAN SAPAROEA (1980) in the loess-covered hilly region in the south of the province of South Limburg (Netherlands). This region is intersected by the valley of the small Geul river in which a peat deposit is found locally, covered by a bed of fluviatile loess containing a continually higher percentage of sand in an upward direction. Colluvial loess deposits are found along the margin of the valley. The study revealed that fluvial sedimentation of the loess started as early as the Sub-boreal period when the Neolithic or Bronze Age folk had begun clearing forest for farming. The colluvial deposits were formed during the Iron Age and Roman era in the Sub-atlantic period, when the region had become extensively farmed. The latter finding agrees with a palynological investigation of translocated soil material from mountain slopes covered with loess in Luxemburg (RIEZEBOS and SLOTBOOM 1974).

It is notable that the relatively old Deposit 3 (the top of which represents the level of occupation during the Middle Bronze Age) has much more extensive levees or splays than Deposit 4 (cf. p. 34). The increased supply of sandy clay from the flood water of the Rhine during Sedimentation Phase 3 is apparently due to the agricultural activities of the Early Bronze Age or Neolithic dwellers. The relatively high silt percentage of this clay (cf. p. 36) shows that much of it was derived from a loess-covered landscape.

After the Middle Bronze Age human influence was stepped up. The destruction of extensive parts of the forest vegetation reduced the water-storage capacity in the hinterland and this affected the fluviatile regime. The rivers had to cope with increased masses of water during relatively short periods, resulting in an irregular flow of the Rhine. In the low-lying Lower Betuwe area not only was the river level subject to increased fluctuations, but also the water table beyond the river bed, in the adjoining river-clay soils. With the changed regime the sediment load of the river branches had increased due to intense erosion in the hinterland.

It may be assumed that the more irregular river level was the main factor involved in the change in the type of levee formation. The periodic lowering of the water table to a far greater depth and for much longer periods during Sedimentation Phase 2 than during the earlier Sedimentation Phases gave a firm consistency to the river clay soil more near the river channels, which had hitherto been rather slushy and easily erodable (cf. p. 35). As the soil had become well-aerated to a greater depth, a denser vegetation of trees and shrubs may be assumed to have formed a stand there. The reduced susceptibility to erosion resulting from these factors (ROHDENBURG 1971), the vegetation referred to, which greatly retarded the flow of the flood water at high river levels, and the increased supply of sediment, led to the formation of well-developed levees along the river channels. The formation of the levee splays which are so characteristic of Sedimentation Phases 3 and older was largely checked by the same factors during Sedimentation Phases 2 and 1.

It cannot be reasonably assumed that the cyclic character of the sedimentation during Sedimentation Phases 2 and 1 was affected by the above mentioned factors. This, for instance, is proved by the fact that the usually very well-developed fossil vegetation horizon at the top of Deposit 2a, which represents a stage of highly stagnating river activity and fluvial sedimentation, is synchronous with the Iron Age and Roman era. Agriculture had then become very widespread and soil erosion in the hinterland very intense. The average high river levels were apparently so low during these periods that the formation of the vegetation horizon was quite unaffected by the highly increased mass of suspended sediment in the river water.

The renewed sedimentation during Sedimentation Phase 1 began towards the end of the Roman era, when the natural forest vegetation largely regained the ground it had lost during and before the flourishing period of the Roman era. The expansion of the forested area and simultaneous shrinking of the farmed area is clearly reflected in pollen diagrams from various areas along the Rhine (cf., for instance, PAAS and TEUNISSEN 1978).

The configuration of the soil pattern of Deposit 1 tallies with the theory that most of the river branches crossing the mapped area had silted up towards the end of Sedimentation Phase 2 (cf. p. 25). Meander belt formation no longer occurred inside the mapped area.

It may be supposed that the concentration of the flow in the two river channels of the Lower Rhine and Waal outside this area was promoted by human interference in the fluvial system during the Roman era.

It is known from an ancient source (TACITUS Hist. V, in SEBUS 1923), that the Roman Army commander Drusus constructed a pier in the Rhine at about the time of the birth of Christ. It was located where the Rhine bifurcated into the two main branches of the Lower Rhine and Waal, (cf. fig. 2). This pier forced the stream to follow mainly the Lower Rhine, the northern branch, which was then the frontier river of the Roman empire in this region. The artificial change in the direction of flow is echoed in the following quotation from TACITUS (in SEBUS 1923): 'When Civilis the Batavian commander had the pier removed

(69-70 A.D.) the Rhine began to flow in a sloping bed[1] towards the Gallic side. After thus, as it were, having been diverted, the narrow bed[2] between the isle[3] and the German area[4] gave it the appearance of adjacent lands'.

Possibly the pier was not the only construction promoting the flow through the frontier river course. Most likely other piers were built near the mouths of river branches splitting off from the Lower-Rhine towards the interior of the Lower Betuwe, to achieve a maximum effect of the stream diversion.

It may be assumed that the late- and post-Roman vegetational history can be traced in the clay bed of Deposit 1. The lower section of the clay bed often has a relatively heavy soil texture (cf. p. 27), which is most probably connected with reduced erosion in the hinterland when the natural forest vegetation made its marked recovery, during the time of migration of the nations. The higher section, showing a more sandy texture, reflects the mediaeval agricultural expansion, when the erosion again increased.

[1] the bed of the Waal.
[2] the bed of the Lower Rhine.
[3] the present Betuwe, where the Batavians lived.
[4] the region north of the Betuwe.

14. SUMMARY

This physiographic study of the eastern section of the Lower Betuwe follows up a similar investigation in an easterly adjoining fluvial area of the Rhine (HAVINGA 1969). It is based on a very detailed soil survey up to 2.20 m depth, supplemented by some series of borings to the top of the Pleistocene sand soil, the results of which are shown in the enclosures.

In the basins five overlying clay beds are distinguished and the upper part of a sixth within 2.20 m depth. These are designated from above to below, i.e. from late to old, by the numerals 1, 2a, 2b, 3a, 3b and 4. The separate layers can be distinguished by the occurrence of a fossil vegetation horizon at the top. But such a horizon often has only a fragmentary spread.

Each clay bed forms part of a separate Deposit. This consists of a meander belt of coarse sand covered with a layer of sandy clay several dm thick, the latter extending laterally over clay beds of the older Deposits and merging into a layer of heavy basin clay at some distance from the meander belt. The picture is completed by fossil river gullies, overflow gullies, levee splays and ancient culture soils.

The vegetation horizon at the top of Deposit 2a represents the soil surface in the Roman era, and that at the top of Deposit 3a in the Middle Bronze Age. Both are usually well-developed. The vegetation horizons at the top of Deposits 2b and 3b are generally less marked or widespread and do not represent an occupation level in the mapped area.

The accumulation of the clay beds corresponds to a cyclic sedimentation process connected with a fluctuating climate. During a stage of intense fluvial activity a clay layer was deposited; during a stage of low activity the sedimentation stagnated and a vegetation horizon was able to develop.

During the successive Sedimentation Phases 4 to 1 the sedimentation pattern and sedimentation environment underwent some change. Before and during Sedimentation Phase 2 several river branches crossed the mapped area and rarely changed their course. As a result of fluvial erosion and resedimentation, the meander belts were continuously rejuvenated. Consequently their present state usually represents Sedimentation Phase 2. But most of the circular meander belt in the western part of the mapped area forms part of Deposit 3; with the exception of a narrow longitudinal section in its western half it escaped the rejuvenation process after the end of Sedimentation Phase 3a.

During the latest Sedimentation Phase (1) active river branches were practically only found beyond the river dikes along the present Lower Rhine and Waal. The branches in the mapped area had become silted up towards the end of Phase 2.

The system of sharply defined, well-developed levees known from the present river clay landscape of the Lower Betuwe, only developed after Sedimentation Phase 3a. During and prior to this Phase the levees had a more or less fragmentary nature, often with erratic contours and numerous lobate or narrow protracted splays. Sedimentation of the sandy clay in this pattern was conditioned

by a very wet environment, as may be concluded from the pedogenetic soil characteristics of Deposit 3. A similar sedimentary structure is found at the present soil surface in other parts of the world, e.g. in the Rima-Sokoto river basin in Nigeria.

The occupation pattern in the Middle Bronze Age was adapted to the special environmental conditions. Unlike the Roman era occupation (on Deposit 2a) it was not especially concentrated along watercourses but mainly on low ridges of sandy clay (splays) in the basin.

Deposits 4 and older have a soil pattern similar to Deposit 3, but differ from the latter in having much less extensive levees and levee splays.

We attribute these alterations to human influence. As a result of the continuously greater destruction of the natural forest vegetation in the hinterland since Neolithic times, soil erosion constantly increased. This resulted in an ever-increasing mass of sediment in the downstream, mapped area: after Sedimentation Phase 4 the levee deposits expanded; from Phase 3 to Phase 2 the percentage of peat in the basins became nil. The better development of the levees since Sedimentation Phase 2 is undoubtedly connected with an alteration in the fluviatile regime (more highly fluctuating river level), which was also a result of the greatly increased deforestation.

The substantial alteration in the river system in the mapped area just before the latest Sedimentation Phase (1) was probably due to the Roman occupation (construction by Drusus of one (or more?) piers in the river channels).

The cyclic sedimentation can be correlated with those established in the downstream perimarine fluvial area and the upstream fluvial area along the lower course of the Rhine in Germany and along the Main. This means that a fossil vegetation horizon in the Lower Betuwe is contemporaneous with a peat layer or a fossil vegetation horizon in the clayey formation in the former area and with a pedogenetic soil profile of e.g. the 'Braunerde' type in the other areas. This soil profile developed in the clay layer (Hochflutlehm) covering the sand and gravel deposit which arose during a stage of fluvial activity.

The wide meander belt between Lienden and Maurik has a complex sedimentary structure. It includes several compartments of varying age, all of which fall within the same Sedimentation Phase 2.

A close study of the relative position of the former watercourses and the nature of the gully fill in the various fossil gullies enabled us to establish to some extent the changes undergone by the complex system of watercourses and their function since the final stage of Sedimentation Phase 3.

SAMENVATTING

Deze fysiografische studie van het oostelijke deel van de Neder-Betuwe is het vervolg van een overeenkomstig onderzoek in een oostelijk aangrenzend rivierkleigebied van de Rijn (HAVINGA 1969). De studie berust op een zeer gedetailleerde bodemkartering tot 2.20 m diepte, aangevuld met enkele reeksen van boringen tot aan de bovenkant van de Pleistocene zandondergrond, waarvan de resultaten zijn weergegeven in de bijlagen.

In de komgebieden worden binnen 2.20 m diepte vijf boven elkaar gelegen kleilagen aangetroffen en het bovenste deel van een zesde. Deze zijn van boven naar beneden, van jong naar oud, met de cijfers 1, 2a, 2b, 3a, 3b en 4 aangeduid. De afzonderlijke lagen zijn te herkennen door de aanwezigheid van een fossiele vegetatiehorizont aan hun bovenzijde, die veelal donkergrijs van kleur is, maar vaak ook moeilijk te onderscheiden. In veel gevallen heeft zo'n horizont een fragmentarisch karakter.

Elk van de genoemde kleilagen maakt deel uit van een afzonderlijke Afzetting. Deze omvat een meandergordel bestaande uit grof zand, afgedekt door een verschillende dm dikke laag van zandige klei, welke laatste zijdelings over kleilagen van de oudere afzettingen heenloopt en op zekere afstand overgaat in een laag zware komklei. Fossiele riviergeulen, overloopgeulen, uitstulpingen van de oeverwallen van zandige klei en oude-kultuurgronden voltooien dit beeld.

De vegetatiehorizont aan de bovenzijde van Afzetting 2a was het bodemoppervlak in de Romeinse tijd, die aan de bovenzijde van Afzetting 3a in de Midden-Bronstijd; beide zijn meestal zeer goed ontwikkeld. De vegetatiehorizonten aan de bovenzijde van de Afzettingen 2b en 3b zijn meestal minder duidelijk, komen minder verbreid voor en vormden geen bewoningsniveau in het gekarteerde gebied.

De laagsgewijze afzetting correspondeert met een cyclisch sedimentatieproces, dat door klimaatwisselingen moet zijn bepaald. Tijdens een fase van sterke rivieraktiviteit werd een kleilaag afgezet; tijdens een fase van geringe aktiviteit stagneerde de opslibbing en kon zich een vegetatiehorizont ontwikkelen.

In de loop van de opeenvolgende Afzettingsfasen 4 t/m 1 traden er veranderingen op in het sedimentatiepatroon en het sedimentatiemilieu. Tot en met Sedimentatiefase 2 doorsneden verschillende rivierarmen het gekarteerde gebied. Verplaatsing van rivierlopen kwam weinig voor. Als gevolg van de fluviatiele erosie en hersedimentatie verjongden de meandergordels zich voortdurend. Zij maken in hun huidige vorm dan ook in het algemeen deel uit van Afzetting 2. Alleen de cirkelvormige meandergordel in het westelijke deel van het gebied behoort grotendeels tot Afzetting 3; behoudens een smalle overlangse strook in zijn westelijke helft, ontsnapte deze aan de verjonging na het einde van Afzettingsfase 3a.

Tijdens de laatste Afzettingsfase (1) waren praktisch alleen nog de buitendijks stromende Neder-Rijn en Waal aktief. De binnendijkse rivierarmen waren aan het einde van Fase 2 dichtgeslibd.

Het systeem van scherp begrensde, goed ontwikkelde oeverwallen zoals dat

van het huidige rivierkleilandschap van de Neder-Betuwe bekend is, kwam pas na Afzettingsfase 3 tot ontwikkeling. Tijdens en voor die Fase waren er oeverwallen met een min of meer fragmentarisch karakter, vaak grillige contouren en talloze lobvormige of smalle langgerekte uitstulpingen in de richting van de kom. De sedimentatie die tot deze vormen leidde, was gebonden aan een zeer nat milieu, zoals ook af te leiden valt uit de pedogenetische bodemkenmerken van Afzetting 3. Elders in de wereld, b.v. in het Rima-Sokoto rivier bassin in Nigeria kan dezelfde sedimentaire structuur ook aan het huidige bodemoppervlak worden aangetroffen.

Het bewoningspatroon in de Midden-Bronstijd was aangepast aan de bijzondere milieu-omstandigheden. In tegenstelling tot de bewoning in de Bataafs-Romeinse tijd (op Afzetting 2a) was die niet speciaal aan waterlopen gebonden, maar vooral aan lage ruggen van zandige klei in de kom.

Afzetting 4 en de nog oudere Afzettingen hebben een overeenkomstig bodempatroon als Afzetting 3. Zij onderscheiden zich van de laatstgenoemde echter door een veel geringere verbreiding van de oeverwallen en oeverwaluitstulpingen.

De auteurs schrijven de genoemde veranderingen aan menselijke invloed toe. Door een voortdurend toenemende vernietiging van de natuurlijke bosvegetatie in het achterland, sinds het Neolithicum, nam de bodemerosie steeds toe. Dit leidde tot een voortdurende toename van de hoeveelheid sediment in het, benedenstrooms gelegen, gekarteerde gebied: Na Afzettingsfase 4 breidden zich de oeverwalafzettingen uit; van Fase 3 naar Fase 2 verdwijnt het aandeel van veen in de kommen zo goed als geheel. De meer geprononceerde oeverwalontwikkeling sinds afzettingsfase 2 houdt ongetwijfeld verband met een verandering van het regime van de rivier (sterker fluctuerende waterstand), die eveneens met de sterk toegenomen ontbossing gepaard ging.

De sterke wijziging in het riviersysteem in het gekarteerde gebied kort voor de laatste Afzettingsfase (1), is waarschijnlijk door de Romeinse occupatie tot stand gebracht (Aanleg van een of meer (?) pieren in de rivierlopen door Drusus).

De cyclische sedimentatie kan worden gecorreleerd met die, welke geconstateerd is in het benedenstroomse perimarine fluviatiele gebied en in het bovenstroomse fluviatiele gebied langs de benedenloop van de Rijn in Duitsland en langs de Main. Dit betekent, dat een fossiele vegetatiehorizont in de Neder-Betuwe synchroon is met een veenlaag of een fossiele vegetatiehorizont in het kleipakket in het eerstgenoemde gebied en met een pedogenetisch bodemprofiel van bijvoorbeeld het 'Braunerde' type in de andere gebieden. Dit profiel is aanwezig in de kleiige laag (Hochflutlehm) welke de afdekkking vormt van de zand- en grindafzetting die tijdens een fluviatiel aktieve fase ontstond.

De brede meandergordel tussen Lienden en Maurik heeft een ingewikkelde sedimentaire structuur. Deze omvat verscheiden kompartimenten van verschillende ouderdom, welke echter alle binnen dezelfde Afzettingsfase, 2, vallen.

Aan de hand van een nauwkeurige bestudering van de ligging ten opzichte van elkaar van de voormalige waterlopen en de aard van de geulopvulling in de verschillende fossiele geulen, kon tot op zekere hoogte worden nagegaan,

aan welke veranderingen het ingewikkelde systeem van de waterlopen, alsook de functie ervan, onderhevig is geweest sedert het laatste stadium van Afzettingsfase 3.

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ACKNOWLEDGEMENTS

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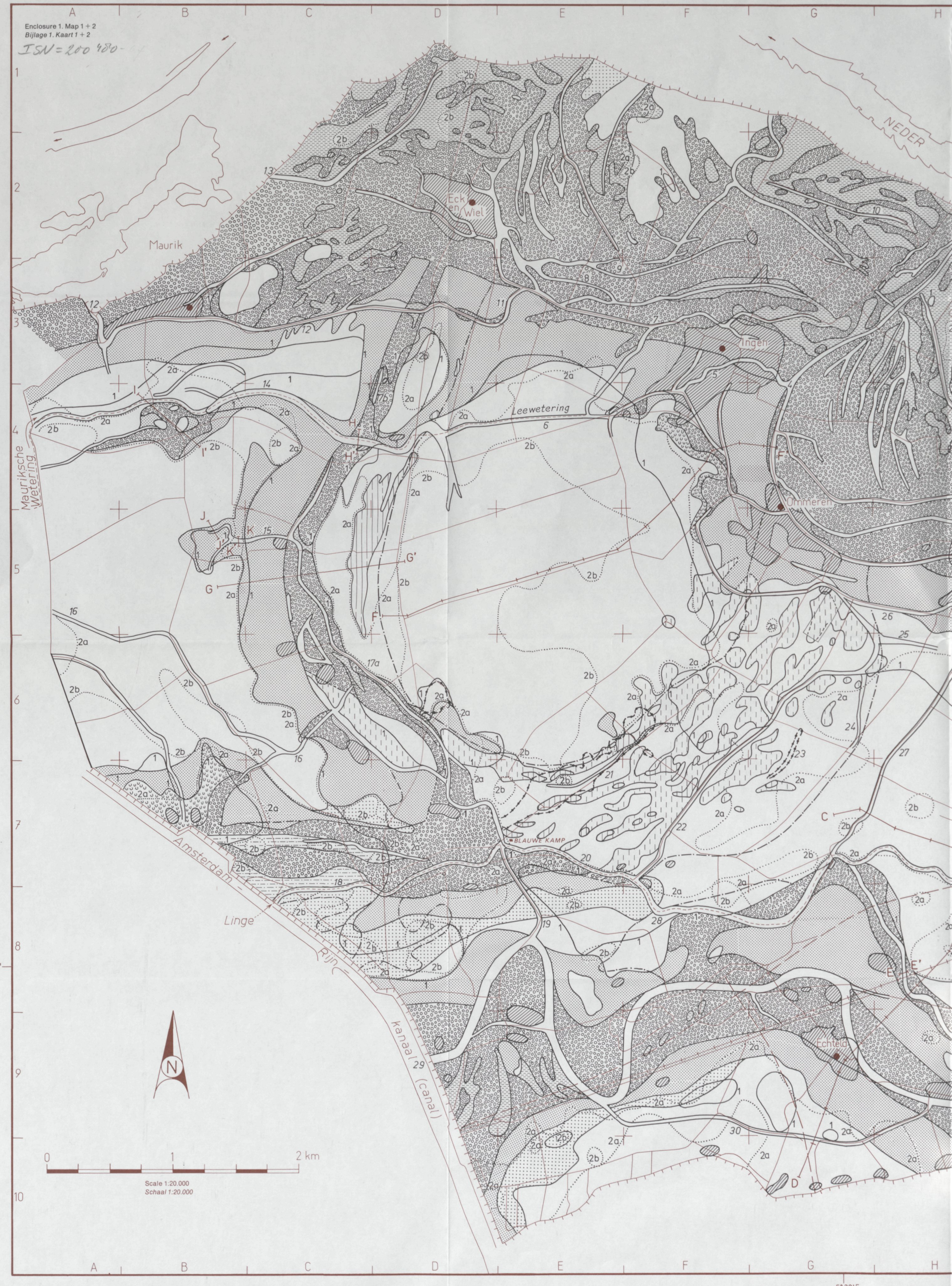
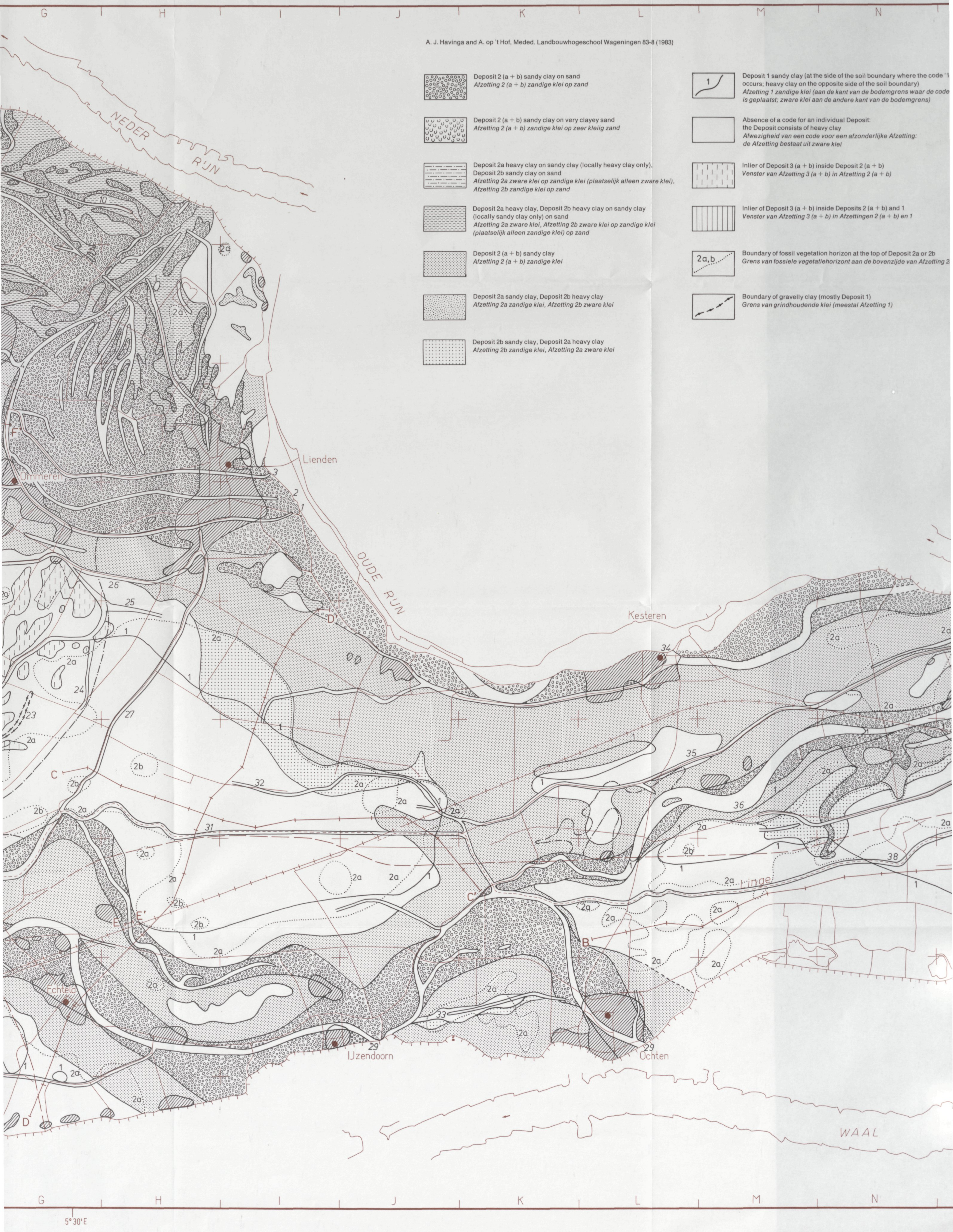
Enclosure 1. Map 1 + 2
Bijlage 1. Kaart 1 + 2
ISN = 200 480




G
H
I
J
K
L
M
N
A. J. Havinga and A. op 't Hof, Meded. Landbouwhogeschool Wageningen 83-8 (1983)
Deposit 2 (a + b) sandy clay on sand
Afzetting 2 (a + b) zandige klei op zand
Deposit 2 (a + b) sandy clay on very clayey sand
Afzetting 2 (a + b) zandige klei op zeer kleiig zand
Deposit 2a heavy clay on sandy clay (locally heavy clay only), Deposit 2b sandy clay on sand
Afzetting 2a zware klei op zandige klei (plaatselijk alleen zware klei), Afzetting 2b zandige klei op zand
Deposit 2a heavy clay, Deposit 2b heavy clay on sandy clay (locally sandy clay only) on sand
Afzetting 2a zware klei, Afzetting 2b zware klei op zandige klei (plaatselijk alleen zandige klei) op zand
Deposit 2 (a + b) sandy clay
Afzetting 2 (a + b) zandige klei
Deposit 2a sandy clay, Deposit 2b heavy clay
Afzetting 2a zandige klei, Afzetting 2b zware klei
Deposit 2b sandy clay, Deposit 2a heavy clay
Afzetting 2b zandige klei, Afzetting 2a zware klei
1
Deposit 1 sandy clay (at the side of the soil boundary where the code '1 occurs; heavy clay on the opposite side of the soil boundary)
Afzetting 1 zandige klei (aan de kant van de bodemgrens waar de code is geplaatst; zware klei aan de andere kant van de bodemgrens)
Absence of a code for an individual Deposit: the Deposit consists of heavy clay
Afwezigheid van een code voor een afzonderlijke Afzetting: de Afzetting bestaat uit zware klei
Inlier of Deposit 3 (a + b) inside Deposit 2 (a + b)
Venster van Afzetting 3 (a + b) in Afzetting 2 (a + b)
Inlier of Deposit 3 (a + b) inside Deposits 2 (a + b) and 1
Venster van Afzetting 3 (a + b) in Afzettingen 2 (a + b) en 1
2a,b
Boundary of fossil vegetation horizon at the top of Deposit 2a or 2b
Grens van fossiele vegetatiehorizont aan de bovenzijde van Afzetting 2
Boundary of gravelly clay (mostly Deposit 1)
Grens van grindhoudende klei (meestal Afzetting 1)
NEDER RIJN
OUDE RIJN
Lienden
Ommeren
Kesteren
Linge
Echteld
IJzendoorn
Ochten
WAAL
5°30'E

3 (1983)

re klei),

Deposit 1 sandy clay (at the side of the soil boundary where the code '1' occurs; heavy clay on the opposite side of the soil boundary)
Afzetting 1 zandige klei (aan de kant van de bodemgrens waar de code '1' is geplaatst; zware klei aan de andere kant van de bodemgrens)

Absence of a code for an individual Deposit: the Deposit consists of heavy clay
Afwezigheid van een code voor een afzonderlijke Afzetting: de Afzetting bestaat uit zware klei

Inlier of Deposit 3 (a + b) inside Deposit 2 (a + b)
Venster van Afzetting 3 (a + b) in Afzetting 2 (a + b)

Inlier of Deposit 3 (a + b) inside Deposits 2 (a + b) and 1
Venster van Afzetting 3 (a + b) in Afzettingen 2 (a + b) en 1

Boundary of fossil vegetation horizon at the top of Deposit 2a or 2b
Grens van fossiele vegetatiehorizont aan de bovenzijde van Afzetting 2a of 2b

Boundary of gravelly clay (mostly Deposit 1)
Grens van grindhoudende klei (meestal Afzetting 1)

Fossil river gully etc. (the numbered gullies are referred to in the text)
Fossiele riviergeul enz. (naar de genummerde geulen wordt in de tekst verwezen)

Boundary of meander belt of Deposit 3 (a + b)
Grens van meandergordel 3 (a + b)

Soil boundary uncertain
Bodemgrens onzeker

Ancient settlement soil of the Batavian-Roman era and/or Middle Ages
Oude-kultuurgrond uit de Bataafs-Romeinse en/of Middeleeuwse Tijd

Litho-stratigraphical section with reference marks at the site of borings > 2.20 m
Litho-stratigrafische doorsnede met dwarsstreepjes ter plaatse van boringen > 2.20 m

Kilometre co-ordinates taken from the Topographical Map of the Netherlands
Kilometer-coördinaten, overgenomen van de Topografische Kaart van Nederland

Main road
Hoofdweg

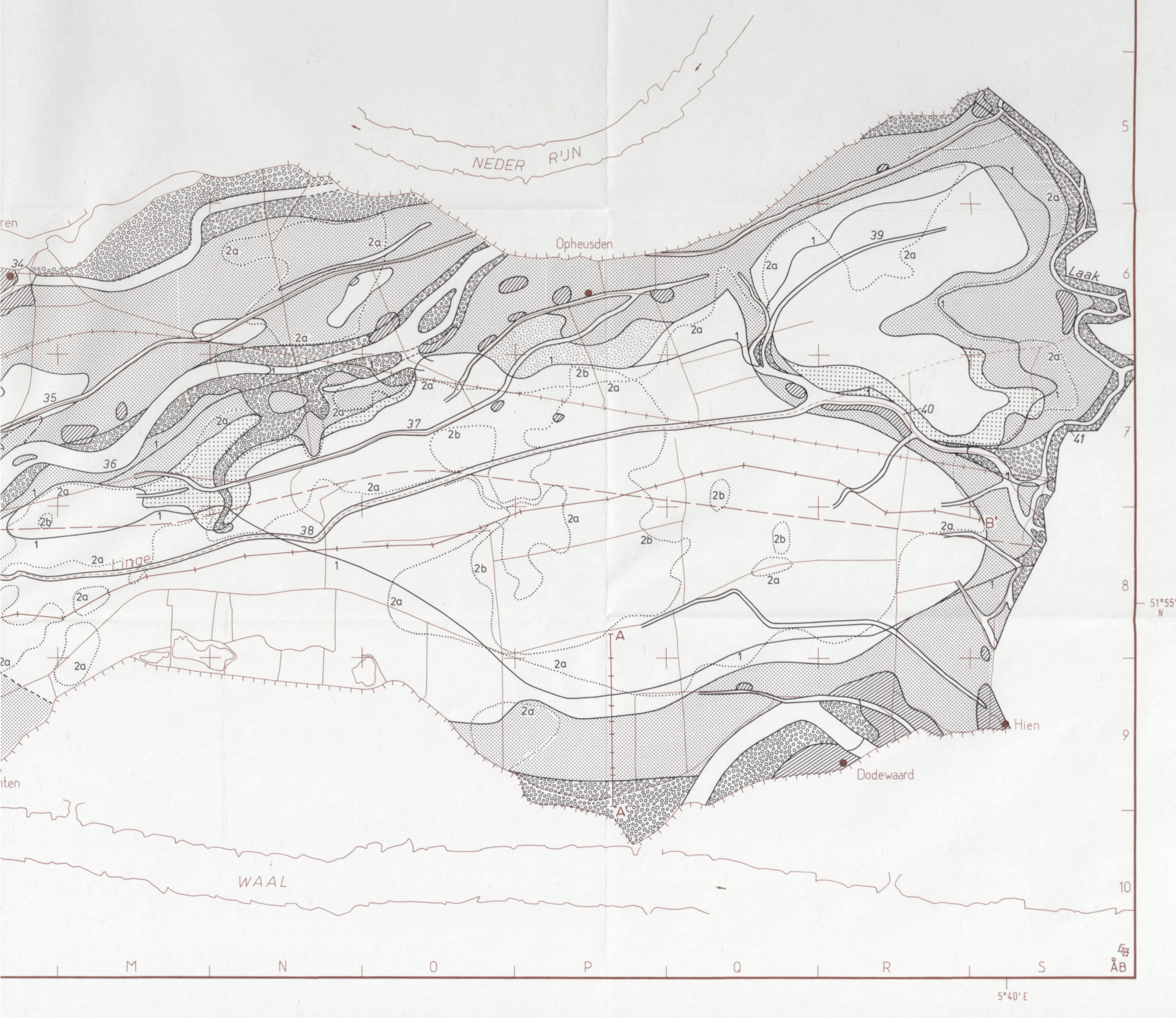
Secondary road
Secundaire weg

Railway
Spoorweg

Main watercourse
Hoofdwatergang

River-dike
Rivierdijk

Mediaeval church
Middeleeuwse kerk



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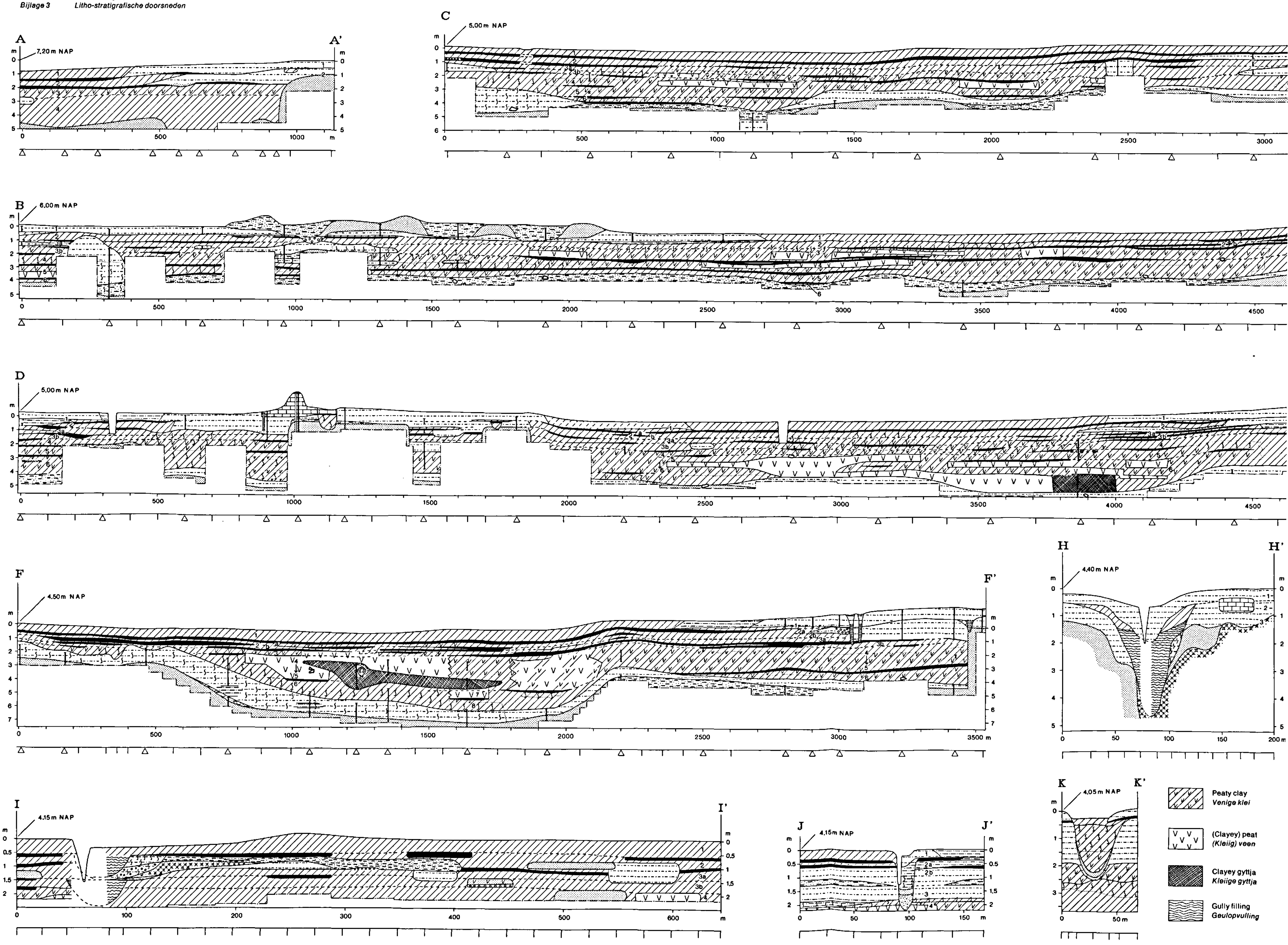
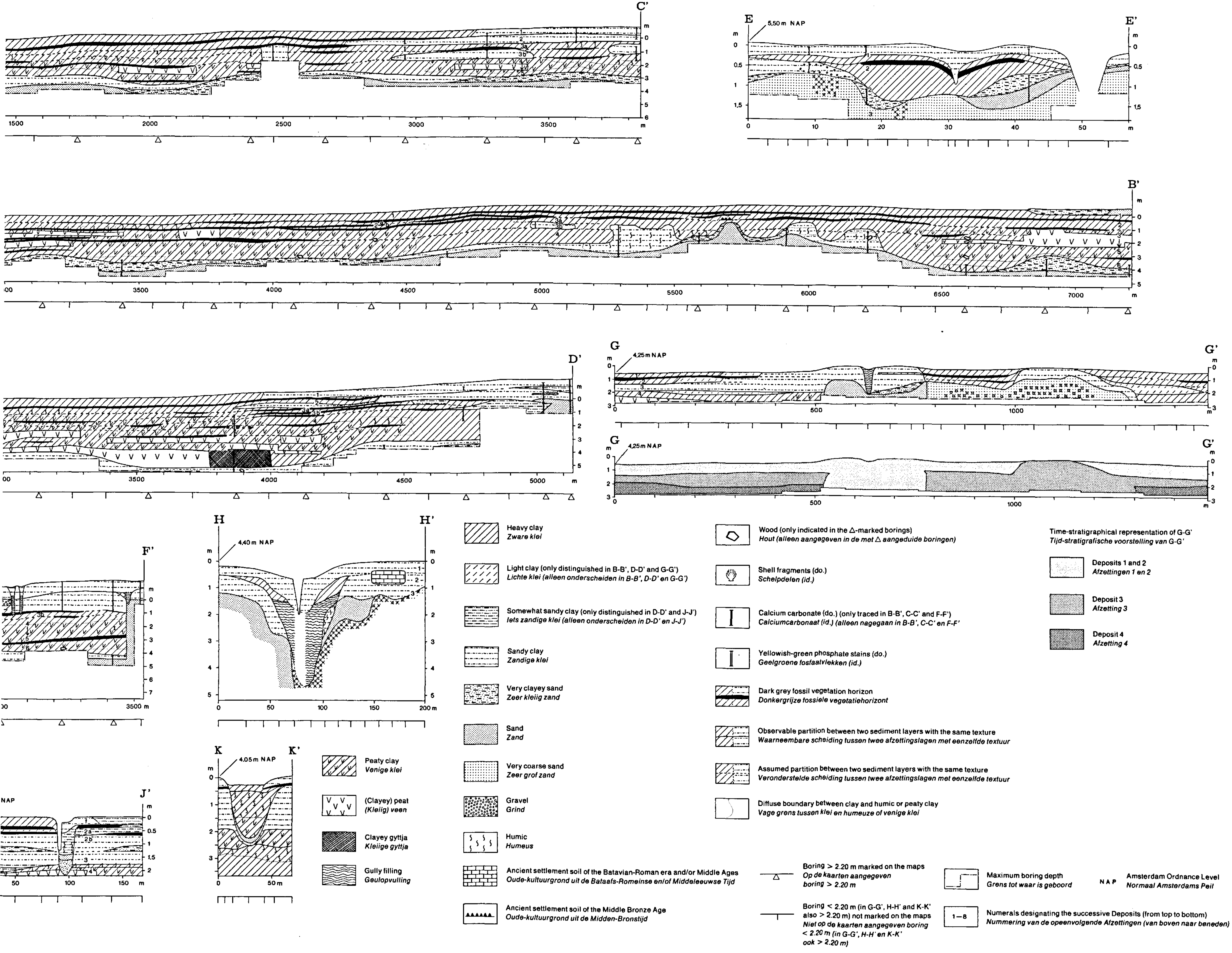
Enclosure 3 Litho-stratigraphical sections
Bijlage 3 Litho-stratigrafische doorsneden





C'
1500
2000
2500
3000
3500
E
5,50 m NAP
E'
B'
D'
G
4,25m NAP
G'
H
4,40 m NAP
H'
F'
3500 m
K
4,05 m NAP
K'
J'
50 m
200 m
Heavy clay
Zware klei
Light clay (only distinguished in B-B', D-D' and G-G')
Lichte klei (alleen onderscheiden in B-B', D-D' en G-G')
Somewhat sandy clay (only distinguished in D-D' and J-J')
Iets zandige klei (alleen onderscheiden in D-D' en J-J')
Sandy clay
Zandige klei
Very clayey sand
Zeer kleiig zand
Sand
Zand
Very coarse sand
Zeer grof zand
Gravel
Grind
Humic
Humeus
Ancient settlement soil of the Batavian-Roman era and/or Middle Ages
Oude-kultuurgrond uit de Bataafs-Romeinse en/of Middeleeuwse Tijd
Ancient settlement soil of the Middle Bronze Age
Oude-kultuurgrond uit de Midden-Bronstijd
Peaty clay
Venige klei
(Clayey) peat
(Kleiig) veen
Clayey gyttja
Kleiige gyttja
Gully filling
Geulopvulling
Wood (only indicated in the △-marked borings)
Hout (alleen aangegeven in de met △ aangeduide boringen)
Shell fragments (do.)
Schelpdelen (id.)
Calcium carbonate (do.) (only traced in B-B', C-C' and F-F')
Calciumcarbonaat (id.) (alleen nagegaan in B-B', C-C' en F-F'
Yellowish-green phosphate stains (do.)
Geelgroene fosfaatvlekken (id.)
Dark grey fossil vegetation horizon
Donkergrijze fossiele vegetatiehorizont
Observable partition between two sediment layers with the same texture
Waarneembare scheiding tussen twee afzettingslagen met eenzelfde textuur
Assumed partition between two sediment layers with the same texture
Veronderstelde scheiding tussen twee afzettingslagen met eenzelfde textuur
Diffuse boundary between clay and humic or peaty clay
Vage grens tussen klei en humeuze of venige klei
Boring > 2.20 m marked on the maps
Op de kaarten aangegeven
boring > 2.20 m
Boring < 2.20 m (in G-G', H-H' and K-K' also > 2.20 m) not marked on the maps
Niet op de kaarten aangegeven boring < 2.20 m (in G-G', H-H' en K-K' ook > 2.20 m)
Time-stratigraphical representation of G-G'
Tijd-stratigrafische voorstelling van G-G'
Deposits 1 and 2
Afzettingen 1 en 2
Deposit 3
Afzetting 3
Deposit 4
Afzetting 4
Maximum boring depth
Grens tot waar is geboord
NAP
Amsterdam Ordnance Level
Normaal Amsterdams Peil
1—8
Numerals designating the successive Deposits (from top to bottom)
Nummering van de opeenvolgende Afzettingen (van boven naar beneden)


Enclosure 2. Map 3 + 4
Bijlage 2. Kaart 3 + 4
ISN = 200 400
A B C D E F G H
1 2 3 4 5 6 7 8 9 10
Maurik
Eck en Wiel
Ingen
Ommeren
Echteld
NEDER RIJN
Mauriksche Wetering
Amsterdam - Rijn kanaal (canal)
Linge
BLAUWE KAMP
N
0 1 2 km
Scale 1:20.000
Schaal 1:20.000
51°55' N
5°30'E

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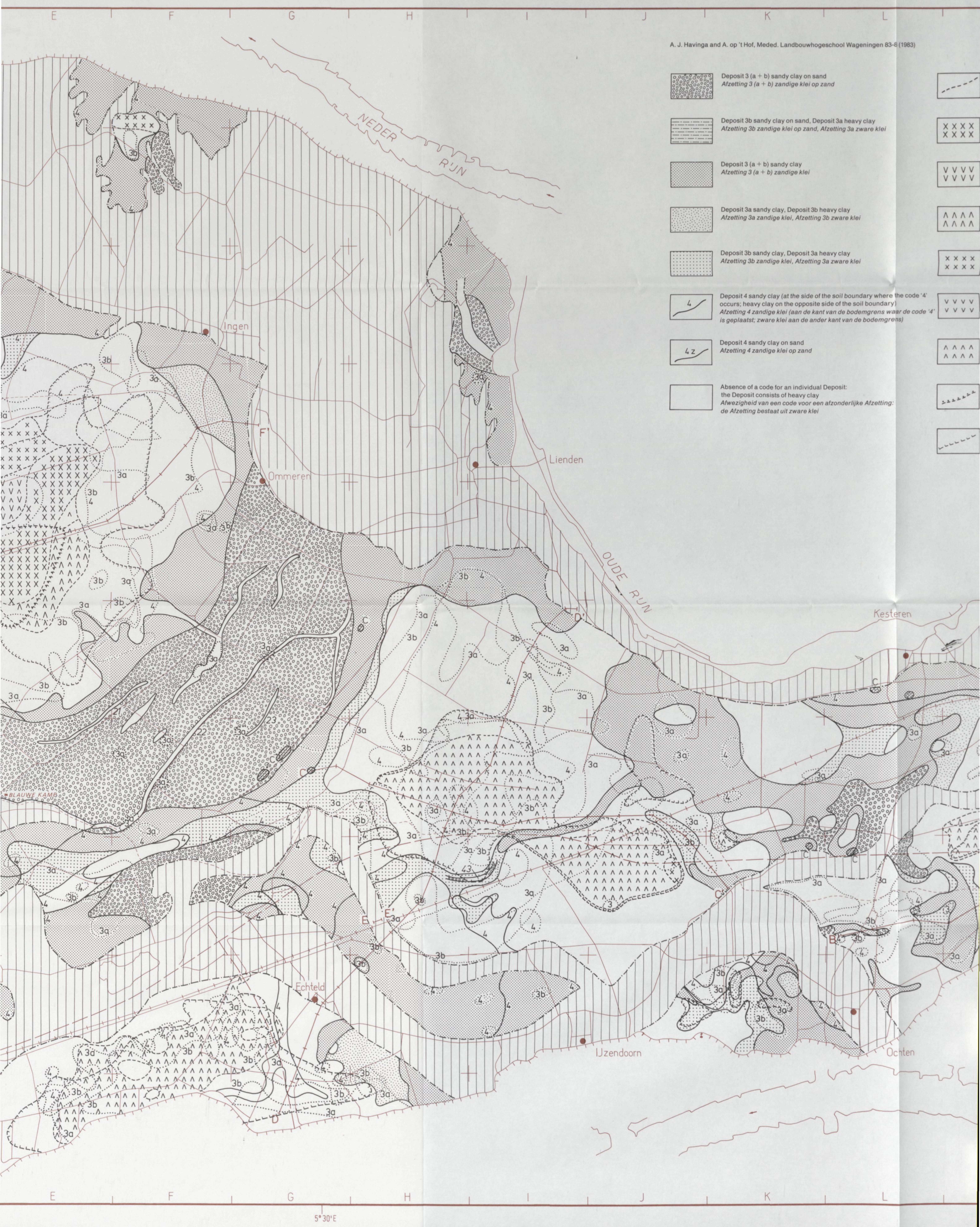
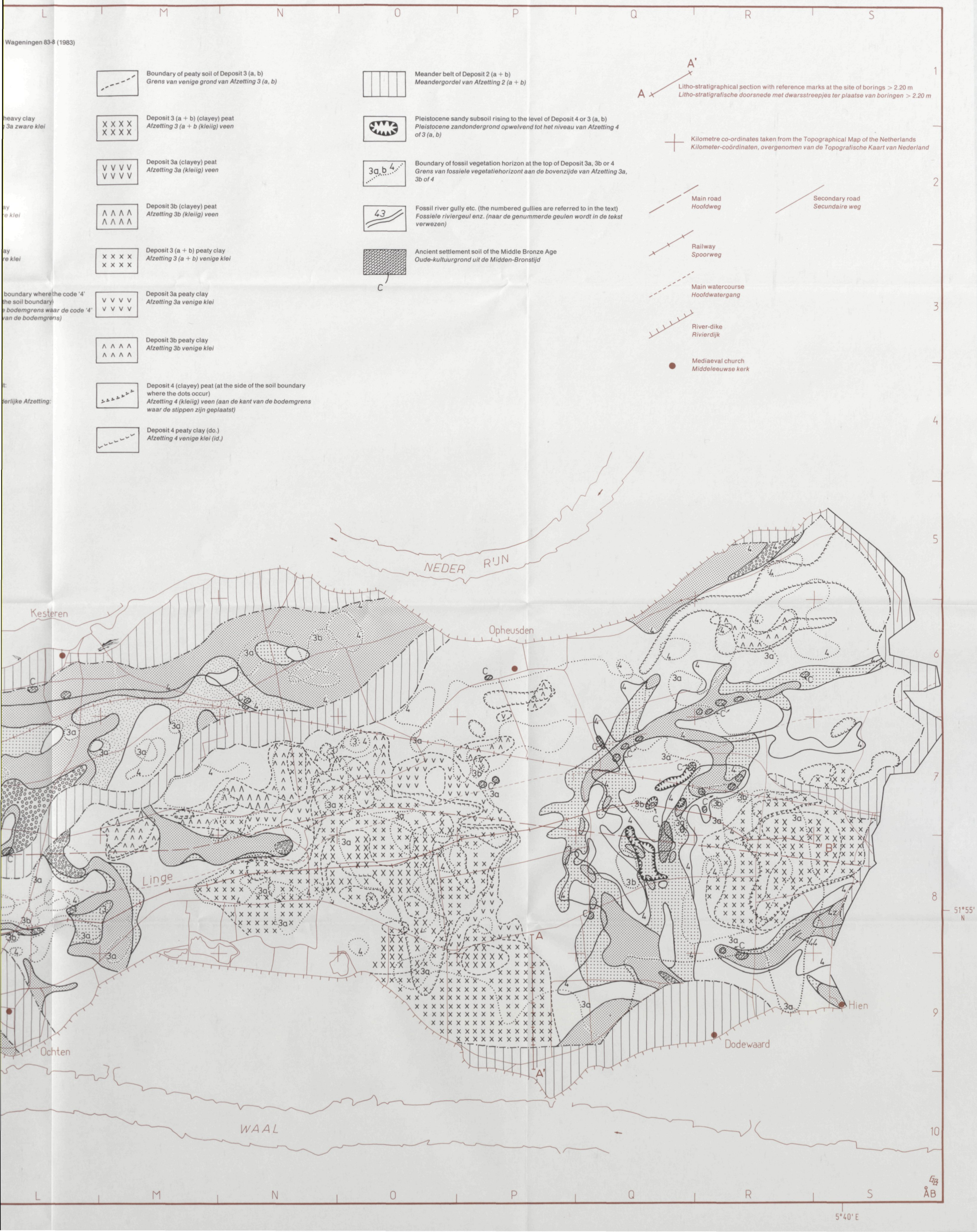
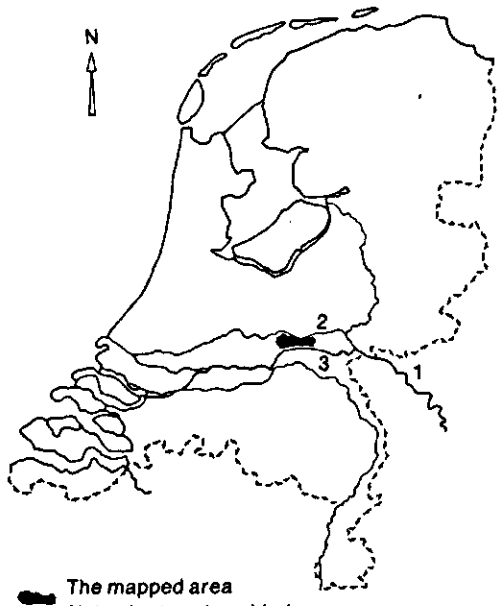



L M N O P Q R S
Wageningen 83-8 (1983)
heavy clay
3a zware klei
ay
e klei
ay
re klei
boundary where the code '4'
the soil boundary)
bodemgrens waar de code '4'
van de bodemgrens)
t:
derlijke Afzetting:
Boundary of peaty soil of Deposit 3 (a, b)
Grens van venige grond van Afzetting 3 (a, b)
Deposit 3 (a + b) (clayey) peat
Afzetting 3 (a + b (kleiig) veen
Deposit 3a (clayey) peat
Afzetting 3a (kleiig) veen
Deposit 3b (clayey) peat
Afzetting 3b (kleiig) veen
Deposit 3 (a + b) peaty clay
Afzetting 3 (a + b) venige klei
Deposit 3a peaty clay
Afzetting 3a venige klei
Deposit 3b peaty clay
Afzetting 3b venige klei
Deposit 4 (clayey) peat (at the side of the soil boundary where the dots occur)
Afzetting 4 (kleiig) veen (aan de kant van de bodemgrens waar de stippen zijn geplaatst)
Deposit 4 peaty clay (do.)
Afzetting 4 venige klei (id.)
Meander belt of Deposit 2 (a + b)
Meandergordel van Afzetting 2 (a + b)
Pleistocene sandy subsoil rising to the level of Deposit 4 or 3 (a, b)
Pleistocene zandondergrond opwelvend tot het niveau van Afzetting 4 of 3 (a, b)
Boundary of fossil vegetation horizon at the top of Deposit 3a, 3b or 4
Grens van fossiele vegetatiehorizont aan de bovenzijde van Afzetting 3a, 3b of 4
Fossil river gully etc. (the numbered gullies are referred to in the text)
Fossiele riviergeul enz. (naar de genummerde geulen wordt in de tekst verwezen)
Ancient settlement soil of the Middle Bronze Age
Oude-kultuurgrond uit de Midden-Bronstijd
Litho-stratigraphical section with reference marks at the site of borings > 2.20 m
Litho-stratigrafische doorsnede met dwarsstreepjes ter plaatse van boringen > 2.20 m
Kilometre co-ordinates taken from the Topographical Map of the Netherlands
Kilometer-coördinaten, overgenomen van de Topografische Kaart van Nederland
Main road
Hoofdweg
Secondary road
Secundaire weg
Railway
Spoorweg
Main watercourse
Hoofdwatergang
River-dike
Rivierdijk
Mediaeval church
Middeleeuwse kerk
NEDER RIJN
Kesteren
Opheusden
Linge
Ochten
Dodewaard
Hien
WAAL
51°55' N
5°40' E
1 2 3 4 5 6 7 8 9 10

Enclosure 4A
Bijlage 4A

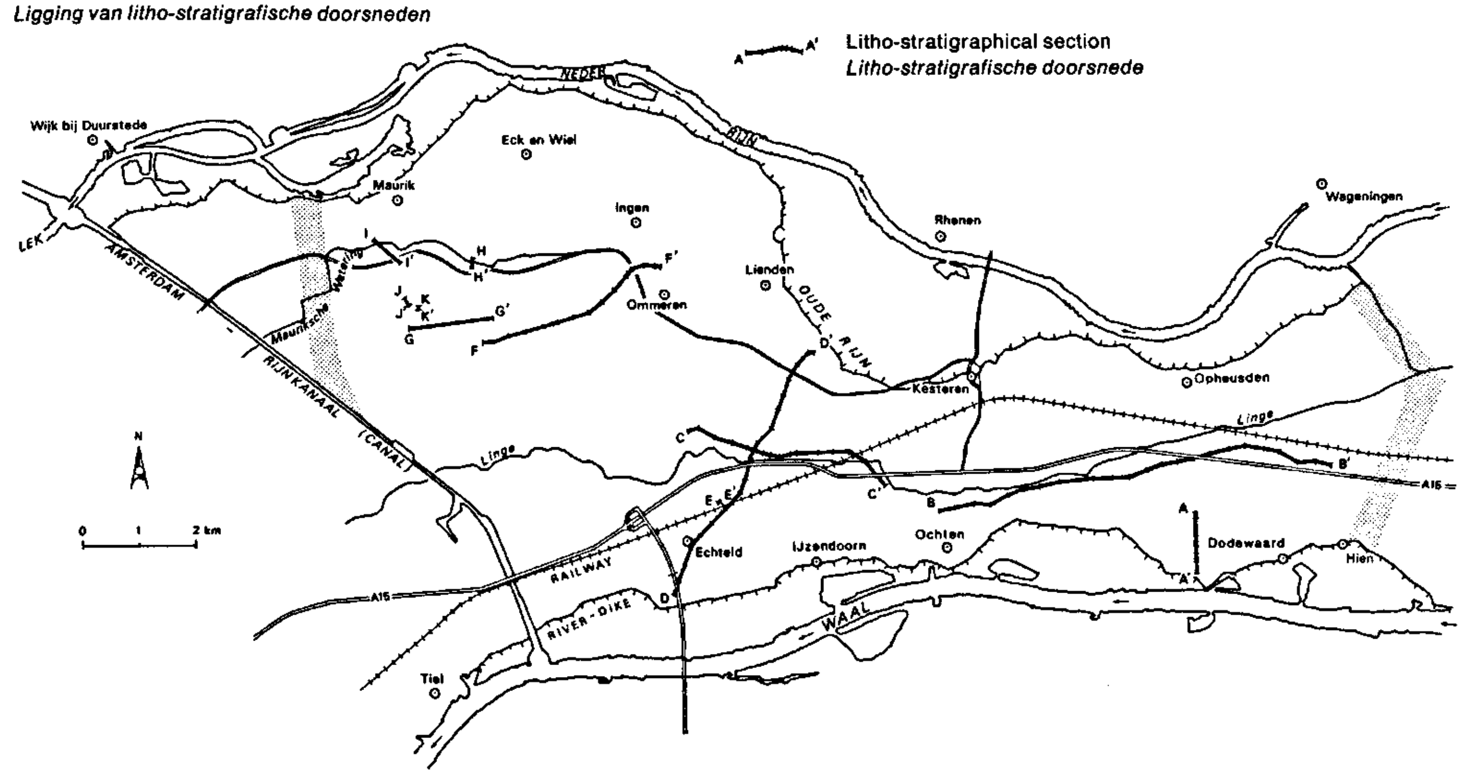
Location of the mapped area
Ligging van het gekarteerde gebied



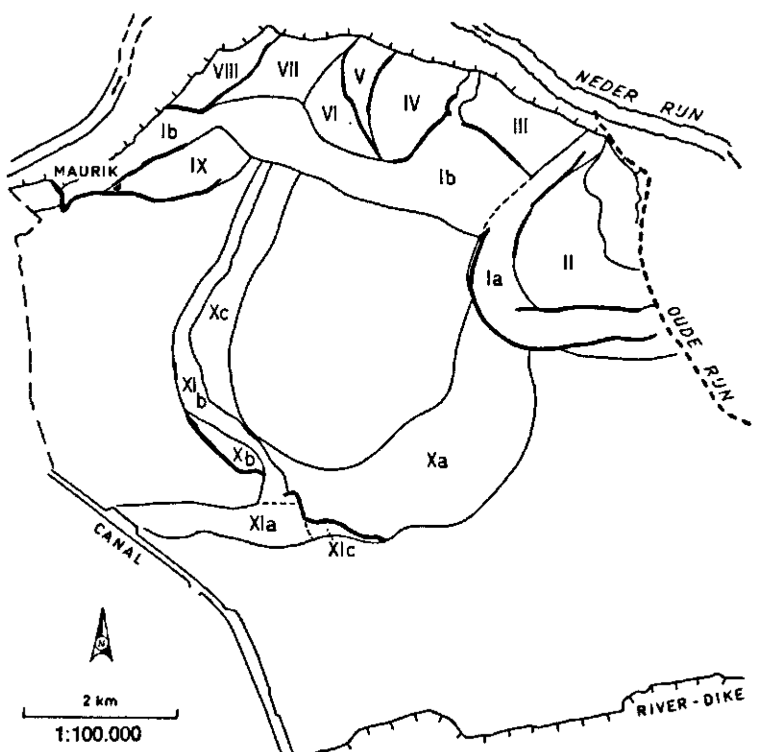
The mapped area
Het gekarteerde gebied

1 Rhine Rijn | 2 Lower Rhine Neder Rijn | 3 Waal Waal

Location of litho-stratigraphical sections
Ligging van litho-stratigrafische doorsneden



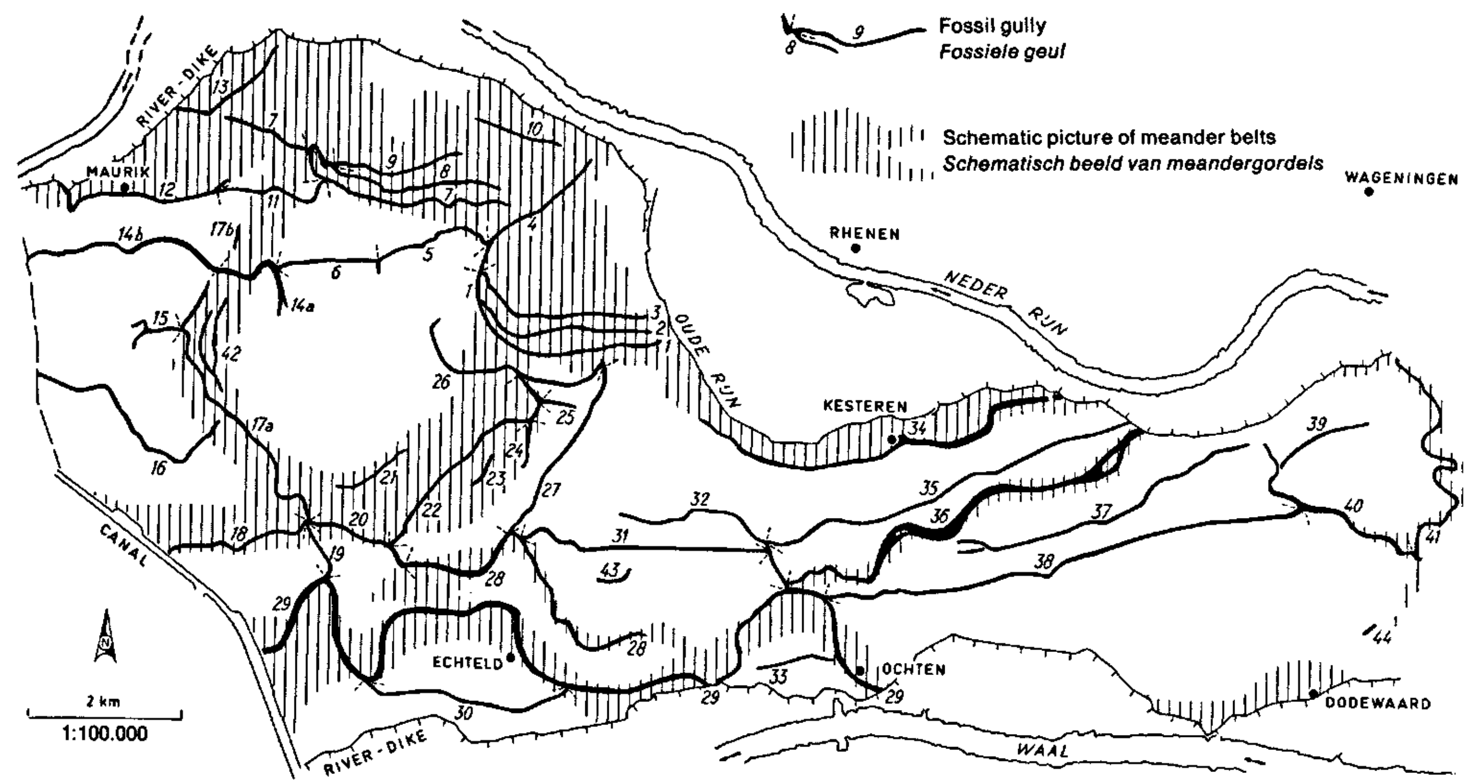
View of meander belt compartments
Overzicht van meandergordelkompartimenten



Fossil gully bordering a compartiment
Fossile geul langs een kompartiment

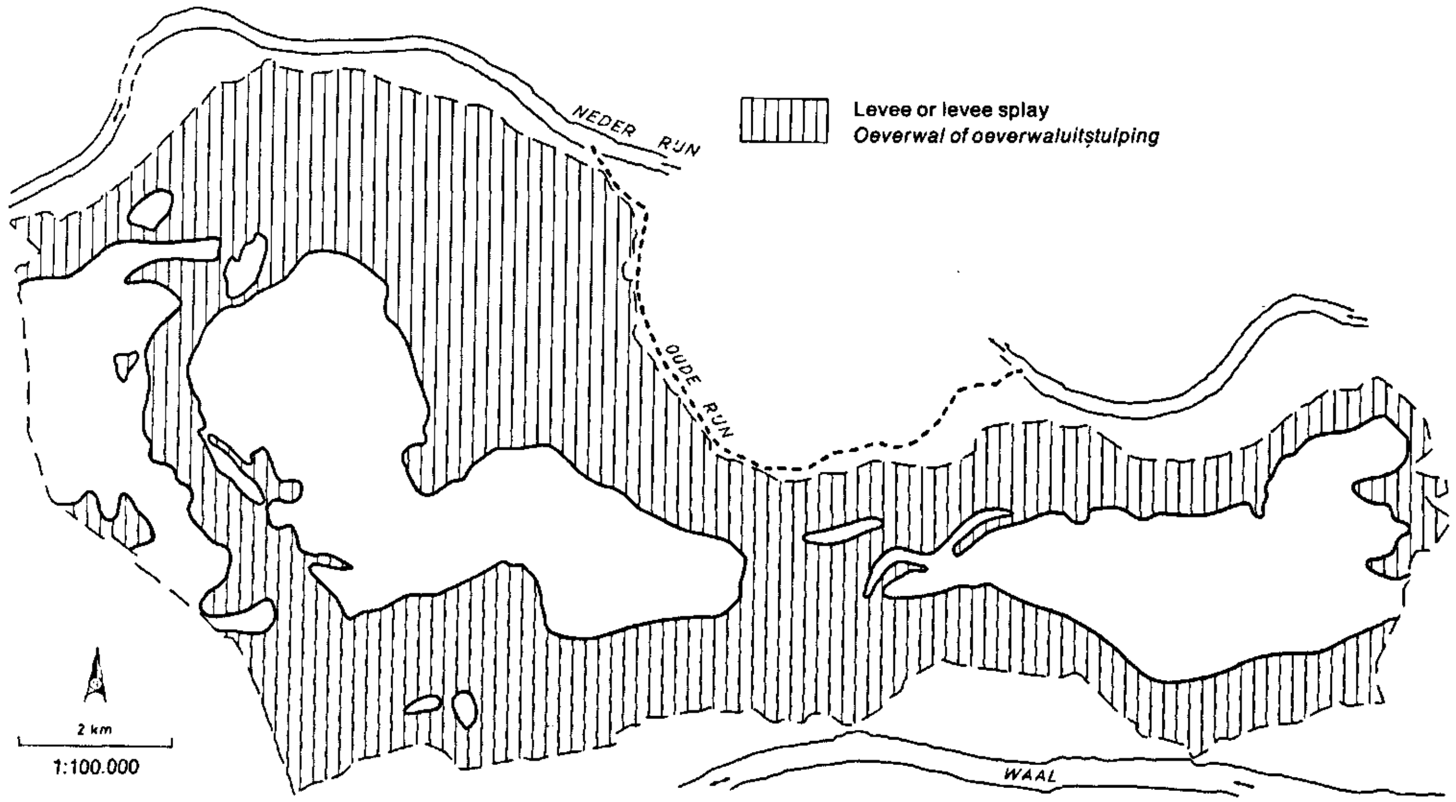
I, II, etc. The various compartments
De verschillende kompartimenten

View of fossil gullies referred to in the text
Overzicht van fossiele geulen waarnaar in de tekst wordt verwezen

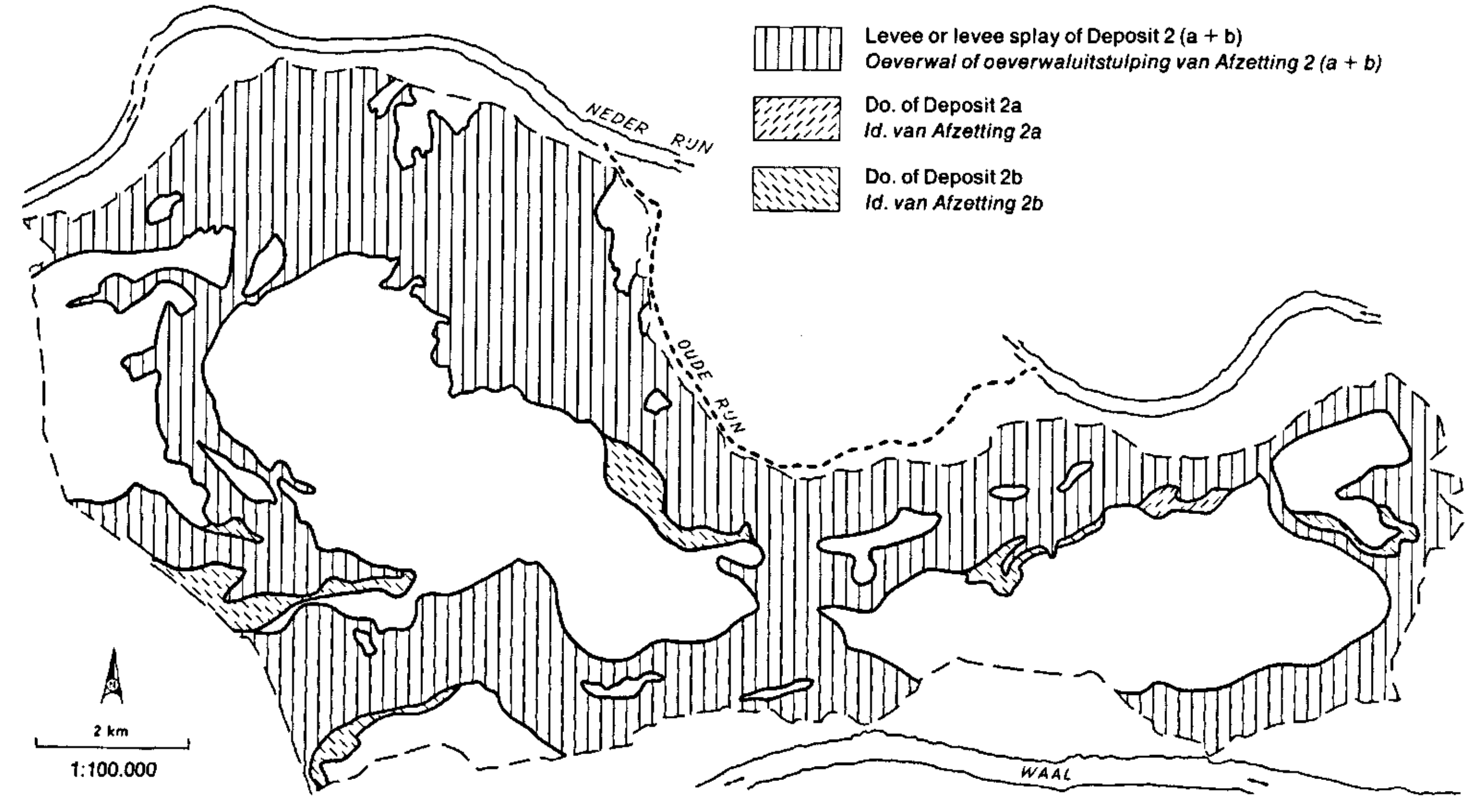


Enclosure 4B
Bijlage 4B

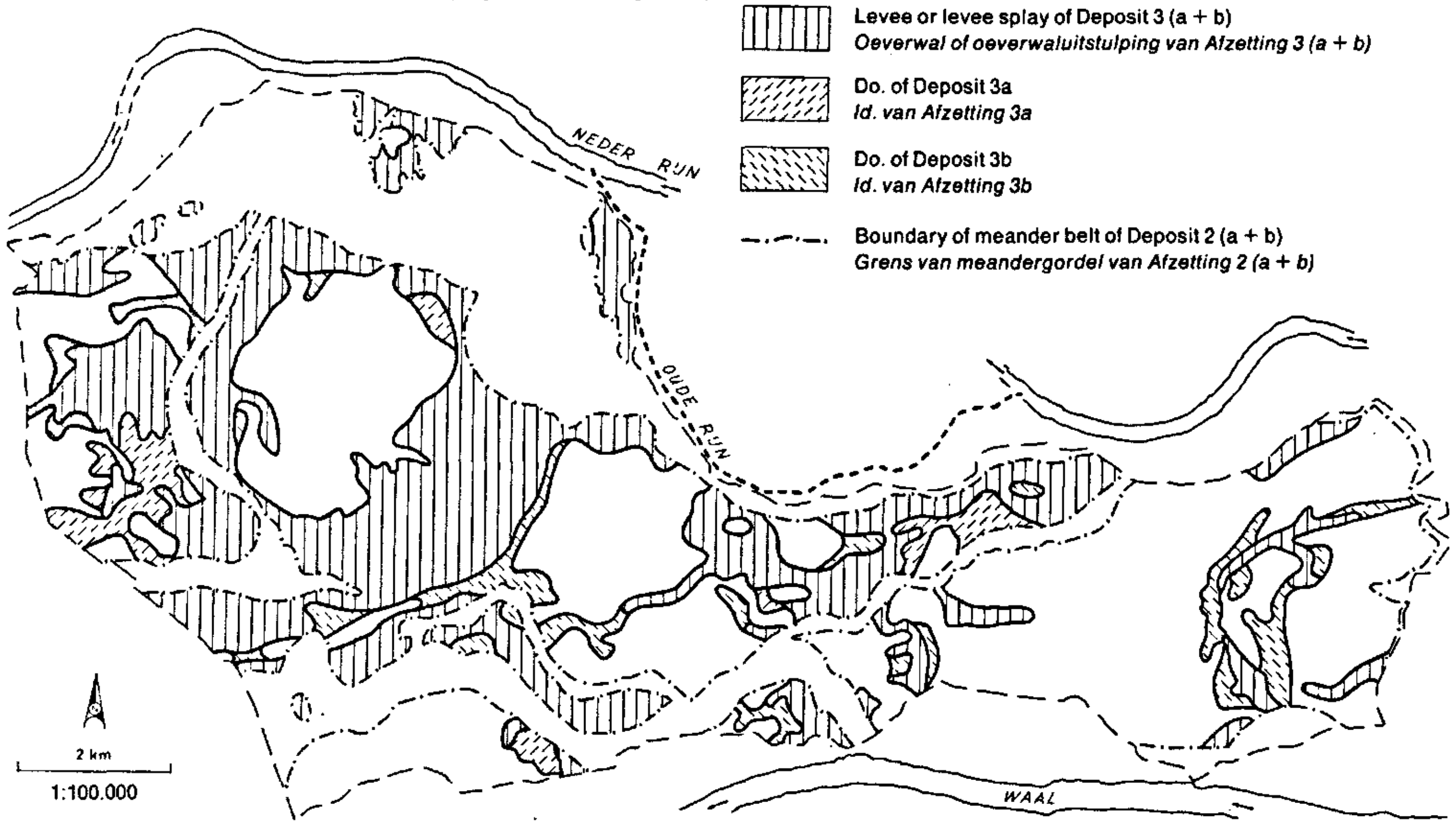
View of levees and levee splays of Deposit 1
Overzicht van oeverwallen en oeverwaluitstulpingen van Afzetting 1



View of levees and levee splays of Deposit 2 (a, b)
Overzicht van oeverwallen en oeverwallenuitstulpingen van Afzetting 2 a, b)



View of levees and levee splays of Deposit 3 (a, b)
Overzicht van oeverwallen en oeverwaluitstulpingen van Afzetting 3 (a, b)



View of levees and levee splays of Deposit 4
Overzicht van oeverwallen en oeverwaluitstulpingen van Afzetting 4