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631.442.4:631.472.6(492.823)

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A PHYSIOGRAPHIC ANALYSIS OF A PART OF THE BETUWE, A DUTCH RIVER CLAY AREA

Een fysiografische analyse van een deel van de Betuwe, een Nederlands rivierkleigebied

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1. SITUATION OF THE MAPPED AREA

The mapped area occupies about 1800 ha. It forms part of the 'Betuwe', a river clay landscape bordered by the two river branches 'Nederrijn' and 'Waal' which divide off from the Rhine about 18 km south-east of the mapped area. The situation is shown in fig. 1.

The soil surface occurs about 7 to 7.50 m above the mean sea level (NAP).[1] Most of the area consists of river basin soils, which is conducive to a comprehensive physiographic investigation. This is related to the fact that clay beds deposited during earlier sedimentation phases are only intact below the basins of the more recent river deposits. Where levees are now found, older clay beds are largely absent owing to erosion and resedimentation by the younger river courses.

The Nederrijn and Waal were embanked in the Middle Ages. Due to this and several other factors not mentioned here, it is impossible to specify what the discharge capacity rates were under the original natural conditions. The present total discharge capacity of the two river branches is about 2000 m^3/sec at the medium summer level, the maximum total discharge capacity being about 9000 m^3/sec. The fall at the medium summer level is about 10.5 cm/km in the environment of the mapped area. The distance from the river mouths is about 120 km. Ebb and flow affect the river water level as far as about 16 km west of this area.

[1] NAP – 'Nieuw Amsterdams Peil' ('Amsterdam Ordnance Datum').

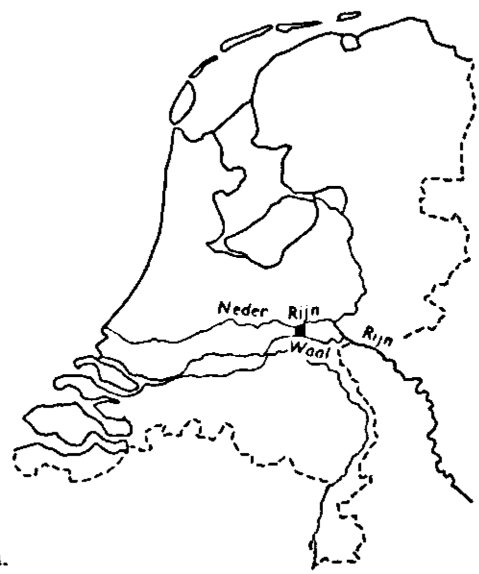

FIG. 1. Situation of the mapped area.

2. THE INVESTIGATION.

The physiographic survey is partly based on data obtained during a soil survey practice for students of the Agricultural University. However, the soil classification employed for this survey was particularly concerned with agriculture, so that the relevant soil map was only partly suitable for our purpose. Ten borings were made per ha to a depth of 1.20 m.

The density of the network of observations in the present physiographic survey is very variable. At many places the borings were even closer together than stated above, for instance, where fossil river gullies could not be traced in soil topography. But most of the area has a less detailed network of borings, the minimum number per ha being one. They are 2.20 m deep, which is sufficient to provide an insight into the geological structure of the aggregate Holocene sediments in this part of the river clay area.

The classification units are mainly based on a few separate values, viz. texture, presence or absence of humic or peaty matter, presence or absence of a vegetation horizon, and the presence or absence of remains of ancient settlements. During the survey the separate values were noted on a field map in combination with numerals denoting depths below the soil surface. Drawing the soil pattern on the map often required careful consideration of the proper arrangement of the data obtained within the various deposits distinguished (cf. p. 7). Occasionally a more or less subjective interpretation was inevitable.

The soil texture was determined in the field by assessing the clay content of the soil. The soil matter was kneaded and rubbed between the thumb and forefinger. It was decided not to assess more than one texture fraction in the soil material as otherwise the reliability of the data obtained might have been affected. The clay percentages were occasionally checked by laboratory analysis. Many laboratory analyses of the 5 to 20 cm thick topsoil were available from the LABORATORY FOR SOIL AND CROP TESTING, OOSTERBEEK. These were kindly placed at the author's disposal by the STATE AGRICULTURAL ADVISORY OFFICE.

The 1 and 2 – lines (see p. 11 and 12) in the area north of the Wuust were corrected from A. OP 'T HOF's very detailed horticultural soil survey of the same area (at press).

3. COMPILATION OF THE MAPS

The geographical-topographical background of the maps is a picture in which the actual situation is greatly reduced. The villages are only indicated by the mediaeval church. The two maps (enclosures 1 and 2) show the physiographical soil conditions to a depth of 2.20 m. The sections (enclosure 3) elucidate the often fairly complex geological structure of the soil to this depth and, also, give an impression of the type and thickness of the underlying Holocene sediments.

Within a depth of 2.20 m it was possible to distinguish three river clay beds and part of a fourth, forming part of an equal number of river deposits (cf. below). They were formed during four successive sedimentation phases, separated by three phases of stagnating river activity, during which the dark grey vegetation horizons developed (cf. figs. 2 and 3 and p. 39). The deposits are designated by reference numerals 1, 2, 3 and 4 from young to old or from above to below. As far as possible the individual deposits are shown as separate physiographical units. Deposits 1 and 2 are very similar as regards the position of their various physiographical elements. The same is true of deposits 3 and 4, whereas the two pairs show a good deal of divergency. For clearness of understanding the various deposits are therefore combined on two different maps (1+2 and 3+4). However, the meander belts of deposits 1 and 2 are also given on map 3 + 4, insofar as their presence implies an outline of the more sandy textured parts of deposits 3 and 4.

FIG. 2. Dark grey vegetation horizon at the top of deposit 2.

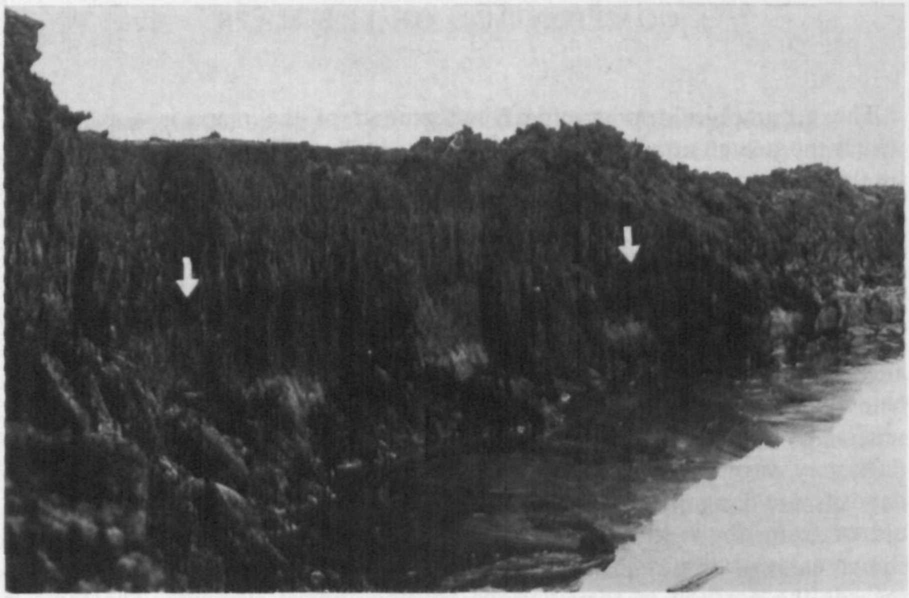

FIG. 3. Dark grey vegetation horizon at the top of deposit 3.

Each deposit essentially consists of a meander belt of coarse sand covered by a sandy clay bed of several dm as top stratum deposit; this becomes laterally merged in a clay bed which is also several dm thick, covering an older deposit, and consisting of a zone of sandy clay of varying width along the meander belt, and of heavy basin clay further away. The picture is completed by fossil river channels, overflow gullies, levee splays (see p. 18) and ancient culture soils. All these constituents are shown on the maps as a pattern of lines of varying intricacy in combination with a numeral denoting to the deposit in question.

The levees are found at the side of the lines representing a levee-basin transition, where the code is placed.

To some extent the soil pattern obviously depends on the texture classes selected. In the present investigation texture is classified as shown in table I.

A clay bed will not always change its texture simultaneously over its entire depth. Where one and the same bed partly consists of heavy clay and partly of sandy clay, a mark is added to the deposit numeral (see the legend).

TABLE 1. The various texture classes.

Name	Clay ($< 2\mu$) percentage
Heavy clay	> 35
Sandy clay	35–13
Very clayey sand	13– 9
Sand	< 9

Addition of the Z character indicates the occurrence of coarse sand, occasionnally mixed with some clay (up to 9%). This material is found both in the meander belts and in several levee splays. Course sand with a higher clay content (9–13%) is denoted by the letter z.

Humic or peaty matter occurring in the heavy clay in fossil gullies or basins is not shown on the maps. Humic matter in fossil gullies is always shown in the sections as it does not invariably fill the entire gully. The sections do not represent the material in heavy clay in the basins, where it is usually found below the oxidized zone. But peaty material, which is not so regularly distributed throughout the clayey soil, is always shown where found.

4. THE RELATIONSHIP BETWEEN SOIL PATTERN AND THE TEXTURE CLASSES DISTINGUISHED.

As stated above, p. 8, the soil pattern of a map depends to some extent on the criterion selected for the texture boundary between the sandy clay in the levees and the heavy clay in the basins. If, for instance, the criterion had been 40% clay content instead of 35%, as in the present investigation, the basins on the map would have been reduced to a greater or lesser extent, but without a substantial change in their outlines.

If instead of the clay fraction (< 2 μ) we had used, for instance the < 16 μ-fraction, as was commonly done in earlier Dutch soil surveys, the position of the outlines of the basins would only have been slightly shifted if the correct < 16 μ- fraction percentage had been chosen as a texture boundary. This is because the < 2 μ- fraction – percentage: < 16 μ- fraction-percentage ratio, is constant within certain (not too wide) limits in the different, variously textured Dutch river sediments.

This does not apply when the texture varies within narrow limits around the critical percentage over a more extensive area. Under such conditions even slight variations in the above-mentioned ratio will obviously have a great effect on the situation of the soil boundaries on the map. A situation of this kind is found in the area north of the Wuust. Here the 1-line is of an unusual pattern in squares 2DE (cf. p. 11). This pattern would not have been found if the texture classes had been based on their < 16 μ- fraction content. This was evident from textural analyses in this area made by the laboratory mentioned on p. 6.

To give an impression of the particle size distribution in the sandy clay of a levee or heavy clay in a basin, a number of analyses are given in table II. Textures represented by sample nos. 9 and 10 in the table are only found in dark grey vegetation horizons (cf. p. 24).

TABLE II. Particle size distribution of a number of variously textured river clay samples.

Sample no.	Texture classes expressed as percentages					
	< 2 μ	2–16 μ	16–50 μ	50–105 μ	105–210 μ or: > 105 μ	> 210 μ
1	11	5	7	12	65	
2	19	11	8	10	52	
3	19	17	22	18	24	
4	32	30	22	6	10	
5	33	27	32	5	2	1
6	40	31	24	2	1	2
7	50	29	18	2	1	+
8	61	30	8	1	–	–
9	70	25	5	–	–	–
10	78	17	5	+	–	–

5. GENERAL SOIL CONDITIONS

5.1. The individual deposits

Deposit 1

The fossil river channels (map 1 + 2) must be attributed to both deposits 1 and 2. Their course will not have shifted considerably since the formation of deposit 2 (cf. p. 34). There are also several fossil overflow gullies of the same age. Two types may be distinguished, viz. the normal one connecting a river course with a basin, mainly occurring in the area south of the Wuust, and another less commonly found, connecting with river courses via a basin. The latter occurs in the area north of the Wuust (cf. p. 21).

The various meander belts also form part of both deposits 1 and 2, the latter being by far the most important in this respect (cf. p. 33).

The sandy clay-heavy clay transition (1-line) broadly parallels the meander belts and the Rhine (Nederrijn)dyke.

There are several points at which the soil pattern merits closer attention: north of the Wuust (squares 2DE) the 1-line shows an eastward protrusion. The north-south oriented meander belt in the western part of this area (squares 23C) is not paralleled by the 1-line at some distance to the east, as might have been expected, this line being found in the space occupied by this belt. South of the Wuust and north of Hien (square 5D) a north-south oriented fossil river gully is found without a sandy clay zone belonging to deposit 1 on either side. In a broad zone along the Waal dyke deposit 1 forms a very sandy and very thick sediment. In disagreement with an earlier theory (Egberts 1950) it is assumed to have been mainly formed during the period preceding embanking in the Middle Ages and not as a result of more recent dyke breaches.

A peculiar phenomenon is that unlike the other deposits described below, deposit 1 has no levee splay formation.

More or less circular or protracted packets of ancient settlement soil are found scattered over the whole area, bordering the fossil river gullies and occasionally the overflow gullies. Formation of this settlement soil began at the level of the fossil vegetation horizon overlying deposit 2. It continued until after deposit 1 had come into existence. Hence this soil may be considered as forming part of both deposits 2 and 1.

Deposit 2

A very wide meander belt along the eastern side of the mapped area is represented on the map by a narrow strip of coarse sand, forming only its extreme western part. The fossil gully of the former large river course in this belt is outside the area represented by the map.

In the southern part of the mapped area, in a wide zone north of the Waal dyke, there are three narrower arched meander belts. The middle one is cut by the eastern one, whereas the fossil river gully in the middle belt has no contact with the gully bordering the northern side of the eastern belt.

Narrow meander belts occur along the former Wuust river and its western branches.

The 2-line indicating the sandy clay-heavy clay transition is of a fairly complex pattern in the area north of the Wuust. This is due to the presence of several lobe-shaped levee splays (cf. p. 18). The splays often occupy the deeper part of deposit 2 only, i.e. along the narrow meander belt in squares 23D, forming the western limit of the mapped area. The latter splays partly consist of coarse sand and have been scoured into the subjacent deposit 3.

South of the Wuust the 2-line usually has a smooth course more or less parallel to the meander belts. At one point, however, west of Zetten, in squares 4EF, this course is apparently affected by a tongue-shaped levee splay. North of Hien the 2-lines show a marked divergence from the 1-line pattern. Whereas the latter indicates a sandy clay-heavy basin clay-sandy clay succession from south to north, the soil pattern in deposit 2 represents a south-north oriented poorly developed levee between two neighbouring basins.

Outside the mapped area bipartition of clay bed 2 may be found. This is connected with a local vegetation horizon about 80 cm below the soil surface.

Deposit 3

Only two fragments remain of the meander belt system present during the formation of deposit 3. The rest was 'rejuvenated' during the subsequent sedimentation phases 2 and 1. The fragments are found near the Rhine dyke in squares 12CDE and along the concave side of the middle arched meander belt in deposit 2, north of the Waal dyke, in squares 6DE. Of the former river courses only one fragment was found, i.e. in the meander belt fragment near the Rhine dyke.

Course sand is found in the meander belt fragments and various levee splays, viz. in the fairly short tongue-shaped levee splay at some distance north of the Waal dyke (squares 7GH) and in the very protracted levee splays crossed by the railway (Tiel-Elst) and just south of it. In the protracted splays, however, it is mainly concentrated in isolated patches.

Sandy clay is almost solely confined to levee splay configuration. Parts of lobe-shaped splays cut in varying degrees by the more recent meander belts of deposit 2, fringe these belts in the Eastern and Southern part of the mapped area. The three very protracted splays have an unusual configuration. They run parallel over a long distance without actually touching. The northern splay connects two opposite meander belts, whereas the middle and southern splays only touch one of the belts, viz. the eastern and western one respectively. Absence of contact between splay and belt was ascertained by a very detailed system of borings.

The levee splays may be as thick as deposit 3 or only form part of it (either the upper (3') or the lower ('3) part). In this case the sandy clay-heavy clay or heavy clay-sandy clay transition usually occurs half-way down deposit 3 and sometimes rather lower. This is found in all the splay types distinguished. In this connection the three very protracted splays show the following pattern.

The northern one is fringed by a zone where the sandy clay alternately occupies the higher or lower part of deposit 3, the middle splay consists of sections representing 3 and '3 profiles alternately, while the eastern part of the southern splay is mainly of the same composition as 3'.

A bipartition at the same level as in the levee splays was also found locally in the basin clay proper, viz. between the former Wuust river and the northern one of the very protracted levee splays. It is shown by a dark grey, discontinuous vegetation horizon, or by a thin heavy clay layer containing wood remains. The latter is only found at a few points where the former is absent.

The northern very protracted splay is distinguished from all other levee splays found in having a fossil gully throughout its length. In addition to this continuous gully, fragments of other gullies were also traced in it. On the map these fragments resemble some heavy clay patches in the northern part of the same splay. The latter are of a quite different origin, however. They represent small fragments of a basin which were spared during the process of levee splay formation. These phenomena are clearly seen in section NO of enclosure 3.

The above-mentioned continuous gully and gully fragments had silted up before formation of deposit 2 began. This is concluded from the position of the vegetation horizon overlying deposit 3, as shown in the various cross-sections (enclosure 3).

The fragment of the former river course mentioned on p. 12 did not fossilize at this period but was introduced into the overflow gully system which operated at later periods.

Numerous culture sites are scattered over the greater part of the mapped area outside the meander belts of deposits 2 and 1. They are chiefly concentrated on the levee splays in or around the basins. Thus out of the 29 culture sites found, 21 are on a splay and 8 on the basin soil proper. Most sites are very small, although some represent a vast settlement. The latter are found along the continuous gully in the very protracted levee splay (square 5D), north of the middle of the three arched meander belts, and in the south-eastern part on and around the tongue-shaped levee splay, in square 7G.

There is no connection between the position of the culture sites in deposit 3 and those shown on map 1 + 2.

Deposit 4

No dark grey vegetation horizon was observed in the basins between 2.20 m depth and the pleistocene subsoil, although it must be admitted that this is not a feature common to all the Betuwe river basins. Elsewhere in the Betuwe one or more vegetation horizons may sometimes be found below 2.20 m.

No fragment of a meander belt system has been left in deposit 4. Only a 4_z-zone was found south of the Rhine dyke; this zone fringes the 3z-zone described under deposit 3. It must have originally been connected with a meander belt of deposit 4, at approximately the same site as the meander belt of deposit 3.

Lobe-shaped levee splays are frequent. They are found in the same kind of position as in deposit 3. A tongue-shaped splay occurs in the south-eastern part of the mapped area (square 6H). Two very protracted levee splays partly coincide with the northern and central of the three very protracted levee splays of deposit 3. Where the splays belonging to the two successive sedimentation phases coincide they appear to form a single sediment, but its complex nature was revealed by a thin, heavy-clay horizon, found here and there at the same level as the vegetation horizon overlying deposit 4.

As in deposit 3, isolated patches of coarse sand are surrounded or covered by sandy or heavy clay. The patches in both deposits partly represent the same occurrence of coarse sand. An excavation in square 5F, made for extracting sand, afforded an in situ observation of a soil profile consisting of basin clay on coarse sand (see fig. 4). Where the coarse sand reached its highest point below the soil surface it was covered by 15 dm of heavy basin clay, i.e. within reach

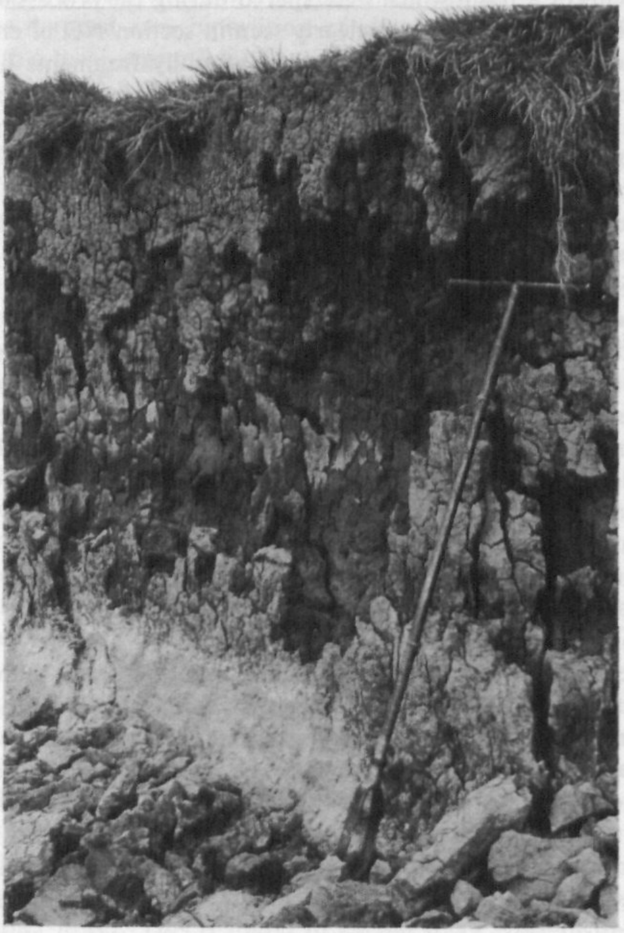

FIG. 4. Basin clay on Pleistocene sand (in square 5F).

of deposit 3. At a distance of 30 m from either side of this point the top of the coarse sand gradually sank to 22 dm, i.e. within reach of deposit 4. There was a remarkably sharp transition between the two types of sediment. It was formed by a heavy clay bed only 1 dm thick, mixed with some coarse sand.

The situation described is an argument in favour of local cropping up of the pleistocene sandy subsoil. But in many other cases where a shallow coarse sandy subsoil was found, it was difficult to assess its true, pleistocene or holocene, character.

Pleistocene subsoil

The sections (enclosure 3) show that sand or sandy clay frequently occurs at a depth of 4 to 5 m where it is covered by heavy basin clay. It is assumed to represent the more or less undulating top of the pleistocene subsoil. The study of this sediment was outside the present investigation.

5.2. Topography of the tops and thickness of the successive clay beds

The topography of the terrain coincides with the top of deposit 1. Generally speaking it forms a plain sloping slightly to the west. Except for this slope the differences in height between meander belts and basins do not usually exceed 8 dm.

As each of the clay beds 1, 2 and 3 is of a fairly uniform thickness over the entire area mapped, the tops of the subsequent clay beds below deposit 1 show a topography more or less parallel to that of the present soil surface.

This is clearly visible in the soil profiles where the top layer of the clay beds developed as a dark-grey vegetation horizon. Where the present soil surface represents the top of a meander belt, the various vegetation horizons (or top layers of a different composition) are naturally interrupted. A more pronounced relief is shown locally by the top of deposit 3, viz. at scattered points above various levee plays belonging to this depsosit.

The thickness of clay beds 1, 2 and 3 are mostly about 5, 5.5 and 8.5 dm respectively, so that the tops of all four successive clay beds occur at a depth of about 0, 5, 10.5 and 19 dm respectively.

Closer examination of the soil stratigraphy revealed the following more detailed data: north of the Wuust the upper clay bed is mostly 5 dm thick, here and there in the central part of the basin 4 dm, and near the Rhine dyke 6 dm, occasionally 7 dm. South of the Wuust, including the area west of Hien, this clay bed is also mostly 5 dm thick, 4 dm locally in the basin and particularly above the very protracted levee splays of deposit 3, often 6 dm in the southern part of the mapped area, outside the basin, and 7 to 8 dm near the Waal dyke, especially in the south east. Near the Waal dyke the clay of deposit 1 is distinguished by a very light texture.

North of the Wuust clay bed 2 is usually 6 dm thick and alternately 6 and 5 dm in the basin. The lobe-shaped levee splays with coarse sand, bordering the narrow meander belt in the western part of the mapped area (squares 23CD), increase the depth of deposit 2 by several decimetres near this belt, the splays having scoured into the subsoil. Eastward they gradually thin to a thickness more usually found in clay bed 2. The bottom of clay bed 2 is mostly found at a depth of 11 dm; near the Rhine dyke the depth is 12 dm. South of the Wuust, including the area west of Hien, clay bed 2 is usually 6 dm thick where its texture is fairly sandy. Near the Waal dyke it is thinner than was expected, the maximum depth not exceeding 5 dm. In this part of the mapped area the clay was relatively heavily textured, but did not answer to the specifications for heavy clay. A 4 to 5 dm thick heavy clay bed is common in the basin. The first figure relates more particularly to the south-eastern part and the part of the basin where the three very protracted levee splays of deposit 3 are found in the subsoil. Above the culture sites on these splays the thickness may be reduced to 3 dm or even less (cf. section TU). The bottom of clay bed 2 is usually found here 12 dm below the present soil surface outside or in the border zone of the basins. In the more central part of the basin it is found at a depth of 11 to 9 dm, occasionally 8 dm. The latter depth coincides with that of the vegetation horizon dividing clay bed 2 which here and there is outside the mapped area (cf. p. 24). But unlike the situation there, in the mapped area a vegetation horizon at 8 dm was never found in combination with another at about 11 dm.

In this connection it is obviously meaningless to speak of thickness of the sandy clay of deposit 2 above the meander belts. In this position clay bed 2 represents a top stratum deposit instead of a cover overlying an older sediment.

The thickness of clay bed 3 usually fluctuates around 9 and 10 dm, but 8 or 11 dm may sometimes be found. Its top occurs at the same depths as the above-mentioned bottom of clay bed 2. The bottom of clay bed 3 usually fluctuates around 18 and 21 dm. Here and there an upper and lower limit of 17 and 22 dm was found.

The variations in thickness of clay bed 3 are more closely connected with the occurrence of peaty material than with differences in the texture of the clay. Thus west of Hien clay bed 3 is usually peatier as well as a little thinner than elsewhere in the mapped area.

Where levee splays with coarse sand have scoured into the deeper subsoil clay bed 3 may be considerably thicker. For a local bipartion in deposit 3, cf. p. 12.

The cross-sections of enclosure 3 show a fairly level soil surface and little variation in thickness of each of the subsequent clay beds. This is mainly due to the position of the sections within the soil pattern shown by the maps. They are located where sandy clay beds form part of the soil profile or where the heavy basin clay beds of deposits 1 and 2 are relatively thick, i.e. near the border of the basins. A quite different factor is that clay bed thicknesses had to be interpolated over fairly long distances, which means that the picture is somewhat idealized (dotted lines). Deposits 1 and 2 are shown as a thinner clay bed in sections E F and R S.

6. DETAILED DESCRIPTION OF THE VARIOUS PHYSIOGRAPHICAL ELEMENTS

6.1. Meander belts, levees and levee splays

The meander belts shown on the maps were mainly formed together with deposit 2 (cf. p. 33).

The subsoil in the meander belts consists of coarse sand or shows an alternation of coarse sandy and clayey horizons. The top of this coarse sandy subsoil usually occurs between 7 and 15 dm below the present soil surface. The bottom could not be bored with the technical means at the writer's disposal, but it is almost certain that in the large meander belts it makes contact with the sandy pleistocene subsoil. Below the small belts there may possibly be an intermediate bed of heavy basin clay.

A meander belt has a top stratum deposit overlying the coarse sandy subsoil and usually consisting of finely textured sandy clay. It has a stratified texture in the lower part and is homogeneous above, whereas the clay content in the sediment usually increases in the same upward direction. It may even become as heavily textured as basin clay. This situation may also obtain in the levee between meander belt and basin. Heavy clay constituting the upper part of a levee or meander belt may occur as a miniature basin outside the basin area proper, or as a filling of the lower parts of the accretion topography of a point bar.

Although a manifest accretion topography was not found (or identified) in the mapped area, elsewhere in the Betuwe it is fairly common.

Where the clay beds of deposits 2 and 1 have a sandy texture there is not usually a clear division between them. This is often partly the result of soil mixing caused by biological activity which may be intense in a fairly light-textured river clay soil under hydrological favourable conditions (Hoeksema 1953).

The meander belts are usually flanked by a sandy clay zone covering an older clay bed, the latter often representing a former basin. This zone is often of a uniform width over a fairly great distance, e.g. north of Andelst where it is about 400 m wide. The soil surface in the sandy clay zone usually slopes a little in the direction of the basin, resulting in a maximum difference in height of 4 dm between the margin of the meander belt and that of the basin. This slope is partly due to a gradual thinning of the sandy sediment, partly to compaction of the underlying heavy basin clay. Towards the central part of the basin the soil surface sinks further (maximum 4 dm), partially depending on the peat content of the basin clay.

These differences in height are relatively slight, but it seems likely that they were even less before artificial drainage was employed.

A transition zone consisting of sandy clay covering another clay bed is not always found between meander belt and basin. This is very well illustrated in squares 5 DE where there is an abrupt transition. Contrary to expectation, this transition is not accompanied by a marked descent of the soil surface. This is due to a sandy clay deposit at some depth in the basin soil.

Where a transition zone is found it may alternate between a smooth border against the basin and protrusions of variable morphology penetrating the latter. These protrusions are found in deposits 2, 3, and 4 but not in deposit 1. Those in deposits 3 and 4 are not, however, intact but represented by fragments of varying size, their adjacent parts having been eroded during the formation of the more recent meander belts of deposits 2 and 1 (cf. p. 32).

As stated, the protrusions are very variable; they may be large or small, tongue- or lobe-shaped, cut deeply into the underlying clay beds or just contact the vegetation horizon at the top of the latter, only covering a small vertical distance in the soil profile, and have a coarse sandy texture or one resembling relatively heavy sandy clay in a levee. Intermediate structures or textures may also occur.

Similar sedimentary formations are well known from published evidence. They have been termed crevasse deposits (RUSSELL 1942), crevasse tongues (KRUIT 1955), crevasse splays (ALLEN 1965), basin splays (ALLEN 1965, p. 127), flood plain splays (HAPP 1940) or splay deposits (HAPP 1940). They are described as having been formed at the mouth of a crevasse channel cut through a levee, or near a restricted low section in a levee, and having a fan- or occasionally tongue-like shape. It is said of crevasse channels that they often branch in the crevasse deposit they have formed, but according to KRUIT (1955) the tongue-shaped deposits in the Rhone delta have no gully at their crest. The various crevasse or splay deposits usually extend several dm above the surrounding basin clay, but there are some whose surface is practically at the same level.

The terms employed by the above authors are not quite appropriate to the levee protrusions studied by the present writer. The term 'crevasse deposit' is inapplicable because a crevasse through a levee is only exceptionally found in our area (square 3D, p. 21). On the other hand the term 'basin splay' is too restricted in meaning since coarse sandy matter from a meander belt or the nearby part of the adjoining levee may also have a protruding configuration within the levee proper. The writer prefers the term 'levee splay', previously used in this article, as indicating that only a protrusion of an inner or outer part of a levee is concerned.

The top of the levee splays in the mapped area occurs at somewhat varying levels. In most cases it is found at the same level as the top of the contemporaneous clay bed outside the splay or somewhat below. But there are also levee splays extending some dm above the surrounding contemporaneous clay bed. They usually consist in part of coarse sand and very sandy clay, viz. the tongue-shaped one west of Zetten (squares 34F), the lobe-shaped one south of the Wuust (square 4E), both belonging to deposit 2, and the tongue-shaped splay in the south-eastern part of the mapped area (squares 7GH) and the very protracted splays near the railway, all of which belong to deposit 3.

The latter have several separate elevations each occupying a very small area.

The levee splays in deposit 3 do not rise to such an extent as to affect the present soil surface topography, the reason being that the covering clay beds become thinner as the subsoil rises. It is only the most westerly part of the levee splay in squares 7GH mentioned above that has such an elevated top as to cause a slight elevation of the soil surface (cf. profile TU, enclosure 3).

Apparently both tongue- and lobe-shaped splays may contain coarse sand. A tongue-shaped splay of this type is also found in deposit 4 in square 6H. This has an abundance of rounded pieces of wood, peat and clay, as well as plant remains among the very coarse sand. All this material had the appearance of being shaped by running water. This sediment apparently resulted from a sudden breach in a levee. The organic matter was only below the oxidized part of the soil, as is also the case where more finely-textured levee splays contain finely-divided humus.

Lobe-shaped splays forming the deeper part of deposit 2 and containing coarse sand are found bordering the meander belt in the western part of the area north of the Wuust (squares 23D).

Coarsely-textured levee splays are often scoured into the subjacent clay bed or beds, the lobe-shaped ones usually only a few dm, the tongue-shaped ones to a much greater depth (to as far as 2 m).

Lobe-shaped splays without coarse sand are more heavily textured than most tongue-shaped splays without this material, but are usually distinctly sandier than the surrounding basin clay. In most cases there is an abrupt transition. Where the texture approaches that of basin clay, as is sometimes the case, it is a moot point whether the requirements for a splay are met.

At several places two levee splays belonging to deposits 3 and 4 respectively coincide, apparently forming a single levee splay about double the usual thickness. But their bipartition can generally be established because a thin heavy-clay bed or dark grey vegetation horizon is found in between at scattered points.

As regards the bipartion of deposit 3 mentioned on p. 13, a stratum of this kind has never been found extending half-way down the deposit where both its lower and upper part represents a sandy clay.

The northern of the three very protiacted levee splays near the railway (cf. p. 12) has an interesting structure. At both ends it has developed well, but is nearly interrupted half-way along. It looks as though two levee splays coming from two opposite meander belts have just come into contact. This theory is supported by the fact that each of the other two neighbouring levee splays, which are very protracted, only comes into contact with one of these meander belts, viz. the western and eastern respectively.

The very protracted northern splay has another feature distinguishing it from all others, i.e. the continuous fossil gully among the splay sediment, mentioned on p. 13.

With the exception of a layer of varying thickness (o–c. 8 dm) below the soil surface, the physiographical elements described in this section contain more or less calcium carbonate.

6.2. Fossil river gullies

Practically all fossil river gullies belong to deposits 1 and 2 (cf. p. 34). The top of the fillings is found at the present soil surface or immediately below clay bed 1 (cf. p. 35). In the terrain they are usually in the form of depressions one or more dm in depth, but in many cases the soil surface is not lowered. The fossil gullies are a few dozen metres or less in width. Lengthwise their shape varies from almost straight to extremely meandering. No relationship was established between shape and texture of the sediments in the gullies.

A gully filling usually consists of heavy clay which is more or less humic and sticky. The oxidized zone often contains vast accumulations of red-brown trivalent iron compounds, but plant fragments are scarce or absent. In the reduced zone below the filling may resemble clay in the reduced zone in a basin soil, or have a more gyttja-like character and contain an abundance of minute plant fragments. Shell or valve fragments may also be present. Near the usually coarse sandy bottom of a gully, the clay is often very peaty, and coarse sand may be homogeneously blended or present in several thin strata.

The foregoing is illustrated by the following profile descriptions. Profile No. 1: 0–6 dm, somewhat humic, sticky and rusty heavy clay; 6–11 dm, very humic, very sticky and very rusty heavy clay; 11–16 dm, clayey peat mixed with some coarse sand; 16–18 dm, humic coarse sand; 18 dm, coarse sand. Profile No. 2: 0–5 dm, slightly humic and rusty heavy clay; 5–15 dm, very humic and very sticky clay containing abundant accumulations of rust-coloured iron compounds; 15–20 dm, coarse sand mixed with gravel.

Former river gullies are sometimes silted up with sandy clay, especially near the contact with a river course which supplied the soil matter for the filling. Where a filling of sandy clay is somewhat humic, sticky and rusty, it is readily identified. Identification becomes more difficult when moderate stickiness is the only feature distinguishing such a filling from normal sandy clay in a levee soil. Even this feature may be absent. In many cases a slight concentration of small shell fragments will still indicate the presence of a former gully.

Somewhat humic, sticky and rusty sandy clay may also occur as a lateral transition zone between a gully filling consisting of heavy clay and the adjoining normal sandy clay of the levee. Elsewhere in the Betuwe, outside the mapped area, sandy clay of similar kind was found locally at some depth in a transition zone between basin and levee.

Where a fossil river course is bordered by a former settlement, archaeological remains or soil matter rich in phosphate often form part of the gully filling.

6.3. Fossil overflow gullies

A fossil overflow gully branching off from a former river course cuts through a levee and usually has a dead end in the basin. It is generally rather narrow (up to c. 30 m), not very deep (10–15 dm) and filled with the kind of humic, sticky and rusty heavy clay found in a fossil river gully. Its bottom may be more sandy, but coarse sand is not usually found. It also forms a slight depression in the terrain, but in the basin it becomes very shallow and narrow and has a very indistinct end. Near this outlet the basin topography may show an intricate pattern of slight depressions, caused by water erosion, which is very difficult to map even when an extremely detailed survey is made. This feature is very well seen north of Hien (squares 5D) where several overflow gullies penetrate the basins.

But viewed in a wider context it can be seen that overflow gullies rarely appear to have created a special sedimentation pattern. Thus in most cases sandy levee material does not extend into a basin along an overflow gully.

Here and there overflow gullies have to some extent influenced soil texture, for instance north of Hien where coarse sandy matter extends slightly into the basins along the overflow gullies mentioned above, and north-west of Dodewaard (square 6A), where sandy matter was found constituting the bottom of an overflow gully as far as about 1800 m from the point where the gully enters the basin. The following soil profile was found at this point: 0–8 dm, heavy clay, somewhat humic to below; 8–10 dm, very sandy clay; 10–22 dm, heavy basin clay.

An entirely different type of overflow gully is found dividing off form the river branch in the western part of the area north of the Wuust, just south of the Linge (square 3D). It is branched, and forms a depression about 1 m deep and some m wide between irregularly formed, very sandy narrow levees. This relief levels down at an increasing distance from the mouth. Outside the narrow levees the soil surface has a very irregular but little pronounced relief. It is so oriented in the concave bend of the river levee that the gully does not reach the neighbouring basin.

This gully was apparently formed as a result of a more or less catastrophic breach in the river bank, after which it was suddenly cut off from the river course and thus, from any further sedimentation.

Unlike the overflow gullies described above, its morphology resembles that of the crevasses described in published evidence (see p. 18).

The following two soil profiles were found in and next to the gully: profile No. 1: 0–7 dm, fairly sandy clay, very rusty below 3 dm; 7–10 dm, fairly sandy clay, humic, very sticky and rusty; 10–10.5 dm, coarse sand and gravel; 10.5–11 dm transition zone; 11– dm, heavy basin clay. Profile No. 2: 0–5 dm, very sandy clay; 5–7 dm, very sandy clay of an irregular texture; 7–8 dm, clayey sand; 8–17 dm, alternately clayey sand and sandy clay; 17–17.5 dm, transition zone; 17.5–dm, heavy basin clay.

Profile No. 1 in the gully is situated 7 dm lower than profile No. 2 on the narrow levee.

6.4. Transitional form between fossil overflow gully and fossil river gully.

In the area north of the Wuust three east-west oriented fossil gullies were mapped. These connect different river branches, thereby crossing the adjoining levees and the basin in between. In the terrain the gullies are difficult to make out as they only have a very shallow depression along the bank of a ditch. The true nature of the gully fillings is revealed by the presence of shell fragments and an abundance of rust-coloured iron accumulations at scattered points some metres from the ditches.

These fossil gullies have a dual nature. They resemble a fossil river gully in that they form a connection between various former river branches, the central of the three even merging into a fossil river channel at its eastern end. Originally the latter probably continued its course within the meander belt, past the point of contact with the middle gully. Insofar as they are not bordered by levees or have a sandy bottom, the three fossil gullies closely resemble the overflow gullies described above.

Another fossil gully of this type is found in the southeastern part of the mapped area (squares 7HI).

Presumably they mainly operated when the rivers were at a high level.

6.5. Fossil basin drainage gullies

Outside the mapped area the survey brought to light fossil gullies filled with humic heavy clay, crossing a levee and having a dead end near or in the basins on either side of the levee. The existence of active basin drainage channels in a similar situation in the former natural river clay landscape of the Betuwe was assumed by Pannekoek van Rheden (1942) as early as 1942.

It may be assumed that after the river courses in the Betuwe had silted up, these drainage channels still had a certain function. Even after the rivers were finally embanked in the Middle Ages, flooding of the basins did not cease and water was still conveyed from one basin to the other via the drainage channels. Hence they could never have silted up as completely as the former river courses.

During the reclamation of the basins in the Late Middle Ages the residual gullies in the silted basin drainage channels must have been deepened and widened by man and connected with the straight drainage channels newly dug across the basins. This is how the Linge river was formed (Pannekoek van Rheden 1942), a water course considered as a true river in earlier published evidence.

6.6. Gully-like depressions

Here and there in square 2D depressions having a depth of some dm were found with a topography somewhat resembling that of a fossil gully. But unlike the latter they are perfectly straight and have a soil profile similar to that outside the depression. These depressions were always found at some metres distance, parallel to a ditch. Their origin is unknown.

6.7. Basin clay

The top of the heavy basin clay of deposit 1 has a brownish hue over a certain depth. This may be more or less pronounced and also cover a greater or lesser depth in the soil profile, depending on hydrological soil conditions. In the more central part of the basin, where the water table was usually very high, the brown horizon has developed very poorly.

Below the brown upper horizon the clay has a grey hue interrupted at certain depths by dark grey zones 1 or 2 dm thick, representing the successive vegetation horizons. Heavy basin clay of deposit 2 differs from similar clay in the adjoining heavy clay beds in having a lighter tint and iron moulds of a rather orange hue instead of red. This orange hue is most striking in the area north of the Wuust.

The depth of the transition between the oxidized and reduced zone in the heavy basin soils varies considerably from place to place. Thus south of the Wuust the depth does not exceed 14 dm, or somewhat below the top of deposit 3, whereas it may amount to 18 or 19 dm, or just above the bottom of this deposit, in other parts of the mapped area. The thickness of the oxidized zone approximately corresponds to the present artificial drainage of the soil. Originally the oxidized zone must have been confined to clay beds 2 and 1, or possibly to the latter only. An exact statement cannot, of course, be given as it is impossible to trace accurately the hydrological soil conditions in the former natural landscape.

The oxidized zone in heavy basin clay is characterized by a prismatic or angular blocky soil structure. The interior of the structural elements exhibits a dense micro-porosity due to Tubifex (DOEKSEN AND MINDERMAN 1963) or some other biological agents during the sedimentation of the clay. Unlike the macrostructure, it has no connection with the actual soil forming processes. The interior of the structural elements has a reddish hue due to trivalent iron compounds, whereas the non-porous coatings forming the exterior are mainly grey. In the transition zone to the totally reduced clay, found below, red iron compounds often form a cylindrical wall, some mm in thickness, around (former) root holes.

Heavy basin clay in its reduced state is waterlogged, slushy and sticky, besides being more or less humic or, more locally, peaty. Macrographically it is often difficult to distinguish from the humic heavy clay below the oxidized zone in a fossil river gully (cf. p. 20).

6.8. VEGETATION REMAINS IN BASIN CLAY

Heavy basin clay may be more or less peaty, that is it may contain a greater or lesser mass of fossilized roots of sedges, grasses and various other herbs preferring a wet soil. Remains of alder and willow tree roots may also occur, but these are usually fairly scarce. Plant remains of this kind are not found in the oxidized zone.

Examination of the soil profiles in the wall of the excavation (cf. p. 14) revealed an intense concentration of fossilized tree roots both in a zone some dm thick in the heavy clay immediately above the sandy subsoil and in the latter. It could not be established how far these roots penetrated the sand since the latter reacted as quicksand during boring. The roots belong to alder (*Alnus*), oak (*Quercus*) and possibly other trees. Large tree stems were found on the soil surface around the excavation among the excavated matter.

Dense tree growth was apparently possible on the heavy basin clay in the former natural landscape where soil wetness was greatly reduced by a permeable subsoil not far below the then soil surface.

A slighter concentration of fossilized stems and branches of these tree species was found in the walls of a newly dug ditch in the basin north of Dodewaard (square 6C), viz. on the dark grey fossil vegetation horizon at the top of deposit 3. As to the hydrological soil condition, it may be assumed that this former soil surface near Dodewaard also represented a relatively dry milieu.

6.9. VEGETATION HORIZONS

A vegetation horizon is characterized by a darker (see figs. 2 and 3) colour and usually heavier texture than in the adjacent clay beds. Its distinctness often varies greatly from place to place, even where there is no other visible evidence of varying soil conditions. Over lesser or greater distances a vegetation horizon may also show complete interruptions, i.e. it cannot be established by means of the usual visual profile examination in the field. This is a main reason why stratification in the Dutch river clay basins has so often been overlooked in the past.

The term 'laklaag' (lack layer) is commonly used by the Dutch soil scientists as denoting a fairly or very dark grey vegetation horizon in basin clay. This term mainly refers to a pedo-morphological aspect (colour) and should not therefore be used in a stratigraphical description.

Although the dark coloured and heavily textured type is mainly restricted to the basins proper, fairly characteristic vegetation horizons are not completely absent from sandier parts of the river clay landscape, as is sometimes suggested in published evidence. A dark grey fossil vegetation horizon may also be found on top of a sandy clay bed below a covering heavy clay bed, on top of a heavy clay bed covered by a sandy clay bed, or even between two clay beds of the same sandy texture. Although a clear vegetation horizon between two sandy clay beds is usually more heavily textured (30–35% clay) than above or below, a fairly sandy dark grey vegetation horizon is occasionally found.

It was sometimes found when surveying Betuwe basins outside the mapped area, that the number of fossil vegetation horizons within a depth of 2.20 m was greater near the border than in the more central part of a basin. Here and there a vegetation horizon showed bifurcation into two separate similar horizons.

The vegetation horizon at the top of deposit 3 shows an abnormal aspect in the vicinity of the more important Bronze or Stone Age settlements in squares 5DE. Here it is slacker and stickier than usual and full of intense rust-coloured spots, somewhat like the filling of a fossil river gully above the reduction horizon.

South-east of the Wuust (square 3F) the same horizon shows a quite different and also abnormal aspect, viz. an abnormal thickness (2 or 3 dm) and a peculiar brownish hue. In this neighbourhood it contains a very high concentration of vast concretions of iron, maganese and lime. Similar, although smaller concretions are also found elsewhere in deposit 3, in the vegetation horizon or below, but not in the same quantity.

6.10. Very dark-grey heavy basin clay over the entire depth of deposit 3

West of Dodewaard deposit 3 shows an alternation of small areas of usual grey heavy basin clay and darker grey, very peaty heavy clay. A transition zone some hundred metres in width contains non-peaty clay of an extremely dark grey, almost black colour, much the same as in a marked vegetation horizon. The extent to which this colour may be due to similar soil-forming processes in both cases is still a matter of speculation.

6.11. Lime in basin clay

Finely-divided calcium carbonate in basin clay is only found in the deeper beds occurring in a state of reduction. Its distribution in the soil profile is usually rather haphazard. The part of the soil profile containing calcium carbonate is sometimes distinguished by a somewhat sandier texture. The transition between calcareous and non-calcareous clay is diffuse. Even peaty clay may be calcareous, particularly when the structure of the peaty matter suggests that it was transported by running water.

The shallower part of the basin soils occurring in an oxidized state have no finely-divided calcium carbonate, although smaller or larger concretions of lime are not uncommon among the non-calcareous heavy basin clay (cf. p. 40). These may even be abundant locally. Abundant lime concretions are more common, however, at some depth in the sandy clay of a levee.

It should be mentioned that basin soils having finely-divided calcium carbonate in the upper and lower part of the soil profile are sometimes found elsewhere in the Dutch river clay area.

6.12. Ancient settlement soils

6.12.1. *Settlement soil of the Batavian-Roman and Mediaeval Periods*

As stated on p. 11 formation of the settlement soils shown on map 1 + 2 generally began at the level of the fossil vegetation horizon of deposit 2, or, which comes to the same thing, when formation of this deposit had practically ceased.

The various culture sites date from the Roman and/or mediaeval period. Of those investigated archaeologically by MODDERMAN (1949) all appeared to have been inhabited during both periods. Here and there the archaeological finds pointed to a culture even predating the Roman period, viz. belonging to the pre-Roman Iron or La Tène culture. In the writer's view, several of the culture sites not investigated by MODDERMAN must have been inhabited during the Roman period only (c. 50 B. C. to c. 400 A.C.), especially the unraised ones now covered by the upper part of deposit 1. It may also be assumed that a few culture sites were not formed before the early Middle Ages.

At present a certain part of the culture sites is always inhabited; they are occupied by one or more farms or a village.

Culture soil of the Roman or mediaeval period is easily recognized by its black colour, high or very high humus content, its greenish-yellow phosphate stains, charcoal, potsherds of a special type, bone fragments and occasionally gravel intermingled with the clay.

A culture site occupies an area of from 0.8 to 15 ha and a thickness of from 3 to 25 dm, which implies a very wide variation. A small site probably represents a former farm isolated in the open field.

A thin layer of settlement soil usually only rises slightly above the normal surface level of deposit 2 and is therefore covered by the upper part of the clay bed of deposit 1. A similar situation may sometimes be found where a thick settlement soil layer occurs (cf. section G H), but in most cases the settlement soil then rises above the top of deposit 1, forming a more or less elevated part of the present soil surface. The culture sites also vary extensively as to where the bottom of the culture soil is found in the soil profile. The depths vary between some dm and about two metres below the top of deposit 2, which means that the bottom is often below the top of deposit 3. It will be not surprising to find that here and there culture soil of the Roman era contacts culture soil of the Bronze or Stone Age. Such situation was found in squares 2D and 3E.

In the writer's view such a contact does not necessarily imply continuous habitation. Much more probably it was formed because waste matter was buried deeply in the soil by the former inhabitants during the Roman era or, for instance, because a well became filled with it.

High elevations (c. 14 dm) composed of settlement soil are common where villages or farms are now found. Most of these were raised in the Middle Ages as a protection against the floods which were very frequent and dangerous at this period of imperfect dyke construction (MODDERMAN, in: EDELMAN et al. 1950).

The settlement hills are mainly composed of culture soil of a relatively homogeneous texture. One striking exception is the very high hill of Hemmen. Its irregular composition, as illustrated by the following profile description, suggests that it was constructed in a relatively short time:

0–11 dm, black clayey sand, moderate culture influence; 11–16 dm, clayey sand with reworked aspect; 16–19 dm ,sand; 19–20 dm, black sandy clay, moderate culture influence; 20–40 dm, thin sandy clay and clayey sand beds showing yellowish phosphate stains, up to 24 dm; 40–45 dm, coarse sand of the meander belt.

An interesting complex of three settlement soil elevations rising about 1 m above the surrounding terrain is found on either side of the western part of the Wuust. Unlike the one described above, these were constructed of very homogeneous material. The following soil profile was bored in one of them:

0–10 dm, black very sandy clay, greatly affected by culture; 10–12 dm, dark grey very sandy clay moderately affected by culture; 12–20 dm, thin sandy clay and sand beds with stains of phosphate; 20–25 dm, unaffected humic basin clay.

The two northern hills are connected and merge at their eastern and western side into parcels situated at a lower level, in which the upper 7 dm have a very dark-grey colour, without other features characteristic of ancient settlement soil. These parcels are cut by v-shaped trenches 65 cm deep and some metres wide, parallel to the Wuust. The southern brink of the two hills is steep and borders a zone some dozen metres wide along the fossil Wuust river, which has a very level surface and lacks culture evidence in the soil profile. The following profile was bored here:

0–5 dm, sandy clay; 5–12 dm, thin sandy clay and sand beds; 12–17 dm, coarse sand.

The soil in the settlement elevations was probably dug out of the present wide trenches and the flat zone along the Wuust.

Ancient culture soil from the Roman era may sometimes be found bordered by a zone several hundred metres in width, showing very slight traces of arable farming. This feature is confined to deposit 2, but was nowhere observed in the area mapped.

6.12.2. *Settlement soil of the Late Stone and Bronze Age*

The culture soil on map 3 + 4 is time-stratigraphically connected with the vegetation horizon of deposit 3. It dates from both the Late Stone Age and Bronze Age. The archaeological investigation of one of the culture sites by R. S. Hulst (1967), described below, revealed settlement during the Late Neolithic (1800–1700 B.C.) and Middle Bronze Age (1500–1000 B.C.). But it is not yet known whether these two periods are also represented together in all the other sites found. It is possible that only one of the periods mentioned, or another part of the Neolithic or Bronze Age is represented in a minor or major part. But it is assumed that in general most importance is to be attached to the Bronze Culture.

The culture soil is often fairly difficult to discern in the soil matter bored because its only difference from the normal vegetation horizon of deposit 3 where this is well developed is a more blackish hue occurring over a somewhat wider vertical distance. In many cases, however, it is more easily recognized as it occurs as a fairly thick and very humic layer (fig. 5). It may be sticky and mixed with an abundance of rusty accumulations consisting of trivalent iron compounds. To some extent this appearance resembles the filling of a fossil gully. The iron accumulations may also form roundish dark-brown, hard concretions. Other features more characteristic of the culture soil are greenish-yellow phosphate stains (only rarely found in this type of culture soil), coarse sand or gravel blended with the clay (this is more frequently encountered), small potsherds containing minute fragments of white gravel, diagnostic of the cultures in question, acute-angled fragments of white quartz pebbles as well as intact specimens, small pieces of baked clay, charcoal and bone (fig. 6). Locally

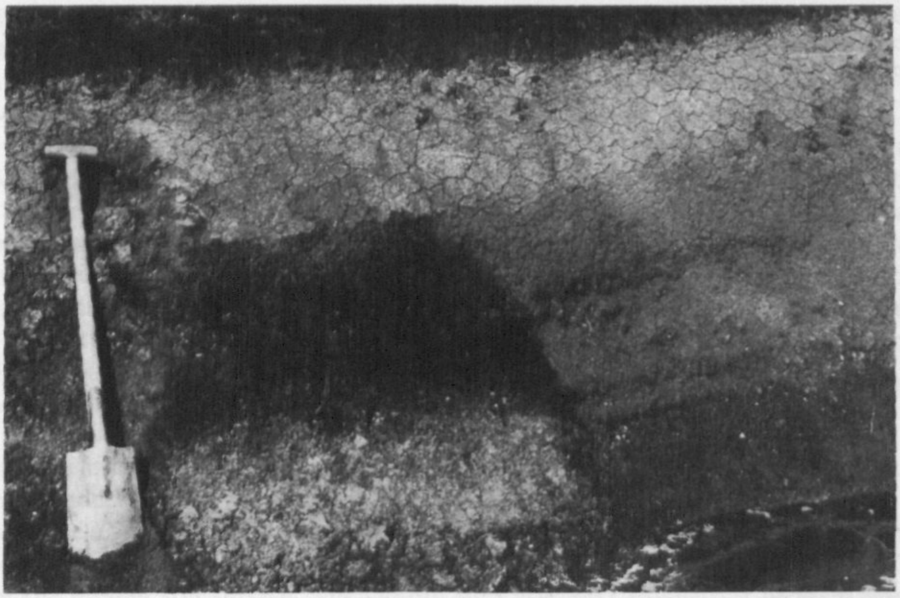

FIG. 5. Settlement soil of the Bronze Age.

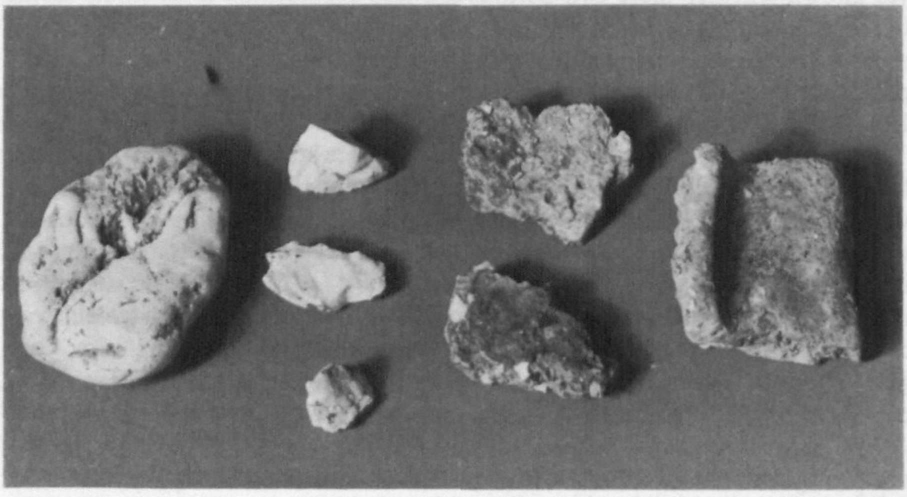

FIG. 6. White quartz pebble, acute-angled fragments, and potsherds containing minute fragments of white gravel, all found in settlement soil of the Bronze Age. (× 0.75). (Photo: Z. VAN DRUUTEN).

these culture remains are abundant, but outside the concentrations, most of which are sharply defined, they are very scarce.

Mention should be made of a find of a large white pebble among heavy clay, with no other evidence of culture or vegetation horizon, at exactly the level where the top of deposit 3 might be expected. The nearest settlement was found at a distance of several hundred metres.

The settlement soil normally occurs over a vertical distance only slightly exceeding that of the vegetation horizon of deposit 3. In most cases a thickness of 2 to 4 dm was recorded, but occasionally a greater thickness was found of up to 7 dm. The culture sites situated on levee splays are elevated compared with the surrounding basin soil of deposit 3. However, the difference is usually only a matter of a few dm, so that the top of the culture soil occurs at 9 or 8 dm below the present soil surface. A shallower occurrence (7 dm) was only sporadically found. This position differs strikingly from that occupied by the small patches of culture soil scattered over the basin proper or on some lobe-shaped levee splays. These occur 10 to 11 dm below the present soil surface, i.e. the normal depth of the vegetation horizon of deposit 3.

Many culture sites occupy a very small area of a few ares. They often show an abrupt horizontal transition from culture soil to clay unaffected by human activity. In the present writer's view they represent an isolated farm of dwelling-house. The extensive sites may occupy up to 25 ha and represent a complete village. This was very well demonstrated by R. S. HULST[1] during an archaeological investigation, undertaken as a follow-up of the archaeological results of the present physiographical survey. In a certain part of the extensive culture site north of Hien excavated by HULST (in square 5D) he found traces in the soil of several farms or dwelling-houses of different types and small granaries. These buildings were constructed at two different periods, Late Neolithic and Middle Bronze Age, each being represented by a different type of potsherd. A close examination of the stratigraphical position of each of the latter showed that no difference could be found between the ground levels of the two cultures (R. S. HULST, private communication).

6.12.3. *Possible culture evidence in the lower part of deposit 2*

North of the Wuust two areas occur where, with interruptions of varying extent, clay belonging to deposit 2 has the appearance of being affected by human culture but without features which might be considered as unmistakable evidence of this. From about 25 cm beneath the top of deposit 2 to below, the clay becomes increasingly dark grey and fine charcoal particles become more abundant. In most cases these features end at the bottom of deposit 2, but occasionally at a higher level. The dark grey clay is often very sticky.

The picture shown by the map suggests that in squares 2D and 3E some connection exists between this dark grey clay and true culture soil of Roman age. However, in square 3E, between the latter soil and the dark grey clay is a

[1] State Service for Archaeological Investigation.

layer of normal, unaffected clay. There is a vertical contact in the other square but this was certainly caused by digging activities (as assumed on p. 26).

6.13. Traces of former parcelisation

In the wall of an east-west oriented, newly-dug ditch cutting the Late Stone or Bronze Age site in square 5D investigated by R. S. Hulst (see p. 29), the present writer found traces of numerous fossil ditches having an approximately north-south orientation. The cross-section through the ditches showed the filling material to be grey heavy clay forming a marked contrast to the black culture soil between the ditches.

The dark grey walls of the ditches could be traced a little above the top of the culture soil, after which they became blurred among the grey heavy basin clay of deposit 2. But the situation with respect to the vegetation horizon at the top of deposit 2 could not be exactly ascertained owing to the absence of a clear junction or clear interruption between this vegetation horizon and the ditch walls. In any case it is likely that the ditches date from Roman or more recent times. The writer has not yet succeeded in finding a former settlement in the neighbourhood with which the ditches could be logically connected.

The fossil ditches show up as minor depressions in the relief of the present soil surface, so that their position with regard to the modern parcelisation could be exactly observed. It appeared that the fossil ditches have practically the same orientation as the actual ones, but that no relationship exists as to the distances between the fossil ditches and the distances between the latter. Unlike modern parcelisation, the width of the ancient parcels varies extensively. The following series of figures showing the widths of the successive ditches and parcels in metres was ascertained going from west to east along the modern ditch: 1–13–2–10–1–11–1–13–1–8–1–12–2–15–1–11–1–13–1.25–15–1–10–1.25–17–1–15–1–13–1.5 m.

6.14. Partition between clay beds belonging to two successive deposits

A vegetation horizon affords the most certain evidence of a partition between clay beds belonging to two successive deposits. But such characteristic feature is not always shown by the soil, and one has to rely on other evidence, e.g. the particular colour of one of the clay beds or the presence of peaty matter in one of them. If minor amounts of calcium carbonate are found over a slight vertical distance at a constant depth among non-calcareous, heavy clay in a basin soil, the lime-containing clay will coincide with the lowest part of a separate clay bed.

Differences in soil texture in the vertical soil profile may indicate a time-stratigraphical partition, but the site of the textural change in the profile may be misleading in this respect. Thus it was often found that in a soil consisting of sandy clay on heavy clay, the partition occurred some dm below the textural change instead of at the same level. In explanation of this phenomenon it is assumed that after a period of stagnating flooding activity of the rivers renewed sedimentation had little effect in the beginning, in contrast to later on (cf. DE JONG, HAGEMAN and VAN RUMMELEN 1960).

Where renewed sedimentation has supplied sandy clay from the beginning, a 1 to 2 dm transition zone of intermediate texture may be found between the sandy clay and a heavy clay bed below.

7. DISCUSSION

7.1. Meander belts

The width of the Rhine and Waal as shown on the map shows good agreement with that of several large meander belts in the Betuwe and other parts of the Dutch river clay area (cf. for instance the soil map of the Bommelerwaard, in Edelman et al. 1950).

This would imply that some meander belts, now having a narrow fossil river gully, represent a former river course of approximately the same width as the present belts. Apparently meander belts sometimes formed because a wide river channel became filled with coarse sandy material. This process occurred when the channel was in a state of deterioration until the discharge capacity had decreased to such an extent that sedimentation of heavy clay began. During this latest phase a more or less meandering heavy clay plug ('fossil river gully') was formed and often covered the entire length of the meander belt.

The writer had an opportunity of examining a cross-section of a part of a wide meander belt. The clay plug appeared to be situated in a former river channel several hundred metres wide, filled with alternating coarse sandy and clayey strata, the latter being fairly humic and rich in plant remains in the reduction zone of the soil (below a depth of 2.20 m). Outside the river bank, which was marked by some tree stumps near the top of the reduction zone, there was a considerable reduction in the number of clayey horizons and these were not of a humic appearance.

The clay plugs in the meander belts on the map usually show meanders of varying size, although straight sections may occur and even extend over a long distance. Morphologically the term 'meander belt' is inapplicable where this represents a straight section of a former wide river channel. It might be preferable to employ a different term containing no reference to river course morphology.

A meander belt formed during a certain sedimentation phase obviously excludes the occurrence of another meander belt of a previous sedimentation phase on the same site.

There are many river channels which did not leave a meander belt during the successive sedimentation phases, thus continuously 'rejuvenating' the belts in a longitudinal direction. This was a common process in the mapped area. Since the rejuvenation process did not necessarily extend over the entire width of the belts at all points, greater or lesser lateral parts of previous stages may always be intact.

A meander belt left by the river course during an earlier sedimentation phase is always found at a certain depth below the present soil surface, covered by one or more clay beds of more recent date. Such a belt may be cut into longitudinal fragments by the meander belts connected with the more recent clay beds.

As stated on pp. 13 and 12 no remnant of the meander belt system belonging to deposit 4 has been left, but two lateral fragments were found of deposit 3.

But it was not always possible to establish whether or not a certain part of a meander belt represents a previous stage which escaped the rejuvenation process. This is due to the fact that the top of the coarse sandy subsoil in a meander belt is fairly undulating and there is often relatively little difference between the general level of the tops of two successive meander belt systems.

The situation of the levee splays belonging to deposits 4 and 3 permits a rough localisation of the former meander belts of both sedimentation phases at the site of the following actual meander belts: the large meander belt from Andelst via Zetten to the Rhine dyke in the North, where it turns west, the arched belt east of Hien, and the belt west of Dodewaard (squares 67 B C).

North of the Wuust, in square 3D, a very narrow and protracted levee splay belonging to deposit 3 makes contact with the meander belt deviding off from the Wuust meander belt to the north. In this case a reconstruction of the kind described above is inadmissible. When the survey was extended more to the west it was found that the splay continued on the other side of the belt by which it was apparently cut.

The meander belts shown on the map 1 + 2 chiefly belong to deposit 2 and otherwise to deposit 1. Owing the factors mentioned above the exact proportions of each cannot be ascertained. It may be assumed, however, that deposit 1 is only represented in the coarse sandy subsoil where the top of this soil occurs at a shallow depth (e.g. 7 to 8 dm) below the soil surface at a not too far distance from the fossil river gully. This is the case, for instance, at the concave side of the wide bends of the Wuust and the fossil river near Dodewaard.

In fact, the only completely intact meander belt system is that belonging to deposit 1, but this is, so to speak, concealed by the meander belt system of deposit 2.

7.2. Levee splay formation

Levee splay formation must usually have started immediately after a period of stagnating flooding activity, at the beginning of a new sedimentation phase. This is inferred from the fact that, apart from the splays scoured into a subjacent older clay bed and usually having a coarse sandy texture, the levee splays are always situated directly on top of the subjacent older clay bed (occasionally on top of a sub-stage of the deposit to which it belongs, c.f. p. 12). The bottom of a levee splay was never found at a certain distance above.

Levee splays without course sand and not scoured into the subsoil represent the more common type in the mapped area. These are unlikely to have been formed as a result of a sudden breach in a levee. Since the top of a meander belt and the soil surface near the border of a basin are about the same height, it follows that crevassing cannot have been a frequent process.

The most frequent cause of levee splay formation must have been river water crossing a greater or lesser depression in a levee during high river levels. It must have had a moderate velocity, fast enough to carry sandy clay from the levee into the basin, but too slow for conveying coarse sand.

The top of a levee splay without coarse sand usually occurs at the same level as the top of the surrounding clay bed belonging to the same deposit, or somewhat below. The deeper part often has a stratified textural composition. The formation of such a splay may have taken the greater part of a complete sedimentation phase, so that strictly speaking this represents a transitional form to a normal levee.

A very protracted splay may be considered as resulting from an unsuccessful attempt of the river to divide. If moreover it contains a gully over its entire length, like that described on p. 13, it represents a structure intermediate between a levee splay proper and a levee with river channel.

7.3. Former river courses

All the fossil narrow river gullies filled with heavy clay shown on map 1 + 2 represent very well the position of the river channels which were active during the mediaeval and Roman periods. This can be clearly seen from their route along the ancient culture sites.

It cannot be ascertained how far the river branches had already silted up in the Roman era as a result of declining river activity. But since during the following phase of renewed activity resulting in deposit 1, sandy clay was deposited over a zone of a width often comparable with that of the sandy clay of deposit 2, it may be concluded that the capacity of the river branches was more or less unimpaired. There is no more reason to assume that the capacity increased considerably after the Roman era; the soil map affords no evidence of the possible effects of a sudden strong reactivation.

Thus it does not show any levee splay formation in deposit 1. Nor is there an indication of stream diversions of varying importance; the culture soils are usually close to the fossil river gully. (This situation might have partly resulted, however, from a certain shifting of the settlement in accordance with some gradual shifting or narrowing of the river course. In this connection it is interesting to note that some culture sites are clearly marked off from soil not affected by human culture, apparently as a result of erosion and resedimentation by the neighbouring river course).

The foregoing remarks do not apply to the former river branches in the wide environment of the Waal river dyke. Here deposit 1 is represented as a much thicker and sandier clay bed than in the other parts of the mapped area. This situation apparently reflects an important change in local river activity during the latest sedimentation phase. The Waal probably owes its present course and great width to the same change. This would agree with Hoeksema's theory (in Edelman et al. 1950, p. 86) who describes the soil conditions along the same river in the Bommelerwaard, about 24 km west of the mapped area. He assumes that in this area the present Waal channel was formed as a result of a river diversion in the post-Roman period. Pons (1957, p. 58) assumes that this and other river diversions or important changes in discharge capacity occurred at the same time in several parts of the Dutch river clay landscape. He would place these changes in the 9th century A.C. when the mouth of the Rhine near Katwijk silted up.

But the first mention of the existence of a river named Waal comes from an older period, viz. the Roman historiographer TACITUS (c. 55–120 B.C.), who wrote: 'The river Rhine at the beginning of the Batavian country[1] divides as it were into two streams and keeps its name and turbulent course in the branch in which it flows along Germany[2] until it falls into the Ocean. As a wider and calmer river it flows along the Gaulish frontier (meanwhile changing its name; it is called Waal by the inhabitants); afterwards it again changes its name into that of the Maas river and falls with its very wide mouth in the same Ocean'. (Ann. II, 6. In: SEBUS 1923, p. 29–30). According to this authority the Waal must have been an important river branch as early as the period preceding the latest sedimentation phase. Possibly the most likely explanation is that the special soil condition in the southern part of the mapped area is mainly due to a sudden diversion of the Waal to its present course during the beginning of the formation of deposit 1.

The light-textured clay bed of deposit 1 near the Waal dyke is in striking contrast with the underlying heavier-textured deposit 2. Texture and other morphological soil features in deposit 1 are often even unaffected by the fossil gullies in deposit 2. Such a phenomenon is rarely found outside the area in question. Evidently the river channels had already silted up completely before the sedimentation of deposit 1 began. This may also be concluded from the fact that the fossil river branch in the arched meander belt east of Hien has a dead end (square 6F). Moreover this branch is situated in a heavy clay area as far as deposit 1 is concerned. Another argument is that culture soil from the Roman period covers one of the fossil overflow gullies north of Hien (square 6D).

Before the active river system had been permanently forced out of the Betuwe by embankment in the Middle Ages, all river channels in the mapped area had silted up. Ditches forming the present artificial drainage system were excavated in the lowest part of the slight depressions the fossil channels formed in the terrain.

It may be assumed that the construction of primitive dams preceding the definitive embankment promoted silting in the river channels, but no certainty is possible.

After the definitive embankment, river course diversions continued outside the river dykes. This is very well, though indirectly, shown by the present excentric situation next to the river dykes of so many mediaeval churches in the Betuwe, for instance those of Dodewaard and Hien, which must have been situated in the centre of these villages in the Middle Ages.

In the river clay landscape a notable feature of the present river dykes is the large number of pools. Most are more or less circular, although a more protracted type also occurs. Three specimens of the latter are to be found near the Waal

[1] The present Betuwe.
[2] At present the part of the Netherlands north of the Rhine.

dyke in squares 7FG. South of the Waal protracted pools are more common. According to PONS (1957) these were formed as a breach in a natural levee preceding the embankment of the river clay area. Hence they would have been formed quite differently and also at a different period from the circular pools which PONS assumes to have arisen in the usual way as a result of dyke breaches.

This theory does not tally with the situation in the area shown by our map. The soil pattern clearly demonstrates that the three protracted pools mentioned above are situated where a fossil river course in deposit 2 crosses the dyke. The pools no doubt arose from a dyke breach which will have been induced by the fossil river channel in the subsoil.

7.4. BASIN DRAINAGE CHANNELS AND OVERFLOW GULLIES

According to PANNEKOEK VAN RHEDEN (1942, p. 669), a basin entirely surrounded by levees in the natural landscape drained its excess water via the lowest parts of the levee system either into an active river channel, or, when the channel had silted up and so become fossil, into a basin on the other side of the levees. In the latter case narrow transverse gullies were scoured through the levees. Because the soil surface in the Betuwe has a generally westward slope, drainage must have occurred on the western side of the basins.

In the present writer's view, overflow gullies joining river channel and basin via a levee were often a possible contributory factor in this process so long as the river channel remained intact. Occasionally a gully was scoured in the basin between two overflow gullies at opposite parts of the basin (cf. p. 21). This system formed both an inlet and outlet for the flood water during high water in the river courses.

A remarkable feature of the position of the overflow gullies is its lack of any connection with the position of the levee splays found in deposit 2. Apparently the overflow gullies shown on the map date from a time when levee splay formation was already complete. They must have operated during the phase of stagnating river activity in the Roman era (which does not, of course, imply that all flooding activity ceased). This is supported by the fact that culture sites of this period sometimes border an overflow gully (squares 45G). It may be assumed that during the next phase of renewed river activity a greater or lesser number of overflow gullies silted up and newly-formed ones took over their function, but this could not be established from field observations. There were probably few alterations. This also agrees with the absence of any levee splay formation in deposit 1.

Fossil overflow gullies connecting two basins via a levee having no active river course were only found outside the map area. The specimens studied appeared to have scoured deeply into the coarse sandy subsoil of the meander belt, whereas in front of their western outlet a vast sediment of sandy clay and coarse sand from the levee was found. The position of this material in the soil profile indicated that the gully was formed during a phase of intensive river activity.

A fairly complex structure in the natural basin drainage system is sometimes found where a combination of overflow gullies of the types described above and fragments of partly silted-up river channels marks the route taken by the flood water when crossing a levee. But neither this type of drainage was found in the area shown.

7.5. PEAT

In the mapped area peaty material is mainly found in deposit 3. It mostly consists of remnants of sedges *(Carex)* and grasses *(Gramineae)* roots, roots of alder *(Alnus)* and willow *(Salix)* occurring more incidentally. The peaty matter is usually mixed with clay, forming peaty clay, or, more locally, clayey peat.

It is remarkable that wood peat substantially consisting of the remnants of alder *(Alnus)*, willow *(Salix)*, ash *(Fraxinus)*, oak *(Quercus)* and elm *(Ulmus)* does not occur in the Betuwe. This type of peat is very common in the river area in the western Netherlands, where it forms a broader or narrower zone parallel to the rivers (BENNEMA 1949).

In the writer's view, the hydrological regime connected with the specific physiographical-topographical soil conditions in the Betuwe is largely responsible for the absence of the latter type. Where luxurious tree growth occurred on the levees, the environment was highly oxidative for most of the year, that is, unsuitable for any peat formation. On the other hand, the basins were flooded for so long and to such a depth that here the environment was quite unsuitable for a dense tree growth of even the marshy type. It was only here and there in a basin where special soil conditions temporarily allowed of a better drainage that a dense growth of various tree species as alder *(Alnus)* and oak *(Quercus)* occurred (cf. p. 23). But the wood-peat formation stage was never reached.

In the western part of the Netherlands the soil pattern formed by relatively small basins surrounded by relatively elevated levees, characteristic of the Betuwe area, alternates with another type, which, in the above way, gave way to an environment neither too wet for dense tree growth nor too dry for peat formation.

7.6. VEGETATION HORIZONS

Much uncertainty exists about the true nature of the dark-grey fossil vegetation horizons, and the type of vegetation connected with their formation and the substance producing the darkish hue remain unknown factors. Could the original vegetation have been a forest or herb vegetation, or a combination of the two? Even this simple question has remained unanswered and will, in fact, be difficult to answer owing to the scarcity or absence of vegetative remains and pollen grains in the dark -grey vegetation horizons.

The following, not very well-supported statements are found in the literature. According to PIJLS (1948) a dark-grey vegetation horizon should be taken as the pedogenic inheritance of the root system of a former poplar *(Populus)* forest. HOEKSEMA (in EDELMAN et al. 1950, p. 87) thinks the horizon may represent a former litter layer of such a forest. VAN DIEPEN (1952) believes that two different types of vegetation are to be distinguished, viz. a poplar *(Populus)* forest (p. 144) or an horse-tail *(Equisetum)* vegetation (p. 143), each producing another litter type and consequently a differently coloured vegetation horizon. Finally, the present writer would refer again to the finds of alder *(Alnus)* and oak *(Quercus)* remnants on a fossil vegetation horizon in the neighbourhood of Dodewaard (cf. p. 24).

The characteristic dark-grey colour of a vegetation horizon so often mentioned in the literature may easily mislead the research worker thinking of a high humus content as is commonly found in the A-horizon in other soil types. But it can be clearly seen from Table III that the humus content in the fossil vegetation horizons cannot be an important factor in this respect.

TABLE III: Humus (H) and Clay (C) ($< 2\mu$) rates in four basin clay soils in the Bommelerwaard containing a dark-grey fossil vegetation horizon. (After EDELMAN et al. 1950).

Soil profiles	Percentages							
	1		2		3		4	
	H	C	H	C	H	C	H	C
Clay bed above the fossil vegetation horizon	4.5	50	1.7	68	2.8	64	1.8	60
Dark-grey fossil vegetation horizon	2.2	73	2.3	81	1.4	69	2.4	74
Clay bed below the fossil vegetation horizon	1.2	48	–	–	0.9	48	2.0	58

Whilst carrying out palynological work on various dark-grey fossil vegetation horizons Dr. B. POLAK[1] was repeatedly struck by the countless numbers of microscopic black particles. She believes that it is these particles, and not a high humus content, that are responsible for the dark hue of the horizons. The particles closely resemble similar material in the A_1-horizon of certain fossil podsol profiles covered by drift sand which were palynologically studied by the present writer (HAVINGA 1962, 1963). A further correspondence between the two different horizons is that the A_1-horizon of the podsol profiles mentioned also contained very little pollen. In the view of Dr. POLAK and the present writer, the absence or infrequency of pollen and the presence of countless black particles strongly suggest the effect of fire, although it must be admitted that chemical analysis has not yet been employed to show whether the black particles are, in fact, small fragments of charred plants.

It may seem a strange theory that a vegetation in a basin could catch fire. However, according to Dr. W. G. SOMBROEK[2] (oral communication), fires are

[1] Department of Regional Soil Science, Geology and Mineralogy of the Agricultural University, Wageningen.

[2] F.A.O. Merim Lagoon Basin Project, Uruguay.

a constantly recurring feature of the grassy swamps in the basins of the Surinam river landscape.

The very heavy texture of the clay in the dark grey fossil vegetation horizon (cf. the data in table III), is repeatedly considered in the literature as affording proof of slight flooding activity of the rivers for a fairly long period. As far as concerns the fossil vegetation horizon on top of deposit 3, the same may be concluded from the presence of the numerous Late Stone Age and/or Bronze Age culture sites both on the levee splays situated at a slightly higher level than the surrounding basin clay and on the basin clay profiles proper.

According to EDELMAN (1950, p. 51) soil surveyors have sometimes found the characteristic dark-grey horizon connected laterally with a peat bed. This phenomenon has been adduced in support of the theory that such a horizon is to be regarded as a former vegetation floor during a period of stagnating fluvial sedimentation. (cf. also VAN DIEPEN 1952, p. 142; PONS 1957, p. 45).

The present writer, however, found that deposit 3 here and there contains peaty clay or clayey peat over the entire depth of the deposit, merging laterally into a non-peaty basin clay bed confined between two dark-grey vegetation horizons.

Since a vegetation horizon at the top of a clay bed was formed at the end of a sedimentation period during which a peat bed may have developed, it will be evident that it can only be stratigraphically connected with the top of a peat bed. A connection is always lateral, never vertical. It is only when the top of a peat bed is very clayey that it may merge above into a dark-grey vegetation horizon closely resembling that found in ordinary basin-clay soil.

The assumption of a lateral connection between a fossil vegetation horizon and a fairly thick peat bed is, in fact, illogical. It would imply that growth of *Carex* peat (the common type in the Betuwe) occurred during a dry phase and above the level of a vegetation horizon, or under soil conditions too dry for the related type of peat.

It was mentioned on p. 24 that the number of fossil vegetation horizons sometimes increases near the border of a basin. The provisional explanation of this local phenomenon is as follows: In the more central part of a basin soil conditions favour vegetation horizon formation only during a long period of extremely stagnating flooding activity which has repercussions throughout the river clay area. At a somewhat higher level in a basin, i.e. near its border, soil conditions are usually drier, so that a vegetation horizon may already be formed during a shorter period of stagnating flooding activity or a less marked decline of this activity, when the central part was still too wet for such soil formation.

7.7. FACTORS DETERMINING LIME CONTENT IN BASIN CLAY

It may be concluded from the occurrence of lime in the deeper part of the basins, as described on p. 25, that when this material was deposited the basins were flooded to a fairly great depth.

According to BENNEMA (1953), PONS (1957) and ZONNEVELD (1960) calcium carbonate will always come into or be in solution where there is a dense marshy vegetation on a basin soil flooded to some extent, the flood water being in a state of stagnation. Such conditions give rise to a soil environment which is fairly anaerobic and rich in carbonic and other organic acids. When a basin is more deeply flooded and the flood water betimes renewed, the calcium carbonate which either sedimented as small rock fragments or precipitated biochemically or, possibly, chemically, will be well preserved in the accumulating clay.

Such conditions may be found where a basin is completely encircled by levees, or they may be connected with a basin surface level fairly low with regard to the surrounding levees. This may have caused a more rapid influx of flood water during high river levels and thus locally also a somewhat coarser texture of the suspended soil material.

It may be assumed that when the upper non-calcareous part of the basin soils were formed, soil conditions more closely resembled those described by the above-mentioned authors. It is very unlikely that the clay originally contained much calcium carbonate which was afterwards washed out. Factors contraindicating such a theory are the very heavy texture of the basin clay, its vast swelling capacity, and the generally very high water table. But in this connection it should again be noted that a fairly high lime content is sometimes found elsewhere in the Dutch river clay area in a basin in both the upper and lower part of the soil.

The occurrence of lime concretions among non-calcareous basin clay is usually associated with calcareous sandy clay not far below in the subsoil. The present writer assumes this to be due to upward water transport during high water level in the river channels. This process must have been of relatively short duration and always occurred when a high level alternated with a low one in a period of slight rainfall. It was only then that fragmentation of the heavy clay coincided with the water supply from below. The dissolved calcium hydrocarbonate (and also the iron and manganese compounds) entrained by the water must have crystallized around existing nuclei of the same composition during a period of renewed dessication, thus forming increasingly larger concretions.

7.8. Connections between the textural compositions of superposed deposits

It was stated on p. 31 that a 1 to 2 dm transition zone of intermediate texture may occur between a sandy clay bed and a heavy clay bed situated below. Such a transition zone may occasionally have arisen through erosion of the topmost part of the heavy clay bed and simultaneous supply of sandy clay by flood water in a turbulence of varying strength. It is only in the case of a sudden violent influx of water through a breach or crevasse in a levee that the heavy clay bed may have been affected by this process to a greater depth.

Biological activity is another cause of mixing of the material of superposed clay beds. Depending on local hydrological and textural soil conditions, it may have influenced the soil profile over a greater or lesser depth. In the map area this process rarely affected the upper part of a soil profile to the extent of completely obscuring all features inherent to the sedimentary stratification. Even where soil conditions were very conducive to biological activity one can usually see a soil profile boundary more or less intact between deposits 1 and 2. Thus in a fairly thick, greyish-brown homogenized sandy clay soil, a 10 cm or somewhat thicker clay bed, of a texture slightly heavier than in the clay above or below, is often found at a depth corresponding to the top of deposit 2.

Deposit 1 sometimes shows variations in texture in the horizontal plane which must also be attributed to biological activity. This can be seen, for instance, in the soil profiles near Zetten in squares 34EF. In this area it has a sandier composition above and near the levee splay in deposit 2 than at a greater distance from this splay. Sandy material from deposit 2 must have been carried upward and blended with the heavier clay of deposit 1 as a result of faunal activity. There is no reason to assume that the sandier clay in deposit 1 was supplied by direct fluvial sedimentation.

A river clay soil consisting of heavy clay largely lacks faunal life and therefore shows little effect of homogenization. It would be rather surprising to learn that this is also the case where a soil of this type occurs at a level not very much lower than that of a neighbouring, intensely homogenized sandy clay soil. The explanation is that heavy river clay masks any favourable effect to be expected from a relatively high topographic position. This is connected with the mechanical and hydrological properties of this type of clay.

It is only in recent years that artificial drainage in the river clay area has been intensified to such an extent that even in heavy clay soils the ground water level is no longer an obstacle to biological activity. In future we may expect a considerable improvement in the soil structure resulting from natural processes, especially as these are of a kind which are intensified by the effect already produced. Consequently the differences in soil texture between deposits 1 and 2 will become increasingly blurred or even disappear altogether at several points. This will result in a soil pattern differing from that shown on the present map.

7.9. Spread of the Late Stone Age and/or Bronze Age culture sites

The Late Stone and/or Bronze Age culture sites in the Betuwe are chiefly concentrated in the basins of the mapped area. This is largely due to the special soil conditions in these basins at these periods, as caused by the numerous levee splays in deposit 3. The splays, being rather higher, must have created an environment generally more suitable for settlement than the basin soils proper. The culture sites found outside the levee splays could only have been occupied as well during the driest phase in the period of stagnating river activity between the periods of formation of deposits 3 and 2.

Bronze Age culture sites were also found outside the area shown, for instance, a number near Opheusden[1] 5 km west of Hemmen, and one south of Kesteren[2] 9 km west of Hemmen.

In the writer's view, the levees around the basins where the numerous culture sites occur must have been occupied by a far greater number of settlements than in these basins during the Late Stone or Bronze Age. This theory is not disproved by the present absence of culture sites of these periods from the levees. This absence is due to the fact that the actual levees represent a more recent formation resulting from 'rejuvenation' of the original levees on which the Late Stone Age or Bronze Age dwellers lived. The present levee system would be an excellent example of an 'archeological window'.

It may be assumed that the ancient inhabitants covered a far greater part of the Betuwe than can now be traced. It is worth noting in this connection the Bronze Age culture site discovered by R. S. HULST (1966) some years ago near Leerdam, about 42 km west of Hemmen, in a river clay area just outside the Betuwe. The archeological remains were found in a very dark-grey vegetation horizon about 50 cm below the present soil surface in a 1 m thick heavy basin clay bed which covered a sandy clay deposit.

Cultural remains from the Late Neolithic and Bronze Age are also sporadically found in the marine clay area in the western Netherlands, especially in West Friesland in the northern part of the province of North Holland, about 100 km north-north-west of the mapped area. Here Late Neolithic potsherds dating from about 1900–1850 B. C. were found on a marine clay deposit called 'West Frisian I deposit' formed about 2100–1900 B. C. A more recent marine clay bed called 'West Frisian II deposit' formed about 1650–1250 B. C. is known to contain several Bronze Age tumuli. The latter were dated from 1400–1000 B. C. (Pons and Wiggers 1960, p. 3, 11 and 26). These dates are accordant with those of the archaeological finds in the Betuwe (cf. p. 27).

7.10. STRATIFICATION OF THE RIVER CLAY IN OTHER PARTS OF THE BETUWE

It has not been ascertained as yet how far the description of the stratification of the river clay in this article has a general validity for the entire Betuwe area. A provisionary survey outside the mapped area revealed, however, that elsewhere the number and position of dark-grey vegetation horizons may vary considerably.

[1] The first find here was done by Miss. D. H. van Adrichem Boogaert, Miss. E. M. Donker and Mr. D. Eisma in 1960.

[2] By Ir. K. J. Hoeksema (Department of Regional Soil Science, Geology and Mineralogy of the Agricultural University, Wageningen) and Dr. P. Modderman (State Service for Archaeological Investigation) in 1958.

8. SUMMARY

A physiographical investigation of the Holocene sediments in a Dutch river clay area (cf. Fig. 1), was performed by applying a combination of a very detailed survey of the soil to a depth of 2.20 m and a reconnaissance survey of the deeper part of the soil, up to the top of the Pleistocene sandy subsoil. The soil condition to a depth of 2.20 m is shown on two soil maps (enclosures 1 and 2), while enclosure 3 shows several sections of the soil to this depth and below.

Within the basin areas three superposed clay beds and the upper part of a fourth, numbered 1, 2, 3 and 4 from above to below, often separated by a dark-grey vegetation horizon are found up to a depth of 2.20 m. A subdivision of deposit 3 (and of deposit 2 outside the area represented by the maps) was occasionally recorded. The vegetation horizon at the top of clay bed 2 was the soil surface in the Roman period, that at the top of deposit 3 in the Late Neolithic and Bronze Age. Numerous patches of ancient culture soil at the levels of these two vegetation horizons bear witness to a fairly dense habitation during these periods.

Each of the clay beds distinguished forms part of a separate river deposit. The latter consists of a meander belt composed of coarse sand and covered by a top stratum deposit of sandy clay several dm thick, which laterally merges in a clay bed overlying an older deposit. This clay bed consists of sandy clay in a wider or narrower zone along the meander belt, and of heavy basin clay further away. Fossil river gullies, overflow gullies, levee splays (see below) and ancient culture soils complete the picture. As far as possible the soil pattern of each deposit is shown separately on one of the two soil maps. They are described in chapter 5. The morphology of each of the various physiographical elements constituting a river deposit is described in chapter 6.

The term levee splay is used to denote a protrusion of an outer or inner part of a levee. Most of the levee splays shown on the maps are not identical with the basin splays or crevasse deposits mentioned in published evidence. The splays in the mapped area usually arose more gradually during the formation of the levee with which they are connected.

The four successive river deposits were formed during an equal number of phases of relatively great river activity. The three vegetation horizons came into existence during the intervening phases of slight activity. The older the deposit the more it is eroded and replaced by younger sediments. The meander belts of deposits 3 and 4 were 'rejuvenated' by these processes. Their position could be reconstructed from the occurrence of numerous levee splays in the basins untouched by the erosion process.

Fossil river gullies filled with heavy clay represent the position of the river courses some time before the river clay area was embanked in the Middle Ages. But the courses can only have shifted slightly since the Roman era. An exception is formed by the course of the Waal, south of the mapped area, which was diverted during the latest sedimentation phase. This is inferred from the rela-

tively great thickness and very sandy texture of clay bed 1 north of the Waal dyke.

Overflow gullies were found in deposits 1 and 2 only. Some different types could be distinguished. Their position is unconnected with that of the levee splays in deposit 2.

The presence of a great many culture sites of the Late Neolithic and/or Bronze Age in the basins of the map area is connected with the occurrence of numerous levee splays in deposit 3. A comparable concentration of culture sites in a basin has not yet been found in other parts of the river clay area. It would appear likely that the surrounding levees were even more densely inhabited than the basins. But the culture soils have disappeared owing to the 'rejuvenation' of these levees.

The presence in the Dutch sea clay area of cultural remains contemporary with the remains in the river clay area, enables us to correlate the sedimentation phases in both parts of the Netherlands.

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SAMENVATTING

Een fysiografisch onderzoek van de holocene afzettingen in een deel van de Betuwe (zie fig. 1), werd uitgevoerd met behulp van een zeer gedetailleerde bodemkartering tot 2,20 m diepte, in kombinatie met een overzichtskartering van de diepere lagen, tot aan de bovenkant van de pleistocene zandondergrond. De bodemgesteldheid tot 2,20 m diepte is weergegeven op twee kaarten (bijlagen 1 en 2), terwijl bijlage 3 verschillende doorsneden, die tot grotere diepte reiken, laat zien.

In de komgebieden treft men binnen 2,20 m diepte, drie boven elkaar gelegen kleilagen en het bovenste deel van een vierde aan, die van boven naar beneden met de cijfers 1, 2, 3 en 4 zijn aangeduid. De lagen zijn vaak door een donkergrijze vegetatiehorizont van elkaar gescheiden. Hier en daar werd een tweedeling van afzetting 3 (en buiten het door de kaarten weergegeven gebied ook van afzetting 2) waargenomen. De vegetatiehorizont aan de bovenzijde van afzetting 2 was het grondoppervlak in de Romeinse tijd, die aan de bovenzijde van afzetting 3 in de Laat-Neolitische- en Bronstijd. Talrijke plekken oude kultuurgrond ter hoogte van deze beide vegetatiehorizonten getuigen van een vrij dichte bewoning in deze verschillende tijden.

Elk van de genoemde kleilagen maakt deel uit van een afzonderlijke rivierafzetting. Deze omvat een meandergordel bestaande uit grof zand afgedekt door een verschillende dm dikke zandige-kleilaag, die zijdelings over een oudere afzetting heenloopt en op zekere afstand overgaat in zware komklei. Fossiele riviergeulen, overloopgeulen, uitstulpingen van oeverwallen en oude-kultuurgronden voltooien dit beeld. Het patroon van elke afzetting afzonderlijk is, voor zover mogelijk, op een der beide kaarten weergegeven.

Een bijzondere vermelding verdienen de "oeverwaluitstulpingen", die slechts zelden overeenkomen met de uit de literatuur bekende krevasseafzettingen. Zij kunnen lobvormig zijn of langgerekte vormen vertonen en al dan niet in onderliggende oudere afzettingen zijn ingeschuurd. Er bestaan ook overgangsvormen naar een normale stroomrug.

De vier opeenvolgende afzettingen ontstonden tijdens perioden van betrekkelijk grote, de drie vegetatiehorizonten gedurende tussenliggende tijden van geringe rivieraktiviteit. Naarmate een afzetting ouder is, is hij in sterkere mate geërodeerd en vervangen door jongere sedimenten. De meandergordels van de afzettingen 3 en 4 werden door deze processen "verjongd". Hun ligging kon worden gerekonstrueerd aan de hand van de aanwezigheid van talrijke oeverwaluitstulpingen in de door het erosieproces onberoerde kommen.

Fossiele meestal met zware klei gevulde riviergeulen geven de ligging van de rivierlopen aan, zoals die was juist voordat het rivierkleigebied in de Middeleeuwen werd bedijkt. Sinds de Romeinse tijd kunnen de lopen zich echter maar weinig meer hebben verplaatst. Een uitzondering vormt de loop van de Waal, die zich tijdens de laatste sedimentatieperiode heeft verlegd. Tot deze slotsom leidt de betrekkelijk grote dikte en het zeer zandige karakter van kleilaag 1 in de omgeving van de Waaldijk.

Overloopgeulen, waarvan nog verschillende typen kunnen worden onderscheiden, werden slechts in de beide afzettingen 1 en 2 aangetroffen. De ligging van deze geulen houdt geen verband met de aanwezigheid van oeverwaluitstulpingen.

De aanwezigheid van het grote aantal kultuurplekken van Laat-Neolitische en/of Bronstijdouderdom in de kommen van het gekarteerde gebied, hangt samen met de aanwezigheid van talrijke oeverwaluitstulpingen in afzetting 3. Een vergelijkbare koncentratie van kultuurplekken in een kom is tot nu toe in andere delen van het rivierkleigebied niet gevonden. Zeer waarschijnlijk zijn de omringende stroomruggen nog dichter bewoond geweest. Tengevolge van hun verjonging zijn de kultuurplekken daar echter verdwenen.

In het zeekleigebied komen hier en daar kultuuroverblijfselen van eenzelfde ouderdom als in de Betuwe voor. Hierdoor is de mogelijkheid tot een korrelatie van de verschillende sedimentatiefasen in deze verschillende delen van ons land geboden.

FIGUREN

TABELLEN

10. REFERENCES

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