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SOIL CONDITIONS, SOIL CARBONATES AND FORMER VEGETATION IN THE GEUL VALLEY FROM GULPEN TO MEERSSEN (SOUTH LIMBURG, THE NETHERLANDS)

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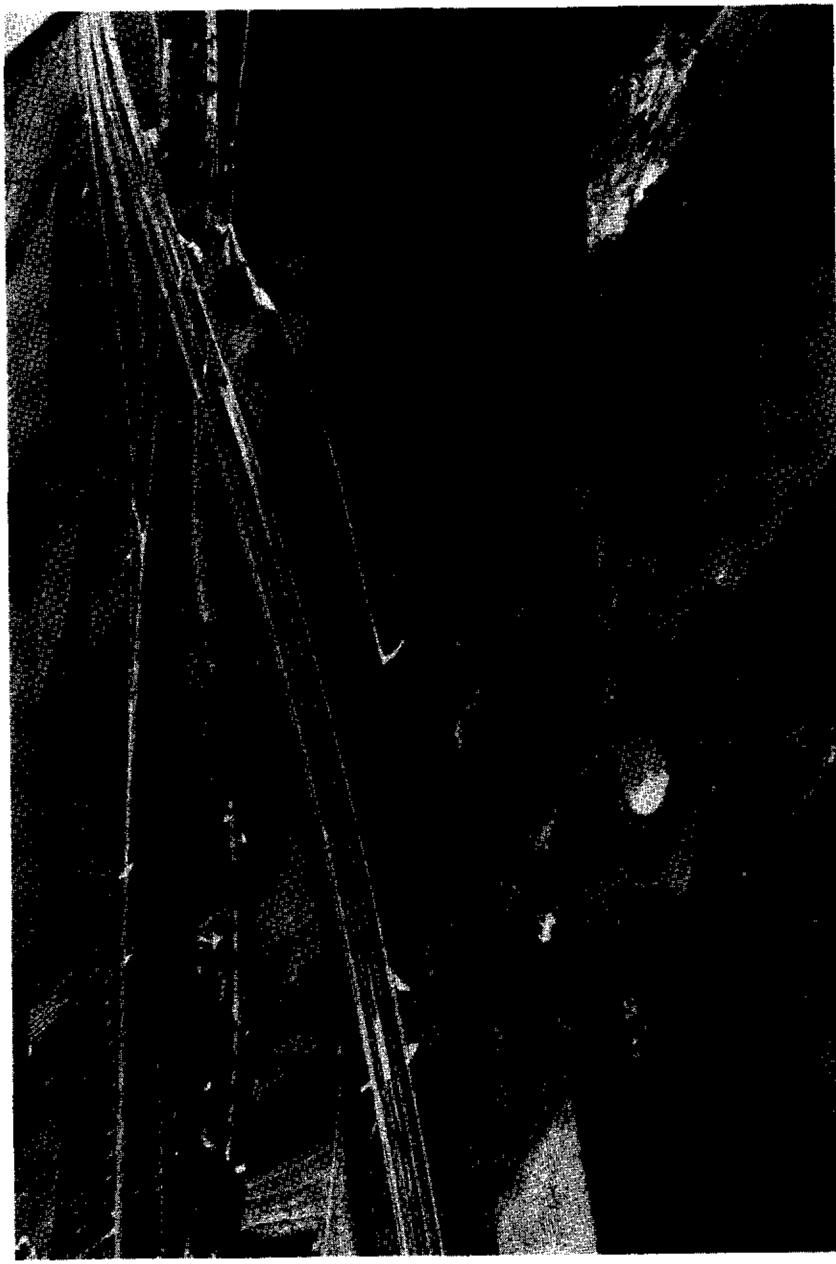

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PREFACE

During five years (1974–78) a soil survey was undertaken by the Department of Soil Science and Geology of the Agricultural University of Wageningen in the valley of the river Geul between Gulpen and Meerssen (South Limburg, The Netherlands). The main purpose was to introduce undergraduate students to soil survey practice. The work consisted in surveying, describing and mapping soils, making cross-sections and estimating the fluctuation of the water table with reference to soil characteristics.

The results form a sound basis for a better understanding of the geology and soils in the Geul valley. Because of the very detailed field work (boring density 25 × 50 m or narrower), much more information was obtained than in the case of a normal soil survey. To complete the survey some special studies and laboratory research were undertaken by the authors in co-operation with graduate students. The results are presented in the following three papers.

The first paper outlines the Holocene stratigraphy of the valley fill in relation to soil conditions. Five sedimentation stages have been distinguished which determined the soils. Hence the legend of the soil map has a marked geological character. The soil pattern reflects the younger sedimentation history of a small river, that occupies a fairly narrow valley.

The incidence and pattern of distribution of carbonates shows marked differences between the various soils. Very detailed field studies were undertaken to explain the relationship between the presence of carbonates, the sedimentation regime of the river Geul, time-dependent decalcification and to the occurrence of fans along the valley border. The results of this investigation are given in the second paper.

During the soil survey it was assumed that a relationship exists between former sedimentation in the valley and former agricultural practices (deforestation) in the surrounding upland, as the texture of the valley soils is often similar to that of the upland loess soils. Extensive and often thick colluvial deposits along the valley borders are evidence of another effect of human activity. To obtain some insight into the age of the fluvial and colluvial deposits and their relationship to agricultural history, two soil profiles were investigated by means of pollen analysis. The results are set out in the third paper.

SOILS AND THEIR GEOLOGY IN THE GEUL VALLEY

W. van de Westeringh

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1. INTRODUCTION

The river Geul rises near Eynatten in Belgium. It enters The Netherlands near Cottessen and flows into the Meuse near Bunde. By then it has covered about 56 km, two-thirds of this distance being in The Netherlands (Fig. 1). From the Dutch-Belgian frontier to Mechelen it flows in a south-north direction, from Mechelen to Schin op Geul it runs north-west and from Schin op Geul to Bunde in a more westerly direction. It receives many small tributaries. Together they form an essential part of the pleasant South Limburg landscape (Fig. 2).

By Dutch standards the Geul is a fast flowing river. The slope varies from about 7.62 m/km near Epen to 1.33 m/km near Houthem. The average is about 3 m/km. Its discharge is very irregular. Near Meerssen the average discharge is

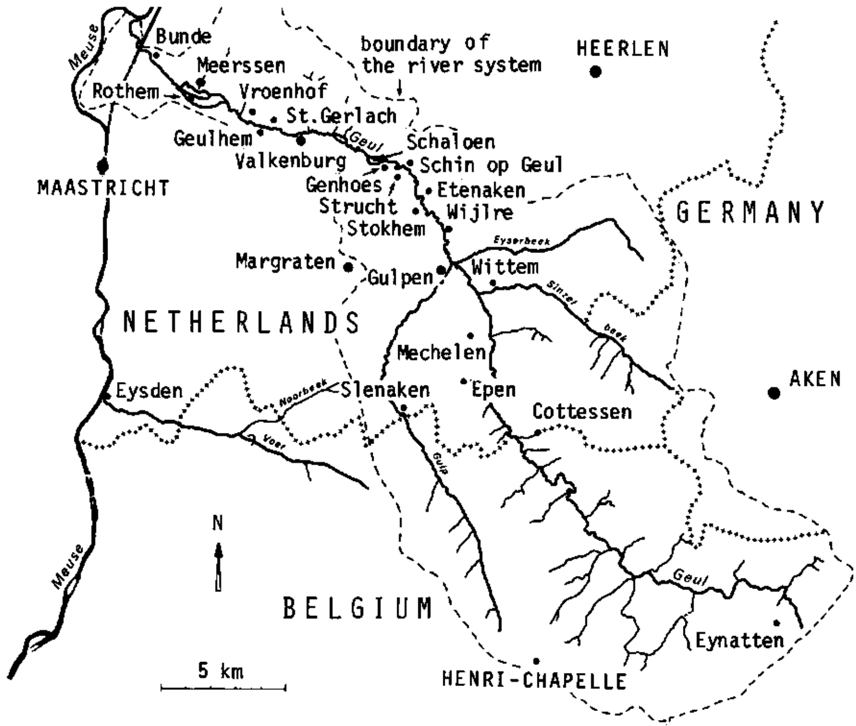


FIG. 1. The river system of the Geul.

FIG. 2. The pleasant landscape of the Geul valley.

about 2,300 l/s; the minimum discharge in recent years was 950 l/s (September 1971), with a maximum of 24,200 l/s in October 1974. In the very wet period of December 1966 the discharge at Valkenburg was about 65,000 l/s (Information supplied by the Limburg Public Works Department).

Under present conditions severe flooding is relatively rare. The last flood was in the spring of 1974. On an average floods occur every two years. The discharge by means of regulation, has been improved so that floods can be prevented or their duration shortened. Locally small areas are more frequently flooded. When floods occur in the late autumn, winter or early spring, there is usually little damage to agriculture, high water levels being generally of short duration. Before the modern regulation of the Geul the river had a natural character. But it should be added that for centuries the water discharges and levels have been influenced by man, e.g. by land reclamation, the construction of watermills, etc.

The geology and soil conditions of the Geul valley also reflect agricultural practices in the South Limburg loess landscape.

2. GEOLOGY

Five different stages could be distinguished in the history of the valley fill in the Geul basin. The first stage is of pre-Holocene age, the other four are Holocene.

2.1. Stage I (fig. 3a)

The shape and the size of the Geul valley indicate a Pleistocene origin. During the formation of the dissected plateau landscape the valley of the Geul, a major tributary of the Meuse, was deepened and widened. As a result of various geological processes the cross section of the valley has become asymmetrical in many places, with one steep side and one gentle slope. Small terrace-like irregularities are occasionally found along the valley walls. At the end of the Pleistocene the dissected plateau landscape has been covered by aeolian loess.

The valley was largely incised in Upper-Cretaceous limestones. In the flood plain of the present valley some metres of Pleistocene gravel were laid down by braided rivers overlying the Cretaceous material. Holocene sediments have been deposited on top of it. These last deposits give the valley its present character.

2.2. Stage II (Fig. 3b)

The temperature rose at the beginning of the Holocene and initiated a new, more thermophilic type of vegetation (Janssen, 1960). This led to a forest vegetation in the whole South Limburg loess area. The natural situation of the

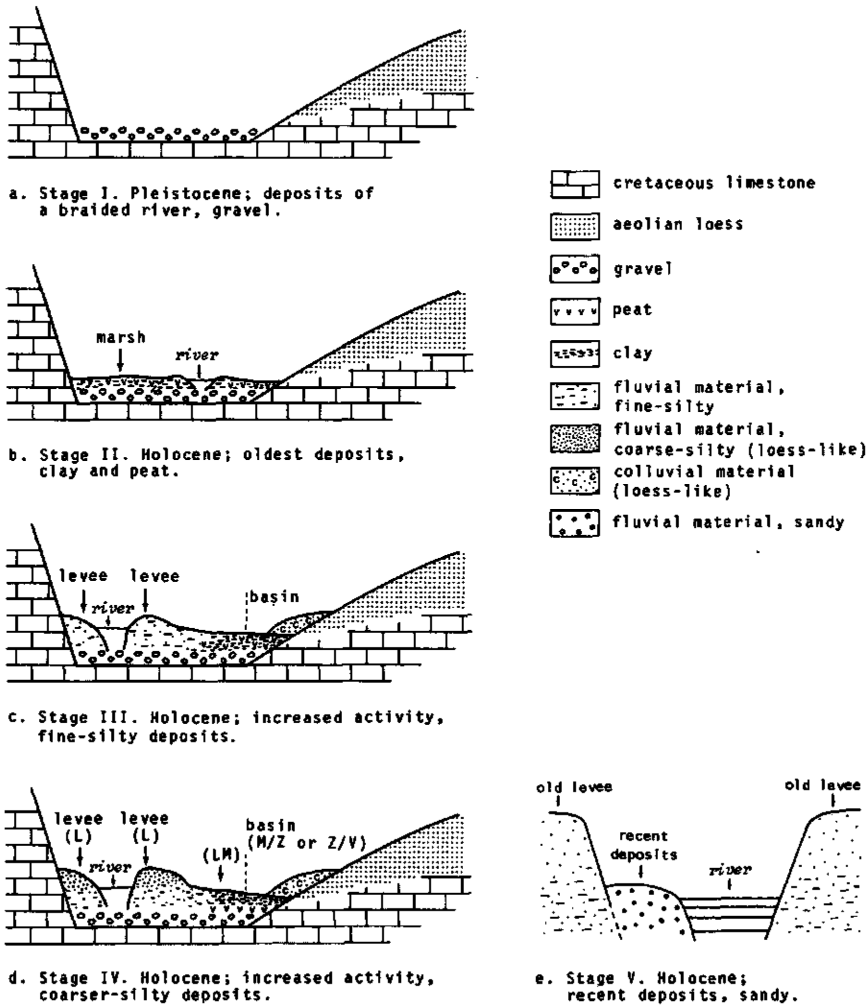


FIG. 3. Stages in the filling of the valley of the Geul.

Geul valley in wooded South Limburg was wetter than at present as a result of its low elevation with respect to the surrounding hills and the occurrence of springs along the valley at points where water rises over heavy, impermeable Lower-Cretaceous clay layers or flows in Cretaceous limestones. The vegetation became a marsh forest (HAVINGA and VAN DEN BERG VAN SAPAROEA, 1980).

At the beginning of the Holocene, in such a densely forested landscape, the river mainly carried groundwater base flow that reached the valley through springs and seepages. In a wooded landscape when precipitation exceeds the evapotranspiration the surplus water does not reach the river via the surface, but through the soil and after deep percolation via the groundwater. At this period the difference between base flow and peak discharge of the river was not great. As the landscape was covered by vegetation the suspended load of the river was small. There was little or no sedimentation. Only some clay was deposited, or else peat was formed.

2.3. Stage III (Fig. 3c)

As long as the entire loess area was under permanent vegetation the discharge and activity of the Geul remained more or less unchanged. It was only slightly affected by climatic changes in the Holocene. The situation was again changed when the vegetation was cleared by man and bare soil became subject to erosion.

The first human settlers in South Limburg to clear some parts of the forest were the Dutch Bandkeramik people. They lived on the boundaries of the level loess plateaus. They were farmers and their arable land was on the plateaus. The coarse-silty top layers of the loess soils had a lower clay content than the fine-silty subsoils and were weakly acidic. This soil condition was conducive to arable farming, as sparse woodland was growing on loamy and weakly acidic soil (Pons, 1973). For reclamation and farming such situations were attractive because:

- it was relatively easy to clear the sparse woodland and reclaim the land,
- the original vegetation was easier to control than on clayey and rich soils,
- tillage of coarse-silty soils was easy.

Owing to the situation of the arable land on plateaus and the sparse forests around the fields on the boundaries of the plateaus and on the hills, the hydrological regime was only subject to slight change. Erosion was not serious and most of the surplus water still reached the river via the groundwater. In this part of South Limburg no settlements of Bandkeramik age have been found (Bakels, 1978), so that little if any silt reached the river and the sedimentation rate was low. The sedimentation pattern in the Geul valley only differed slightly from the situation described in stage II. This was changed when larger parts of the loess area, both on the plateaus and on gentle slopes, were cleared by man. The natural vegetation disappeared and erosion started. It is not known whether erosion will have become serious as early as from the beginning of intensive agricultural practise or later on (at the end?).

It was during the Roman era that large parts of South Limburg were used for arable farming. The clearance of the natural vegetation and resulting erosion then had a marked effect on the regimes of the Geul and other rivers. It caused that the hydrological regime of the loess area was drastically changed and that the suspended load increased considerably. Up to this period the surplus water entered the soil and when the soil was saturated, the water percolated to the groundwater via which it eventually reached the river. But owing to the clearance of the vegetation in hilly areas less water penetrated the soil; in stead it flowed laterally down the slopes. This meant that the surplus water took less time to reach the river, and that the water levels and discharges became higher and more irregular with great differences between base flow and peak discharge. Owing to the greater discharges the current velocity, turbulence and sediment load of the river Geul increased substantially.

Soil particles eroded from the arable land to the lower parts of the landscape (colluvium) or to the rivers that deposited the material in the valleys (alluvium). Loess material, especially the coarse-silty top layers of the loess soils, is very liable to erosion. During heavy rainfall or thaw greater quantities of water and much silt of loess origin (i.e. with a high content of silt particles) entered the river. This was transported and deposited elsewhere.

The river's sedimentation pattern changed compared with that of stage II. Instead of clay and peat the river deposits now consisted of silty loess-like material, with a differentiation of texture from the levees to the basins. VAN DEN BROEK and VAN DER MAREL (1964) also refer to the loess origin of the fluvial soils of the Geul.

2.4. STAGE IV (FIG. 3d)

Later, when more vegetation had been cleared and more land was used for agriculture, esp. for arable, occasionally more water entered the rivers with greater frequency. As a result more water and silt flowed into the Geul; thus its current velocity and sediment load increased. It is the same process as described in stage III but more intensively. Our borings and the work of TEUNISSEN VAN MANEN (1958) clearly showed that most of the soils have a higher clay content in the subsoil than in the upper part of the soil. Apparently two important sedimentation stages should be distinguished. The latest stage must be the result of reclamations even more extensive than those which occurred in the Roman era (see above). It undoubtedly dates from the Middle Ages (HAVINGA and VAN DEN BERG VAN SAPAROEA, 1980).

RIEZEBOS and SLOTBOOM (1978) also point to a relationship between soil erosion, sedimentation and human activity. In Luxemburg they found a change from peat to clayey material that could be dated to the 15th century. Although a climatic reason also might be an important factor, the use of land for farming, especially the increase of the arable/pasture ratio, caused an increased supply of sediment, combined with a rise in the water table or more frequent and extreme flooding by river water. This is in complete agreement with what was found in the Geul valley. The occurrence of many soils with a finer-silty subsoil may reflect a further deforestation or an increased arable/pasture ratio. The change from stage III to stage IV might be post-medieval.

According to BRUNNACKER (1977) about 1000 years ago distinct changes occurred in sedimentation patterns and soil conditions in the valleys owing to a substantional change in river movements. Although slight climatic changes and oscillations of the glaciers in the Alps and of sea level might have been of importance to large rivers, small rivers and brooks were mainly influenced by human interference in the landscape. Deforestation led to erosion and the eroded material accumulated within the small valleys.

2.5. STAGE V (FIG. 3e)

After the Middle Ages the entire loess area was cleared and cultivated except for the steepest hills and poorest soils, where the forests remained. Forests still exist on sites where General Tranchot mapped forests in the beginning of the 19th century. This is a good illustration of the fact that large-scale reclamation has become impossible in recent centuries. Nor, of course did the rivers change their character during this period.

In recent times, farming practices have greatly improved (e.g. better weed control, row culture, reallotment). Otherwise this means that the arable land is exposed for longer periods, thus increasing erosion danger (BOLT et al., 1980). Another important factor is that in the 20th century many roads have been paved, so that overland flow increased. Moreover households use more water than before and all effluent water reaches the rivers through sewerage. These two non-agricultural causes may be the chief factors creating the irregular discharge of the Geul.

The net result is that the Geul sometimes receives more water than before. There is a possibility, however, that a different hydrological regime of the Meuse in former times also influenced the slope and current velocity of the Geul. Under present conditions the river cuts into its former deposits and the recent deposits are at a lower level. It is not the silt but the sand fraction that predominates in the grain-size distribution. Small, distinct terraces are formed (Fig. 4). The sands contain carbonates and are intercalated with organic matter. The

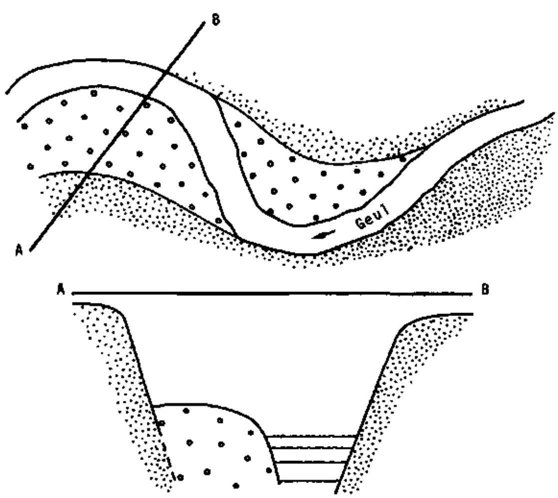


FIG. 4. Formation of small terraces and sandy deposits in recent times (cf. Fig. 3e).

present stream has cut so deeply into its own deposits that the river channel has cut into the Pleistocene substratum of the braided river. Its current velocity is not so great that it has cut into Pleistocene coarse gravel bed. Most of the material (clay and silt) that reaches the river flows to the mouth of the Geul and comes into the Meuse. The recent deposits in the valley are sandy and no longer loess-like.

3. SOIL CONDITION

3.1 SOILS

Most of the deposits in the Geul valley belong to stages III and IV, both in horizontal extent and in vertical depth or soil profile. As described in stages III and IV, the more recent loamy deposits of stage IV have a lower clay content than the loamy deposits of stage III. In many soils the texture trend increases with depth. TEUNISSEN VAN MANEN (1958), BRETELER (1967), DAMOISEAUX (1968) and VAN DE WESTERINGH (1979, 1980) record the same trend for the deposits of the Geul and its tributaries the Gulp and Eyserbeek. But a difference exists in the thickness of the coarse-silty part (e.g. texture L) overlying the fine-silty part (e.g. M) of the soil profiles.

In the Lower Rhine area in Germany it was also ascertained that the older Holocene river deposits have a finer texture than the younger river deposits. In contrast with the situation in the Geul valley several river terraces, all dating from the Holocene, are found at various levels in the Lower Rhine area (BRUNNACKER, 1978).

In general the more recent deposits of stage IV are thicker than the older ones. In the levee position the later stage is thicker than in the basin position. The texture of recent deposits also differs in the levee to basin direction; in the basin position the texture is finer.

Three classes of soil texture have been distinguished, viz. L, M and Z. These three classes record the clay content (lutum %) of the loamy (loess-like) parent material. They correspond to the soil textural classes of the SOIL TAXONOMY (1975):

L : approx. 10–20 % lutum ('coarse-silty')
M: approx. 20–30 % lutum ('fine-silty')
Z : approx. more than 30 % lutum
and V: peat or peaty material.

In general the levee soils have a textural class L over great depth, viz. exceeding 120 cm and sometimes 220 cm. Soils situated at the boundary between levee and basin have textural class L over M (coded LM), viz. within a depth of 120 cm the texture increases from L to M. Such soils show the two stages of geogenesis. An increasing textural trend was also found in many other situations. In the basin positions soils are found with textures of M, MZ, Z or ZV. These not only indicate the basin positions but the two stages of geogenesis.

3.2. Calcareous material

Hitherto no reference has been made to calcareous material in the deposits of the Geul. As stated above, the river sedimentation had been correlated with the clearance of the vegetation and the reclamation of the loess area. When such activities led to soil erosion, loess-like material came into the river and was deposited. Hence sedimentation is a function of erosion and the carbonate content of deposits must be related to erosion.

The natural soil in the loess area covered by forest was a 'brik' soil (De Bakker and Schelling, 1966) or alfisol (Soil taxonomy, 1975). Such a soil had no carbonates and was weakly acidic to a depth of 2.5 to 3.0 m. In other words, non-calcareous loess material was the first to erode.

The carbonate content of the deposits was determined by changes in the sources of eroded material and by the sedimentation pattern in the valley. Decalcification is another process affecting the carbonate content of the soils of the Geul valley. Further information on the carbonates in these soils has been provided by Miedema (1980).

3.3. Hydrology

The Dutch system of 'Gt' (= water-table classes) for characterizing the fluctuations of the groundwater is relatively unimportant for such a small valley as that of the Geul. The groundwater level in the valley largely depends on the height of the river water and this height may vary extensively. Mottling in the soils are evidences of the water fluctuations (reduction spots of a more grayish tint and brown or orange-brown oxidation spots).

The groundwater fluctuations of profiles with a deep homogeneous brown colour without mottles are characterized by a high Gt class (VII), i.e. the mean groundwater is always deeper than 1.20 m. Soils mottled at shallow depth but with a mean lowest groundwater table deeper than 1.20 m have wide groundwater fluctuations and are characterized by Gt V. Soils with higher groundwater levels (both the mean highest and the mean lowest) are characterized by Gt classes lower than V. They are mottled at shallower depth.

The simplified map of groundwater fluctuations in the Geul valley (Fig. 5) shows three main zones of Gt classes: a small zone with high Gt classes along the Geul, a transitional zone with Gt classes of wide groundwater fluctuations, and a zone with low Gt classes. The first zone corresponds to levees, the last to basins. Table I shows the Dutch system of water-table classes (Gt classes).

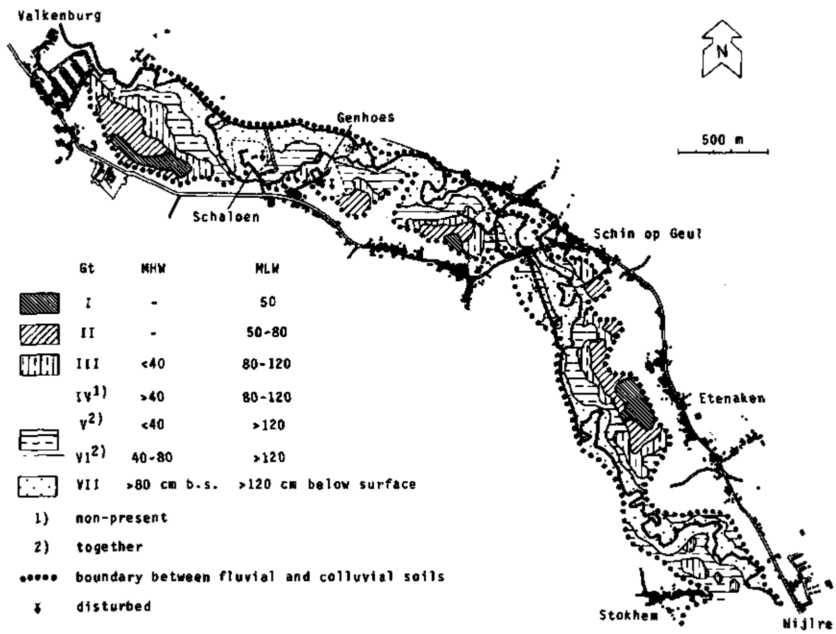


FIG. 5. Simplified estimated groundwater fluctuation ('Gt') map of the valley of the river Geul from Wijlre-Stokhem to Valkenburg.

TABLE I

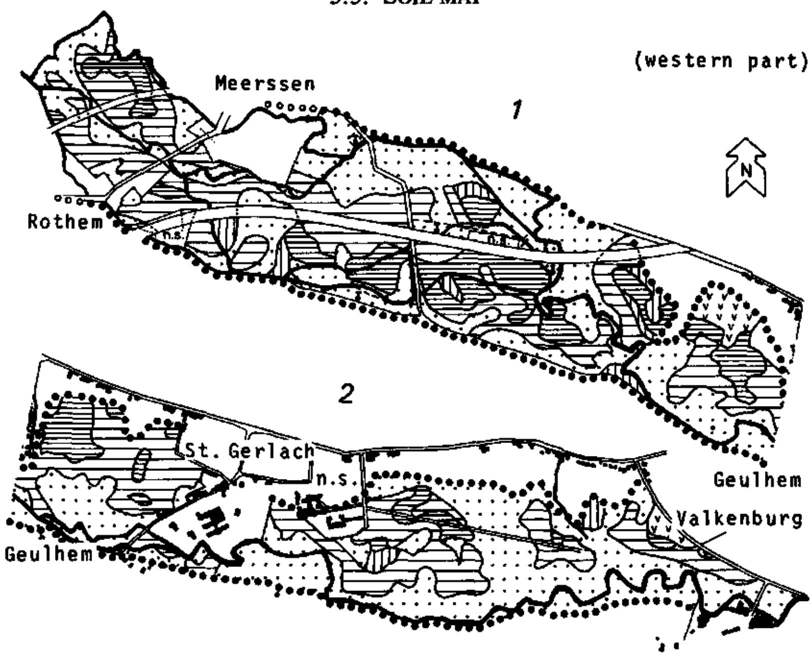
Gt[1]	MHW[2]	MLW[3]	
I	–	< 50	
II	–	50–80	
III	< 40	80–120	
IV	> 40	80–120	
V	< 40	> 120	[1] Gt: water-table class
VI	40–80	> 120	[2] MHW: mean highest water table
VII	> 80	> 120	[3] MLW: mean lowest water table
	(in cm below surface)		(cf. VAN HEESEN, 1970)

3.4. SOIL MAP LEGEND

Three main classes have been distinguished in the texture of the fluvial soils in the Geul valley, viz. L, M and Z, indicating the lutum or clay percentage (= % < 2 micron), i.e. respectively ca 10–20 %, ca 20–30 % and more than 30 % lutum (see 3.1). There is also a class V indicating organic matter contents of over ca 15 % (peaty material and peat). Generally speaking, the texture of the soils is silt loam in which the clay content varies. It is derived from loess soils with a silt loam texture. Soil textures coarser than L, i.e. with less than 10 % clay, only occur in the most recent deposits. These have a sandy texture instead of a loamy one. As these deposits cover so small an area they could not be shown on the soil map.

The map units (Fig. 6) indicate the soil textural classes and combinations of classes to a depth of 120 cm of the soils. Figure 7 shows the texture profiles to a depth of 220 cm of some parts of the Geul valley downstream from Valkenburg. Although a change in textural class is shown on the field maps by means of numerals indicating its beginning (e.g. 1, 2, 3, 4, 5 and 6 respectively denoting its beginning up to 40 cm, from 40 to 80 cm, from 80 to 120 cm, from 120 to 160 cm, from 160 to 200 cm and from 200 to 220 cm), these numerals had to be omitted from Figure 6 because of the scale.

3.5. Soil map



L. coarse-silty soils to 1.20 m

LM_2+LM_3. coarse-silty soils with a fine-silty subsoil, beginning deeper than 0.40 m

LML. item LM_2+LM_3, but with a coarse-silty subsoil, beginning deeper than 0.80 m

LMZ+MZ. item LM_2+LM_3, but with a clayey subsoil; the topsoil is occasionally fine-silty

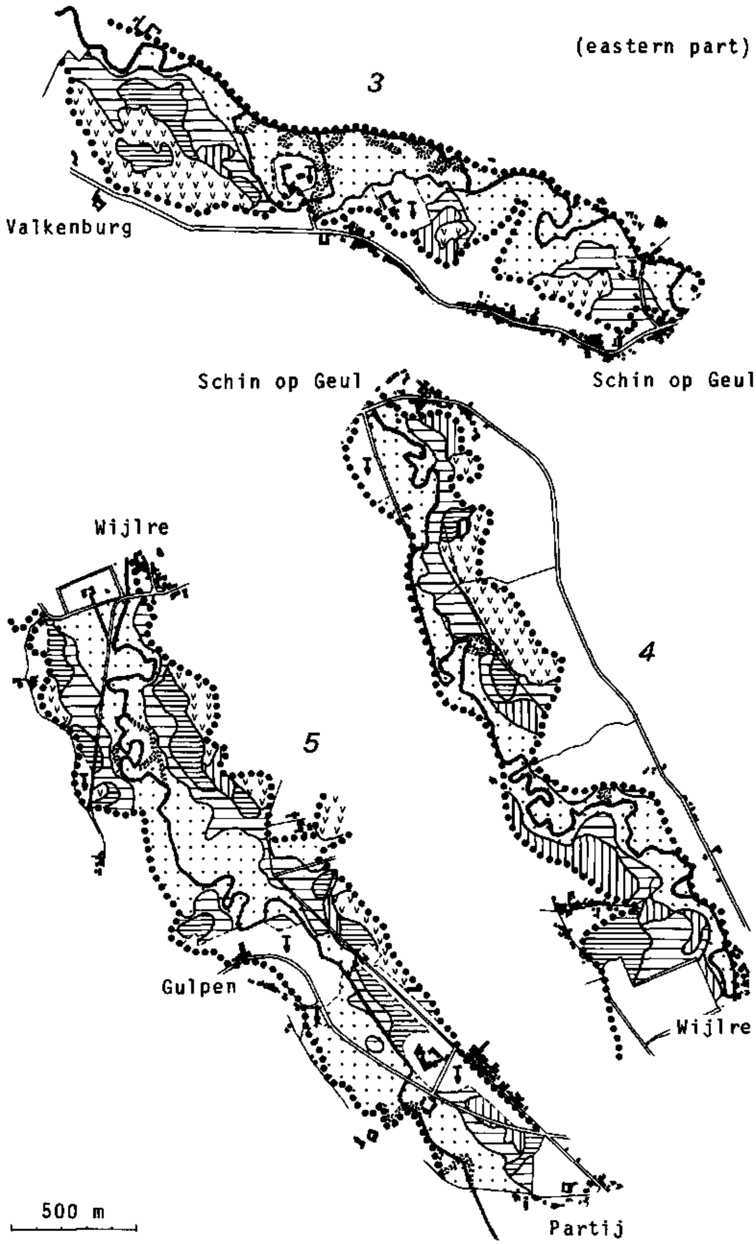
V. fine-silty soils with a subsoil of peat or peaty clay, beginning within 1.20 m

boundary between fluvial and colluvial soils

disturbed

n.s. not surveyed

FIG. 6. Simplified soil map to 1.20 m of the Geul valley from Gulpen to Meerssen.


(eastern part)
3
Valkenburg
Schin op Geul
Schin op Geul
Wijlre
4
5
Gulpen
Wijlre
500 m
Partij

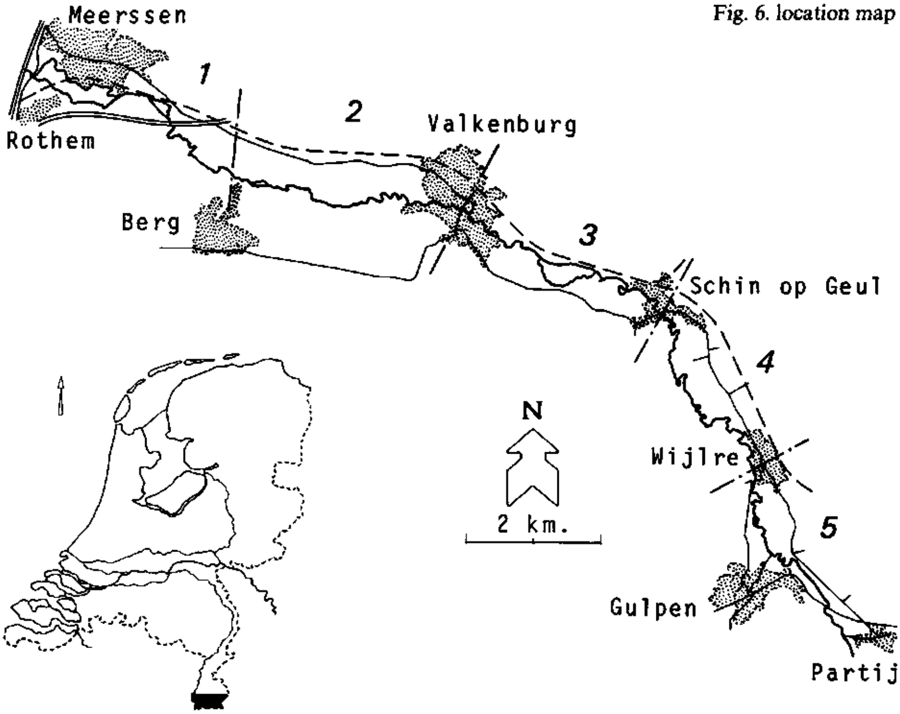


Fig. 6. location map

Figure 6 shows the soil map of the Geul valley from Gulpen to Meerssen, (borings to 120 cm). Figure 7 presents the soil map, based on borings to 220 cm, for part of the valley downstream from Valkenburg. Some general information is given first. Soils in the Geul valley with a level or nearly level surface are regarded as fluvial soils. Soils at the boundary of the valley beneath slopes, and at a higher level than the surrounding fluvial soils, are regarded as colluvial soils. As both fluvial and colluvial soils consist of loess-like material it is difficult differentiate them. Where the Geul has deposited fluvial material the valley is narrow, varying from about 150 m near Etenaken and Strucht to about 600 m near Meerssen. The boundary between fluvial and colluvial soils is very irregular, especially in front of tributary-valleys (cf. 3.6).

One of the most noticeable features of the soil map (Fig. 6) is that at practically every point of the valley the river has only formed one meander belt corresponding to coarse-silty soils (unit L). In general Figure 7 shows that coarse-silty soils (unit L) occur at the same places in the subsoil as in the upper part of the soils. The levees on both sides of the Geul are narrow. The total width of soils of unit L varies from a minimum of 50 m to about 350 m where some branches of the Geul run side-by-side near the castles of Genhoes and Schaloen and the Meerssen watermill.

Another noticeable feature is the comparative rarity of clayey basin soils and peaty soils, the main reason being the narrowness of the vally. Clayey and peaty

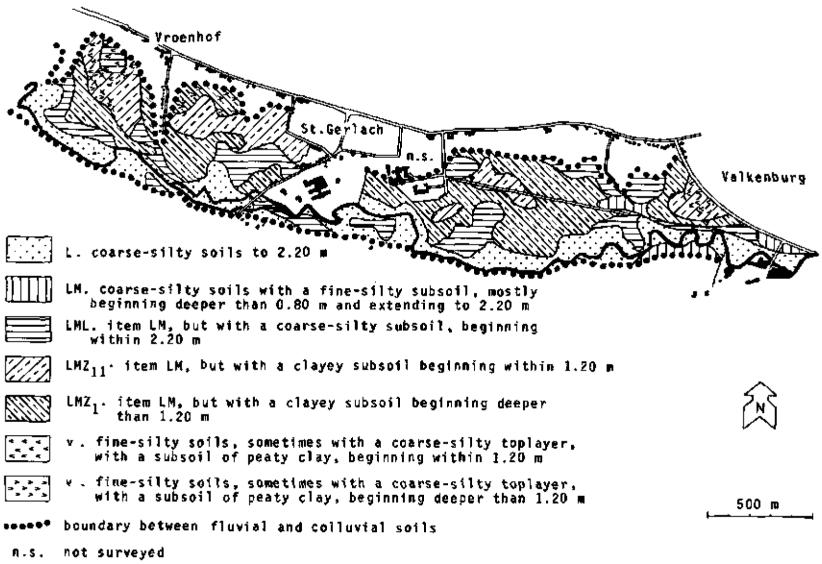


FIG. 7. Simplified soil map to 2.20 m of the Geul valley between Valkenburg and Vroenhof.

soils occurring at the surface (units with textural classes (M), Z and V) are always situated on the other side of the valley as where the river flows.

A typical feature of most map units is that the clay content increases with depth (Table II). It is only the coarse-silty soils of the levees that do not show this increase (Table II). The increase in clay with depth corresponds to the geogenesis of the Geul deposits. The subsoil is formed by material of the first stages, the upper part of the soil by material of later deposits with a coarser texture (see 3.2).

It was shown by cross-sections made in various parts of the valley that the surface level of a peaty soil in the basin position is often higher than that of a levee. At such sites river sidimentation was clearly impossible. In the basins or back swamps fluvial sedimentation might only have been possible after the peat had eroded, or else as a result of improved natural water discharge of the river or artificial drainage of the valley. It was only at certain points on the borders of the valley near slopes where springs occurred that good drainage was impossible and peat was unable to settle.

With the exception of the map unit L of the levees, all others are more or less complex, depending on textural changes in the soil profiles and the map scale. In some areas map units as (M)Z and (M)ZV are related, as they indicate the basin position of the valley. Map units as LM, LML, etc., denote the transition from levee to basin. These soils show the geogenesis of the two main stages of the fluvial soils. The most recent and upper part of the levees (L) has been deposited on a former basin situation (M), or with the same genesis the basin was early situated in a levee situation (L), as found in the oldest levee subsoil.

The soil map of Figure 6 shows a difference in soil conditions upstream and

TABLE II. Soil textures of two profiles. Profile Schin op Geul II, a basin soil (unit MV).

horizon	depth (cm)	particle size distribution < 2 μm	2–15 μm	16–50 μm	> 50 μm	pH KCl	H_2O	organic matter %C	% $CaCo_3$ (Wesemael)
A1	0–8	22.7	22.3	48.4	6.6	6.90	7.1	4.56	2.5
A1	8–16	22.9	21.9	48.6	6.6	6.97	7.1	3.36	3.1
A3	16–26	20.8	20.4	53.1	5.7	6.95	7.2	1.55	4.2
A3	26–37	20.4	23.1	54.2	2.3	7.11	7.3	0.81	0.7
B2	37–50	20.5	21.3	55.5	2.7	7.03	7.2	0.95	1.4
B2	50–62	29.4	29.6	39.9	1.1	6.77	7.2	2.05	0.4
IIC1	62–80	44.6	29.9	24.3	1.2	6.35	7.0	4.31	0.3
IIC2	+ 80	30.2	28.9	34.6	6.3	5.87	6.0	22.7	1.8

Profile Schin op Geul III, a levee soil (unit L).

horizon	depth (cm)	particle size distribution < 2 μm	2–16 μm	16–50 μm	> 50 μm	pH KCl	H_2O	organic matter %C	% $CaCO_3$ (Wesemael)
A1	0– 5	12.8	10.7	51.9	24.6	6.34	6.2	4.36	0.2
A1	5–10	12.4	10.2	52.1	25.3	6.53	6.3	3.46	0.1
A1	10–20	12.0	10.1	51.0	26.9	6.73	7.0	3.33	0.4
A3	20–35	13.0	10.7	58.1	18.2	6.10	6.6	1.32	0
B2	35–50	13.4	12.0	58.8	15.8	6.57	6.9	0.90	0
B2	50–65	13.6	12.0	59.4	15.0	7.05	7.4	0.47	0.3
B2	65–80	12.3	11.3	60.7	15.7	7.06	7.4	0.53	0.2
B3	80–95	11.4	9.9	61.4	17.3	6.67	7.1	0.43	0
B3	95–110	10.2	8.4	63.0	18.4	7.37	7.6	0.29	1.0

downstream from Valkenburg. Basins with fine-silty and clayey soils (M, Z) or peat (V), with or without some coarse-silty material in the upper part of the soil, are only well developed upstream from Valkenburg. Downstream they do not occur or are small. Coarse-silty soils predominate, e.g. more L and LM_2 of LM_3 than upstream where more LM_1 and LM_2 occur. The reason for this phenomenon is not clear. It could be a geological one as a difference in the valley fill on both sides of Valkenburg, or the effect of the Meuse on the sedimentation pattern of the Geul may not have extended beyond Valkenburg. It is not known how changes in the course of the Meuse and Geul may have affected the latter's sedimentation pattern. BECKERS (1929) reported a number of considerable changes. It would seem unlikely that this difference in soil conditions was connected with a different deforestation or occupation pattern upstream and downstream from Valkenburg.

Although the Geul has only formed a single meander belt, downstream from Valkenburg it was possible to survey an old river system. Particularly on the left of the valley between Geulhem and Rothem an old system is present in the subsoil (Fig. 7). This system is also clearly indicated by soil carbonates (MIEDEMA, 1980).

Near Meerssen the Geul has three branches which must be connected with watermills. The soil conditions and soil carbonates of the branches, the Grote (Great) Geul and the Kleine (Small) Geul show that fluvial sedimentation must be fairly recent. The southern branch, the Geulke (little Geul) is a millrace which has scarcely led to any fluvial sedimentation (cf. the soil map).

3.6. FANS

The border between the fluvial soils of the Geul and the colluvial soils along the valley slopes bends towards the valley axis at points where tributary-valleys join the main valley (Fig. 6). In front of these tributary-valleys fan shaped bodies protrude into the main valley. The deposits of which the fans are made, usually are different from those of the adjacent Geul sediments. Clearly the sediments of these fans have been supplied through tributary-valleys. Although the deposits have a loess-like texture, they are different from the fluvial deposits of the Geul. This is most striking where clayey soils of the main valley are in contact with the outer fringes of the fans. In such cases the fan deposits have a coarser texture due to the sudden change in the slope of the tributary-valley, where it enters the plain of the main valley.

The different origin of the parent material is also revealed when masses of calcareous material have been eroded in the catchment area of the tributary-valley; there the fan deposits have calcareous soils. Carbonate detritus derived from the tributary-valleys has also affected the fluvial soils of the Geul (MIEDEMA, 1980).

It is clear from the shape of some fans that man was responsible. They do not have usual round shape, but a straight projection on the rounding (Fig. 8). The morphology of some of the fans gives evidence of human activity. Instead of the

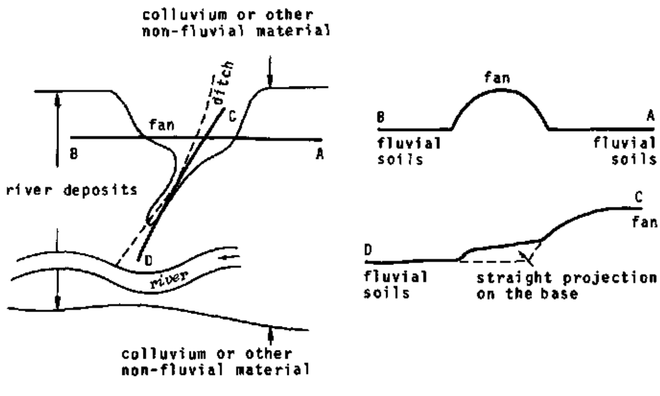


FIG. 8. Sketches of a fan in the Geul valley.

usual semi-circular form, a straight extension is present, that probably is a last remnant of a water course over the fan. The function of such a ditch was and still is to drain the farm land. During most of the year, however, the ditch is dry. The sediment, aggraded in the ditch is removed by the farmers and thrown over the sides. This spoil forms a kind of man-made artificial levee, preventing the surplus water running out of the ditch too fast. So as a result of the ditch, the last remnant of a small tributary in the triburaty-valley, and by farmers' activities in cleaning the ditch, some fans have a straight projection instead of a round shape. Examples are found near Stokhem, Etenaken, in front of the Gerendal and near Vroenhof.

The fans are of recent date and of the same origin as the Geul deposits, viz. clearance of the forests for farming. The centre of the fan may be old where it connects with the point at which a tributary enters the Geul, but the extension of the fan is recent. At some sites the border of the fan overlies peat which means that the genesis of the fans, like that of the Geul deposits, is related to the erosion occurring after the deforestation of the loess area (HAVINGA and VAN DEN BERG VAN SAPAROEA, 1980).

FIG. 9. Fan in front of a dry valley.

4. THE PRESENT LANDSCAPE

Only small and altered remnants have been left of the original marsh forest in the Geul valley. At present the valley consists of farmland, mainly pasture. In earlier centuries, when the drainage was less efficient, a wide area of land was used as meadows. Names with the suffix 'beemd' ('meadow') are a relic of this agricultural land use. Marshy land adjoined the meadows, as indicated by place-names with the suffix 'broek' ('brook').

The difference between the levees and the basins is hardly visible in the landscape. In some places differences in kinds of grasses and herbs show the differences in water-table classes (Gt) of the levees and the basins. This gives a good indication of the hydrological condition, at least where pastures are not too intensively exploited.

FIG. 10. The attractive landscape of the Geul valley: pastures, trees, pollards, the river Geul (l.) and a millrace (r.).

The Geul valley landscape is very attractive (Fig. 10). It is a pastoral landscape and the many poplars and willows along the Geul and in lanes, pollards (willow, alders, ash, hornbeam, etc.), overgrown alder and hawthorn hedges along the meadows and paths give it a special character. Several species of birds find a good biotope in this landscape.

The recent erosion at the outer bends and sedimentation in the inner bends can be seen along the borders of the Geul. The most recent deposits are lower than the older river banks. The vegetation clearly responds to this habitat which is rich in carbonates and nitrogen. And it is only fair to add that river pollution and pollution of the environment and the river banks by human refuse create a great problem for landscape management.

Villages and other buildings are found on the hills along the valley. There are few buildings in the actual valley, e.g. a few farms, castles, water-mills and tea-houses. Unfortunately recent housebuilding (Schin op Geul) and a new motorway (near Meerssen) have upset the character of the valley.

As the valley is important for farming and recreation in South Limburg, we must be on guard against any undesirable development that could destroy the valley landscape. It should also be remembered that the pleasant valley landscape can only be saved for the future provided agriculture continues to remain its essential feature.

5. SUMMARY

By Dutch standards the Geul, a major tributary of the Meuse, is a fast-flowing river. Under present conditions the sedimentation by the Geul is different from the sedimentation under conditions when the loess landscape was under permanent vegetation.

Five stages in the geogenesis of the valley fill could be distinguished. The first stage is of pre-Holocene age, the other four are Holocene. The Pleistocene braided rivers had laid down gravel layers overlying Cretaceous material. In the beginning of the Holocene the Geul had a low activity. In the densely forested loess landscape the river mainly carried groundwater base flow; the suspended load was small. Only some clay was deposited, or else peat was formed.

This situation changed when the vegetation was cleared by man for agriculture. Bare soil became subject to erosion. Instead of penetrating the soil, more surplus water flowed laterally down the slopes. It caused higher and more irregular water levels and discharges of the Geul. The current velocity and sediment load of the river substantially increased. Owing to the coarse-silty and weak acidic top layers the loess soils were very liable to erosion. The river deposits now consisted of silty loess-like material.

Most soils have a textural trend that increase with depth. This increase in clay content corresponds to two main stages in deforestation and resulting erosion. In this part of South Limburg no settlements of Bandkeramik age have been found. Severe erosion occurred in or after the Roman era and the Middle Ages, when large parts of the South Limburg loess landscape were deforested and used for arable farming.

In recent times the Geul sometimes receives more water than before, as result of improved farming practices, paved roads and effluent water from households through sewerage. Under present conditions the Geul has an increased current velocity; the river cuts into its former deposits. The recent deposits are at a lower level. Sand predominates.

Most soils in the Geul valley have a coarse-silty top layer and a fine-silty subsoil. The legend of the soil map is based on three textural classes: L, M and Z

(respectively ca 10–20 %, ca 20–30 % and more than 30 % lutum or clay), and V (peaty material and peat, i.e. more than ca 15 % organic matter).

There is a relation between soil types and soil carbonates. Groundwater fluctuations have been distinguished in Gt classes. Levee soils have high Gt (VII), basin soils lower Gt's (V and lower).

The soil maps show a single meander belt with coarse-silty levee soils (L), clayey and peaty basin soils (M, Z and V) and soils in transition (LM, LML). The surface level of peaty soils sometimes is higher than that of a levee. At sites where springs occurred good drainage was impossible and peat was unable to settle.

The soil map shows a difference in soil conditions upstream and downstream from Valkenburg. Upstream from Valkenburg basin soils are well developed, downstream from Valkenburg a coarse-silty layer is overlying deposits with other textural classes. The reason for this phenomenon is not clear.

A noticeable feature of the valley are the fans in front of tributary-valleys. The border between the fluvial and the colluvial soils bends towards the valley axis. From the shape of some fans it is clear that man was responsible. Instead of the usual semi-circular form of a fan, a straight projection is present, that probably is the last remnant of a water course over the fan. The function of such a ditch was and still is to drain the farm land. The farmers removed the aggraded sediment in the ditch and throwed over the sides.

The present landscape is a landscape of pastures, trees and pollards, hedges, etc. In some places several kinds of grasses and herbs still indicate the hydrological conditions. Birds find a good biotope in this landscape.

The valley is important not only for farming, but also for recreation. Unfortunately recent developments as housebuilding, a new motorway and pollution, have upset the character of the valley. The pleasant character of the valley has mainly been created by agricultural use and it can only be saved for the future provided agriculture continues to remain its essential feature.

6. SAMENVATTING

GEOLOGIE EN BODEMGESTELDHEID VAN HET GEULDAL

De Geul ontspringt bij Eynatten in België. De Geul heeft een lengte van ongeveer 56 km, waarvan 2/3 deel in Nederland (fig. 1). De Geul is een snelstromende rivier, met een gemiddeld verhang van 3 m/km (minimum 1,33 m/km bij Houthem, maximum 7,62 m/km bij Epen). Het gemiddeld debiet van de Geul bij Meerssen bedraagt ongeveer 2300 l/sec (minimum 960 l/sec, maximum 65.000 l/sec).[1] Overstromingen van lage terreinen komen nog regelmatig voor. Grote overstromingen van het gehele dal zijn zeldzamer.

[1] Gegevens van de Provinciale Waterstaat van Limburg.

Uit de bodemkartering en geologische doorsneden is een goed beeld van de Holocene opvulling van het Geuldal verkregen. De geologische opbouw en de bodemgesteldheid weerspiegelen duidelijk de gevolgen van de ontginning en het agrarisch landgebruik (ontbossing, erosie) in dit deel van het Zuidlimburgse lössgebied.

In de geologische opbouw kunnen vijf fasen worden onderscheiden. In fase I (fig. 3a) valt de laat-Pleistocene dalopvulling met grof materiaal, afgezet door een verwilderde rivier.

Fase II (fig. 3b) valt in het oudere Holoceen, toen Zuid-Limburg nog geheel met bos was bedekt. In die tijd had de Geul een veel kleiner en regelmatiger debiet en voerde vooral bronwater af. Er werd weinig mineraal materiaal meegevoerd; de sedimentatie beperkte zich tot zware klei. Ook veen hoopte zich op.

In fase III (fig. 3c) trad er een verandering in de aktiviteit van de Geul op, die een gevolg was van een veranderend leefpatroon van de mens. De mens was van jagen en vissen en verzamelen van voedsel overgegaan op landbouw, wat gepaard ging met ontbossing. Hiervan was erosie het gevolg. De eerste landbouwers, de Bandkeramische bewoners van Zuid-Limburg, troffen op de lössgronden met hun oorspronkelijke lichte en zwakzure bovengronden een betrekkelijk licht bos aan. Zowel de aard van de begroeiing als de bodemkundige eigenschappen van de lössgronden betekenden een gunstige situatie voor de vestiging van de landbouw.

Doordat de agrarische aktiviteiten van de Bandkeramische bewoners zich vooral op de plateaus afspeelden, terwijl de hellingen met bos bedekt bleven, bleef de (geringe) erosie en daarmee ook de sedimentatie door de Geul beperkt. De grote Bandkeramische woonplaatsen waren ver buiten het Geuldal gelegen. In die tijd zal het oorspronkelijke, zeer rustige karakter van de Geul dan ook maar weinig kunnen zijn veranderd. Dit werd anders in de Romeinse tijd toen grote delen van het Zuidlimburgse lössgebied werden ontbost. Erosie trad in versterkte mate op, de rivieren – ook de Geul – kregen meer water en slib af te voeren en er vond veel sedimentatie plaats. Het transporterend vermogen van de Geul was zozeer toegenomen, dat er in plaats van zware klei en veen voortaan afzettingen van een lichtere textuur, voornamelijk lössachtig van samenstelling, sedimenteerden. Het is in het algemeen nog onzeker of de sterkste erosie in het begin of aan het eind van een belangrijke bewoningsperiode plaatsvindt.

Ook in de Middeleeuwen trad er een sterke erosie op. De Geul kreeg nu periodiek zelfs nog meer water af te voeren en had ook hogere stroomsnelheden dan voorheen. Dit leidde tot een versterkte opslibbing met lichtere sedimenten (fase IV, fig. 3d). Veel bodemprofielen bezitten een textuuropbouw van licht-op-zwaar, zodat er twee sedimentatiefasen moeten zijn geweest. Dit moet weer in verband staan met twee belangrijke bewoningsperioden waarin landbouwaktiviteiten met het optreden van erosie plaatsvonden. In de tijd na de Middeleeuwen is de intensiteit van sedimentatie nog verder toegenomen tengevolge van de voortgaande ontbossing, de toegenomen ontwatering en de vergrote waterafvoer (fase V, fig. 3e). De Geul sneed zich nu langzamerhand in tot in de Pleistocene ondergrond. De jongste afzettingen zijn zandig en kalkhoudend en liggen lager dan voorheen (fig. 4).

In het lössachtige sediment zijn drie textuurklassen onderscheiden met resp. 10–20%, 20–30% en meer dan 30% lutum, die op de kaart en hieronder zijn aangeduid met L, M en Z. Venig materiaal of veen is weergegeven als V. De oeverwallen hebben als textuurprofiel L tot 120 cm, vaak ook tot 220 cm. Bodemprofielen buiten de oeverwallen vertonen naar onderen meestal een toename in textuur. In de komgebieden komt in het textuurprofiel de tweeledige opbouw als gevolg van de verschillende erosie- en sedimentatie-intensiteit in de op elkaar volgende kultuurperioden fraai tot uiting.

Voor zover de bodemprofielen kalk bevatten, zijn dit voornamelijk bodemprofielen in oeverwalpositie met een lichte textuur (L). Fig. 5 geeft voor een gedeelte van het Geuldal een vereenvoudigde grondwaterfluktuatiekaart ('Gt'-kaart) weer. Het beeld op deze kaart vertoont een nauwe samenhang met de aanwezigheid van oeverwallen en kommen op de bodemkaart (fig. 6).

De bodemkaart is gebaseerd op de onderscheiding van de textuurklassen L, M en Z en op de aanwezigheid van veen (V), dit alles tot op een diepte van 120 cm (Voor fig. 7 tot op een diepte van 220 cm). Zowel de fluviatiele als de colluviale gronden hebben een lössachtige textuur. Als grens tussen beide is genomen de overgang van een vlak gelegen naar een hellende bodem. Deze grens verloopt onregelmatig, vooral bij die zijdalen waarvoor een colluviale lob ligt.

Sommige van deze lobben, zoals die bij Vroenhof, bezitten een merkwaardig smal uitsteeksel (fig. 8). Dit is ontstaan vooral als gevolg van agrarisch gebruik om het uiteinde open te houden van de zijbeek, die alleen periodiek, namelijk gedurende tijden van veel neerslag, snel invallende dooi en zware regenval bij onweersbuien, in korte tijd veel water afvoerde en die in en voor de uitmonding in het Geuldal veel slib sedimenteerde. Daarom werd dit deel van de zijbeek regelmatig uitgediept en verbreed. Het grondoppervlak ter weerszijden hiervan is daardoor voortdurend hoger geworden.[1]

De Geul heeft slechts één stroomgordel gevormd. De breedte van de oeverwal (eenheid L) is gering, soms maar 50 m. De plaatsen waar zware klei en veen voorkomen, in de kommen, liggen altijd aan de tegenovergestelde zijde van het dal als die waar de stroomgordel ligt. Veel bodemprofielen hebben een kleigehalte dat toeneemt bij grotere diepte.

Er bestaat een verschil tussen de bodemgesteldheid stroomopwaarts en stroomafwaarts van Valkenburg. Kommen met zware klei en veen zijn stroomopwaarts van Valkenburg beter ontwikkeld; stroomafwaarts is er overal een dek van licht materiaal aanwezig. De oorzaak van dit verschil is vooralsnog onduidelijk.

Vermeldenswaard is nog dat tussen Geulhem en Rothem in de ondergrond een oud riviersysteem uit het Holoceen aanwezig is en dat stroomafwaarts van Meerssen de Geul drie takken heeft. Uit de bodemgesteldheid komt naar voren dat twee ervan, de Grote Geul en de Kleine Geul, betrekkelijk jong moeten zijn.

[1] Een dergelijke beek voert vaak de naam van vloedgraaf.

Het Geulke lijkt een echte molenbeek.

Van het oorspronkelijke broekbos in het Geuldal is niets over. Alleen in veld- en plaatsnamen komt de relatie met het oorspronkelijke 'broek' nog uit. Het dal is geheel een agrarisch gebied. Vroeger was het voornamelijk als hooiland ('beemd') in gebruik.

Op veel plaatsen is er nog een betrekkelijk kleinschalig zeer afwisselend landschap met wei- en hooilanden. De grassen- en kruidenvegetatie vertoont op verschillende plaatsen nog duidelijk verband met de hydrologische bodemgesteldheid. Populieren en wilgen langs de Geul en in lanen of als bossen, geknotte bomen van velerlei soort, heggen langs de paden en percelen verhogen de landschappelijke waarde en zijn tevens een goede biotoop voor vogels en insekten. Helaas plegen vervuilingen van velerlei soort, bebouwing (o.a. Schin op Geul), campings, wegen (autosnelweg) en bepaalde agrarische aktiviteiten een aanslag op het landschap.

Het Geuldal heeft zowel voor de landbouw als voor de rekreatie een belangrijke funktie. Verdere ongewenste ontwikkelingen moeten worden voorkomen, waarbij bedacht moet worden dat de landbouw een essentieel element in het landschap van het Geuldal is.

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INCIDENCE AND DISTRIBUTION OF CARBONATES IN THE SOILS OF THE MEANDERING RIVER GEUL

R. Miedema

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1. INTRODUCTION

The published evidence gives little detailed information on the incidence and distribution of carbonates in fluvial soils of the large meandering rivers. Levee soils are predominantly calcareous and a description has been given of their progressively deeper decalcification with age of the levee, leading to complete decalcification of some of the oldest soils (PONS, 1957; VAN DEN BROEK and VAN DER MAREL, 1964; SOIL SURVEY INSTITUTE, 1977). Practically all basin soils are non-calcareous, chiefly as a result of decalcification during sedimentation (BENNEMA, 1953; PONS, 1957). This proces has been described in detail for Dutch estuarine and marine sediments (BENNEMA, 1953; ZONNEVELD, 1960; VAN DER SLUYS, 1970).

But the complex nature of the incidence and distribution of carbonates in the soils of the meander belts of the large Dutch rivers is imperfectly understood.

The fluvial soils of the Geul are a small-scale model of the sedimentation system of the meandering river (VAN DE WESTERINGH, 1980). During a soil survey of this area the presence of carbonates, as determined by the reaction of the soil with 2 M HCl, was one of the characteristics checked at every 10 cm of each augering. At a number of sites the presence of carbonates in the upper 1.2 or 2.2 m of the soils along the Geul was investigated in detail by augerings 1–20 m apart. Micromorphological and chemical observations were made of samples of two profiles, and water samples of the river, two tributaries fed by wells and a well discharging into the river were analysed.

From these data two models were derived with the objective of explaining the incidence and distribution of carbonates in the soils of the meander belt of the Geul. These models are discussed in this paper and it is hoped they may throw more light on the complex incidence and distribution of carbonates in the fluvial soils of the meander belts of the large rivers of the Netherlands.

Some help will also be provided in distinguishing sedimentation phases and former river systems according to the incidence of carbonates in the deeper subsoil.

The presence of fans along the valley border in front of dry valleys (VAN DE WESTERINGH, 1980) is a characteristic feature of this part of the Geul valley and the associated carbonate incidence will be discussed.

2. OBSERVATIONS, INTERPRETATION AND DISCUSSION

2.1. CARBONATES DEPOSITED AS PART OF THE SEDIMENT LOAD

VAN DEN BROEK and VAN DER MAREL (1964) have shown that the carbonates in the alluvial soils of the Geul are almost exclusively $CaCO_3$.

To check the possibility of chemical precipitation of $CaCO_3$ from the water of the Geul, analyses were made of water samples of the river, a well and two tributaries fed by wells. The results are presented in Fig. 1. The well and tributaries fed by wells (from Cretaceous limestone) have the highest concentrations of Ca, HCO_3 and H_4SiO_4 (owing to the solution of Cretaceous limestone and silica leaching from overlying Pleistocene terrace deposits) and have distinctly lower Mg, K, Na, Cl and SO_4 contents than the river samples. Pollution by inorganic fertilizers, organic manure and other human influences may be responsible for the higher concentrations of these ions in the river samples. Intermediate contents are found downstream of the confluence of the Geul with water from wells and tributaries. The pH is fairly constant and ranges from 7.1 to 7.3.

Calculations were made of the ionic strength and the ion activity product (I.A.P. at 25 °C, 20 °C, 15 °C, 10 °C and 5 °C). The former is highest in the wells

TABLE 1. Results of water analyses of the Geul (mol m^{-3})

Sample	($\frac{1}{2}Ca^{2+}$)	($\frac{1}{2}Mg^{2+}$)	(Na^+)	(K^+)	(HCO_3^-)	(Cl^-)	($\frac{1}{2}SO_4^{2-}$)	(H_4SiO_4)	pH	I (a)	I.A.P.: K_{so} (f) 5°C	10°C	15°C	20°C	25°C
Geul near Wylre	4.55	0.67	0.91	0.15	4.06	0.80	1.24	0.47	7.2	.0094	0.30	0.41	0.55	0.70	0.96
Geul near Etenaken	4.51	0.69	0.78	0.13	3.96	0.88	1.13	0.40	7.3	.0092	0.37	0.50	0.67	0.86	1.19
Geul near Keutenberg	4.51	0.69	0.72	0.12	4.03	0.80	0.97	0.40	7.3	.0090	0.38	0.51	0.68	0.88	1.21
Geul near Schin op Geul	4.65	0.66	0.70	0.11	4.18	0.70	1.17	0.44	7.3	.0093	0.41	0.54	0.73	0.94	1.29
Geul near Valkenburg	4.59	0.64	0.77	0.11	4.15	0.90	1.13	0.53	7.3	.0093	0.40	0.53	0.72	0.92	1.27
Well/tributary Etenaken	5.54	0.57	0.35	0.07	5.03	0.64	0.72	0.88	7.3	.0099	0.55	0.76	1.03	1.32	1.83
Well Keutenberg	5.90	0.43	0.19	0.03	4.85	0.66	0.76	0.94	7.1	.0100	0.37	0.49	0.67	0.85	1.18
Well/tributary Schin op Geul	5.31	0.54	0.27	0.06	4.85	0.60	0.65	0.84	7.3	.0099	0.52	0.69	0.92	1.20	1.65
Etenaken downstream	4.95	0.65	0.62	0.11	4.42	0.72	0.98	0.65	7.2	.0095	0.36	0.48	0.65	0.84	1.15
Keutenberg downstream	5.50	0.47	0.29	0.05	4.76	0.60	0.76	0.74	7.2	.0096	0.43	0.57	0.77	0.99	1.36
Schin op Geul downstream	4.67	0.65	0.69	0.11	4.21	0.70	1.13	0.37	7.3	.0093	0.41	0.54	0.73	0.95	1.30

a) I = Ionic strength $= \frac{1}{2}\sum m_i \times z_i^2$ (m_i = concentration ion i in mol dm^{-3}; z_i = valence of ion).

b) Davies equation: $\log \gamma_i = A \times z_i^2 \left(\frac{\sqrt{I}}{1+\sqrt{I}} - 0.2\, I\right) \rightarrow \gamma Ca^{2+}$ and $\gamma HCO_3^- \rightarrow [Ca^{2+}]$ and $[HCO_3^-]$

c) $\frac{[H^+][CO_3^{2-}]}{[HCO_3^-]} = K \rightarrow [CO_3^{2-}]$

d) I.A.P. = Ionic Activity Product = $[Ca^{2+}][CO_3^{2-}]$

e) $\frac{[Ca2^+][CO_3^{2-}]}{[CaCO_3]} = K_{so}$

f) $\frac{I.A.P.}{K_{so}}$ = degree of saturation

The values used for the constants A, K and K_{so} at various watertemperature are taken from GARRELS & CHRIST (1965) and tributaries. Dividing the I.A.P. by the solubility product (K_{so}) of $CaCO_3$ gives the degree of $CaCO_3$ saturation at a given temperature of the water. No supersaturation with $CaCO_3$ occurs at normal water temperatures of the Geul ranging from 3 °C to 15 °C (MRS. BAKKER, pers. comm., 1979). Chemical precipitation of $CaCO_3$ can therefore be ruled out, nor was it observed.

The carbonate particles in the Geul sediments must be derived from sedimentation as part of the sediment load of the river. This conclusion is borne out by a micromorphological study of two levee soils (Schin op Geul and Kapolder). The size of the observed carbonate skeleton grains found scattered in the groundmass is comparable to that of the other skeleton grains; it is larger in the sandier Kapolder than in the siltier Schin op Geul profile. The morphology of the carbonate particles observed ranges from coarse to fine crystalline. The carbonate particles are derived from Cretaceous limestone and calcareous loess. Erosion may bring this material down to the Geul valley where it is taken up by the Geul and deposited downstream. Carbonate particles are also produced by erosion of the river's fluvial calcareous deposits and resedimentation downstream. The coarse crystalline type of carbonate particles originates from limestone fragments and calcareous loess. The fine crystalline carbonate particles are probably secondary carbonates derived from eroded loess profiles redeposited by the Geul and now found scattered in the groundmass. The most recent sediment of the Geul in still unhomogenized sandy loam terraces on a lower elevation than the levee deposits (VAN DE WESTERINGH, 1980) has an invariably high $CaCO_3$ content (8%–10% w/w). Determinations of material showing effervescence with 2 M HCl show that the $CaCO_3$ content in the older, completely homogenized brown silt loam levee soils along the river course ranges from 2–3% (w/w), which is in agreement with the contents given by TEUNISSEN VAN MANEN (1958) and VAN DEN BROEK and VAN DER MAREL (1964). The latter refer to a similar difference in $CaCO_3$ content between fresh sediment and levee soils of the Meuse.

2.2. INCIDENCE AND DISTRIBUTION OF CARBONATES ASSOCIATED WITH THE FLUVIAL SEDIMENTATION REGIME

The sedimentation pattern along the meandering Geul is due to accretion of the inner and erosion of the outer bends. During short periods of flooding sediment is deposited over the entire floodplain. The carbonate distribution pattern was studied in detail in several meander belt sections by augerings 1–20 m apart. The presence of carbonates in the groundmass in layers of a minimum thickness of 20 cm, irrespective of the relative amounts of $CaCO_3$, was mapped in 7 legend units. These are based on a division of the upper 1.2 m into three parts by arbitrary boundaries at 40 and 80 cm. The legend units are shown in Fig. 2.

2.2.1. The simple model

Fig. 2 shows some representative inner bends in which we observe a succession

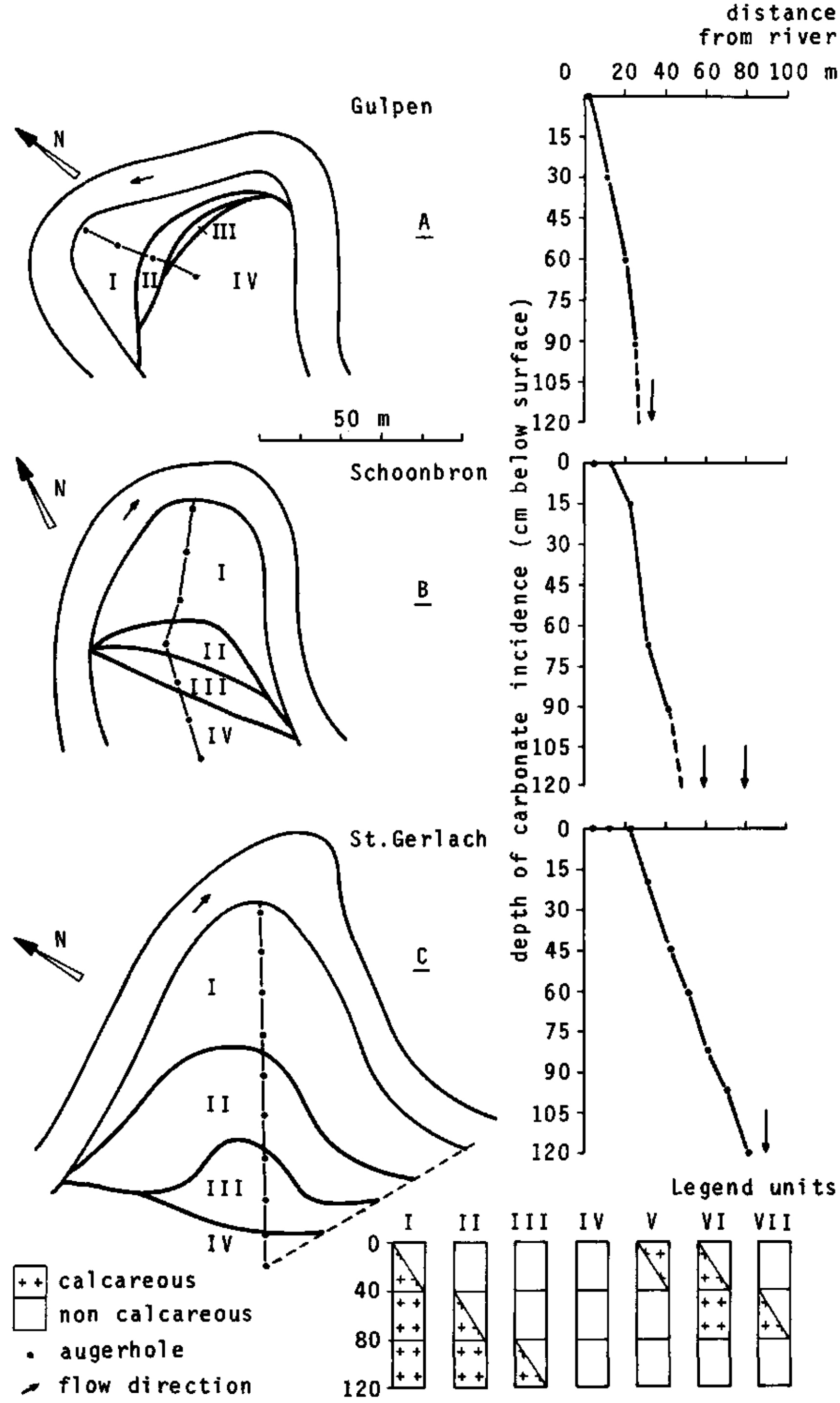


FIG. 2. Carbonate distribution pattern following the simple model in some representative inner bends, and depth of carbonate incidence as a function of the distance from the river.

of arcuate bodies representing legend units I, II and III at an increasing distance from the river. The location of these bends is indicated in Fig. 6. At a still greater distance from the river no carbonates are found within a depth of 1.2 m (legend unit IV).

The accretion of the sediment in such inner bends shows corresponding time-dependent arcuate bodies, thus indicating a difference in age in the sediments in the direction mentioned. The outer bends are in an erosive position, so that the sediment is older than that found in inner bends. It is therefore conceivable that the outer bends contain no carbonates or units with carbonates starting at a greater depth. The micromorphology of the Kapolder (unit I) and Schin op Geul (unit III) profiles shows that the primary carbonate skeleton grains are severely corroded near the boundary between calcareous and non-calcareous material. Secondary carbonates were occasionally observed in and around voids (calcitans and neocalcitans) (Fig. 3), this being due to decalcification. The fact that secondary carbonates were only occasionally observed in the field or in thin sections is due to the discharge of the dissolved $Ca(HCO_3)_2$ by the groundwater which fluctuates with the level of the river. The shape of the graphs showing the depth of carbonate incidence as a function of the distance from the river (Fig. 2) is determined by the fact that the rate of accretion of an inner bend increases with increasing excentricity of the meander combined with decalcification. The latest deposits show shallower decalcification and were deposited over a shorter period of time.

Hence the carbonate distribution pattern is caused by decalcification as a function of the age of the sediment, as determined by the sedimentation pattern in the accreting inner bend. The oldest deposits are farthest from the river in an inner and in outer bend position and have been decalcified to the greatest depth. In the older, deeply decalcified profiles, weak illuvation features were observed in the form of channel matri-ferri-argillans as described by VAN SCHUYLENBORGH *et al.* (1970) in a non-calcareous Geul profile.

2.2.2. *The interference model*

The pattern found in inner bends may be more complex. Fig. 4 shows the observations in two such bends. Their location is also shown in Fig. 6. The pattern observed cannot be explained with the use of the simple model discussed above. In Fig. 4A legend unit I occurs along the river in the form of a wider strip in the eastern part of the bend with an east-west oriented extension, and a fairly narrow strip in the western part. A zone with legend unit II accompanies the zone with unit I, and an island with legend unit III occurs in the western part of the bend. To the north no carbonates were found within a depth of 1.2 m (legend unit IV), but this lies outside the accretion area of the bend.

This asymmetrical pattern of carbonate incidence does not correspond to the accretion asymmetry of the present shape of the meander bend, as one would expect a wider strip of recent sediments in the western part (cf. also the patterns in Fig. 2). The east-west extension of unit I is topographically somewhat lower and scattered coarse, gravelly bedding material was found within a depth of 1.2 m.

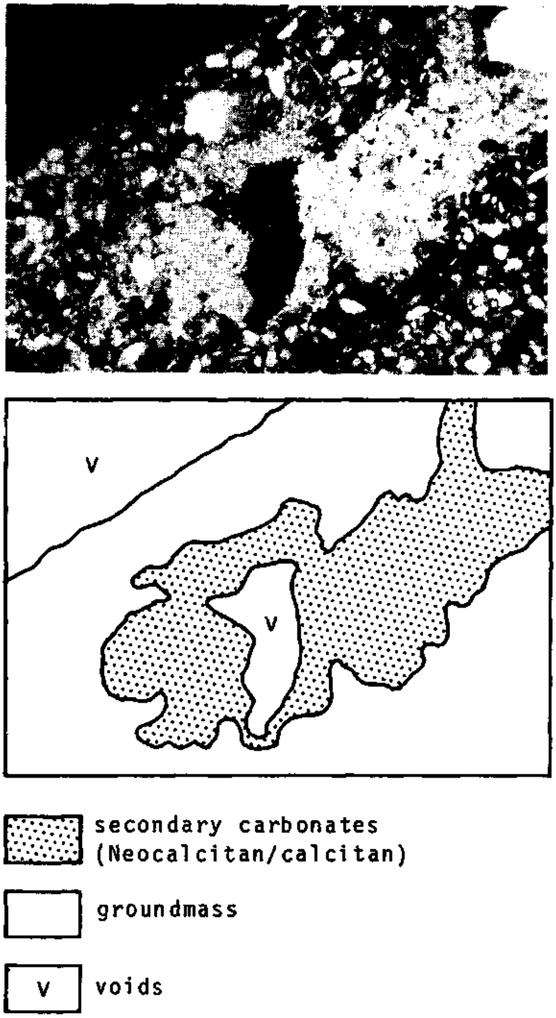


FIG. 3. Secondary carbonates in and around voids in the subsoil of the Schoonbron inner bend.

It would seem likely that changes in the river bed inside the meander belt interfered with the pattern of the simple model. The former channels were filled with more recent calcareous material to almost the same level as the surrounding soils, so that their profiles are not decalcified to the same depth. This can also be seen in the graph showing the depth of carbonate incidence as a function of the distance from the river (Fig. 4B). The Tranchot topographical map of 1803–1820 shows a meander of the same shape; hence the assumed former meander must antedate 1800.

The example in Fig. 4C comes from a part of the Geul valley where TEUNISSEN

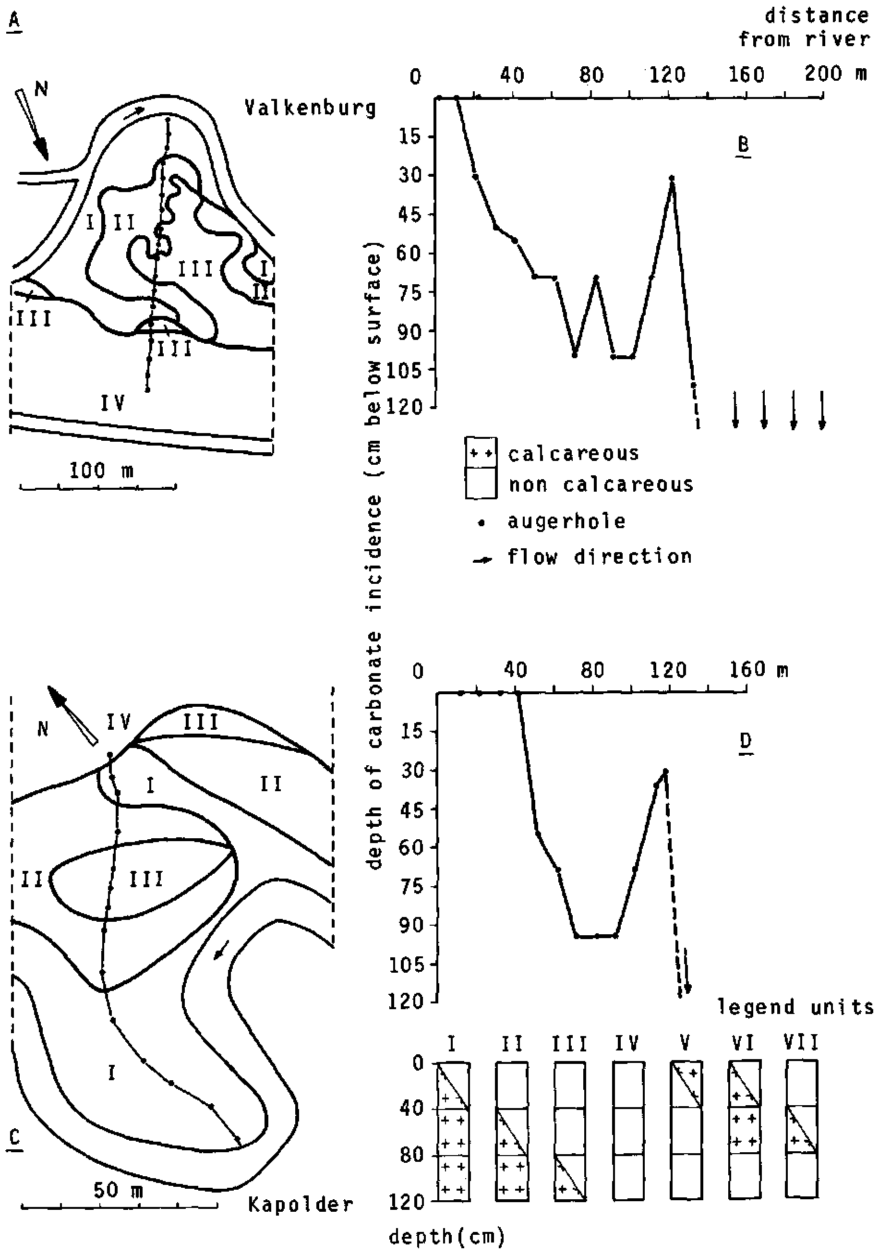


FIG. 4. Carbonate distribution pattern following the interference model in some representative inner bends, and depth of carbonate incidence as a function of the distance from the river.

VAN MANEN (1958) carried out a very detailed soil survey. He found distinct former channels which are responsible for the pattern of carbonate incidence and the associated graph of depth of carbonate incidence as a function of the distance from the river (Fig. 4D). Here too we find an island of decalcified soils surrounded by an area of shallower decalcification.

It can also be seen from Fig. 6 that changes in the river bed must be taken into account to explain the distribution pattern of carbonates; here the old channels near Oud Valkenburg and cut-off meanders near Etenaken are still clearly visible in the field and the distribution pattern of carbonates is in agreement with the sedimentation pattern of the former course of the Geul according to the simple model.

2.2.3. *Sedimentation due to flooding*

Sedimentation due to flooding is responsible for the more heavily textured soils in the transition and basin position (texture classes M and Z; VAN DE WESTERINGH, 1980). These soils are usually non-calcareous as a result of complete syn-sedimentary decalcification under conditions of poor drainage (BENNEMA, 1953; PONS, 1957; ZONNEVELD, 1960; VAN DER SLUYS, 1970). Minor amounts of pyrites and spherical iron hydroxides as oxidation products were observed in the peaty subsoil in thin sections of a basin profile near Schin op Geul and these may have speeded up the process of syn-sedimentary decalcification. The thin layer of L material covering more heavily textured deposits upstream of Valkenburg belongs to a more recent sedimentation stage (VAN DE WESTERINGH, 1980). This layer having been deposited in areas of poor drainage remote from the river, it may have been completely decalcified by a syn-sedimentary process. Alternatively, its age may be such that it has lost its carbonates by the decalcification process described for the levee deposits. But downstream of Valkenburg this deposit is more wide-spread and thicker and is still not completely decalcified. For this reason the extent of carbonates associated with the sedimentation regime of the Geul increases downstream of Valkenburg and calcareous soils are no longer exclusively found in inner bends.

2.2.4. *Subsoil carbonates*

The incidence and distribution of subsoil carbonates (between 1.2 and 2.2 m), on which data are available from 1976, 1977 and 1978 and from deep augering sequences, may provide evidence to support VAN DE WESTERINGH's (1980) theories of important changes in the course of the Geul during its sedimentation history (Fig. 5). In this area the subsoil carbonates are found in lightly textured deposits underlying more heavily textured transition and basin deposits. In the present basin area former filled-in channels can be identified in the field by their somewhat lower topography, pointing to changes in the river bed. This has also been found in other areas now in a basin position with respect to the Geul.

But in extensive areas along the Geul the carbonate incidence in the subsoil is merely the continuation of this incidence in the upper 1.2 m. In such cases the decalcification sequence is extended by types with carbonates starting pro-

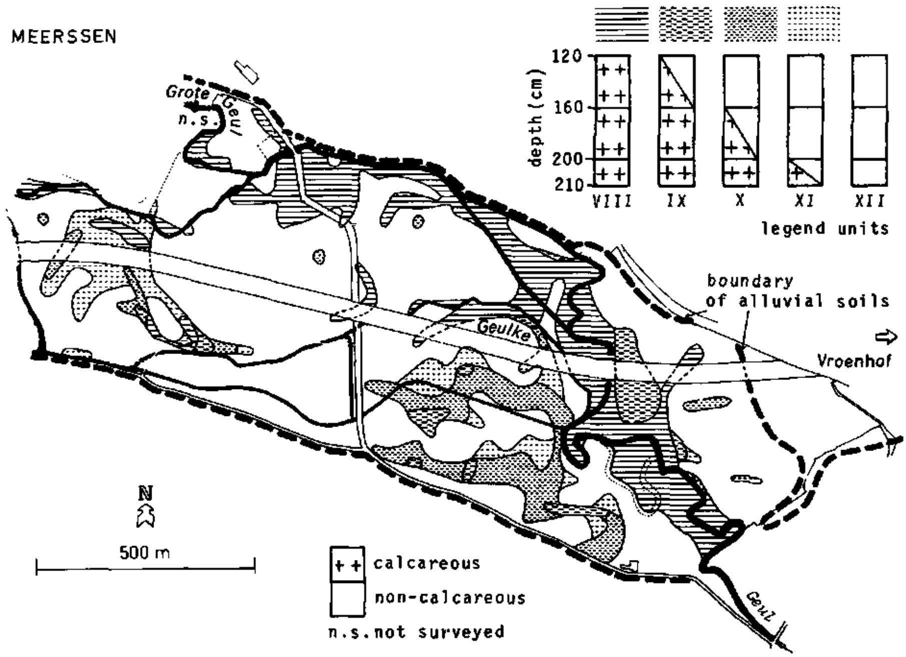


Fig. 5. Incidence and distribution pattern of subsoil carbonates (between 1.2 and 2.2 meters) in a selected area of the Geul valley.

gressively deeper in the subsoil between 1.2 and 2.2 m only, indicating a still deeper decalcification in older deposits at a larger distance from the Geul (sequence I–II–III–IX–X–XI–IV + XII). The texture of these soils remains L throughout the profile.

2.2.5. *Distribution of carbonate incidence associated with the sedimentation of the Geul*

Inspection of the carbonate distribution map (Fig. 6), bearing in mind the theories outlined above, shows that in the south-eastern part of the survey area between Partij and Gulpen only very limited amounts of carbonates along the Geul are found in clearly distinguishable former channels. This agrees with the observations made by VAN DEN BROEK and VAN DER MAREL (1964). The small amount of carbonates is due to the almost complete absence of steep Cretaceous limestone slopes south of Partij. The loess plateaus are not highly dissected and are mainly grassland and forest. Wells feeding the tributaries are derived from the Vaals formation (glauconitic green sand and clay of Cretaceous age; MEERMAN, 1975).

Between Gulpen and Wijlre the carbonates increase along the Geul. Near Wijlre in particular this part of the valley has suffered from fairly frequent flooding (MEERMAN, 1975), so that most of the levee soils may be relatively recent and not completely decalcified. Both the simple model (Fig. 2A) and the interference model are needed to explain the carbonate distribution. TEUNISSEN VAN MANEN (1958) surveyed part of this area and identified distinct former channels within the levee deposits where the interference model has to be used (Fig. 4C, D). Steep Cretaceous limestones slopes occur with very active wells discharging into the Geul and its Eyserbeek tributary (MEERMAN, 1975). The plateaus are more heavily dissected and mainly arable.

Between Wijlre and Valkenburg the carbonates are chiefly found in inner bends, following the simple model (Fig. 2B). Near Oud Valkenburg the carbonate incidence in former channels is very clear. One of the many active wells from Cretaceous limestone in this section discharging into the Geul was sampled and analysed (Fig. 1). The loess plateaus are fairly heavily dissected and are mainly arable.

Downstream of Valkenburg to the division of the Geul in two branches (near Vroenhof) carbonates are also more frequent around outer bends, although in a narrower strip and more deeply decalcified than in inner bends. The distribution can usually be explained by the simple model (Fig. 2C), although the interference model is occasionally needed (Fig. 4A, B). Steep Cretaceous limestones slopes border the valley to the south, but tributaries of the Geul from the north are fed by wells from the Oligocene Cerithien clay overlying Cretaceous limestone (MEERMAN, 1975). The plateaus are less highly dissected and mainly arable.

From the river fork near Vroenhof to the confluence of the three branches west of Meerssen carbonates are found in extensive areas between Grote Geul and Geulke with relatively shallow decalcification. Islands of unit IV surrounded by calcareous soils are a striking feature (Fig. 7A). They are usually surrounded by soils decalcified to 40–80 cm, and surrounded in turn by soils decalcified to 0–40 cm. Many former filled-in channels were observed in the field in the neighbourhood of the unit IV islands. The latest sedimentation phase of L material is widespread in this part of the valley; it is still calcareous and overlies more heavily textured deposits within a depth of 1.2 m (VAN DE WESTERINGH, 1980). This explains why units VI and VII are frequently found as shallower representatives of I and II. The extent and thickness of this latest deposit may be read from Fig. 7B (depth of carbonate incidence in this area). A clear picture of the sedimentation history of this area is obtained by combining Figs. 7A and B with Fig. 5 and comparing the result with the soil map of this part of the valley (VAN DE WESTERINGH, 1980). The carbonate distribution pattern results from the application of the interference model to larger areas; this will no doubt have to be done even more frequently when carbonates are distributed in the soils of the large rivers. Along the branches of the Geul the simple model can be successfully used.

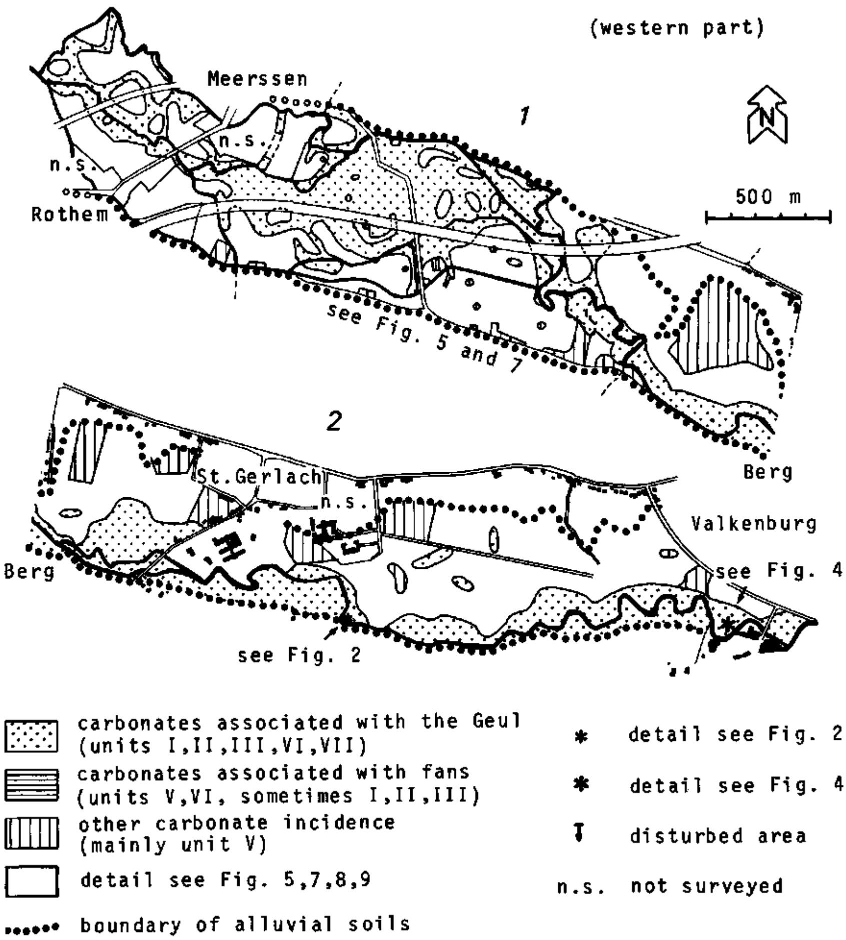
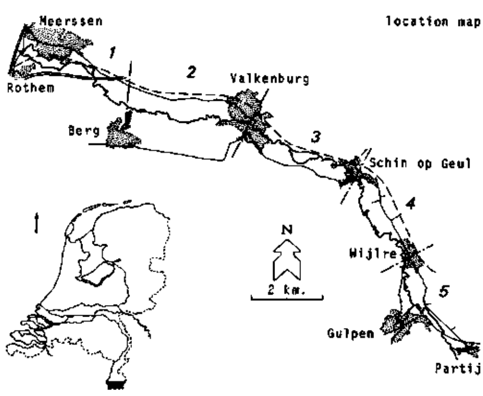
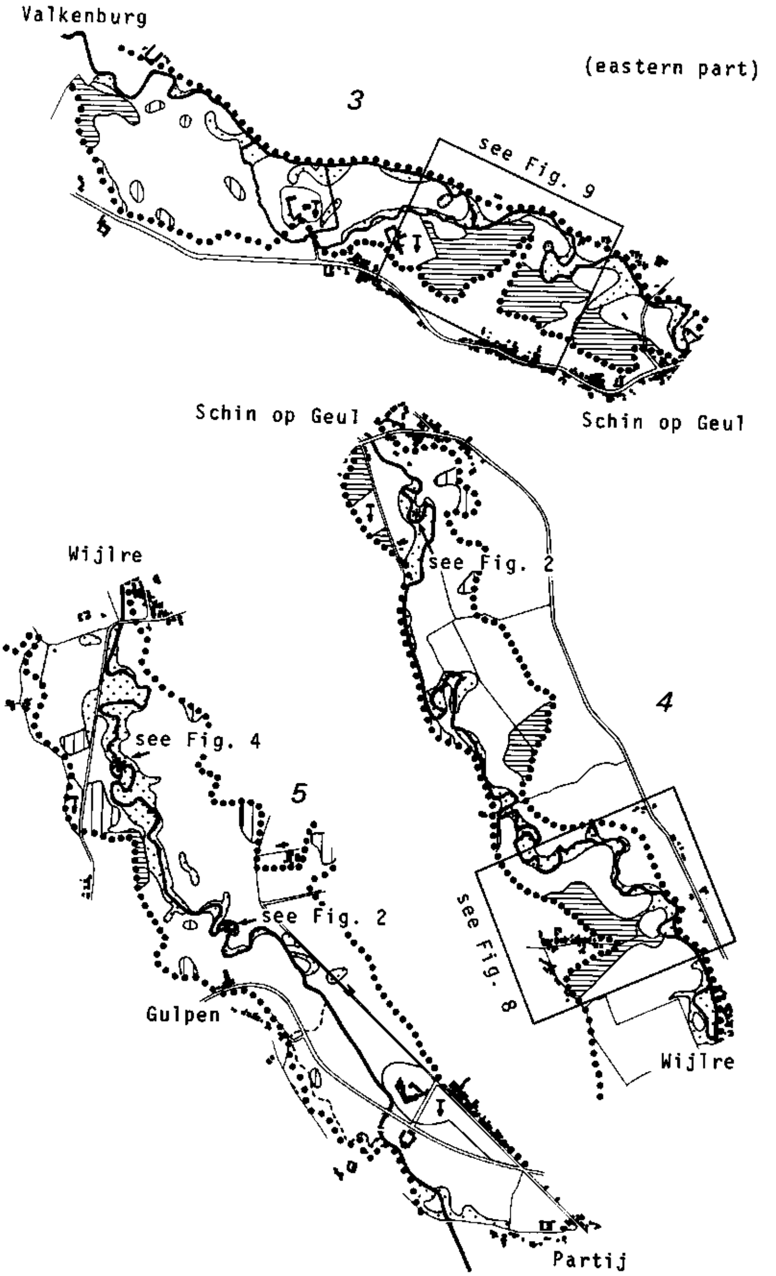
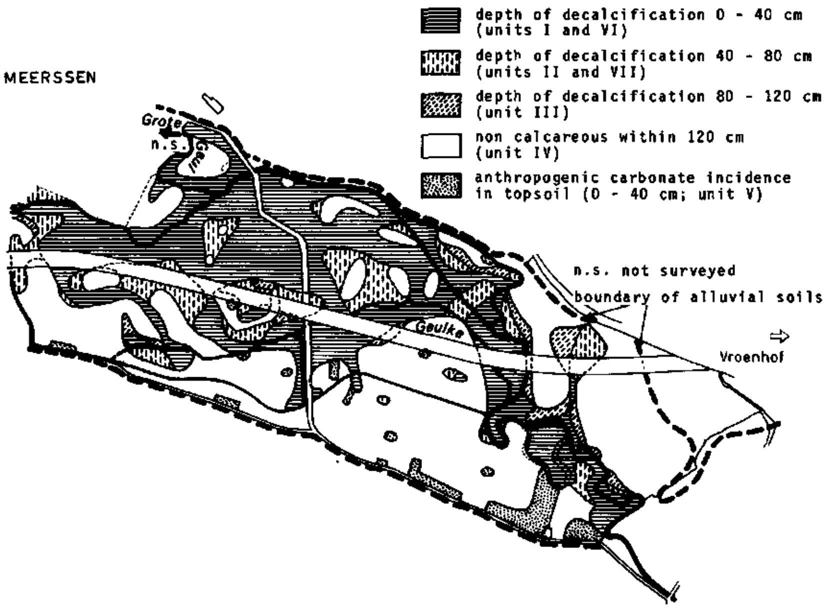


FIG. 6. Distribution of carbonate incidence in the soils of the river Geul (western part and eastern part).




Valkenburg
(eastern part)
3
see Fig. 9
Schin op Geul
Schin op Geul
see Fig. 2
Wijlre
4
see Fig. 4
5
see Fig. 2
see Fig. 8
Gulpen
Wijlre
Partij



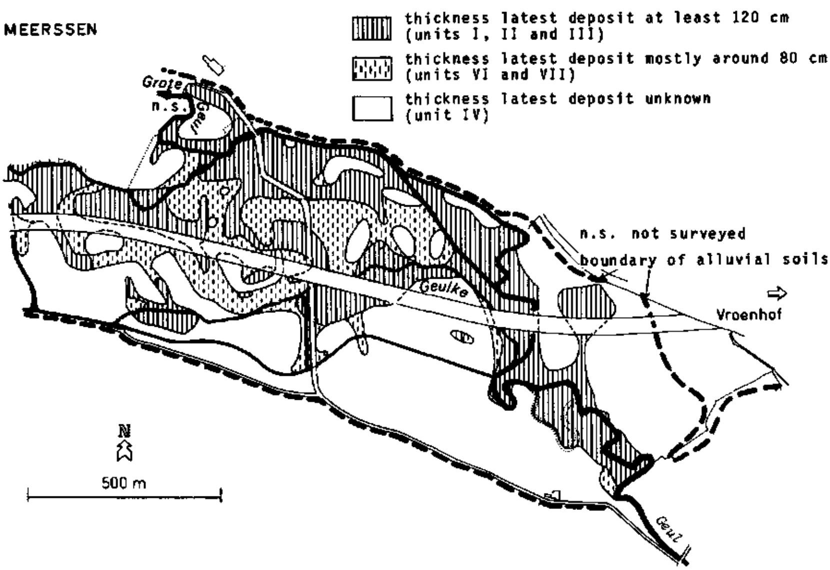


FIG. 7A. Carbonate incidence and depth of decalcification in an area with extensive deposits of the latest sedimentation phase.

FIG. 7B. Thickness of the deposits of the latest sedimentation phase based upon the depth of carbonate incidence, ignoring the depth of decalcification and anthropogenic influences.

2.3. Carbonates associated with fans

Fans are a characteristic feature of the Geul valley and occur along the valley border in front of dry valleys cutting into Cretaceous limestone or Tertiary deposits. The formation of these fans is described by Van de Westeringh (1980).

Where these fans originate from valleys cutting into Cretaceous limestone, the deposited material is calcareous and large areas of carbonates are found near Gulpen, near Stokkem, between Etenaken and Schin op Geul, between Schin op Geul and Oud Valkenburg. Fig. 8 shows that the Stokkem fan (for location cf. Fig. 6) is completely calcareous (unit I) and the calcareous material wedges out over the alluvial soils further away from the fan (succession of units VI and V). The two connections from the fan to the Geul are also distinctly visible. The fan between Schin op Geul and Oud Valkenburg in front of the 'Gerendal' (Fig. 9) shows a succession of units I, II and III from the road to the Geul. In this case progressively deeper decalcification has occurred in the older part of the sediments. Detailed augerings in the fan north-west of Etenaken (Kwantes and Snel, 1976) revealed successive stages of deposition, separated by decalcified intervals overlying peat in the deeper subsoil. Havinga and Van den Berg van Saparoea (1980) have presented palynological data on the age of the sediment overlying peat in the fan south of Etenaken.

Distinct fans are also found downstream of Valkenburg, but here they originate from side valleys cutting into non-calcareous Tertiary deposits, so that the actual fan is non-calcareous and not surrounded by calcareous deposits.

Fig. 6 shows the carbonate incidence associated with fans, and the difference noted above can be clearly seen.

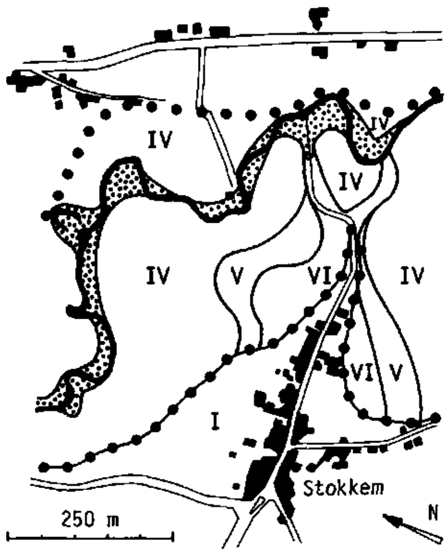
2.4. Other carbonate incidence

This includes calcareous soils at the foot of steep Cretaceous limestone slopes which are due to colluviation and normally excluded from alluvial soils.

Scattered carbonates, often in a basin position and almost exclusively corresponding to legend unit V, very often show sharp, angular boundaries on the map (Fig. 6). In most cases human influence is responsible. Farmers use limestone chips to improve the bearing capacity of the soil, as is known from information obtained in the area between Gulpen and Wijlre and between Valkenburg and St. Gerlach. Near Vroenhof the topsoil of large areas has been contaminated by transport of excavated limestone.

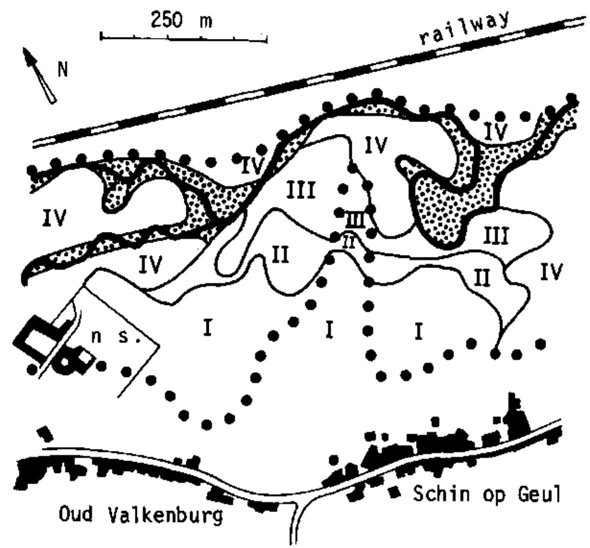
It must, however, be admitted that in some cases no satisfactory explanation can be given.

Summarizing, the incidence and distribution of carbonates linked to the sedimentation regime of the Geul can usually be satisfactorily explained by the use of the two models discussed. Van den Broek and Van der Marel's statement (1964) that the levee deposits of the Geul downstream of Gulpen are calcareous needs modification in view of the variation in extent of the calcareous



I legend unit I, calcareous to 120 cm
VI legend unit VI, calcareous to 80 cm
V legend unit V, calcareous to 40 cm
IV legend unit IV, non calcareous to 120 cm
carbonate incidence associated with the Geul (legend units I,II,III)
• • boundary of alluvial soils

FIG. 8. Carbonate incidence associated with fans; the Stokkem fan.



I legend unit I, depth of decalcification 0-40 cm
II legend unit II, depth of decalcification 40-80 cm
III legend unit III, depth of decalcification 80-120 cm
IV legend unit IV, non calcareous to 120 cm
carbonate incidence associated with the Geul (legend units I,II,III)
• • boundary of alluvial soils
n.s. not surveyed

FIG. 9. Carbonate incidence associated with fans; the Gerendal fan.

part of the levee soils along the valley. Subsoil carbonates in more lightly textured deposits underlying more heavily textured deposits in the present basin positions may help to identify past changes in the river bed. Studies on the dating of the sedimentation phases (HAVINGA and VAN DEN BERG VAN SAPAROEA, 1980) are needed to ascertain the decalcification rate with the use of such modern methods as those described by LEEDER (1975), SALOMONS (1975) and SALOMONS and MOOK (1976).

Another important part of the carbonate incidence can be linked to the presence of fans in front of dry valleys cutting into Cretaceous limestone.

Most of the other carbonate occurrence can be attributed to the human influence responsible for the calcareous topsoil.

3. ACKNOWLEDGEMENTS

I gratefully acknowledge the contributions made by the students KWANTES-DORREPAAL, SNEL, BROEKHUIZEN, VAN HEMMEN, BALTISSEN, DE BOO, OOMEN and VAN DER ZEE, who carried out the detailed investigations needed to check the models described.

I would also like to thank my colleagues for the stimulating discussions on the proposed models and their constructive criticism of earlier drafts of this paper.

4. SUMMARY

Very detailed field research showed that the incidence and distribution of carbonates in the fluvial soils of the meander belt of the river Geul could be explained by the use of two models.

In the simple model the pattern of distribution of carbonates in inner bends of arcuate bodies with a progressively deeper incidence of carbonates according to their distance from the river corresponds to the accretion of an inner bend followed by time-dependent decalcification.

In the interference model the pattern of distribution of carbonates is complicated by changes in the river bed inside the meander belt. The distribution patterns observed can be explained by reconstructing the sedimentation sequence and using the simple model.

The more heavily textured transitional and basin deposits are non-calcareous as a result of synsedimentary decalcification. This enables us to distinguish sedimentation phases, likewise on the basis of carbonate incidence. Evidence of former river systems, sometimes situated in a basin position with respect to the present course of the river (buried levees), is provided by the incidence of

carbonates in the deeper subsoil in lightly textured deposits underlying non-calcareous, more heavily textured deposits.

One peculiar feature is the large areas of carbonates found irrespective of their levee or basin position and associated with fans along the valley border in front of dry valleys cutting into Cretaceous limestone.

It is hoped that the ideas put forward in this paper may throw more light on the little understood complex incidence and distribution of carbonates in the meander belts of the large rivers of the Netherlands.

5. SAMENVATTING

VOORKOMEN EN VERBREIDING VAN CARBONATEN IN DE GRONDEN VAN DE MEANDERENDE GEUL

Het voorkomen en de verbreiding van carbonaten in de fluviatiele gronden van de meandergordel van de Geul kan verklaard worden door gebruik te maken van twee modellen, zoals is gebleken uit zeer gedetailleerd veldonderzoek.

In het eenvoudige model laat het distributiepatroon van de carbonaten in binnenbochten een schilvormige opeenvolging zien, waarbij de diepte van voorkomen van de carbonaten toeneemt met de afstand tot de rivier. Dit patroon is in overeenstemming met de laterale sedimentatie van een binnenbocht, gekoppeld aan een in de tijd voortschrijdende ontkalking.

In het interactiemodel wordt het patroon ingewikkelder door stroomverleggingen binnen de meandergordel. Niettemin kan men de waargenomen patronen verklaren door een reconstructie van de sedimentatiegeschiedenis, waarna het eenvoudige model weer kan worden toegepast.

De in kompositie en in overgangspositie afgezette lutumrijkere gronden zijn kalkloos tengevolge van synsedimentaire ontkalking. Dit biedt de mogelijkheid om ook op basis van kalkhoudendheid sedimentatiefasen te onderscheiden. Het voorkomen van carbonaten in de diepere ondergrond in lichtere afzettingen gelegen onder zwaardere kalkloze afzettingen (begraven oeverwallen), is een aanwijzing voor voormalige stroomsystemen op plaatsen die soms in kompositie liggen ten opzichte van de huidige rivierloop.

Een bijzonderheid zijn de grote oppervlakken kalkhoudende gronden, die onafhankelijk van stroomrug- of kompositie voorkomen, en die samenhangen met colluviumtongen voor droge dalen, ingesneden in de kalksteenafzettingen uit het Krijt.

Hopelijk kunnen de hier gepresenteerde modellen een bijdrage leveren tot de ontrafeling van de momenteel nog weinig begrepen complexiteit van het kalkvoorkomen in de meandergordel van de grote rivieren van Nederland.

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FORMER VEGETATION AND SEDIMENTATION IN THE VALLEY OF THE RIVER GEUL

A. J. Havinga and R. M. van den Berg van Saparoea

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1. AIM OF THE INVESTIGATION

A tentative investigation was made into the age of the loess deposits of fluvial or colluvial origin in the valley of the river Geul. Our aim was to establish whether these deposits could have been the indirect result of the deforestation which began with the introduction of agriculture in the hilly region of South Limburg. If so, they would be of relatively young date.

Being of a tentative kind, the investigation was kept simple and limited in scope. Only two profiles were subjected to pollen analysis, one consisting of fluvial loess on peat and the other of colluvial loess on peat. The peat part of the two profiles was analysed over its entire depth, the covering mineral part near the contact zone only.

2. THE PROFILES STUDIED

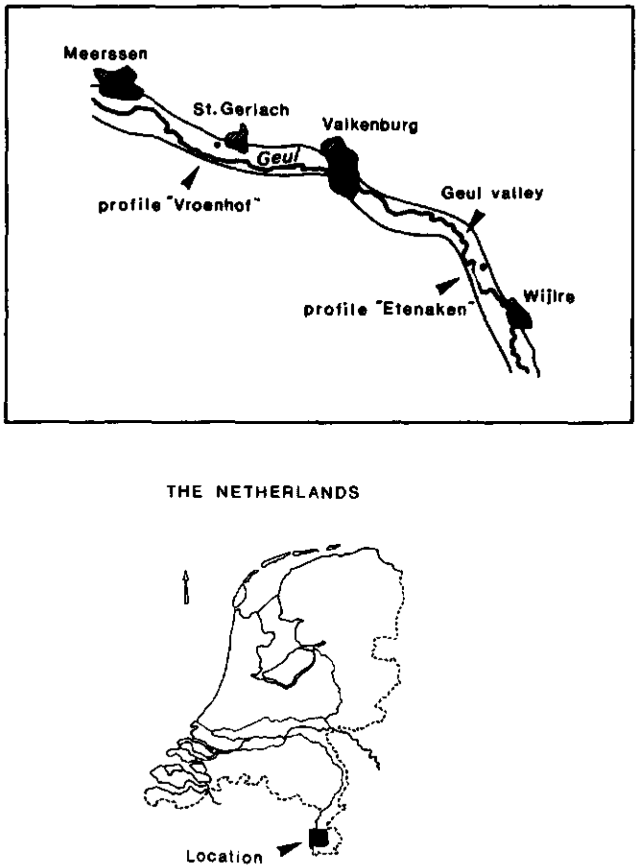


Fig. 1. Location of the two 'Vroenhof' and 'Etenaken' profiles.

The Vroenhof profile is located in a small basin area of the river clay landscape in the Geul valley at a relatively great distance from the river course with its accompanying levees, and out of reach of a colluvium. It consists of an approximately 1.40 m layer of fluvial loess resting on the peat in an undisturbed position.

The Etenaken profile is in a comparable situation as regards the course of the river but located within reach of a colluvium along the margin of the valley. The colluvial material does not rest on a layer of fluvial loess but is in direct contact with the peaty subsoil. This situation suggests that deposition of the colluvial loess may have been preceded by some erosion, leading to the disappearance of the former fluvial loess layer and the top of the peat. Near the bottom of the colluvium it contains peaty particles.

Profile descriptions.
Vroenhof profile

0–141 cm. Fluvial loess.
141–160 cm. Clayey [1] *Carex* peat with fairly extensive decay.
160–170 cm. Humic clay[1].
170–200 cm. Clayey[1] *Carex* peat with fairly extensive decay.
200–250 cm. *Carex* peat with moderate decay.
250– cm. Humic sand.

Etenaken profile

0–220 cm. Colluvial loess with small pieces of baked loam, charcoal, potsherds and some gravel. From 0–60 cm the soil appeared to be raised by human agency.
220–227 cm. Colluvial loess mixed with peaty particles which increase in a downward direction.
227–330 cm. *Carex* peat alternately with fairly extensive decay. Fragments of limestone are present at various depths.
330–360 cm. *Carex* peat mixed with fluvial loess which increases in a downward direction. Locally it is calcareous.
360– cm. Fluvial loess mixed with some peaty material.

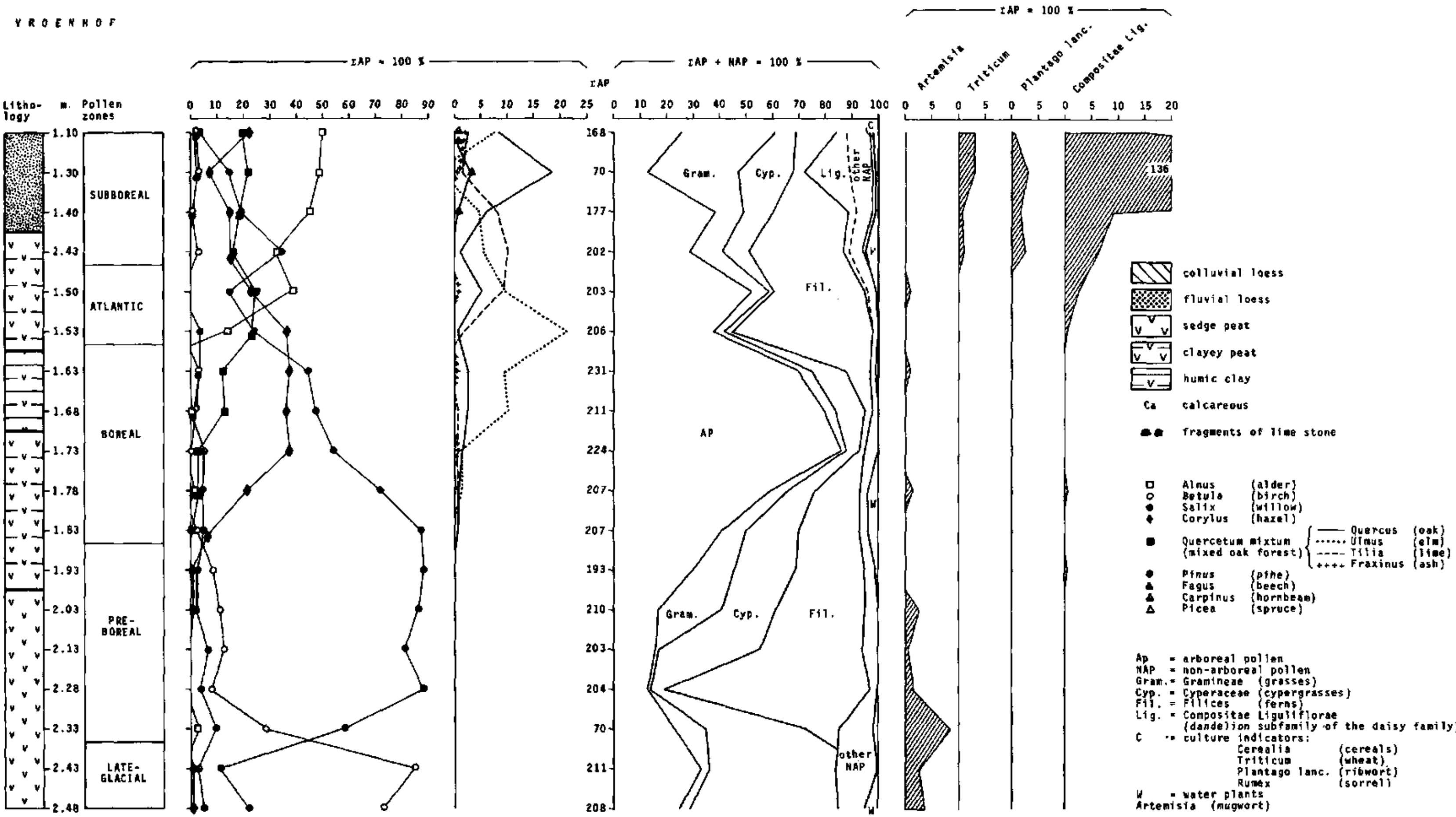
It may be inferred from the occurrence of clayey material in the peat in the Vroenhof profile and the fragments of limestone in the other profile that the peat was periodically flooded during formation. The flood water may have eroded peaty material which could have been deposited elsewhere. Local decay of the peat shows that periods with a low water table must also have occurred. It was at those times that the pollen grains in the peat were attacked by micro-organisms, giving the pollen wall its generally fairly severely corroded appearance.

3. SOME POLLEN ANALYSIS PROBLEMS

Owing to selective pollen corrosion the two pollen diagrams may give a somewhat distorted picture. This would explain why *Carpinus* is represented in the Vroenhof diagram by one pollen grain only viz. in the topmost Subboreal spectrum and is completely absent from the Etenaken diagram, even in the Sub-atlantic zone where it might have been expected (see also p. 56). *Fraxinus* is also absent from the latter diagram. According to the literature both species often show little resistance to corrosion.

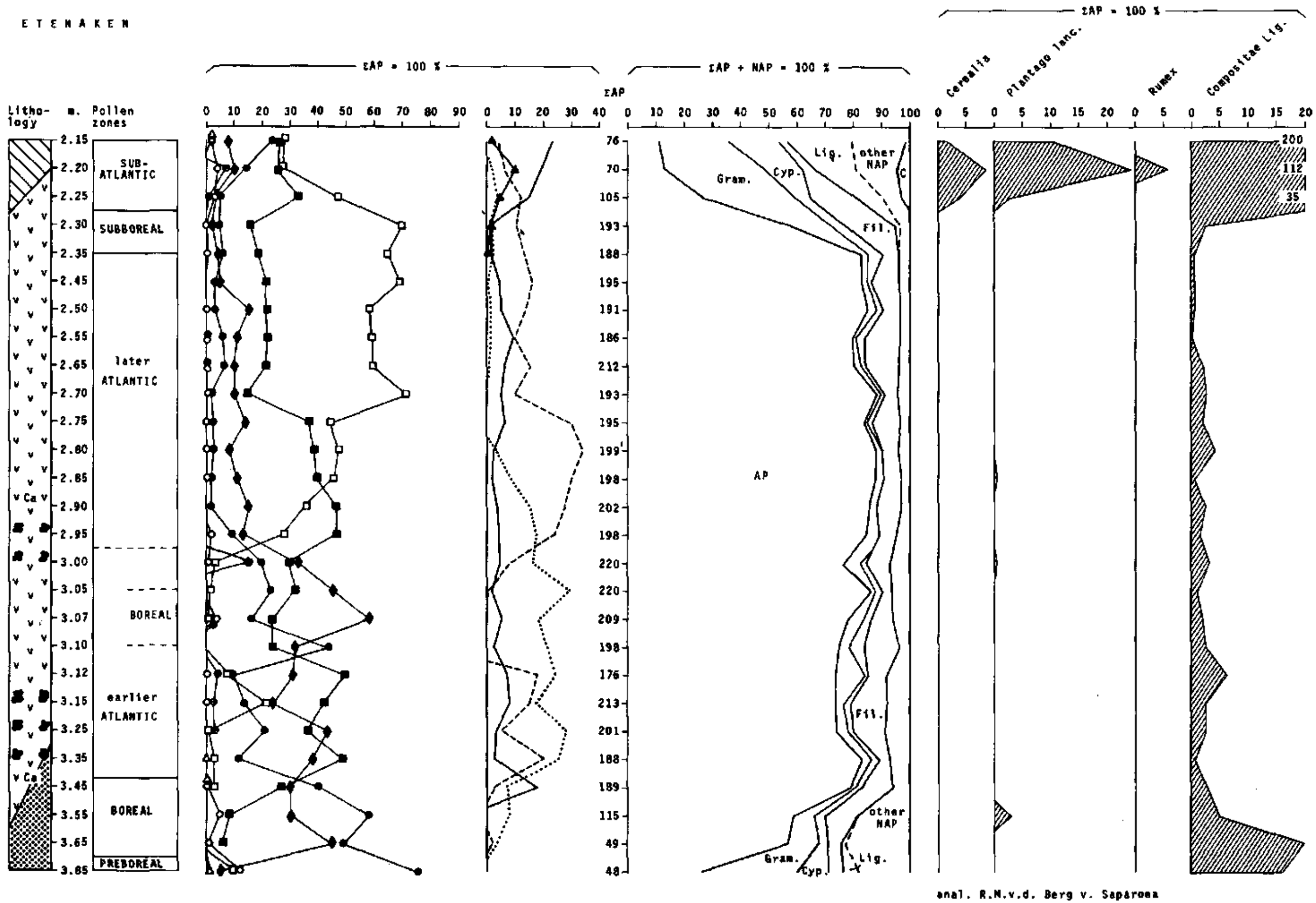
In the mineral subsoil of the Etenaken profile the pollen concentration below 3.65 m was so slight that the samples analysed contained too little pollen to afford a complete spectrum. To obtain a better insight the pollen counts were added to a single spectrum, viz. 3.85 m.

1 The grain-size distribution of the 'clay' component was not analysed, but it may be assumed that it mainly consists of loess.



anal. R.M.v.d. Berg v. Saparoea

E T E N A K E N


ΣAP = 100 %
ΣAP + NAP = 100 %
ΣAP
Litho-logy
m.
Pollen zones
SUB-ATLANTIC
SUBBOREAL
later ATLANTIC
BOREAL
earlier ATLANTIC
BOREAL
PREBOREAL
Gram.
Cyp.
Lig.
other NAP
C
Fil.
AP
Cerealia
Plantago lanc.
Rumex
Compositae Lig.
200
112
35
anal. R.N.v.d. Berg v. Saparoea

4. DESCRIPTION AND INTERPRETATION OF THE DIAGRAMS

In the diagrams the first column shows the lithology of the soil profile, the second the pollen zones, and the third the tree-pollen percentages based on the total of all tree species (including *Corylus*) ($\Sigma AP = 100\%$). The fourth column shows on a larger scale the proportion of each of the four components of the Quercetum – mixtum (Q.M.), *Quercus*, *Tilia*, *Ulmus* and *Fraxinus* and also the representation of *Fagus* and *Carpinus*, neither of which appears before the later Holocene. The fifth column is an overall picture of the vegetation, the percentages being calculated on the basis of combined arboreal pollen and non-arboreal pollen ($\Sigma AP + \Sigma NAP = 100\%$). The values for *Artemisia*, cereals and agricultural weeds are given on the extreme right. *Artemisia* is a common species in Late-glacial pollen spectra and is evidence of open terrain conditions.

The ratio of all arboreal pollen to all non-arboreal pollen ($\Sigma AP : \Sigma NAP$) is usually a good index of the extent to which the surrounding area was covered with forest. A high ratio indicates a dense forest, a low one an open vegetation. To obtain the best impression one should omit from the pollen assemblage considered plant species which grew in the neighbourhood of the sampling site, as otherwise the pollen of these species would be over-represented. To assess the extent to which the more elevated, drier soils in the areas around the two profiles analysed were covered by forest during the periods represented by the diagrams, we could omit the ferns, cyper grasses, part of the grasses and herbs, and also the water plants, all of which had their habitat on the moist soils of the valley floor. The local character of part of the non-arboreal pollen is evident from the fact that the non-arboreal species show so much higher percentages in the Vroenhof diagram than in the Etenaken diagram.

But this method of calculation was found to be ineffective; after omission of the ferns, cyper grasses and water plants for which a moist habitat may be taken for granted, the curve for the $\Sigma AP : \Sigma NAP$ ratio was yet erratic in the Vroenhof diagram. Apparently much of the remaining NAP pollen also came from the moist vegetation near the profile although the actual proportion cannot be determined. As a result we did not construct a diagram giving reduced percentages.

The two diagrams will be discussed together below, to begin with the diagram in which the pollen zone under discussion shows the clearest or simplest pattern.

4.1. LATE-GLACIAL ZONE

The arboreal section of the Late-glacial spectra in the Vroenhof diagram is highly dominated by *Betula*. The low $\Sigma AP : \Sigma NAP$ ratio and the fairly high *Artemisia* percentages indicate an open vegetation. Here and there some birch occurred. *Corylus*, transitory represented by 1 %, was not yet growing in the vicinity.

4.2. Pre-boreal zone

In the Pre-boreal zone of the Vroenhof diagram *Pinus* shows a rapid advance to high values to the detriment of *Betula*. This is a common feature of diagrams from South Limburg and adjacent areas. *Corylus* puts in a definite appearance towards the end of this period. The $\Sigma AP : \Sigma NAP$ ratio is low as a result of local growth of ferns and cyper grasses. At the top of this zone the ratio increases somewhat. During the Pre-boreal period *Artemisia* disappears. The landscape became covered with a uniform fir forest which afforded little space for herb growth.

The only spectrum of Pre-boreal age in the Etenaken diagram has much the same composition as the topmost Pre-boreal spectrum in the Vroenhof diagram although the Filicinae percentage is much lower.

Unlike the latter diagram, the Pre-boreal zone of the Etenaken diagram falls within a deposit of fluvial loess. This coincidence may explain the relatively high *Alnus* value and the representation of *Picea* in this zone in the Etenaken diagram. Both pollen types may have originated from older soil layers and have been redeposited together with the loess material in which they are found.

4.3. Boreal zone

The Boreal zone of the Vroenhof diagram starts with an increase in *Corylus* to the detriment of *Pinus* and the appearance of the Q.M. Thereafter the latter also increases to the detriment of *Pinus*. The increase is chiefly in respect of a single component of the Q.M., viz. *Ulmus*. The $\Sigma AP : \Sigma NAP$ ratio reaches a very high figure. The forest is of a less uniform character than during the Pre-boreal period.

Broadley speaking the Etenaken diagram is a compressed picture of the above Boreal diagram section. One striking difference is the *Quercus* peak at 3.45 m.

4.4. Atlantic zone

The very high $\Sigma AP : \Sigma NAP$ ratio in all Atlantic spectra in the Etenaken diagram indicates a dense forest vegetation.

Pinus shows a marked recession at the beginning of the Atlantic period whereas the Q.M. makes a further advance. *Corylus* provisionally maintains its ground. The beginning of the Atlantic zone is put at the crossing of the *Pinus* and the Q.M. curve (cf. Janssen, 1960). At a much later stage *Alnus* comes to the fore. This phenomenon is also found in a diagram from the more southerly country of Luxemburg (Riezebos and Slotboom 1974), whereas Janssens's diagrams from South Limburg show *Alnus* dominance during the whole Atlantic period as well as during the later stage only. In this connection we also refer to the pollen diagrams from sand soils in the neighbouring part of Belgium (Munaut 1967) in which *Alnus* is of minor importance during the whole Atlantic period.

The Q.M. is first dominated by *Ulmus* and later by *Tilia*. Higher *Ulmus* values followed by higher *Tilia* values are also found in several diagrams from adjacent regions in Belgium and Germany (see JANSSEN 1960, p. 67 and WOILLARD 1975, p. 98). But this succession is not a general rule. For instance, two of JANSSEN's diagrams in which the older part of the Atlantic period is represented, show a dominance of *Quercus* or *Tilia*, whereas in both cases *Ulmus* is last. As in the earlier part each of the three species may dominate in the later part of the Atlantic zone.

Apparently local forest composition had a marked effect on the fossil pollen floras. This must be due to the limited extent of the small peat moors from which the experimental material was taken.

Between 310 and 305 cm the diagram shows an erratic pattern. *Pinus* and *Corylus* occasionally attain high values whereas *Tilia* is missing from two of the spectra. In the Atlantic zone of two of JANSSEN's (1960) diagrams *Pinus* is also temporarily represented with fairly high percentages. He explains this by assuming that the tree still formed part of the forest vegetation of South Limburg during the Atlantic period, or that the high representation is due to certain vegetation conditions as an indirect result of which the proportion of pollen conveyed over a long distance became over-represented in the pollen rain.

We prefer a different explanation and assume that peaty material originating from an older peat layer containing Boreal spectra is inserted in the soil profile at the depth in question. This could be the result of one or more of the inundations to which the peat moor was so often subjected during formation. Peaty material from elsewhere may have been eroded and redeposited at the site of the Etenaken profile (cf. VAN ZEIST 1958/59, p. 24).

Intercalation of an older peat layer in a later peat deposit is a fairly common feature. It is occasionally found near the coast and near or in (former) lakes. Obviously it may also occur in the flood area of a river.

In this connection we would point out that some of JANSSEN's diagrams show a gap, also presumably as a result of erosion.

It is clear from the Atlantic spectra below and above the section in the Atlantic zone just discussed that a mixed oak forest occurred in the fairly close vicinity. Its most important tree was *Tilia*, particularly in the later Atlantic period. But during the earlier part dominance of this tree may also be assumed, despite the fact that the spectra suggest a moderate dominance of *Ulmus*. It should be remembered, that unlike the other tree species, *Tilia* is insect-pollinated and consequently has a relatively low pollen dispersion capacity, which is why it is usually very much under-represented in pollen diagrams.

During the later part of the Atlantic period the Alnetum gained ground in the surroundings of the profile. As increasing *Alnus* percentages are a common feature during this period (see above, p. 53) the most plausible explanation is that near the valley floor the mixed oak forest was superseded by the Alnetum owing to the increasing humidity of the soil. But JANSSEN's diagrams show that local alder growth on carr peat may also have occasionally contributed to a higher proportion of *Alnus* pollen in the pollen rain.

The two Atlantic spectra in the Vroenhof diagram, representing the older and later stage respectively, give a fragmentary picture of a similar vegetation development during the Atlantic period. But unlike the Etenaken diagram they show relatively high *Pinus* and *Corylus* values. The same can be seen in the Sub-boreal spectra above. Now these spectra are all present in clayey peat or fluvial loess, unlike the corresponding spectra in the other profile where fluvial sedimentation did not occur in any form. This is why we assume that the relatively high *Pinus* and *Corylus* percentages are largely due to secondary pollen deposition, i.e. from the flood water. It is striking that the Atlantic spectra rich in *Pinus* in JANSSEN's diagrams (see above) also originate from soil layers deposited in an aquatic environment, viz. peaty gyttja and alder peat mixed with calcareous lake sediment. In this connection we would also point out that relatively high *Pinus* percentages are more commonly found in fluvial sediments in the Netherlands.

4.5. SUB-BOREAL ZONE

In contrast to the common picture the Etenaken and Vroenhof diagrams do not show a clear retreat of *Ulmus* and/or *Tilia* at the transition from the Atlantic to the Sub-boreal zone. The most conspicuous feature of the Sub-boreal zone of the Etenaken diagram is that non-arboreal pollen again dominates arboreal pollen, a position it had lost since the Early Holocene. *Fagus* now appears, but otherwise the zone closely resembles the arboreal section of the Atlantic spectra.

The later part of the Sub-boreal period is absent, tallying with the assumed erosion of the fluvial loess and the upper peat layer (see p. 48). Later Sub-boreal spectra are in fact found in the Vroenhof diagram in which *Quercus* moves up to higher percentages, showing a peak at 1.30 m. *Tilia* and *Ulmus* recede to low values, although the latter moves up again at the top of the zone. *Fagus* is present. *Carpinus* is only found once, viz. in the topmost Sub-boreal spectrum (cf. p. 56). The high representation of the non-arboreal pollen in the Vroenhof diagram is accompanied by the representation of cultivation indicators, viz. cereals and some agricultural weeds. These occur from the bottom spectrum of the zone just below the fluvial loess deposit. The coincidence is good evidence that the forest vegetation declined as a result of reclamation and cultivation of the forested soil in the vicinity. The percentages for the Compositae-Liguliflorae are high in the fluvial loess. This may partly be due to the fact that pollen of this sub-family originated from a secondary pollen source, viz. the eroding cultivated soil, in which it may have occurred in high concentrations (see below, p. 57). The same may also be true of the pollen of the other cultivation indicators.

The above theories do no apply to the Etenaken diagram. The absence of cultivation indicators could mean that during the earlier part of the Sub-boreal farming was only carried out either at a great distance or on a very small scale in the profile environment.

For the relatively high *Pinus* and *Corylus* percentages in the Vroenhof diagram we refer to the discussion of the Atlantic zone in the same diagram.

The Etenaken diagram shows that the change in the composition of the Q.M. continued during the Sub-atlantic. According to FIRBAS (1949, p. 170) a final advance of the oak may be ascertained in landscapes during the Middle Ages (Zone Xa), where, having regard to other observations, an intensified use or destruction of the forest has to be assumed. He assumes that such activities might also have occurred, now and then, during early-historic and prehistoric eras. To some extent this may explain the advance of *Quercus* during the Sub-boreal period shown in the Vroenhof diagram.

4.6. SUB-ATLANTIC ZONE

The Sub-atlantic zone is represented in the Etenaken diagram only. It entirely coincides with the colluvium. In addition to pollen sedimented from the air this deposit naturally contains pollen redeposited together with the eroded loess. The bottom 7 cm may also contain pollen displaced secondarily with the peaty material at that depth in the colluvial loess. Despite these complications the pollen curves are normal.

Fagus shows an advance but subsequently recedes again. *Carpinus* is completely absent, a feature also seen in many Sub-atlantic spectra in JANSSEN's (1960) diagrams. He believes this to be due to a marked human influence on the forest composition but, as mentioned above (p. 49) differential decay of *Carpinus* pollen in the colluvial material may also have been a factor.

Corylus and especially the Q.M. become more important than in the preceding zone. *Quercus* retains its great dominance in the Q.M. The *Alnus* and *Pinus* curves show a marked shift: the first recedes and the other advances. The non-arboreal pollen, which includes a great deal of culture pollen, is now represented with very high percentages.

It may be inferred from the decline in *Alnus* values that during the Sub-atlantic period the lower humid soils near or on the valley floor were also used for farming, the alder carr being cleared to make room for grassland.

The advance of the *Pinus* curve must be an indirect effect of the decline of the forest vegetation in the region in the course of the Sub-atlantic period (cf. JANSSEN 1960), declining production and dispersion of the regional tree pollen resulting in a relative rise in tree pollen conveyed over a long distance. We do not think it could reflect an absolute increase in the precipitation of *Pinus* pollen due to more recent pine plantations because it is hardly likely that the 2.20 layer of colluvium at the bottom of which the Sub-atlantic spectra were found, would have been deposited over its entire depth since such a late date.

5. SOME CONCLUSIONS

The limited scope of the investigation prevents us from drawing any definite conclusions. We believe, however, that a close connection between the type of the Holocene mineral valley fill and the age of the pollen spectra near the bottom of this deposit, as found during this investigation, may be more generally found in the Geul valley. Relatively late spectra can always be expected in the colluvial loess, and in the fluvial loess such spectra will in any case be found in the basin areas where it covers a more or less peaty substratum.

The formation of this fluvial layer began during the period when the landscape was only cultivated to a very limited extent, i.e. the Sub-boreal period, the colluvial deposits being formed later during the Sub-atlantic period and probably mainly since the Roman era when the region was extensively farmed. In this connection we refer to the results of RIEZEBOS and SLOTBOOM's (1974) palynological investigation of soil material from slopes covered with loess in Luxemburg. They concluded that there also colluviation did not become important before the Sub-atlantic period.

Although the *Tilia* percentages in the Sub-atlantic and later Sub-boreal spectra are often low, they may nevertheless indicate that lime played a certain part in the development of the forest vegetation during the more recent Holocene. In this connection we must again remember the tree's relatively low pollen dispersion capacity.

But information on the existence of former lime forests may also be obtained from a quite different source than palynological studies, viz. from ancient documents and place-names (S. VAN DER WERF, oral comm. 1979). Some mediaeval documents show that remnants of lime forests must have existed as late as the Middle Ages. The same conclusion may be drawn from certain place-names in South Limburg, e.g. the village name 'Terlinden'[1] and the farm-road name 'Mheerlindje'[1] found near the village of Mheer. Place-names containing the element 'linde' are also found in the Netherlands outside the South Limburg loess area, in regions where the soil is formed by cover sand. It is interesting to note that high *Tilia* percentages are fairly common in the Atlantic or Sub-boreal zone of pollen diagrams from soil profiles which developed in cover sand.

The high Compositae-Liguflorae percentages in the upper mineral part of both profiles deserve particular attention. These high values should not lead us to draw any conclusions as to the proportion of this sub-family in the vegetations represented. HAVINGA (1962, 1971) and BOTTEMA (1975) showed that high concentrations of Liguliflorae pollen are found fairly frequently in mineral soil as a result of differential pollen preservation or deposition by digger-bees. The latter author notes that environments created or influenced by man (and farmers in particular) often favour the existence of the bees. It may therefore be assumed that part of the Liguliflorae pollen in question originates from cultivated soil

[1] 'Linde' is the Dutch for 'lime tree'.

rich in Liguliflorae pollen. It must have been carried and redeposited together with the eroded soil material which now constitutes the fluvial and colluvial deposits.

6. SUMMARY

A tentative investigation was carried out into the age of the fluvial and colluvial loess deposits in the valley of the river Geul in South Limburg (Netherlands). Two soil profiles were studied palynologically, one consisting of a layer of fluvial loess on peat and the other of colluvial loess on peat. It was found that at the site of the profiles the deposits both date from the era at which agriculture had already made its mark on the landscape. The fluvial sedimentation began during the earlier part of the Sub-boreal period, when the landscape was only cultivated to a very limited extent. The colluvial deposit is of later date, being formed during the Sub-atlantic period, probably mainly since the Roman era when the soil became intensively cultivated.

Special attention is paid to the significance of the *Tilia* percentages and the high Compositae-Liguliflorae percentages in the diagrams.

7. SAMENVATTING

EERTIJDSE VEGETATIE EN SEDIMENTATIE IN HET DAL VAN DE GEUL

Er is een voorlopig onderzoek uitgevoerd naar de ouderdom van de fluviatiele en colluviale lössafzettingen in het dal van de Geul. Daarbij zijn twee profielen palynologisch onderzocht, respektievelijk bestaande uit fluviatiele löss op veen en colluviale löss op veen. Het bleek dat de beide lössafzettingen ter plaatse van de onderzochte profielen stammen uit de tijd, waarin de landbouw zijn stempel reeds op het landschap had gedrukt. De fluviatiele sedimentatie begon tijdens het oudere deel van de subboreale tijd, toen het landschap nog maar in zeer beperkte mate in cultuur was. De colluviale afzetting vond plaats in de subatlantische tijd, waarschijnlijk vooral sedert de Romeinse tijd, toen de bodem reeds intensief werd bebouwd.

De aandacht wordt gevestigd op de aanwezigheid van verschillende toponymen in de streek, waarin de naam van de lindeboom terug is te vinden. Dit wijst erop, dat de linde nog in de Middeleeuwen een niet te verwaarlozen rol in de vegetatie speelde. De lage *Tilia*-percentages in de subboreale en subatlantische pollenspektra van de beide diagrammen zijn mede een gevolg van de reeds zo vaak vermelde slechte verspreiding van het stuifmeel van deze boom.

De hoge Compositen-waarden kunnen op indirekte wijze met de landbouwcultuur in verband worden gebracht.

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