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Late Pleistocene Stratigraphy and Fluvial History of the Dinkel Basin (Twente, Eastern Netherlands)

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Borehole section, electrical sounding, Weichselian (Twente Formation), fluvial aggradation, fluvial erosion, meanders, alluvium, eolian sediments, periglacial features

Netherlands (Dinkel Basin)

Abstract: The glacial Dinkel basin is filled with a sequence of fluvial and eolian sediments. The Late Pleistocene stratigraphy and paleomorphology have been studied by new exposures, boreholes and geoelectric soundings. Special attention is paid to refinements of the lithostratigraphy of the Dinkel valley, which is the type area of the Twente Formation, and to a reconstruction of the paleo-environment during the different periods of the Weichselian.

The valley fill mainly consists of sands with intercalations of loam, clay and peat beds. Three important lithostratigraphic marker horizons have been found within the Twente Formation. All three are accompanied by erosional features. A number of characteristic units have been distinguished, each of them corresponding to specific fluvial or eolian conditions.

During Eemian and Early Weichselian high sinuosity rivers dominated a marshy alluvial plain with locally lacustrine conditions. The Lower Pleniglacial is characterised by deep fluvial incision. This incision was followed by aggradation during the Middle Pleniglacial, with mainly high sinuosity rivers. During the Upper Pleniglacial the rivers attained a braiding pattern. Eolian sedimentation gradually increased. Subsequently, the development of the Beuningen Gravel Bed and deposition of eolian coversands show the dominance of eolian processes in the valley. Renewed fluvial activity started with incisions during the Late Glacial followed by deposition of meandering river sediments.

[Spätpleistozäne Stratigraphie und fluviatile Geschichte des Dinkelbeckens (Twente, östliche Niederlande)]

Kurzfassung: Das glaziale Dinkelbecken ist erfüllt mit einer Sequenz von fluviatilen und äolischen Ablagerungen. Die Spätpleistozän-Stratigraphie und Paläomorphologie würde mit Hilfe von neuen Aufschlüssen, Bohrungen und geo-elektrischen Sondierungen erforscht. Besondere Beachtung galt der Verfeinerung in der Lithostratigraphie des Dinkeltals, des Typusgebietes der Twente-Formation, und einer Rekonstruktion des Ablagerungsmilieus in den verschiedenen Perioden der Weichseleiszeit.

Die Talauffüllung besteht aus Sanden mit Lehm-, Ton- und Torfschichten. Drei wichtige Leithorizonte wurden innerhalb der Twente-Formation gefunden. Diese drei Horizonte sind von erosiven Bildungen begleitet. Einige charakteristische Einheiten sind unterschieden, jede Einheit entspricht spezifischen fluviatilen und äolischen Verhältnissen.

Während der Eemzeit und der Früh-Weichseleiszeit gab es Flüsse mit hoher Sinuosität in einem sumpfigen alluvialen Tiefland, mit lokal lakustrischen Verhältnissen. Das Untere Pleniglazial ist charakterisiert durch einen tiefen fluviatilen Einschnitt. Darauf folgt fluviatile Zuschüttung während des Mittleren Pleniglazials, hauptsächlich durch mäandrierende Flüsse. Während des Oberen Pleniglazials lösten sich die Flüsse in sich überkreuzende Flußarme auf. Äolische Ablagerung nahm allmählich zu. Die Entwicklung der Beuningen-Steinsohle und die Ablagerung von Flugdecksanden zeigen zunächst die Dominanz von äolischen Prozessen im Tal. Erneute fluviatile Aktivität fing mit Einschneidung im Spätglazial an, gefolgt von der Ablagerung von Sedimenten mäandrierender Flüsse.

[Stratigraphie du Pleistocene Superieur et histoire fluviatile du bassin de la Dinkel (Twente, Pays-Bas oriental)]

Résumé: Le bassin glaciaire de la Dinkel est comblé d'une séquence de sédiments fluviatiles et éoliens. La stratigraphie et la paléomorphologie ont été établies par l'étude des affleurements, des forages et des sondages géoélectriques. La lithostratigraphie de la vallée du Dinkel, qui est la région type de la Formation de Twente, a été étudie plus en détail. De plus, l'attention a été dirigée vers la reconstruction du paléomilieu pendant les périodes différentes du Weichselien.

Le comblement de la vallée consiste principalement de sables avec des intercalations de couches de limon, d'argile et de

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tourbe. Dans la Formation de Twente trois niveaux de référence, incorporant des phénomènes d'érosion, sont trouvés. Plusieurs unités lithologiques caractéristiques ont été distinguées et chacune d'elles correspond à des conditions spécifiques fluviatiles ou éoliennes.

Pendant l'Eemien et le Weichselien Inférieur des rivières à grande sinuosité dominaient dans des plaines alluviales marécageuses mais localement à caractère lacustrine. De l'érosion fluviatile se manifestait pendant le Pléniglaciaire Inférieur suivi par aggradation dans le Pléniglaciaire Moyen avec principalement des rivières sinueux. Pendant le Pléniglaciaire Supérieur les rivières étaient du type anastomosé pendant que la déposition éolienne augmentait graduellement. Ensuite, le développement du Cailloutis de Beuningen et la sédimentation de sables de couverture illustre la dominance des processus éoliens dans la vallée. Une action fluviatile renouvelée pendant le Tardiglaciaire se manifeste d'abord par une incision puis par une accumulation des rivières a méandres.

1. Introduction

In the past, several studies of small river basins have been conducted by the Department of Quaternary Geology of the Free University in Amsterdam: in the Drentsche Aa (DE GANS 1981), the Mark valley (VANDENBERGHE et al. 1984; VANDENBERGHE & BOHNCKE 1985) and the Reusel valley (VAN HUISSTEDEN et al. 1985). These studies allowed to reconstruct the fluvial activity in lowland valleys during the Weichselian. It is highly desirable to correlate these results with the fluvial sequences in the type region of the Twente Formation, which groups the continental deposits formed in periglacial conditions during the Weichselian. Therefore it is necessary to gain insight into the Late Pleistocene fluvial history in the Twente area, and to relate this to the chrono- and lithostratigraphical sequence. The Dinkel valley offers good possibilities for this purpose.

A project has been set up for the detailed reconstruction of the paleo-ecology, sedimentary environment and morphology of the Dinkel valley. The first results (this publication) concern the basin geometry, the general chrono- and lithostratigraphy of the fluvial deposits, and a provisional evaluation of the depositional environments.

The relevant part of the Dinkel valley is situated in the Dutch-German border area (Fig. 1). It is situated in the lower course of the river, from the town of Losser northward to the municipality of Denekamp. The river valley is relatively wide, compared to the size of the present meandering river. Bankfull discharge approximates 45 m^3/sec, while the valley width amounts 3 to 5 km. The river valley follows glacial basins of Saalian age. These basins are bordered to the

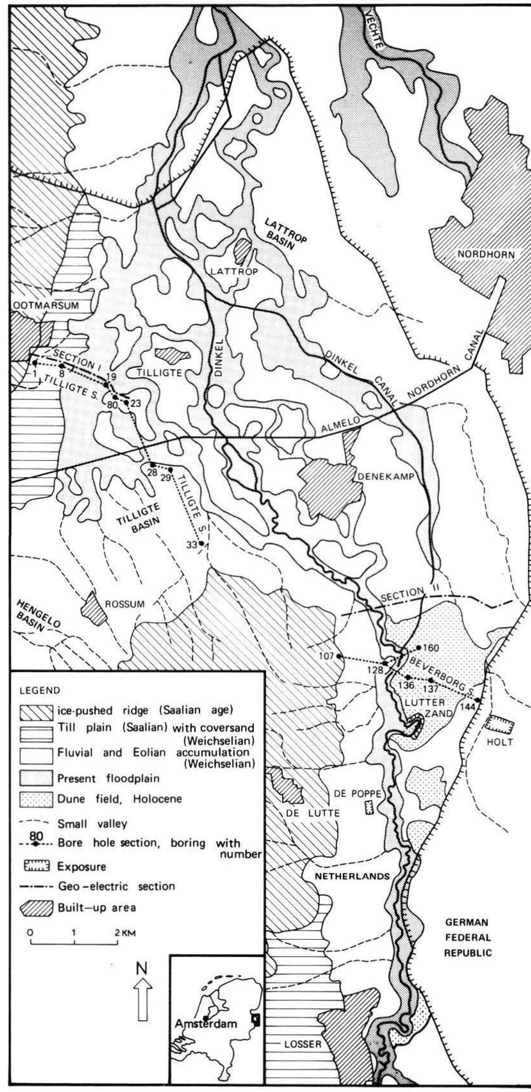


Fig. 1: Location of investigated sites in the study area. Geomorphology after Geomorphological map of the Netherlands, scale 1 : 50 000, sheet 29, Denekamp (Kleinsman et al. 1978).

west by the ice pushed ridges of Oldenzaal and Ootmarsum (Fig. 1). They consist of clay and sand of Tertiary age, and sands of Lower to Middle Pleistocene age. On the eastern valley side, outcrops of Lower Cretaceous sandstones and shales occur. Just south of the town of Denekamp the river valley suddenly widens considerably. Here the river enters the Lattrop basin. The base of this glacial basin is locally found 75 m below the present surface (AELMANS 1975). A second, smaller glacial basin, the Tilligte basin, is also incorporated into the study area. The Tilligte basin forms a gap between the Oldenzaal and Ootmarsum ridges.

The present drainage is directed towards the Dinkel. The water divide with westward flowing rivers in the adjacent Hengelo basin is not very high above the valley floor level of the Dinkel.

The basins in which the actual Dinkel is flowing, have been filled first with glacio-fluvial and fluvial sediments of Saalian age. During Eemian, Weichselian and Holocene times fluvial activity continued, interrupted by peat formation and eolian deposition (VAN DER HAMMEN & WIJMSTRA 1971; DOPPERT et al. 1975). In the German literature this valley fill is known as "Talsande" (GRAHLE 1960). The whole sequence of the Asten Formation (Eemian), Twente Formation (Weichselian) and Singraven Formation (Holocene), which is the main subject of the present study, may be up to 30 m thick and consists of sands with intercalated loam, peat and clay beds (VAN DER HAMMEN & WIJMSTRA 1971).

2. Geoelectric soundings

Geoelectric soundings were used to investigate the depth and sedimentary infilling of the basins. The soundings are grouped in two profiles. One profile (I, Fig. 2) runs from the centre of the Tilligte basin towards the push moraine of Ootmarsum, the other one (II, Fig. 3) crosses the western part of the Dinkel valley at the southern edge of the Lattrop basin (Fig. 1). The two sections comprise Schlumberger soundings with a maximum half electrode distance of 100 to 150 m. They have been interpreted by an interactive automatic method. Borehole data have been obtained in order to overcome the problem of equivalence within the upper layers when determining resistivities by fixing thicknesses. Deep information was only available from a few boreholes and some geoelectric soundings from neighbouring areas (AELMANS 1974).

When the uppermost dry or moist layer is not taken into consideration, the total sequence may be subdivided in three units. A lower unit A is characterized by its low electric specific resistivities which are typical for clays. Some sandy lenses, with higher specific resistivities, are intercalated between the clays. Unit A represents the ice-pushed clayey Tertiary layers, and may contain locally present clayey till. At the eastern side of profile II the strongly dipping Mesozoic substratum (X) is recorded by the electric soundings. In this area it consists of a relatively thin layer of sandstone (= 110 a 120 Ωm, unit X.b) overlying shales (= ca. 35 Ωm, unit X. a.). The upper unit B is quite heterogeneous,

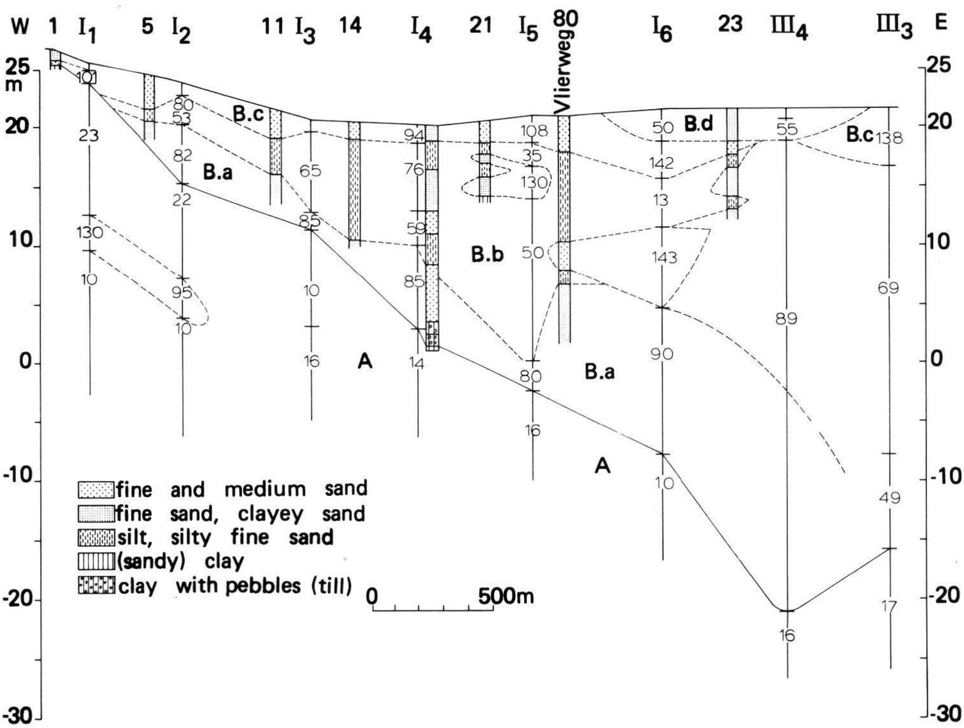


Fig. 2: Geoelectric sounding section Tilligte basin. Location: see Fig. 1. Levels in meters above Dutch ordnance datum. A: Ice-pushed Tertiary clays. B: Basin fill with glacial, fluvial and eolian deposits of Saalian to Weichselian age.

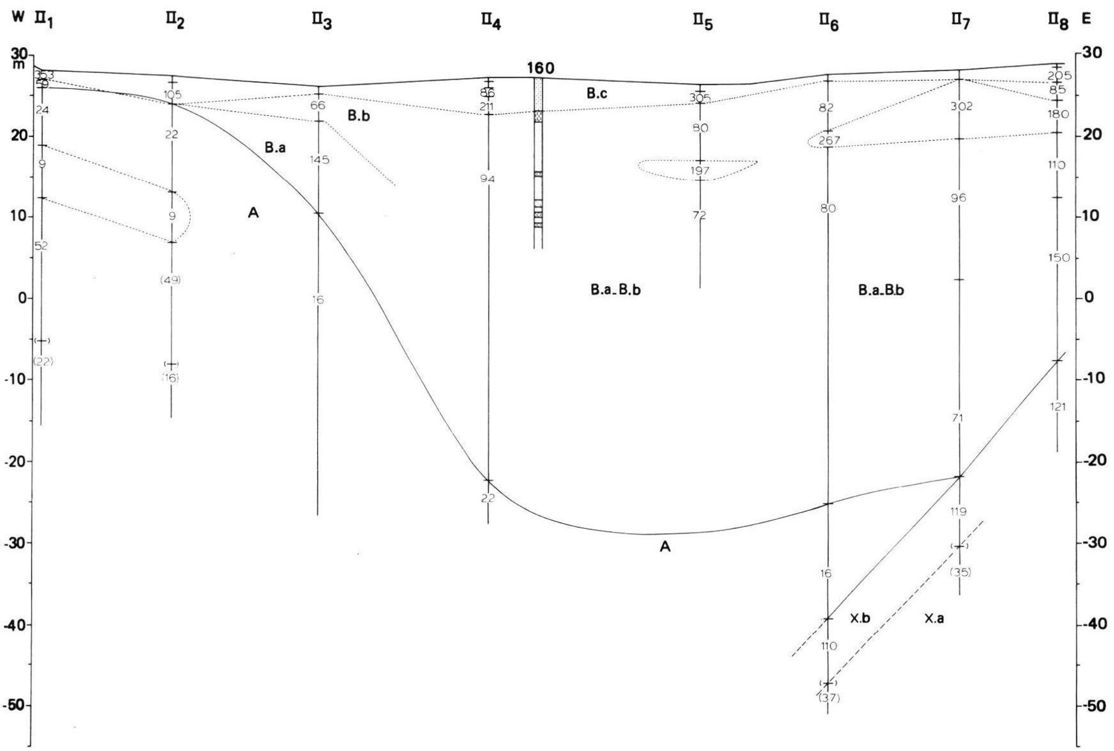


Fig. 3: Geoelectric sounding section Dinkel valley south of Denekamp. See Fig. 1 for location, Fig. 2 for legend. X: Lower Cretaceous shale (X. a) and sandstone (X.b). A: Ice-pushed Tertiary clays. B: Basin fill with glacial, fluvial and eolian deposits of Saalian to Weichselian age.

but all subunits show significantly higher specific resistivities than those of unit A pointing to their sandy character. The boundary between units A and B is close to the surface at the western margins of the two basins near the ice-pushed ridges, and is rather regularly inclined towards the centre of the basin where the largest thicknesses of unit B are found.

The electric specific resistivities within unit B allow, to a certain extent, a further subdivision of this unit. In section I the specific resistivities of the lower unit B.a range between 80 and 90 Ωm. According to borehole data B.a corresponds to medium and coarse sands, which contain in some cases considerable amounts of clay and silt. They may represent fluvio-glacial, fluvial or slope deposits, and possibly small lenses of gravelly till at the base. The overlying subunit B.b shows generally slightly lower specific resistivities (50—76 Ωm) standing for silty and clayey, fine alluvial sands. Very low specific resistivities point to silts and clays, while intercalations of high specific resistivities correlate with sandy gullies. However, the lithologic distinction between these two subunits is not always clear in section I, while in section II the existence of the subdivision is even questionable. On top of unit B.b (or B.a/b) another subunit (B.c) may well be recognized in the two sections by the higher specific resistivities (90 to 300 Ωm). It is a rather continuous layer of which the base reaches a depth of 2 to 6 m. Medium to coarse, gravelly fluvial sands at this level are frequently found in the handmade borings. Finally a local and shallow top layer with rather low resistivities (50—55 Ωm) may be distinguished in section I (B.d). It stands for fine fluvial sediments of limited extent. When comparing the two profiles, it appears that in section II the specific resistivities of all parts of unit B are significantly higher, which indicates that the Dinkel basin is filled mainly by sandy deposits, while the Tilligte basin also contains loamy sediments (B. b). This tendency may be observed in subunit B.c as well, which points to coarse gravelly sands in section II and medium-sized sands in section I.

3. Exposure data

3.1. De Poppe section (Fig. 4, 5)

The outcrop "De Poppe" is situated at the edge of the Dinkel valley and at the foot of the push moraine of

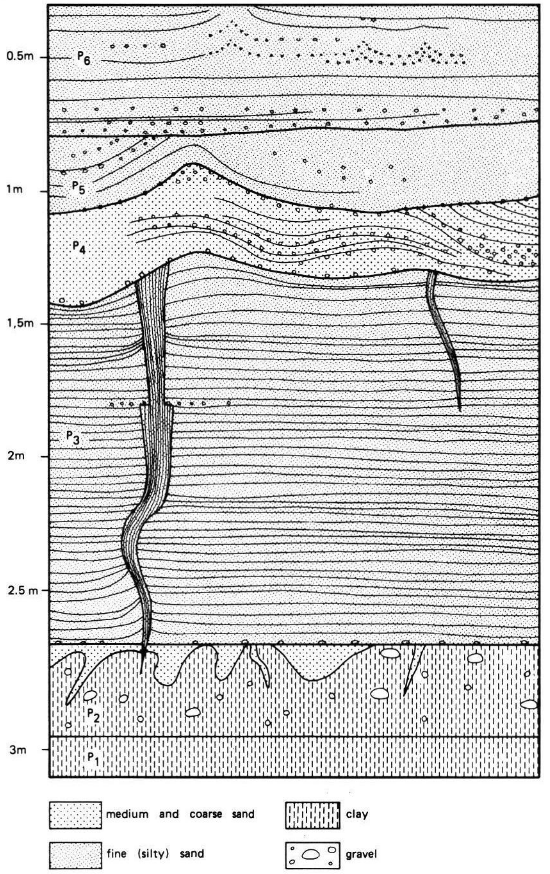


Fig. 4: De Poppe exposure: compound vertical section with lithologic subdivision, sedimentary and periglacial structures. Depth in meters with respect to ground surface.

Oldenzaal (Fig. 1). The subsoil consists of green (sandy) clay with dispersed gravel and stones (unit P1, Fig. 4). It is lime-free and interpreted as a Saalian till with considerable amounts of Tertiary sediments.

The overlying unit P2, only a few decimeters thick, is a diamict of reworked green clay, coarse sand, and pebbles and cobbles of varying size. It may be conceived as a slope deposit originating from the nearby moraine hill, which is composed of sediments similar to those of unit P1. Unit P2 is cryoturbated and subsequently eroded by surficial processes. Fine particles have been washed out, resulting in the formation of a gravel bed at the top of unit P2. From the same level frost fissures start downward.

Unit P3 contains parallel laminae of greenish, very fine, silty sands (ca. 70 μm), alternating with greyish, fine sands (120—150 μm). This ill-sorted deposit (sample 1, Fig. 6) contains varying amounts of silt (up to 25 %), but in all cases only a small clay fraction (less than 6 %). Locally, homogeneous sands occur in thin beds, while shallow gullies are filled with obliquely laminated sands with occasional ripple cross-bedding. These sands are characterised by the presence of a rolling population and by the good sorting of the saltation population. It is certain that fluvial processes have deposited part of the sediments of unit P3, but this fluvial activity has been interrupted regularly (see below), while at the same time loams and fine sands could be deposited by wind action. Thus in the period during which unit P3 was deposited the water of the Dinkel river reached the margins of the valley at flood stages. Unit P3 is locally involuted with an intensity which is strongly related to the silt and clay content. These involutions may be interpreted as cryoturbations. Their relative small amplitude (20—30 cm) indicates a formation in the active layer of a seasonally frozen ground. At the top and within the same unit frost fissures are found (10 cm wide at their top). They show a clear vertical lamination and have caused some upturning at the edge in the adjacent sediments. They are formed during subsequent periods of non-deposition which alternated quickly with periods of sedimentation. Thus the new fissures grew progressively in the older forms resulting in a kind of syngenetic fissure structures. As mentioned, these features developed from the seasonally frozen surface downward and consequently are not associated with (overlying) involutions.

On top of these deposits white, fine, well-sorted sands occur. This unit (P4) is characterized by the presence of beds of cross-laminated, gravel-bearing, coarse sands, and by the gullying lower boundary which is marked by a gravel lag. Although coarser, the sediments of this unit resemble well the local gully sands of the underlying unit P3. The fluvial character is that of a quick, vertical alternation of erosion and fill and lateral channel migration. The boundary to unit P5 may be distinct by the occurrence of a pebble horizon but generally the transition is gradual.

Unit P5 consists of eolian sands which may be locally reworked by running water. Local pebble horizons occur, especially towards the top. The upper part of this unit is disturbed by cryoturbations. They are cut by a continuous not-involuted pebble horizon, which is the boundary with unit P6. The complex of all pebble rows forms the Beuningen Gravel Bed (VAN DER HAMMEN et al. 1967). In between the pebble rows very fine, loamy sands may occur. An ice wedge cast has its top in the upper part of unit P5 just below the involuted zone (Fig. 5). A typical vertically laminated internal part and a block-faulted external part may be recognized (VANDENBERGHE 1983). The wedge testifies of permafrost conditions. Narrow frost cracks start downward from the top of the Beuningen Gravel Bed.

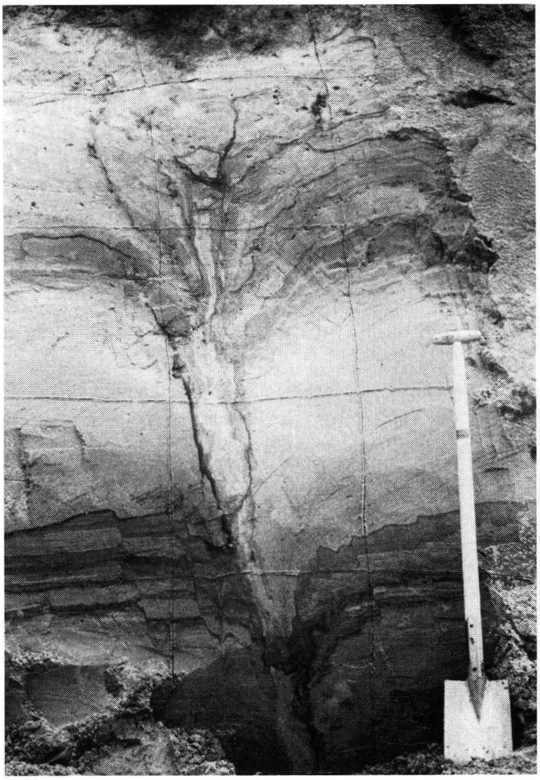


Fig. 5: Ice wedge cast in the De Poppe exposure. Qaudrangle sides on pit face are 0.5 m.

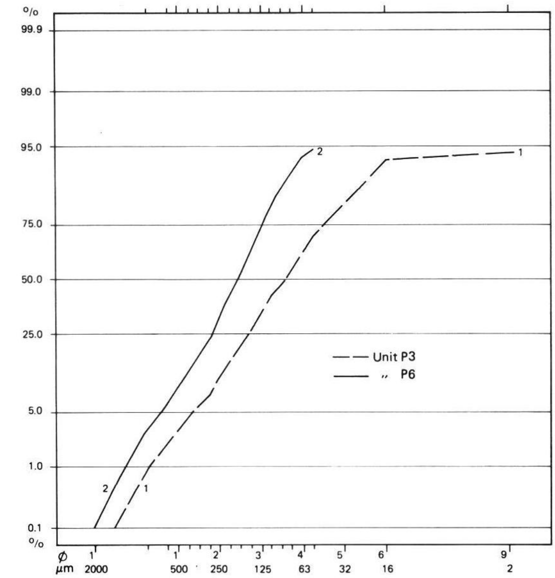


Fig. 6: Cumulative probability curves of granulometric analyses from the De Poppe exposure.

The uppermost unit (P6) is a pale yellow, parallel laminated, slightly loamy coversand similar to the sands of unit P5. Locally, deflation processes have been active, resulting in the development of small pebble horizons. The horizontal lamination may be interrupted by small squeezing-up structures. The modal value of the main population of the grainsize distribution (sample 2, Fig. 5), which is the saltation population, ranges between 120 and 165 μm, the skewness is slightly negative (—0.3 to —0.65) as has been found also in the coversands of other regions (VANDENBERGHE 1977). The cumulative granulometric curve shows the presence of a coarse subpopulation in all samples. It represents the residual lag or rolling component. The ratio between the two subpopulations is variable and reflects the relative importance of wind deposition or wind deflation Units P5 and P6 are known as "Older Coversands" (VAN DER HAMMEN 1951). They are of the aeolian facies type B (RUEGG 1981; SCHWAN 1985).

The Saalian till (unit P1), belonging to the Drente Formation, is separated from the overlying fluvial and eolian deposits by an erosive level. No remains of an Eemian soil or deposit is found here, so that units P2 to P6 represent the Twente Formation of Weichselian age (VAN DER HAMMEN & WIJMSTRA 1971). The two pebble horizons eroding the underlying cryoturbated sediments (top of units P2 and P5) have an important lithostratigraphical significance because of their general occurrence. The horizontal top of the Beuningen Gravel Bed on top of P5 is occurring over large areas in the Netherlands and Belgium (VAN DER HAMMEN et al. 1967; ZAGWIJN & PAEPE 1968; VANDENBERGHE & GULLENTOPS 1977). It has been formed after the degradation of the permafrost which existed at about 18,000 to 22,000 yr. B.P. (VANDENBERGHE 1983). The lower pebble horizon is known as a lithostratigraphic marker from the southern Netherlands (VANDENBERGHE & KROOK 1981; VANDENBERGHE 1981) and is called the "Gilze Gravel Bed" (VANDENBERGHE 1985). It occurs there in the same position as in the De Poppe pit. It could be shown that the Gilze Gravel Bed was formed after the degradation of the permafrost which was present during the lower Pleniglacial (VANDENBERGHE 1983).

3.2. The Holt sand pit

The Holt sand pit is situated just east of the Dutch-German border, 250 m. SE of the easternmost boring of section Beverborg (Fig. 1). The total sequence in this pit (Fig. 7) is 5 m thick, and consists of light grey and yellowish sands. These sands never contain carbonate or organic matter. In all sediments the clay

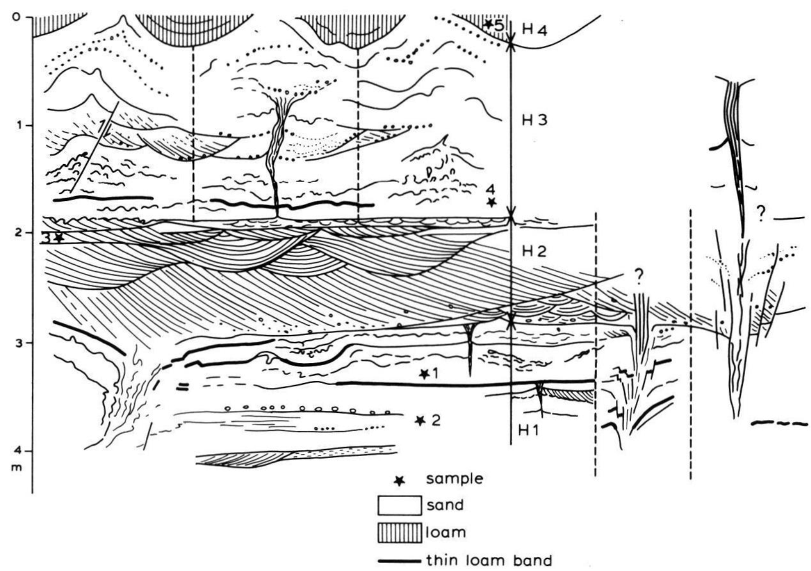


Fig. 7: Holt pit: compound section with lithologic subdivision, sedimentary and periglacial structures. Depth in meters with respect to ground surface.

fraction is nearly absent; even in the finest sediment the clay fraction does not exceed 7 % (Fig. 8).

Unit H1 at the base of the pit consists of fine to medium, loamy sand with coarse lenses. The bulk of this unit shows an alternation of thin parallel beds of loamy and not loamy sands. In addition, thicker sandy loam beds, riple crosslamination, small scour fills and strings of windpolished gravel may be found. Periglacial structures are represented by small frost fissures, small scale deformations and a "vertical platy structure" (VINK & SEVINK 1971). Also ice wedge casts have been found. Some of them appear to be of the syngenetic type. The characteristic bedding type of this unit strongly resembles that of the "eolian sand type B" of the Twente Formation, described by RUEGG (1981). In grainsize samples a well-sorted saltation population dominates (sample 1, Fig. 8), which agrees with the presumed eolian origin (VISHER 1969). Less well sorted layers (sample 2, Fig. 8) indicate reworking by running water. The intercalated small scour fills and crosslaminated sets point to occasional shallow flooding.

The overlying unit H2 is composed entirely of medium to coarse sand. Near its base gravel occurs, which contains high amounts of shale fragments, derived from Lower Cretaceous shales. Sedimentary structures in H2 include different types of cross-bedding, which leaves no doubt of the fluvial origin. Scour-fills indicate streamflow directed towards the north. A grainsize sample (sample 3, Fig. 8) shows that these sands are considerably coarser and less well sorted. Deformation due to periglacial phenomena is rare, except the presence of ice wedge casts, which penetrate this unit from above. H2 generally consists of a channel fill sequence of through-crosbedded sets, followed by a single large tabular cross-bedded unit, overlain by scour fills. At the top 10—20 cms of ripple cross-laminated sand mark the transition to the next unit, H3. The large extension of H2, over a near horizontal erosion surface, and its relatively small thickness, points to quickly migrating channels of large width/depth ratio. The association of lithologies and sedimentary structures which occur within this unit resemble lithofacies associations from sandy braided river examples cited by MIALL (1977). Bar migration or lateral accretion is assumed to be the origin of the tabular cross-bedding. Probably such crossbedding developed during one flood event, as well-marked reactivation surfaces and intercalations indicating lower stage reworking with more quiet flow conditions are rare. Also the scour fills show evidence of only one episode of infill. Besides the topmost centimeters, evidence of low stage flows is lacking in the entire unit. This indicates the dominance of structures due to high discharge events, associated with an arctic nival character of the river (BRYANT 1983). High discharges in this type of river are mainly caused by spring snow melt.

Unit H3 consists of fine to medium sands. A coarse, cross-bedded intercalation is locally found in the middle part of this unit. Strings of wind-polished pebbles are common, especially near the top of H3. Bedding and other sedimentary features within H3

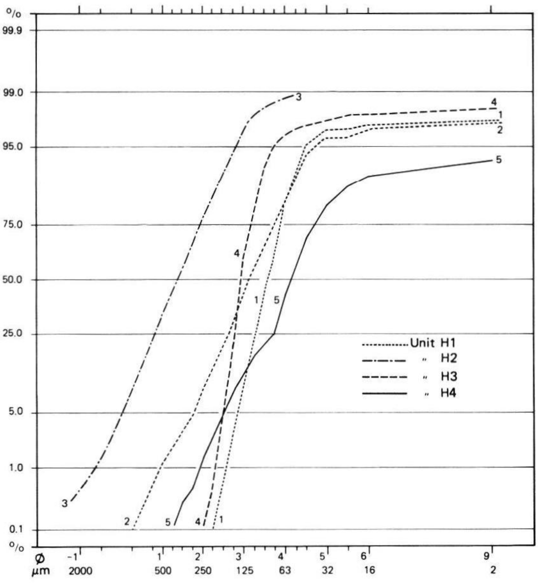


Fig. 8: Cumulative probability curves of granulometric analyses from the Holt sand pit.

have been deformed by cryoturbatic action. At the top of H3 large festoon-like involutions occur. Immediately below these involutions, the original bedding has been strongly disturbed by small-scale flow structures. Also large frost fissures occur near the top of H3, which may grade into ice wedge casts at a lower level. "Vertical platy structure" is common throughout H3. In relatively undisturbed parts, parallel bedding of the same type as in unit H1 is visible. Also, the grain-size analyses are comparable (Fig. 8). This indicates a similar, mainly eolian, depositional environment as that of unit H1. Very well sorted sand is found in a 0.75 m thick intercalation near the base of H3 (sample 4, Fig. 8). This may indicate a more typical eolian depositional feature, possibly a low dune.

Unit H4 is a compact, thinly laminated loam, which is found in the centre of the large involutions at the top of the sequence. The high silt-clay ratio (4.9) of this loam (sample 5, Fig. 8) and the high amount of coarse silt indicates eolian influence, although this is not a typical loess (MÜCHER 1973). Fluvial loams (Fig. 12) all have silt-clay ratios below 4. The fine parallel lamination may be due to deposition of the eolian silt in standing water.

The Beuningen Gravel Bed truncates the large involutions at the top. The gravel bed itself is not well exposed in the Holt pit, as it has been incorporated into the deeply ploughed topsoil. So the sequence at Holt corresponds stratigraphically to the sequence found below the Beuningen Gravel Bed in the nearby Lutterzand exposure (WIJMSTRA & SCHREVE-BRINKMAN 1971). Also the facies types encountered in both outcrops are similar. Both H3 and H1 show the same facies as the "Older Coversand I", H2 is similar to the fluvial sands in the Lutterzand section. H4 is a local phenomen. Loamy beds at the base of the Lutterzand section resemble loamy sand beds which occur within units H1 and H3 at Holt. Loams of this type are also found in other regions, e.g. in the southern Netherlands (VANDENBERGHE & KROOK 1981).

The uppermost loam bed in boring 139 (Fig. 10) has been dated as 27,500 +/— 250 B.P. (GrN-11523). This loam lies approximately 4 m below the level of the lowest loamy bed in the nearby Lutterzand outcrop, and approximately 2 m below the deepest level in the Holt pit. Consequently, both the Holt sequence and the Lutterzand section below the Beuningen Gravel Bed are younger than the loam and peat beds, of which the youngest one is dated at ca. 30,000 BP (VAN DER HAMMEN & WIJMSTRA 1971). They date from the Upper Pleniglacial permafrost period between about 18,000 to 24,000 B.P. (VANDENBERGHE 1983).

4. The borehole sections

The borehole data have been gathered with help of hand auger equipment with a depth range of ca. 10 m. In addition, two borings have been made with hydraulic coring equipment up to a depth of 22 m. Two cross-sections have been compiled from the borehole data (Fig. 9, 10). Table 1 presents a short lithologic description of the lithostratigraphic units of the valley fill in these sections.

Unit B0 and T0 comprise the pre-Eemian substratum of the valley fill. In the Beverborg section (Fig. 9B, 10), it is composed of Tertiary clay or till with a high amount of Tertiary clay. In the Tilligte section (Fig. 9A), also more sandy material is found, which may be slope deposits or fluvio-glacial sediment.

T1 (Table 1) mainly consists of thinly bedded silty, calcareous sand, and some loam beds. The grain size distribution of one of these loams (sample 6, Fig. 12) shows a rather ill-sorted fluvial loam. Recent borehole data suggest, that T1 is older than the Asten Formation. It may represent the Drenthe or Eindhoven Formations (DOPPERT et al. 1975).

Unit B1 consists of laminated, somewhat clayey and humic sand, At the top, peat and gyttja occur. The presence of clay in the sands (sample 1, Fig. 11) indicates fluvial deposition. The gyttja has been deposited in a shallow standing open water environment (section 5, Pollenanalysis), such as a pond in the backswamp area of the river. B1 is of Eemian age and belongs to

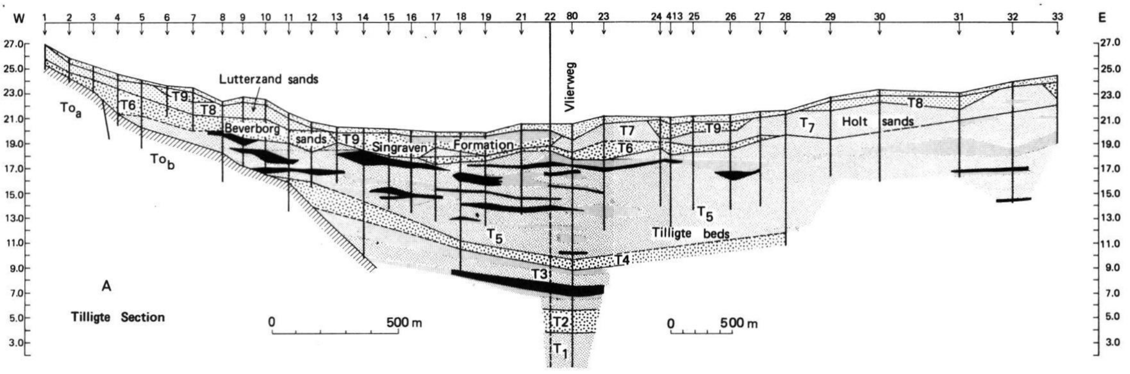


Fig. 9 A: The Tilligte borehole section. See Fig. 1 for location. Horizontal scale is compressed east of boring 22. Levels in m above Dutch ordnance datum.

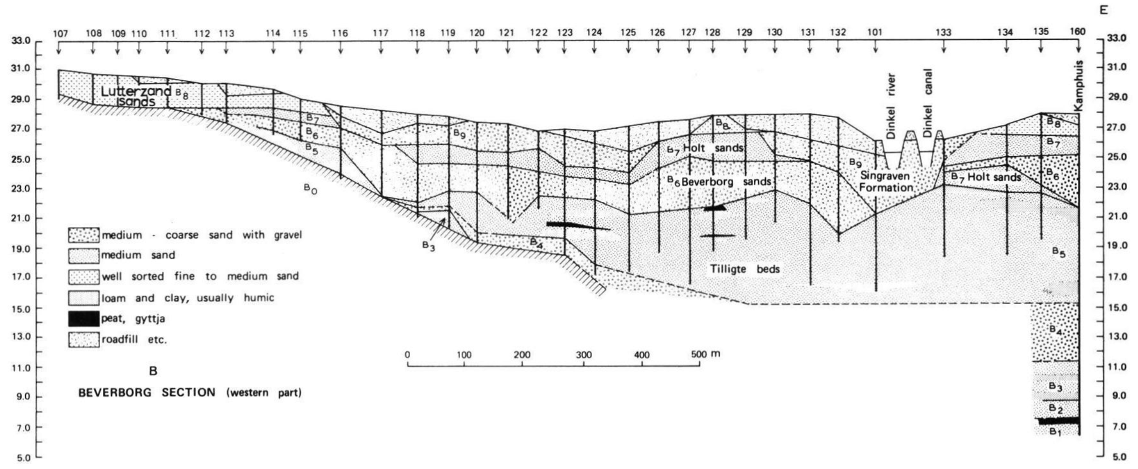


Fig. 9 B: Western part of the Beverborg borehole section. Location: see Fig. 1.

the Asten Formation (VAN DEN TOORN 1967; VAN DER HAMMEN & WIJMSTRA 1971). According to VAN DER HAMMEN & WIJMSTRA (1971) and GRAHLE (1960) this unit may contain high amounts of peat in the Lattrop basin, so the presence of organic sediments in this unit is a common feature. A marshy fluvial plain has been present at that time, without rapid reworking by channel acitivity. An equivalent of unit B1 is not found in the Tilligte section.

T2 and B2 consist of thinly bedded medium sand. Near the base of T2 gravel is found. B3 and T3 mainly consist of clay, loam, gyttja and peat, with sand intercalations. Sample 7 in fig. 12 shows the grainsize distribution of a typical clayey loam from this unit. The sands lack very good sorting (e. g. Fig. 11, sample 2). Both samples clearly represent fluvial sediments. The peat contains wood fragments. It is not unlikely, that a short phase of erosion preceded deposition of T2 and B2, as is indicated by the coarse base of these units. This erosional phase could have removed the equivalent of the Asten Formation in the Tilligte section. T3 and B3 again indicate marshy conditions on the floodplain, with lacustrine conditions locally. Carbonates are absent in T2 and B2; in B3 and T3 some lime may be present in clay beds. Units T2, T3, B2 and B3 have been correlated with the Liendert Member (VAN DER HAMMEN & WIJMSTRA 1971). A radiocarbon dating near the top of T3 resulted in an infinite age (GrN-10840).

B4 consists of calcareous sands. Organic matter is scarce. Coarse sands occur near the base, and medium sand, which may be silty, is found higher up in this unit. The coarse sands represent rather well-sorted fluvial channel sediments (sample 4, Fig. 11), comparable to the fluvial sands in the Holt pit (Fig. 8). The equivalent of B4 in the Tilligte section is apparently unit T4. T4 is much thinner than B4, and is characterised by the presence of gravel in noticeable amounts.

T4 shows more characteristics of an erosional lag deposit. Very probably, T4 is the same erosional level as the gravel bed at the top of unit 2 in the De Poppe exposure. As such, it may be correlated with the "Steinsohle 1" of ZAGWIJN & PAEPE (1968) or the Gilze Gravel Bed in the southern part of the Netherlands (VANDENBERGHE 1985), which are of Lower Pleniglacial age. T4 and B4 mark an important phase of valley erosion, which is also known from the river valley of the Vechte river (TER WEE 1966), to which the Dinkel is a tributary, and from other parts of the Netherlands (VAN DEN TOORN 1967; DE GANS 1981, VAN HUISSTEDEN et al., 1985; VANDENBERGHE et al., 1984).

Unit T5, B5 and unit P3 in the De Poppe pit have been grouped together in the same lithostratigraphic unit, for which the name "Tilligte Beds" has been chosen. The Tilligte section (Fig. 9A) provides a type section for this unit (T5). They form the most important sediment body of the valley fill, with a thickness up to 8 m. The main characteristics of this unit are the presence of loam and peat beds, and the abundance of lime, both in the sands and the loams, especially in the lower part of this unit. Lime gyttjas occur frequently. Towards the top of the unit, the carbonate content usually decreases.

The Tilligte Beds are mainly of fluvial origin. Grainsize analyses (Fig. 11, sample 4, 5) show a well-developed suspension population, a moderately- to well-sorted saltation population, and in most cases the presence of a rolling population. This is indicative of fluvial sedimentation (VISHER 1969). Sequences of faintly graded sand beds up to 15 cm thick are common sedimentary structures in the cores. These graded beds probably represent sets of cross-bedded strata. In the fine-grained sediments modal values in the coarse silt fraction are common. Loams in the Tilligte Beds are somewhat coarser than those of the underlying units T2, T3 and B1—B3 (Fig. 12, sample 8). In the Tilligte section, loam and peat beds are more numerous than in the Beverborg section. Two facies types of the Tilligte Beds in fact exist: one with a high amount of fine grained beds (more than approximately 25 % of total thickness), another facies with a lower amount. In the fine facies, gravel is very rare, in contrast to the coarser facies. Instead, intraformational clasts of loam and peat are common. Recent borehole data suggest, that the coarser facies is restricted to the Dinkel valley south of Denekamp. Some cores from the fine facies contain anomalously thick sequences of loam and fine humic sand. These fine sequences may be interpreted as abandoned channel fills. Such fills belong to the more reliable criteria for the erstwhile presence of high sinuosity channels (MIALL 1977; JACKSON 1978). Also the high loam and peat content of the sequence is more normal for high sinuosity systems. More detailed data will be necessary however. For the coarse facies of the Tilligte Beds, a braided river origin cannot be excluded.

Some indications for eolian influence within the Tilligte Beds exist (see description of the De Poppe exposure). This may have been restricted to the valley margins, such as at the De Poppe site. A computer automated search of the core descriptions provided only a few beds which satisfy eolian sand criteria. However, the frequent occurrence of bimodal grainsize distributions with a mode around 150 μm and a coarser mode, may point to a primary eolian origin for part of these fluvially transported sediments.

The Tilligte Beds may represent the Mekkelhorst Member, from which the presence of loam and peat beds has been reported also (VAN DER HAMMEN & WIJMSTRA 1971), and the loamy and peaty beds in the adjacent Hengelo basin (ZAGWIJN 1974). Radiocarbon dates (to be published seperately) from the borehole sections show ages over 27,000 B.P., so this unit is of Middle Pleniglacial age.

Above the Tilligte Beds a rather thick sandy sequence occurs. These sands correlate with the sequence at the Holt sand pit, 200 m east of the Beverborg section. The lithology of these sands strongly differs of that of the Tilligte Beds. Peat beds are absent, and loam beds are very rare. If present, these never contain organic matter in appreciable amounts. Carbonate also is absent. Even in loamy beds, only relatively low amounts of clay may be found.

Two different units have been distinguished within this sand sequence. The Beverborg Sands (B6, T6), as typically developed in the eastern part of the Beverborg section, consist of medium to coarse, cross-bedded sand, usually with gravel. Unit H2 in the Holt pit and unit P4 in the De Poppe pit belong to this unit. In the Lutterzand section and the New Dinkel Canal section (VAN DER HAMMEN & WIJMSTRA 1971) the "Upper Sands of the Mekkelhorst Member" correspond to the Beverborg Sands. The Holt Sands (B7, T7), for which the Holt sand pit provides a type section, consist of fine to medium, often loamy sand. Very fine gravel, strings of pebbles and coarse sand lenses may occur, but they never dominate this unit. Sometimes sandy loam beds may be found. Unit H1, H3 and H4 in the Holt pit and unit P5 in the De Poppe pit belong to the Holt Sands, as well as the eolian deposits of the "Older Coversands I" of the Lutterzand and New Dinkel Canal sections (VAN DER HAMMEN & WIJMSTRA 1971). If the total sequence is sufficiently thick, the distinction between Beverborg and Holt Sands also can be made within the borehole sections, using grainsize criteria and sedimentary

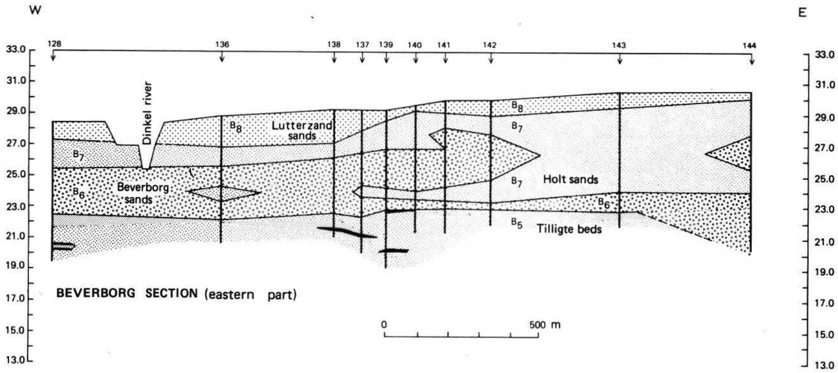


Fig. 10: Eastern part of Beverborg section. Location: see Fig. 1. Legend: see Fig. 9B.

structures. Both units occupy the same lithostratigraphic position, above the Tilligte Beds and below the Beuningen Gravel Bed. Generally, the Beverborg Sands underly the Holt Sands. In thick sequences however, both units may interfinger. Often the underlying Tilligte Beds have been eroded to some extent before deposition of the Beverborg Sands.

The sections and outcrops prove, that the Holt and Beverborg Sands are strongly related genetically. The Beverborg Sands represent the active river reaches at that time, while the Holt Sands probably were deposited on "overbank" reaches of the river or low fluvial terraces. BRYANT (1983) notes the presence of higher terrace-like reaches with eolian deposition along the valley margins of arctic rivers. The edge of such a terrace may have been preserved beneath a cover of eolian sand between boring 139 and 137 of the Beverborg section (Fig. 10), where a low step is present at the top of the Beverborg/Holt Sands. The depositional system of the Holt and Beverborg Sands show the abundant presence of eolian deposition next to fluvial deposition, mainly under permafrost conditions. The eolian activity indicates generally drier climatic conditions. The youngest date obtained from the Tilligte Beds suggests, that the Holt and Beverborg Sands are of Upper Pleniglacial age.

Three sources of lime may have contributed to the high lime content of the lower part of the Pleniglacial sequence. The Cretaceous limestones in the upper course have not been a very important source, as also in areas, which have no contact with this source area, abundant lime-rich sands occur. Eolian dust may have contributed to the lime content of loams in the Tilligte Beds. Another source however, especially for the sands, may be the lime-rich tills of the Drenthe Formation. In this hypothesis, not decalcified tills in the upstream part of the basin could have been removed by increased surficial or gully erosion and redeposited downstream in the basin (B4, T4 and the Tilligte Beds). Gradually, the amounts of lime-rich till diminished, so that the redeposited sediments contained less lime (upper part of Tilligte Beds and Beverborg/Holt Sands).

The next overlying unit (B8/T8, L u t t e r z a n d S a n d s) consists of typical, well-sorted, often somewhat loamy sands. They comprise the Older Coversand II, and the Younger Coversands (VAN DER HAMMEN & WIJMSTRA 1971). Unit P6 in De Poppe also belongs to this unit. The Coversand sequence is of eolian origin (VAN DER HAMMEN 1951). Permafrost structures are absent in these sands (WIJMSTRA & SCHREVE-BRINKMAN 1971; VANDENBERGHE 1983). The presence of the Older Coversand II near the centre of the valley indicates very dry conditions and low fluvial activity. Hydrologic changes of this kind have been noted in other valleys also (DE GANS 1981; VANDENBERGHE et al. 1984; VAN HUISSTEDEN et al. 1985).

At the top of both sections local incision fills and veneers of clay and peat occur (B9, T9). The incision fills show two facies types. Along the Dinkel, medium to coarse sands of considerable thickness are found, which sometimes contain large amounts of iron-cemented sand pebbles. Elsewhere shallow incisions filled with humic and peaty matter occur. All incisions usually contain sand with much gravel at their base. In the Tilligte basin glauconitic sands are common. The iron-cemented sand pebbles which occur in the sands along the Dinkel are probably derived from illuvial horizons of Holocene soils. Recent sand deposits exposed along the banks of the Dinkel near De Poppe show a distinct horizontal bedding. Individual beds are structureless and can be traced over long distances. This bedding probably represents overbank deposition during flood stages. These units have been correlated with the Singraven Formation (DOPPERT et al. 1975; VAN DER HAMMEN & WIJMSTRA 1971). According to VAN DER HAMMEN & WIJMSTRA (1971) sedimentation of this unit started already during the Late Glacial. This is a phenomenen of regional significance (VANDENBERGHE & BOHNCKE 1985).

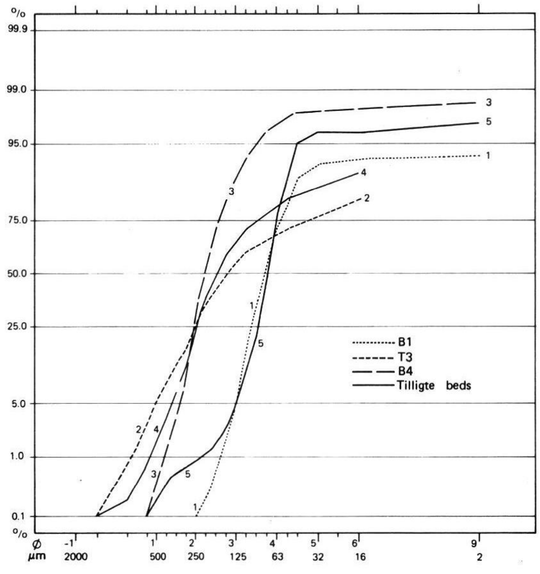


Fig. 11: Cumulative probability curves of granulometric analyses of sands in the borehole sections.

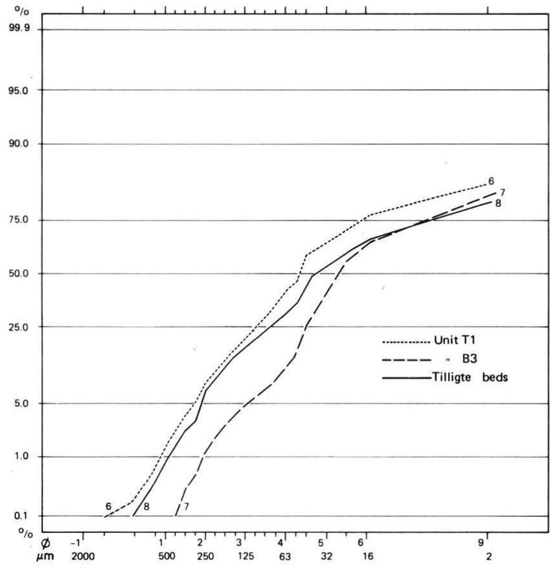


Fig. 12: Cumulative probability curves of granulometric analyses of loams in the borehole sections.

5. Pollenanalysis

The lowest 80 cm of the boring Kamphuis consists of about 55 cm of a sandy peaty deposit with wood fragments and a ca. 25 cm thick gyttja deposit on top of it. A series of 15 samples has been analysed for pollen, spores, fruits, seeds, mosses, fungi, algae, invertebrates and some morphologically characteristic micro- and macrofossils of unknown identity ("Types"). The complete results of this study are given by VAN GEEL et al. (1985). The present chapter deals with the palynostratigraphy, and in addition some general information from the abovementioned study is given below.

In combination with the stratigraphic position of the studied deposit the treepollendiagram (Fig. 13) leaves no doubt that we are dealing with an upper Eemian deposit. The forest elements are: *Abies, Acer, Alnus, Betula, Carpinus, Corylus, Fraxinus, Ilex, Picea, Pinus, Quercus, Salix, Taxus, Tilia* and *Ulmus*. The forest history during the Eemian in N. W. Europe is known in detail and for the subdivision of the treepollendiagram the zonation criteria of ZAGWIJN (1961, 1983) are used.

The zones E1, E2, E3 and E4 are not represented in the diagram. The trends of the treepollen curves show that the deposit corresponds with the zones E4b, E5 and E6a. The main characteristics are:

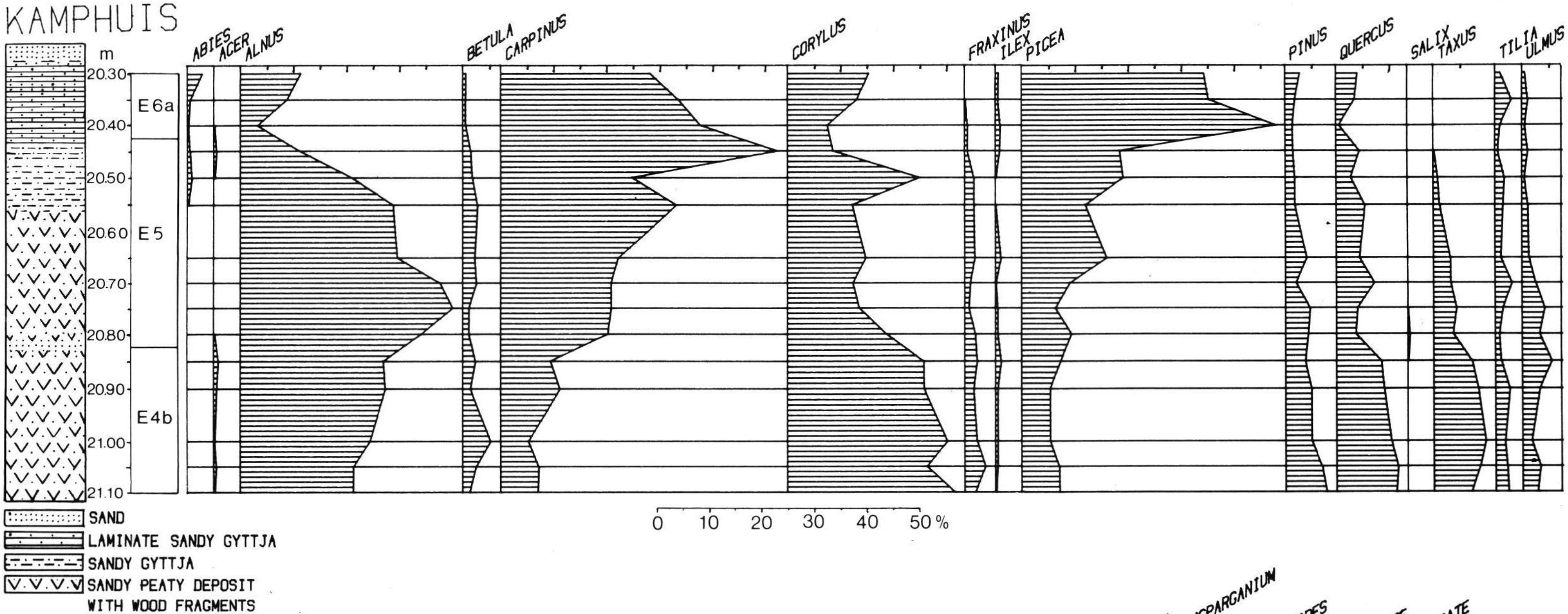
Zone E4b (samples 21.10—20.85)
The curve of *Corylus* shows a decline, *Taxus* attains 5—10 %. The percentages of *Carpinus* pollen increase.

Zone E5 (samples 20.80—20.45)
Carpinus rises to 30—50 %, the percentages of *Picea* pollen also show a rise, *Alnus* shows a maximum and subsequently a sharp decline. *Taxus* disappears in the upper part of the zone.

Zone E6a (samples 20.40—20.30)
Picea pollen attains a maximum, the percentages of *Abies* pollen rise somewhat, *Alnus* shows low values, *Carpinus* declines.

The pollen diagram shows the characteristic upper Eemian forest succession, *Corylus, Carpinus* and *Picea* being the successive dominant dry forest taxa. According to ANDERSEN (1964) the changes in forest composition during the upper Eemian are related with acidification of the soils, but in the present case there are no indications for such an acidification. *Ericales* do not show a rise and mosses and strictly local aquatic taxa indicate a continuation of the base rich conditions (VAN GEEL et al. 1985). The presence of pollen of *Ilex* and *Hedera* during the period of zone E6a indicates that the final dominance of *Picea* was not caused by a decline of mean temperatures (IVERSEN 1944; cf. fig. 11 in ZAGWIJN 1961). The decline of the deciduous forest elements enabled the extension of the weakly parasitic fungus *Ustulina deusta* of which an increasing amount of ascospores was found. Considering its present ecology this fungus can have played only a secondary role in the degradation of the deciduous forest.

In conclusion, the upper Eemian forest succession, especially the degradation of the deciduous forest and



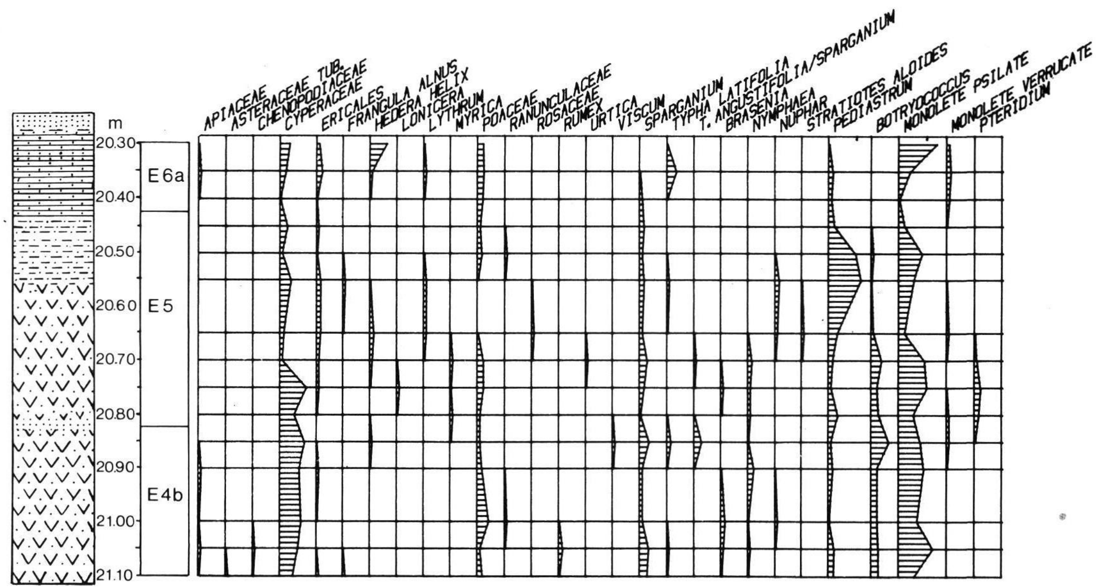


Fig. 13: Pollen diagram of lowest organic bed in boring Kamphuis (160).

Tab. 1: Characteristics of lithostratic units in the valley fill. Unit numbers starting with B: Beverborg section only; numbers starting with T: Tilligte section. — = absent, + = present in minor amounts, + + = abundant.

Unit Name or Number	Lithology Description					
	Sand characteristics			loam/	peat/	carbonate
	size	other	colour	clay beds	gyttja beds	
Singrven formation: T9, B9	fine to coarse	humic matter	varying	+ +	+	—
Lutterzand sands: T8, B8	fine to medium	silty, well sorted	light yellow	—	—	—
Holt Sands: T7, B7	fine to medium	silty	light grey	+	—	—
Beverborg sands: T6, B6	medium, coarse	gravel	light grey	—	—	—
Tilligte Beds T5, B5	fine, medium,	intraclasts	dark grey	+ +	+ +	+ +
T4	coarse	gravel	grey	—	—	+ +
T3	fine to medium	silty	greenish grey	+ +	+ +	+
T2	medium, coarse	gravel	greenish grey	—	—	—
T1	medium	silty	greenish grey	+	—	+ +
B4	medium, coarse	gravel, silty	grey	—	—	+ +
B3	fine to medium	silty	greenish grey	+ +	—	+
B2	medium		greenish grey	—	—	—
B1	fine to medium	silty, peaty	greenish grey	+	+ +	—

the development of *Picea* forest cannot be explained satisfactorily at the present state of knowledge.

6. Lithostratigraphical and paleogeographical synthesis

The detailed data of exposures and borehole sections provide considerable detail to the lithostratigraphic subdivision of the upper part of the Twente Formation. Several lithostratigraphic marker horizons can be distinguished:

1) An erosional level at the base of the Tilligte Beds, locally accompanied by coarse sands (B4). This level also marks another important lithological change, a transition from sediments poor in lime to lime-rich sediments.

2) The boundary between the Tilligte Beds and the Beverborg/Holt Sands. Important lithologic changes associated with this boundary are the change from calcareous to non-calcareous sediments, the disappearing of humic beds and the decrease in clay content of the sediments. Usually, this boundary shows erosional features.

3) A third, very important lithologic marker is the well known Beuningen Gravel Bed (VAN DER HAMMEN & WIJMSTRA 1971).

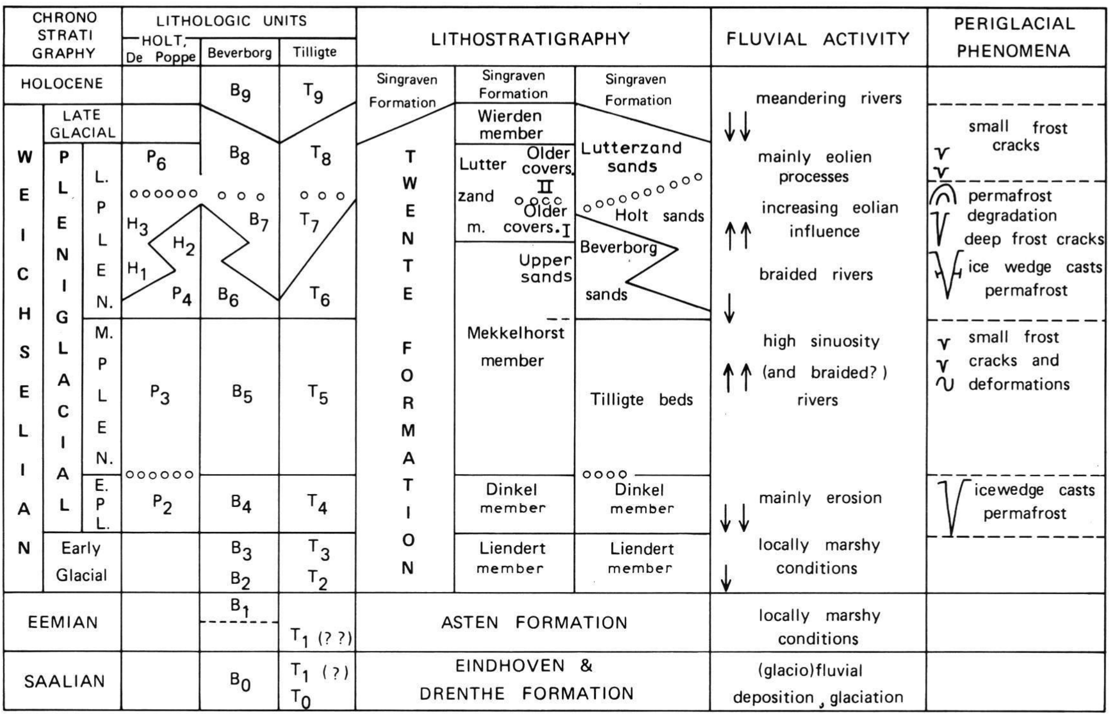


Fig. 14: Correlation scheme of stratigraphy, fluvial activity and cryogenic processes in the study area. The left part of the lithostratigraphic column according to DOPPERT et al., 1975; middle part according to VAN DER HAMMEN & WIJMSTRA, 1971; right part: present study. ↑↑ = strong aggradation, ↓ = minor erosion, ↓↓ = deep incision.

The former two horizons have not been distinguished as sharply before. The Beuningen Gravel is a significant lithostratigraphic marker and is used insofar as a boundary between two genetically and lithologically different units in the present study. As a consequence, the lithostratigraphic subdivision of VAN DER HAMMEN & WIJMSTRA (1971) has been modified (Fig. 14). As more data are still being collected, only informal names have been assigned to the units for the time being.

The post-Saalian fluvial history started with marshy conditions and the presence of high sinuosity rivers during the Eemian and Early Weichselian. After the Eemian probably a minor erosion phase occurred. The virtually limeless sediments testify of deep decalcification as part of the weathering processes in the drainage basin. Erosion and river downcutting took place during the Lower Pleniglacial. This erosion liberated fresh, not decalcified substratum, which contributed abundant lime to the valley fill. Cryoturbatic deformations indicate the presence of permafrost. Elsewhere ice wedge casts have been found, dating from this period (VANDENBERGHE 1983).

Following this erosion, fluvial aggradation occurred during the Middle Pleniglacial. The channel configuration of the trunk river in the valley remains uncertain, but in the glacial basins sinuous channels may have been present. Pollen data from the Middle Pleniglacial prove the presence of a treeless tundra landscape (VAN DER HAMMEN & WIJMSTRA 1971; ZAGWIJN 1974; KOLSTRUP & WIJMSTRA 1977). Indications for the presence of permafrost have not been found however.

After 27.500 B.P. a marked change in sedimentation style occurred, preceded by minor erosion. Increasing eolian sedimentation and ice wedge casts point to a drier, colder climate with permafrost. The river channels developed a braided pattern. These rivers probably showed arctic nival discharge characteristics. A satisfying explanation for the absence of lime in these sediments has not been found yet. At the top of the Beverborg/Holt Sands, large involutions indicate degradation of the permafrost (VANDENBERGHE 1983). These involutions have been cut off at their top by the Beuningen Gravel Bed, which represents another phase of erosion. Deflation by wind action has played an important role in this erosion (ZAGWIJN & PAEPE 1968). Eolian sedimentation dominated afterwards throughout the whole valley during the last part of the Upper Pleniglacial.

The Late Glacial deposits show a restoration of the fluvial activity while eolian sedimentation remained important locally until the Holocene. Gully incision and sedimentation of sands and clays with organic matter took place. This activity continued into the Holocene, with several phases of incision and infilling (VAN DER HAMMEN & WIJMSTRA 1971).

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