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Notes on the Tertiary and Pleistocene geology of East Gelderland, The Netherlands

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With 13 figures

Zusammenfassung. Für den Raum des östlichen Teiles der Provinz Gelderland wurden, im Hinblick auf den für die Zukunft zu erwartenden starken Anstieg des Trink- und Industriewasserbedarfes, in den Jahren 1964 bis 1967 die hydrogeologischen und wasserwirtschaftlichen Verhältnisse eingehend untersucht. Einige der wichtigsten aus diesen Untersuchungen gewonnenen geologischen Ergebnisse werden kurz dargelegt.

Das rund 162 500 ha große Arbeitsgebiet zwischen der deutsch-niederländischen Grenze und dem Fluß IJssel kann vom morphologischen Standpunkt in zwei unterschiedliche Landschaften unterteilt werden: das ostniederländische Tertiär-Plateau, das von marinen tonführenden Sanden und schweren Tonen des Oligo-Miozän aufgebaut ist, und ein pleistozänes Becken, in dem vorwiegend grobkörnige Sande und Schotter des Rheines und schotterführende fluvioglazialen Sande abgelagert worden sind.

Auf der Grundlage von einigen älteren Einzelarbeiten, 400 älteren Bohrungen, 100 Explorations- und Produktionsbohrungen, die von der Wassergesellschaft „Ost Gelderland" in dieser Gegend abgesenkt wurden, und 130 neuen Explorationsbohrungen des Instituts für Kulturtechnik und Wasserwirtschaft in Wageningen sowie mehrerer geoelektrischer Einzelarbeiten wurde erstmals ein zusammenhängender und leicht faßbarer Einblick in die Untergrundverhältnisse des Arbeitsgebietes gewonnen.

Auf dem Tertiär-Plateau sowie in dem Pleistozän-Becken wurden mehrere begrabene Talsysteme verschiedenen Alters und unterschiedlicher Richtung nachgewiesen. Die Herkunft und die stratigraphische Lage der Talaufschüttungen wird kurz erörtert.

Bei einem dieser begrabenen Täler handelt es sich um einen Arm des Rheines, der vom Dorf Dinxperlo an der Staatsgrenze im Süden bis am Dorf Borculo im Norden des Arbeitsgebietes im Untergrund nachgewiesen werden konnte. Die in diesem Flußarm abgelagerten schotterreichen Grobsande weisen in ihrer Schwermineral-Zusammensetzung (mit besonders hohen Gehalten an vulkanischen Mineralen wie Augit) deutlich auf Rhein-Ablagerungen hin. An einer Stelle werden die Sande von saalezeitlichem Geschiebelehm bedeckt, womit erwiesen ist, daß der Rhein-Arm aus der frühen Saale-Eiszeit oder dem späten Holstein-Interglazial stammt.

Ein zweites begrabenes Talsystem, ebenfalls aus der Saale-Eiszeit, konnte nachgewiesen werden von der Stadt Vreden in Deutschland über Winterswijk und Aalten nach Dinxperlo, wo es wieder die Staatsgrenze überquert. Das Tal wurde vom Schmelzwasser im Hochglazial ausgeräumt und später mit glaziofluvialen Ablagerungen aufgefüllt. Das Schmelzwasser-Tal quert den genannten ehemaligen Rhein-Arm, ist also etwas jünger. Die Tiefe des Talbodens nimmt in südwestlicher Richtung beträchtlich zu, erreicht in der Nähe von Dinxperlo etwa 70 m unter Meeresspiegel. Hieraus geht hervor, daß während der Saale-Eiszeit der Meeresspiegel mindestens 100 m tiefer gelegen haben muß als heute.

Abstract. A detailed hydrogeological survey was carried out in the eastern part of the province of Gelderland from 1964 to 1967. The objective of this survey was to provide basic data required for the planning of a further extension of the present groundwater extraction, in order to meet the increasing demand for water for domestic and industrial use. In this paper some of the more interesting findings of the geological investigations are given.

The investigated area has two main geomorphological landscapes: part of the East-Netherlands Tertiary Plateau, consisting of fine-grained marine sediments, and a Pleistocene basin, filled with predominantly coarse grained sediments of fluvial and fluvioglacial origin.

The horizontal and vertical extension of the different geological formations in the subsurface could be indicated more precisely than had been the case. Based on the results of many, old as well as new, borings, geo-electrical surveys and heavy mineral analyses, a number of buried channel systems could be located. The various geological formations and buried channel systems are briefly discussed. One of these channels represents a former branch of the river Rhine. It could be traced in the subsurface from Dinxerlo near the Netherlands-German border in the south, to the village of Borculo in the north. The channel has been filled with Rhine sediments which are extremely

rich in volcanic minerals. Its age is Early Saalian or somewhat older. Another buried channel of Saalian age could be traced from Vreden (Germany), via Winterswijk and Aalten to Dinxperlo where it again crosses the border with Germany. Its depth increases in a downstream direction and near Dinxperlo the bottom of the channel is about 70 m below present sea level, a depth also reached in another channel near Zelhem, indicating that during the Saalian the sea level was at least 100 m lower than at present.

Introduction

The present demand for water for domestic and industrial use in the eastern part of the province of Gelderland is entirely met by the exploitation of groundwater. As this demand for water is rapidly increasing, and with a view to agricultural interests, it was necessary to investigate the problem of a further groundwater extraction, within the scope of a study of total water resources management.

For this purpose an extensive hydrogeological investigation has been carried out in this region over the last few years. Some of the results have already been published (DE RIDDER 1966; CSONKA 1967; ERNST, DE RIDDER & DE VRIES 1970). The principal aim of this paper is to summarize the newly opened aspects concerning the general subsurface geology and some geological findings as the depth and the relief of the surface of the Tertiary deposits and the occurrence, direction, depth and age of the different buried channel systems.

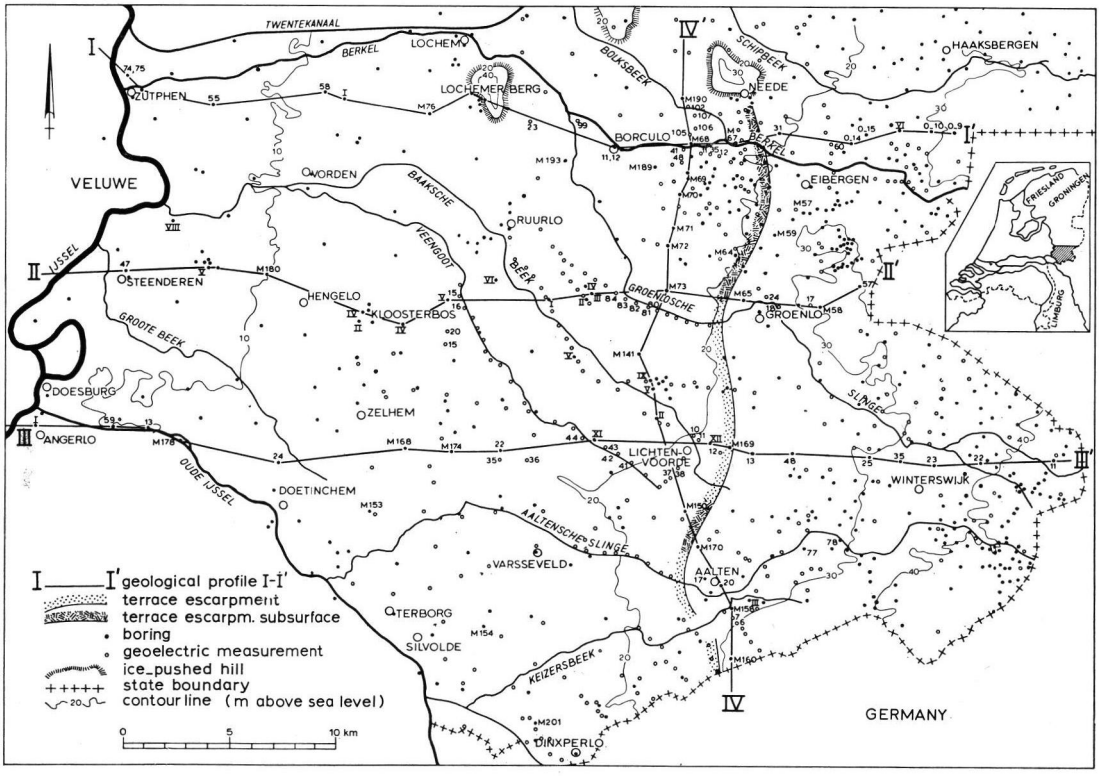

Fig. 1. Map of East Gelderland, showing the general topography, the location of the borings, geo-electrical measurements and geological sections.

Location of the Region

The investigated region is located between the Netherlands-German border and the river IJssel. It is bounded in the north by the line Zutphen-Lochem-Haaksbergen and in the south by the river Oude IJssel (fig. 1). Its area is about 1625 km².

Available Data

As a basis for this investigation the following data were available:

- the well logs of 400 borings from the boring archives of the Geological Survey at Haarlem,
- the well logs of 100 exploration and production wells, drilled by the Water Supply Company 'Oostelijk Gelderland' N.V. at Doetinchem,
- the well logs of 130 new wells drilled by the Institute for Land and Water Management Research (ICW) at Wageningen for the purpose of this study,
- grain-size analyses (ICW) of the samples from 9 borings,
- heavy mineral analyses (ICW and Geological Survey) of the samples from 101 borings,
- macropalaeontological, respectively micropalaeontological and palaeobotanical analyses of the samples from respectively 9, 13 and 7 borings, carried out by the Geological Survey,
- the results of an extensive geo-electrical survey carried out by the Working Party Geo-electrical Research, T. N. O. at Voorburg.

Geomorphological Setting

From a geomorphological point of view, two different landscapes can be distinguished in the investigated region: part of the East-Netherlands Tertiary Plateau and a Pleistocene basin. The boundary between these two landscapes is formed by the line from Aalten in the south, via Lichtenvoorde, Groenlo, Eibergen towards the Needse Berg in the north. East of this line, which at some places is marked by a terrace scarp several metres high, locally affected by land ice, Tertiary and Mesozoic deposits are found at shallow depth, or even at the land surface. West of this terrace scarp, the Tertiary layers dip steeply and are covered by Pleistocene sediments which fill the basin.

Although generally flat, the region has some higher parts, e.g. the Lochemer Berg (south of Lochem) and the Needse Berg (north of Neede), which are ice-pushed hills, made up of pre-Saalian sands and clays.

On the East-Netherlands Tertiary Plateau, as well as in the Pleistocene basin, a number of buried channels is present, filled with Middle-Pleistocene or fluvioglacial deposits (Faber 1960; Csonka 1967; de Vries & van Rees Vellinga 1971).

Stratigraphic and Palaeogeographic Situation

Pre-Tertiary

In contrast with the major part of the Netherlands, Mesozoic rocks occur at shallow depth in the extreme south-eastern part of the investigated area, for example east of Winterswijk. They chiefly consist of shale, marl, limestone and sandstone. This area has strongly been affected by tectonic movements, an excellent review of which has been given by Harsveldt (1963).

Tertiary

Eocene

Deposits of the Eocene have not been found in East Gelderland, except in the north-east near the village of Haaksbergen where Eocene sands and clays occur at shallow depth.

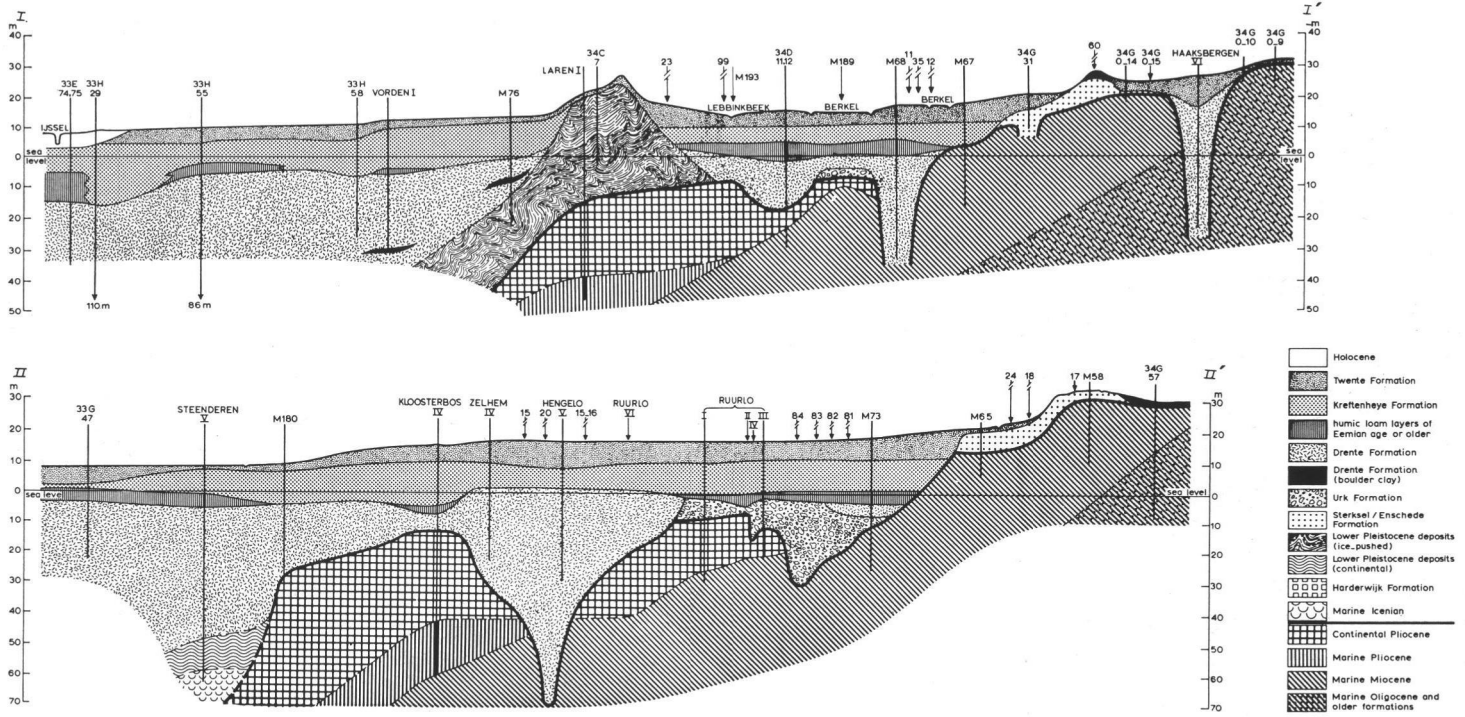

Fig. 2. Geological sections I and II, for location, see fig. 1.

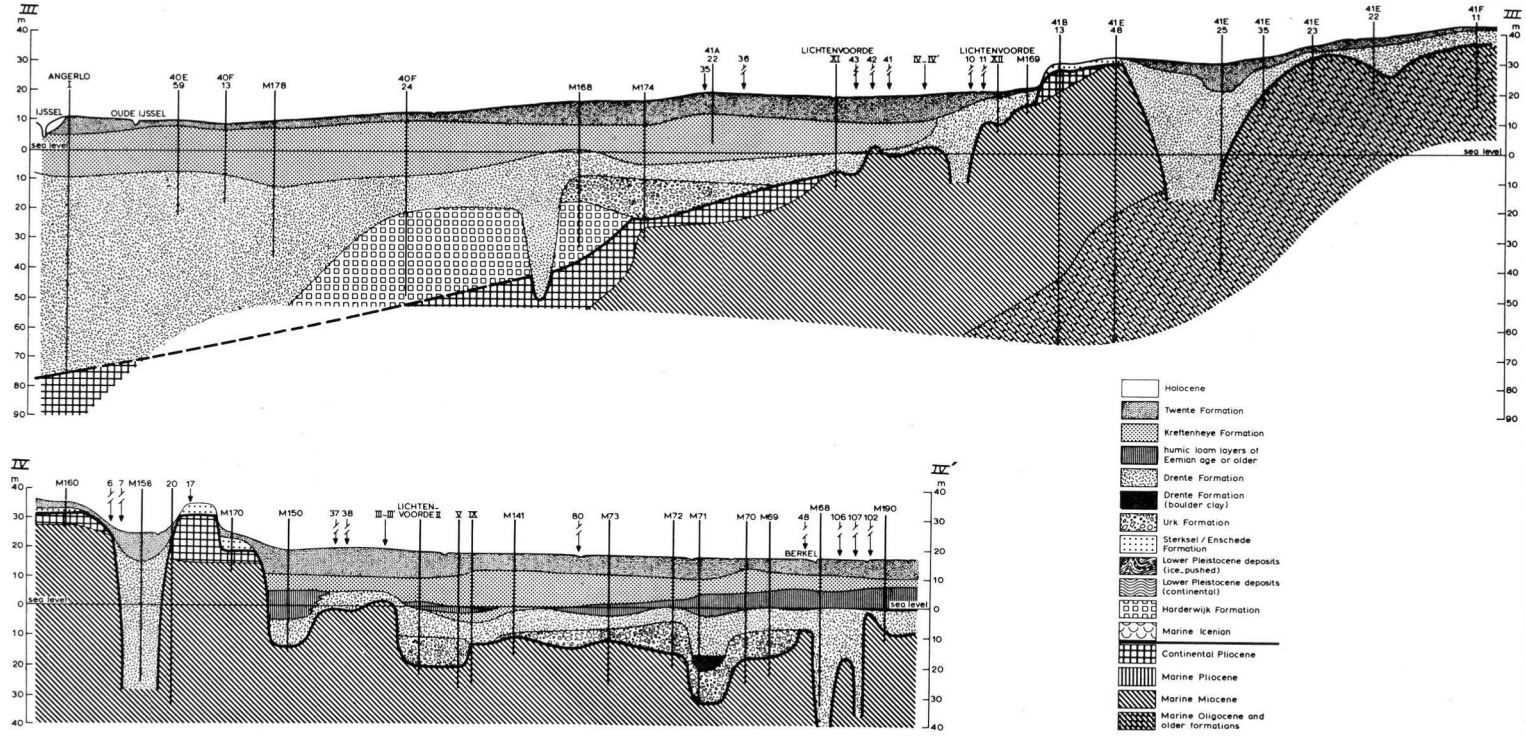

Fig. 3. Geological sections III and IV, for location, see fig. 1.

Oligocene

The oldest Tertiary deposits found in the region are of the Lower- and Middle-Oligocene. These layers, which consist of heavy clays, sandy clays and clayey sands, dip steeply from the terrace scarp in a westerly direction. The borings in the Pleistocene Basin have not struck the Oligocene because of its great depth. On the plateau the thickness of the Oligocene sediments could only be established in a few borings which showed about 5 to 30 m. In the geological sections and maps of this paper the above-mentioned deposits have been taken together as 'Oligocene and older deposits' (fig. 2, 3 and 4).

Miocene

Marine Middle-Miocene deposits occur nearly everywhere in the subsurface of East Gelderland, although in the western part of the basin their presence could not be demonstrated because of a lack of sufficiently deep borings in that area.

On the plateau thin layers of the Middle-Miocene, which consist of clays and clayey glauconite-bearing sands, are found at shallow depth. At some places these deposits are absent and the Oligocene clays are directly covered with Pleistocene sediments.

In the Pleistocene basin the Miocene deposits occur much deeper — at one place as much as 60 m below present sea level (Section II, Kloosterbos IV) — while their thickness increases westward (figs. 1—4). The actual thickness is not known because of a lack of deep borings.

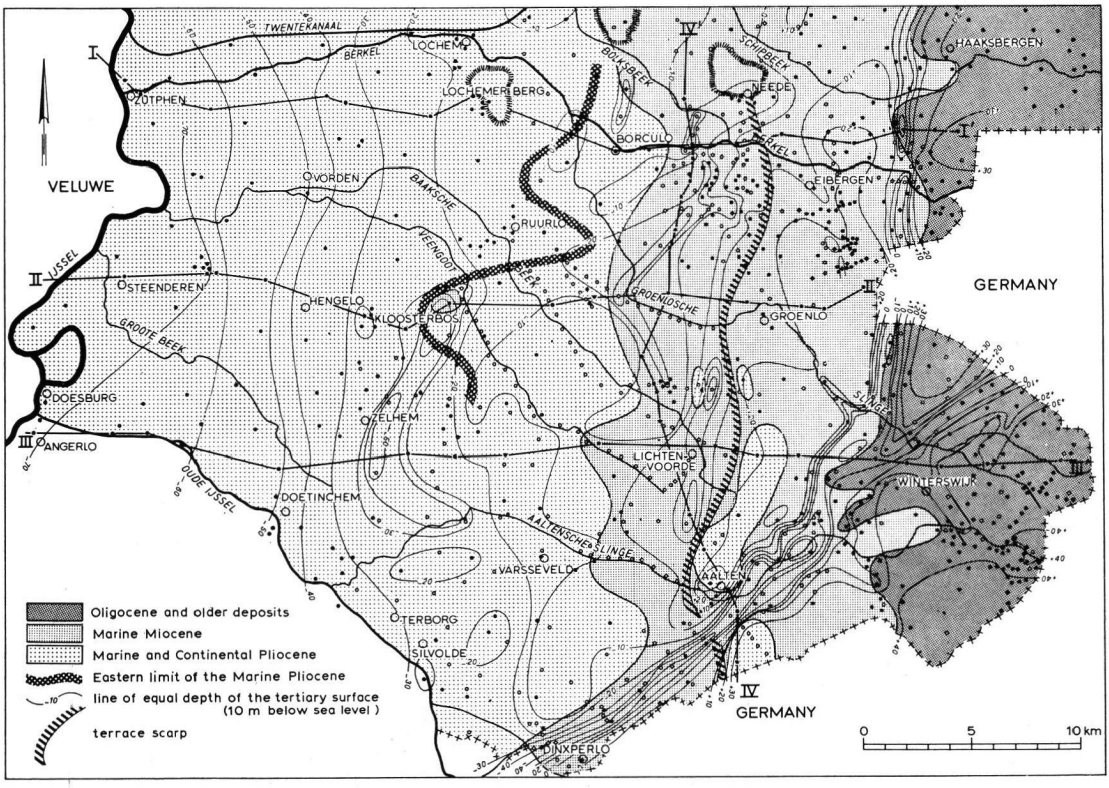

Fig. 4. Oligocene, Miocene and Pliocene deposits in East Gelderland, and the depth of their surface with respect to sea level.

Pliocene

Marine Lower-Pliocene has been found in the central part of the Pleistocene basin and in the neighbourhood of Lochem (figs. 2 and 4). These deposits consist of moderately fine sands, sometimes silty, with many remains of shells and foraminifera (VAN VOORTHUYSEN 1964; ZAGWIJN 1965). The heavy mineral composition is generally characterized by the presence of tourmaline, metamorphic minerals, zircon, and often a high percentage of hornblend (Kloosterbos IV, figs. 1 and 7). The thickness of the marine Pliocene could be established in the Kloosterbos IV boring only, where 18 m was found (Section II, fig. 2).

At many sites on the plateau and in the basin, Middle-Pliocene of continental facies has been perceived, though at different depths and in varying thicknesses, probably due to post-depositional erosion. On the plateau it occurs at shallow depth and in thin layers, especially near the terrace scarp, but also at some other places.

The continental Pliocene sediments consist of highly sorted, middle fine to moderately fine sands with little silt. At some places thin layers of clay and peat have been found. Heavy mineral analyses of the sands show the presence of tourmaline, metamorphic minerals, and a high percentage of zircon (M 154, Kloosterbos IV and M 201, fig. 6 and 7).

Pleistocene

Marine Icenian

Until recently, the presence of marine Icenian was unknown in East Gelderland. The most easterly borings in which it had been found, are west of the river IJssel, where Icenian occurs at a depth of respectively 102 m and 137 m below sea level (VAN VOORTHUYSEN 1954).

In the new boring V near the village of Steenderen, about 6 km east of the river IJssel, a sticky humic sandy loam with foraminifera was struck at a depth of 69 m below sea level (VAN REES VELLINGA & DE RIDDER 1965). The microfauna consisted of *Elphidiella* cf. *arctica, Elphidium selseyensis, Streblus batavus,* some specimen of *Elphidium excavatum,* 1 *Elphidium pseudolessonii* and 1 *Elphidium crispum,* a fauna typical of the marine Icenian (VAN VOORTHUYSEN 1965).

As far as is known to us, this is the first and most easterly finding of the marine Icenian in East Gelderland and it confirms VAN VOORTHUYSENS (1954) view that during the Icenian the coast line may have been located some 10 km east of the present course of the river IJssel (fig. 8).

Harderwijk Formation

In boring V near Steenderen the marine Icenian is overlain by a 10 m thick layer of middle fine, browngrey sand (figs. 1, and 2, Section II). This sand has a rather high content of light green glauconite and a high lime content. The most important heavy minerals in this sand are garnet, hornblend, staurolite, metamorphic minerals, tourmaline and zircon (22 per cent).

The microfauna of this sand consists of *Asterigerina gürichi staeschei, Uvigerina hosiusi, Elphidium inflatum, Bulimina elongata, Pullenia bulloides,* and *Uvigerina tenuipustulata,* a fauna indicating a Lower-Pleistocene position of the sand (VAN VOORTHUYSEN 1965). A more precise stratigraphic division was not possible.

At several sites in the south-western part of East Gelderland the continental Pliocene is overlain by white and light grey sands, mostly coarse and sometimes medium fine, which consist for the major part of transparent quartz (figs. 2, 3 and 8). The sands contain some silt, gravel, and glauconite is present. Heavy mineral analyses show a composition of

predominantly tourmaline, metamorphic minerals, zircon and some per cents of topaz. Such minerals as garnet, hornblend, epidote and saussurite are almost always entirely absent (fig. 6, M 153).

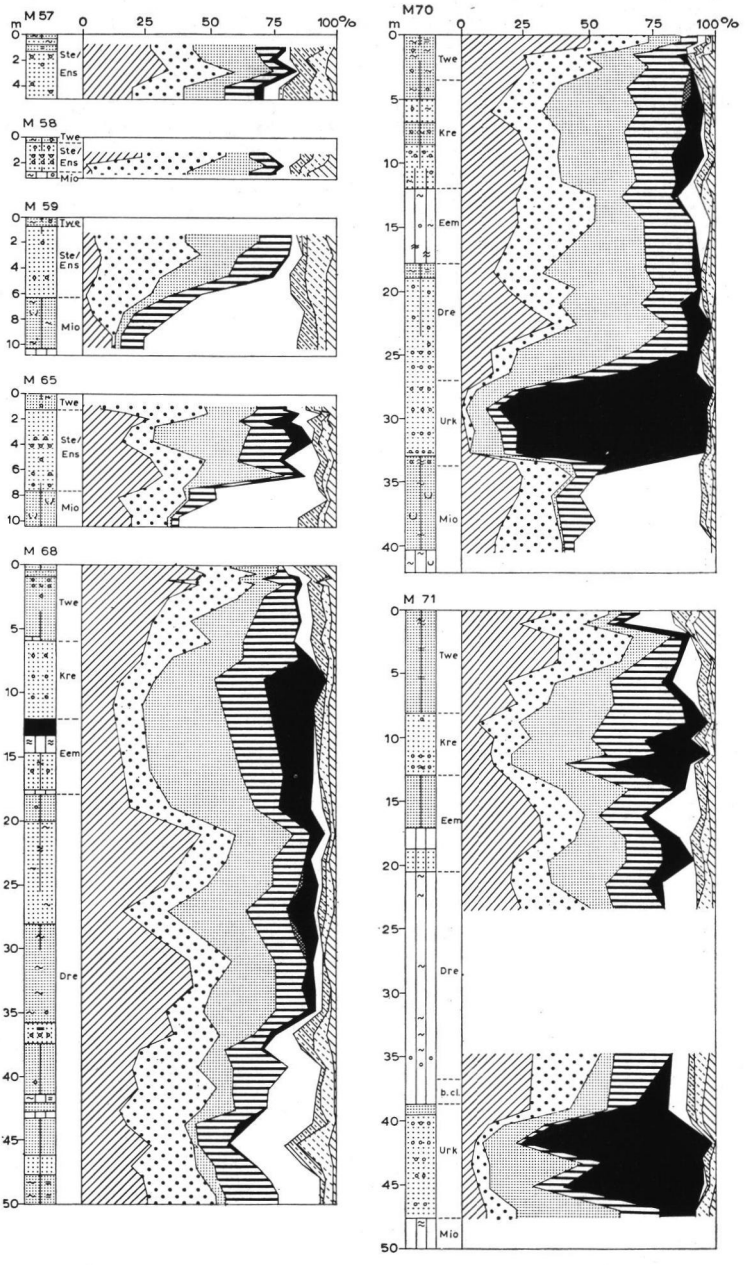

Fig. 5. Heavy mineral analyses of samples from the borings M 57, M 58, M 59, M 65, M 68, M 70 and M 71. For location of these borings, see fig. 1.

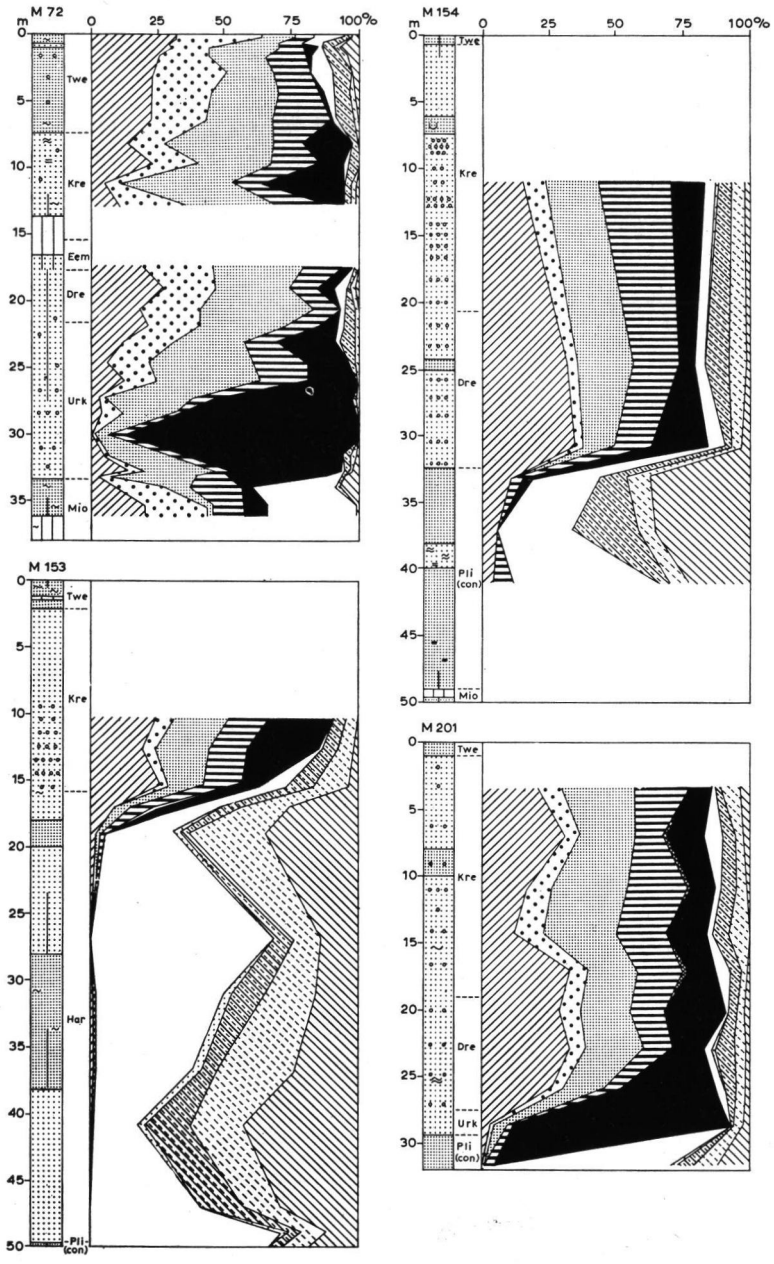

Fig. 6. Heavy mineral analyses of samples form the borings M 72, M 153, M 154 and M 201. For location of these borings, see fig. 1.

As to the stratigraphic position of these sands, one possibility could have been Pliocene. The glauconite and heavy mineral association would favor this assumption, although topaz is generally not present and the content of zircon is higher in the Pliocene deposits. In this connection, it is interesting to refer to a statement of the Netherlands Geological Survey

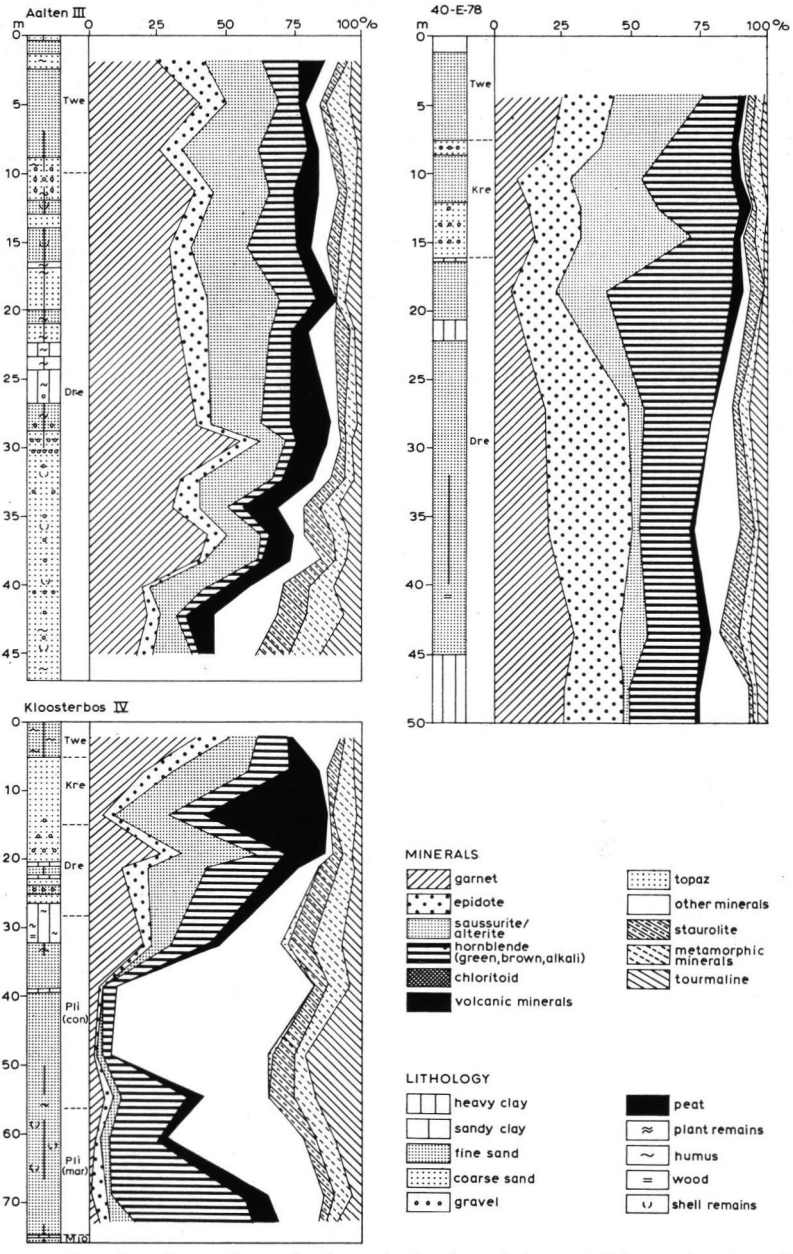

Fig. 7. Heavy mineral analyses of samples from the borings Aalten III, Kloosterbos IV and 40-E-78. For location of these borings, see fig. 1.

(1968) that palaeobotanical studies in the vicinity of Doetinchem have shown that deposits, hitherto named fluvioglacial (Drente Formation), should be placed in the Pliocene (Reuverian). The lithology of the sands under discussion, however, does not correspond with that of the Pliocene deposits occurring elsewhere in East Gelderland. The Pliocene deposits consist chiefly of highly sorted moderately fine to middle fine sands.

A fluvioglacial origin of the sands is unlikely. Some palaeobotanically clearly defined Drente deposits show a different heavy mineral composition and northern components among the scarce gravel in these sands have not been found.

Elsewhere in the Netherlands and in the adjacent German areas, these white sands also occur (CROMMELIN 1953; MAARLEVELD 1956; DE JONG 1956; ZONNEVELD 1958; ANDERSON 1968). Apart from the question whether all these sands are of the same origin, there is still uncertainty as to their stratigraphic position, either Pliocene, or Lower-Pleistocene. In the opinion of the present authors, the lithology of the white sands in East Gelderland, the transparency of the sand grains, the high content of metamorphic minerals, the relatively low content of zircon and the presence of topaz, as well as the areal distribution of the sands, are in favour of the assumption that the white sands belong to the Lower-Pleistocene. After EDELMAN & MAARLEVELD (1958) and ZONNEVELD (1958) these continental Lower-Pleistocene sediments, for which an easterly and northeasterly origin is supposed, are in this paper named Harderwijk Formation (fig. 8).

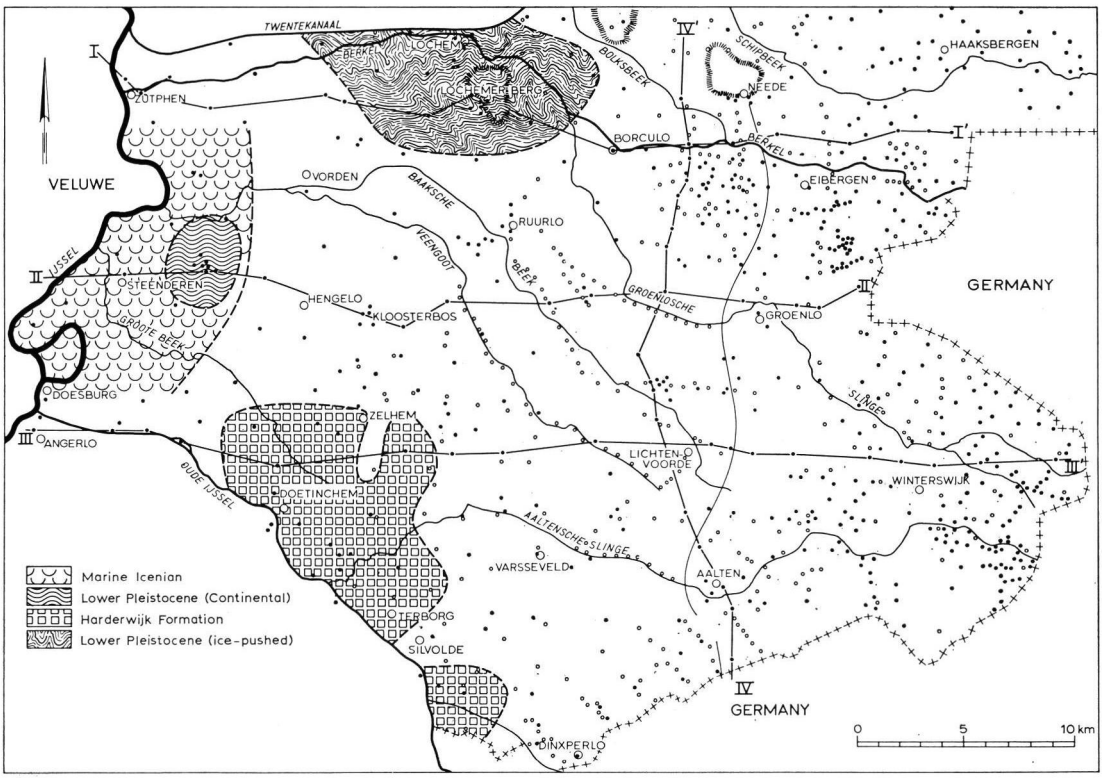

Fig. 8. Lower-Pleistocene deposits in East Gelderland.

Sterksel/Enschede Formation

This formation occurs in local patches on the East-Netherlands Plateau and there is, as yet, no evidence that it is also present in the Pleistocene basin. The brownish coarse sands of this formation, which are often rich in heterogeneous gravel, overlie the Tertiary deposits of the plateau.

Heavy mineral analyses have shown the presence of such minerals as garnet, epidote, saussurite and hornblend, an association characteristic of the Sterksel Formation, well-known from the southern part of the Netherlands (ZONNEVELD 1958; DE RIDDER, HONDIUS & HELLINGS 1967).

However, these typical Rhine sediments show minor admixtures of sediments provided by tributaries from the east or northeast, as is proved by the presence of small percentages of such heavy minerals as tourmaline, metamorphic minerals, zircon and sometimes topaz (figs. 5—7). This heavy mineral association is characteristic of the Enschede Formation, well-known in the northern and central parts of the Netherlands (ZONNEVELD 1958). Since the deposits seem to be a mixture of both formations, they are indicated as the Sterksel/Enschede Formation (fig. 9).

On the plateau the formation is found at shallow depth or at the land surface and its thickness varies from some metres to 12 m, depending on its occurrence as a remainder of a terrace (High terrace), or as a filling of a gully. At three sites on the plateau traces of buried channels have been found, which most likely have been filled by Sterksel/Enschede deposits (figs. 2, 3 and 10).

Initially, the formation was present throughout the investigated area but in a later stage of a dropping sea level, the river Rhine incised a valley into its own deposits. During this process most or all of the formation in the Pleistocene basin was eroded away and the remainder on the East-Netherlands Plateau became a terrace.

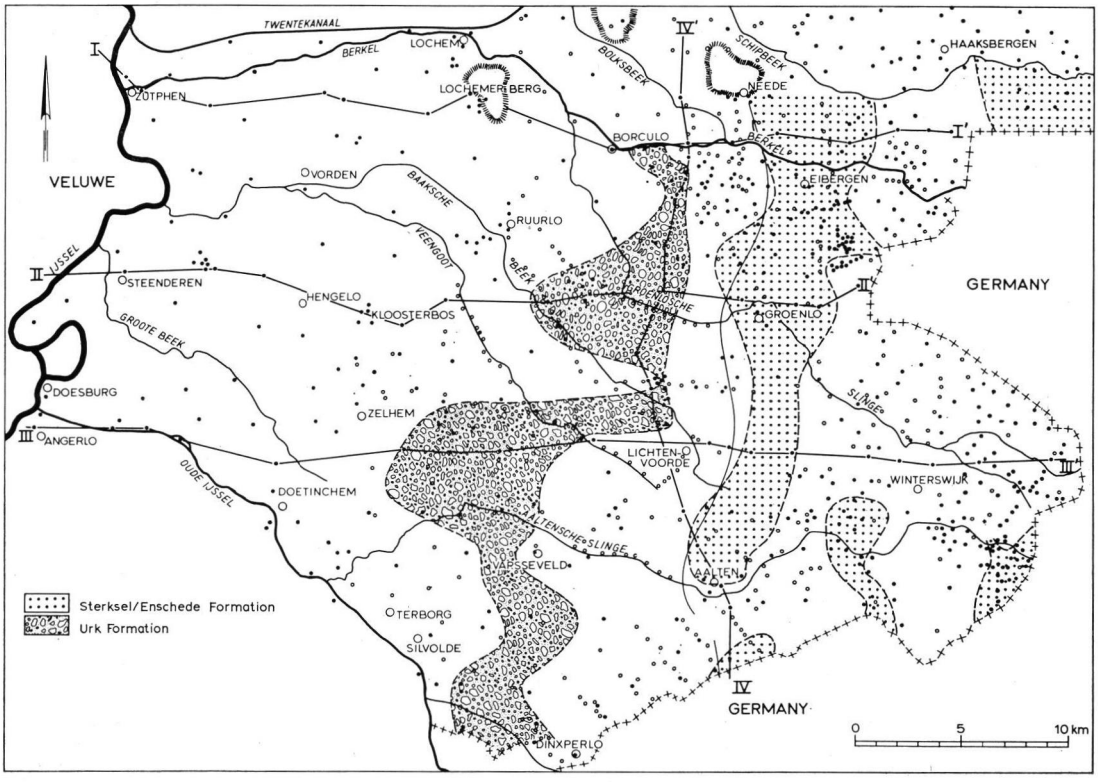

Fig. 9. The Sterksel/Enschede Formation and the Urk Formation in East Gelderland.

Urk Formation

The present investigations in the Pleistocene basin have revealed the presence of a buried valley which is fairly deeply incised into the Miocene and Pliocene surfaces. The first indications of this valley were obtained from some borings south-east of the village of Borculo (M 70, M 71 and M 72, fig. 1). The sediments that fill this valley consist of coarse, gravel-bearing sands whose heavy mineral composition is strikingly different from the other deposits of the region. Apart from the usual Rhine association of garnet, epidote, saussurite and hornblend, a high to very high content of volcanic minerals, especially augite, was found. Sediments so rich in augite were unknown to occur in East Gelderland (figs. 5—7).

In a later phase of the investigations, parts of this valley could also be located in the neighbourhood of Lichtenvoorde, Ruurlo, Zelhem and finally also near Dinxperlo, close to the Netherlands-German border (figs. 2, 3 and 9).

In several borings near these villages the augite-bearing sands were found at various depths and in different thicknesses, depending on the occurrence as a fill of a deep channel or the remainder of a terrace. Erosion during the Saalian Ice Age may also have reduced the initial thickness, which was found to vary from about 1 to almost 30 m.

It appears that this buried channel crosses the Netherlands-German border near Dinxperlo from where it could be traced to Borculo in the north. Although there is at present no evidence that it extends in north-western direction towards the former Zuiderzee, such an assumption seems probable and should be further investigated.

As to the age of this buried channel, it is noted that in boring M 71 (figs. 1, 5 and 3, Section IV) a layer of loam was found, covering the augite-bearing sands. This loam was grey-brown and had a silt plus clay (particles smaller than 0.016 mm) content of 21 per cent. Also, it contained some gravel components of northern origin. A palaeobotanical analysis of this loam revealed a fluvioglacial origin. On account of the high content of Hystrichosphaeridae, it appeared justified to conclude that the loam was a Saalian boulder clay (ZAGWIJN 1961). The underlying augite-bearing sands may, therefore, be early Saalian in age, or older. Nowhere else has any clay or layer been found intercalated within or overlying the augite-bearing sands, so a more precise stratigraphic position of the sands cannot be established at this moment.

Elsewhere in the Netherlands, for example in the Noordoostpolder (former Zuiderzee), augite-bearing sands have also been found (WIGGERS 1955). In this area these sands are covered by clays of Holsteinian age. The same applies to augite-bearing sands in the vicinity of Mook and Cuijk, south of Nijmegen (ZONNEVELD 1958). These augite-bearing sands are known as the Urk Formation.

Other Rhine deposits with a high content of augite have been found at various places in the north, the west and the south of the Netherlands. These deposits are younger than those of the Urk Formation and they are named Vianen Formation (ZONNEVELD 1958).

Investigations by TER WEE (1966) and recent discussions have led to the abandonment of the division into the Urk and Vianen Formations, and only one formation, the Urk Formation, has been retained, based as it is on a well-defined type area (VAN DER HEIDE & ZAGWIJN 1967).

Consequently, in the sections and maps of this paper the augite-bearing sands in East Gelderland have been indicated as Urk Formation (fig. 9).

Holsteinian

In the Needse Berg, north of the village of Neede, clay beds have been found from an interglacial phase before the area was covered by land ice (VAN DER VLERK & FLORSCHÜTZ

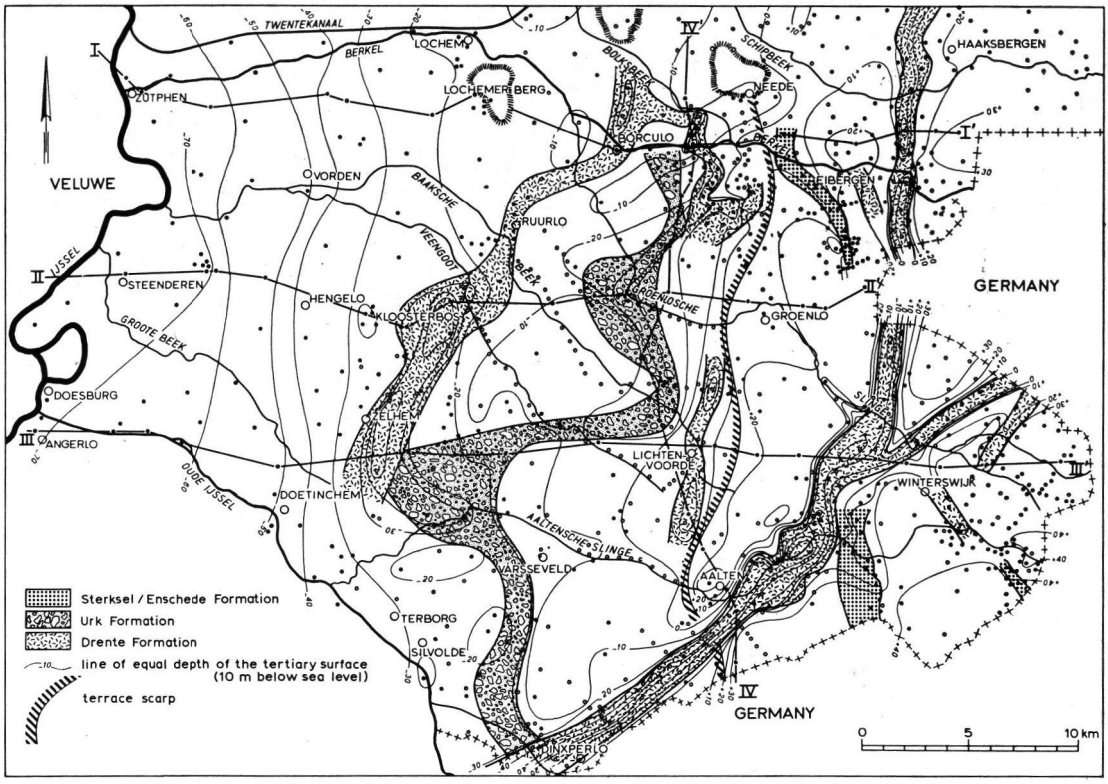

Fig. 10. Location of some buried channels in East Gelderland.

1950). These beds have been dated Holsteinian, based on the fossils which they contained and the disturbance by the advancing ice tongues.

Till now the presence of Holsteinian deposits in the subsurface of East Gelderland could not be proved. However, palaeobotanical analyses of the humic, sticky clays found in two borings (Kloosterbos II and IV, figs. 7 and 2, Section II) at a depth of about 20 m below the land surface, have shown that these clays had been deposited during an interglacial or interstadial, younger than 'Gromerian'. The choice was limited between Eemian and Holsteinian, the latter being thought preferable by ZAGWIJN (1964, 1965). However, taking into account the depth of the clay beds and the data from other borings in the vicinity, the present authors have, for the time being, assumed an Eemian age.

Drente Formation

The Drente Formation, which dates from the Saalian, has been deposited before, during and after the region was covered by Scandinavian land ice. It is present throughout the investigated area and consists of coarse and fine sands, clay and sometimes even peat. The heavy mineral composition shows garnet, saussurite, hornblend and volcanic minerals as the most important, while in the deeper layers sometimes metamorphic minerals occur in increasing quantities (borings M 68, Aalten III and 78, east of Aalten, figs. 1, 5 and 7). It is obvious that, in general, the heavy mineral composition is influenced by the reworked sediments of other underlying formations.

The thickness of the Drenthe Formation varies from a few metres at some sites on the East-Netherlands Plateau to 70 and 100 m in the western parts of the Pleistocene basin. On the plateau as well as in the basin, the thickness often depends on the occurrence of glacial channels in the subsurface.

The presence of buried glacial channel systems in East Gelderland was already demonstrated by FABER (1960), fig. 11. But the recent investigations have considerably improved our knowledge as to the location, depth and direction of these channels, fig. 10 (DE RIDDER 1966; CSONKA 1967; DE VRIES & VAN REES VELLINGA 1971). Some of these buried channels are probably former distributaries of the pre-Saalian Rhine. They were deepened by melt water and probably by land ice, and later filled with glacial outwash deposits.

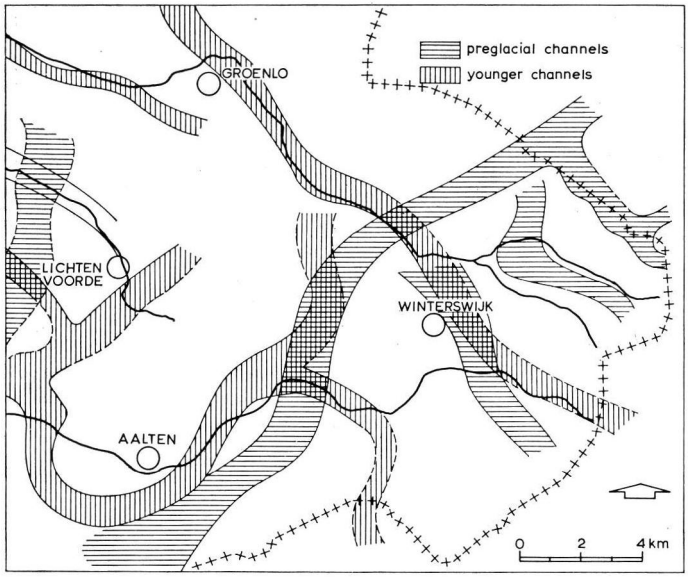

Fig. 11. Pre-Saalian and younger buried valley systems according to FABER (1960).

The most remarkable example is the channel which can be traced in the subsurface from Vreden (Germany) via Winterswijk and Aalten to Dinxperlo (figs. 10 and 3, Section III and IV). The channel deepens southwestward and near Dinxperlo its bottom lies deeper than 70 m below the present sea level, indicating that during the Saalian the sea level was at least 100 m lower than at present.

The sediments that fill this channel consist chiefly of coarse sands, although fine sands and clays also occur. The clay bed in boring Aalten III at a depth of 28 m below the land surface has been provisionally dated Saalian (ZAGWIJN 1964). Locally the sediments consist of reworked material of Tertiary and older deposits, e. g. in boring 77, east of the village of Aalten (fig. 1). This may have been caused by fluvioglacial transportation or solifluction (VAN VOORTHUYSEN 1967; ROMEIN 1967).

Another buried channel, extending from Haaksbergen southward (fig. 2, Section I), seems to be part of the Vreden-Aalten system.

Other traces of buried glacial channels were found in the neighbourhood of Lichtenvoorde, east of Borculo and between Borculo and Zelhem. At some sites the bottom of these channels were also reached at 70 m below sea level (CSONKA 1967). It is obvious that the various buried channels formed part of the Saalian system, whose direction differed completely from that of the present rivers and brooks in East Gelderland.

Eem Formation

Towards the end of the Saalian the land ice retreated to the north and left behind a landscape of which the land drainage was for a long time badly developed. In low lands and poorly drained depressions, layers of fine silty sands, clays and peat ware deposited. At several places in East Gelderland, e. g. in the borings M 64, M 68 and Vorden I (figs. 1 and 12) such layers have been found and palaeobotanically established as the Eem Formation (ZAGWIJN 1961, 1965). In other borings the humic clays, found at about sea level, have been assumed to belong to this formation.

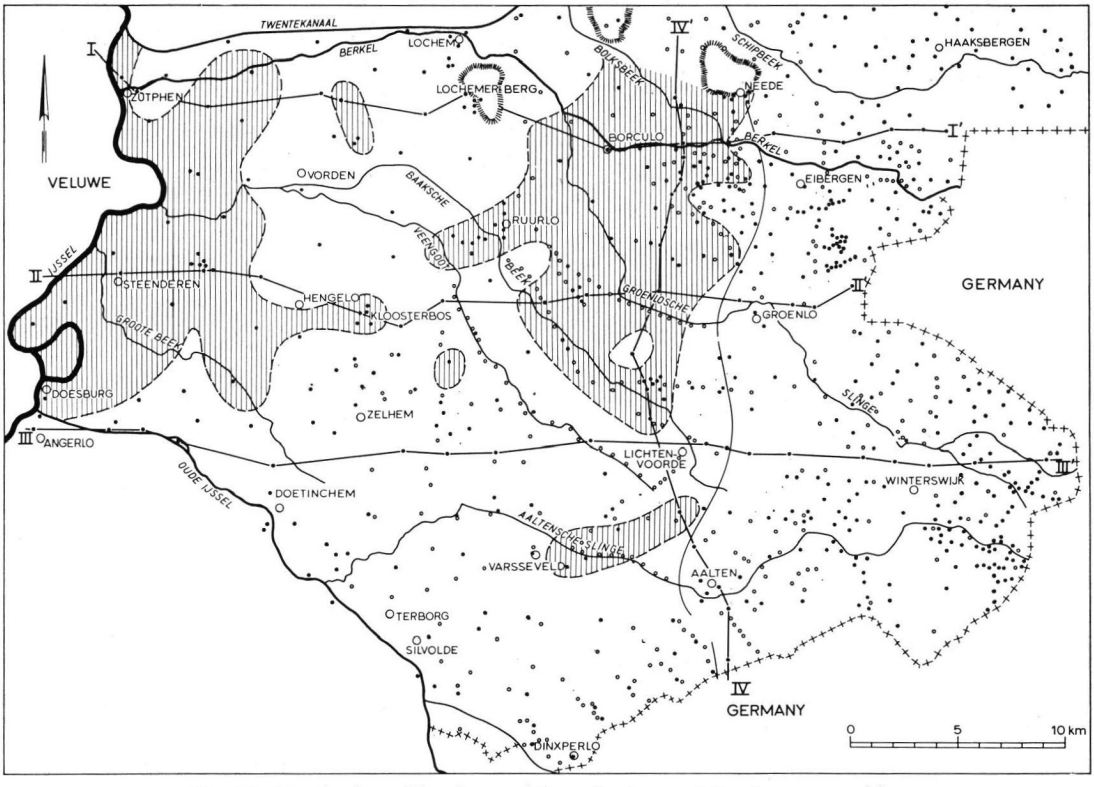

Fig. 12. Distribution of humic peaty loam horizons of Eemian age or older.

Most of the Eemian deposits appear to occur overlying the Drente Formation. Only in the neighbourhood of Lichtenvoorde were they found intercalated within the overlying Kreftenheye Formation.

In other parts of the Netherlands clays and peat layers found in the younger Pleistocene deposits, have been labelled as Eemian (BURCK 1949, 1951; ZONNEVELD 1958) and consequently the underlying Pleistocene sediments would be Saalian in age. However, ZAGWIJN (1961) found a different situation in Wanssum (North Limburg). Here clay layers overlying the Veghel Formation (Holsteinian-Saalian, fig. 13) have been dated palaeobotanically as Eemian. In the same area a clay bed covered with peat and gyttja found within the Kreftenheye Formation, was established as being a deposit from the Amersfoort Interstadial of the Weichselian.

In the opinion of the present authors, the clay and peat layers overlying the Drente Formation in East Gelderland generally belong to the Eem Formation. However, since

palaeobotanical analyses of the clays intercalated within the Kreftenheye Formation were not available, a Weichsel interstadial age cannot be completely excluded.

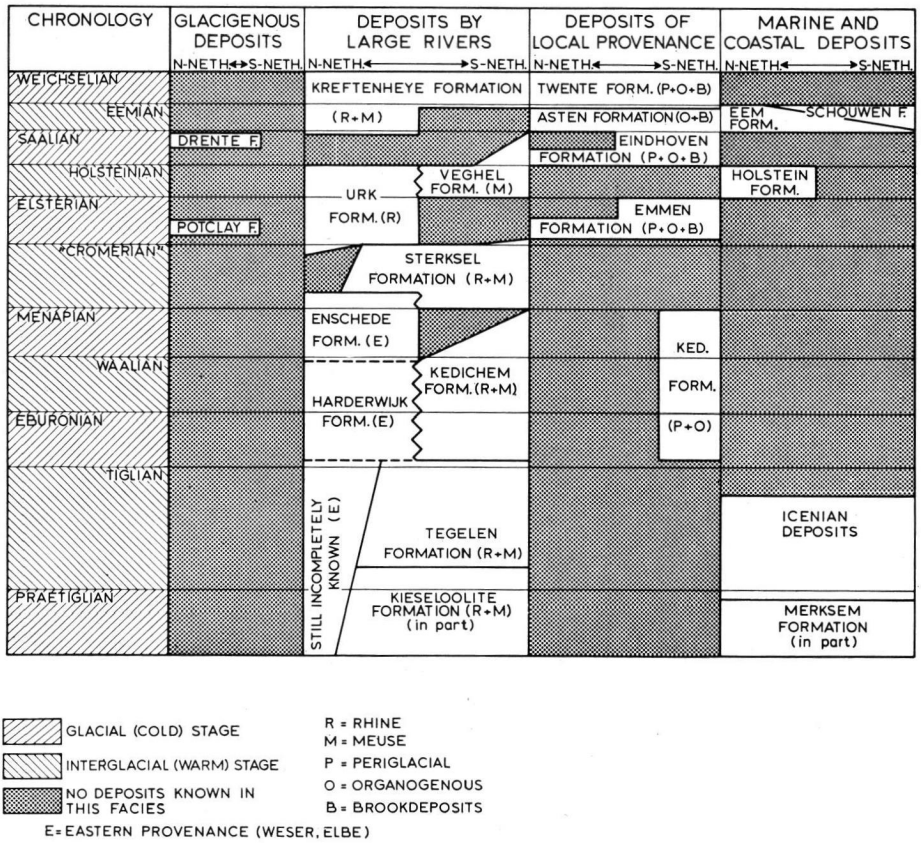

Fig. 13. Stratigraphic division after ZAGWIJN (1967).

Kreftenheye Formation

When the Saalian land ice was retreating, the Rhine again found its way across East Gelderland. Between the ice-pushed hills of the Veluwe (west of the river IJssel) and the terrace scarp in the east, the river incised slightly into the fluvioglacial subsurface. The sediments, which were laid down in this wide valley are known as the Kreftenheye Formation. It consists of brown-grey, heterogeneous coarse sands, which are gravel-bearing. The thickness of the formation varies from 10 to 20 m.

The boundary between the Kreftenheye Formation and the Drente Formation is often hard to notice, as the former partly consists of reworked fluvioglacial sediments and the formations pass into each other rather imperceptibly. At several places, however, humic clays of the Eem Formation occur between the Drente Formation and the Kreftenheye Formation.

In the upper layers of the Kreftenheye Formation the heavy mineral composition shows a typical Rhine association of garnet, epidote, saussurite and hornblend, with 10 to 20 percent of volcanic minerals (M 72, M 201, fig. 6).

Although the Kreftenheye Formation is found almost everywhere in the Pleistocene basin, it is not present on the East-Netherlands Plateau and on the ice-pushed hills, as the Rhine did not overfill the Pleistocene basin and the deposits were not laid down on these hills (fig. 2 and 3).

Twente Formation

In the Weichsel (Würm) glacial time the sedimentation of coarse deposits of the Kreftenheye Formation ended because the Rhine took a more westerly course. During the later part of the Pleniglacial and the Late-Glacial, fine wind-blown sands covered the fluviatile sediments. These sands — with a few exceptions on the East-Netherlands Plateau and in the IJssel valleys — are found over the whole area of East Gelderland. The upper layers have been laid down in ridges, thus giving the landscape a slightly undulating relief.

The thickness of the Twente Formation generally varies from 0 to 12 m, the greatest thicknesses found directly west of the terrace scarp and as a valley fill near Haaksbergen.

The sediments of the formation consist of well-sorted, moderately fine sands, often humic and sometimes silty. In this paper the alluvial deposits on the valley bottoms of the rivers and brooks have been included in the Twente Formation.

Summary and Conclusions

In the investigated area two landscapes can be distinguished: the East-Netherlands Plateau and the Pleistocene basin. The boundary between these two landscapes is formed by a terrace scarp, which at some places is visible at the land surface and at other sites could be traced in the subsurface by means of borings. Locally, the terrace scarp has been affected by the land ice, whereas solifluction and melt water streams have also disturbed its initial form.

On the East-Netherlands Plateau Mesozoic rocks and Tertiary marine deposits are found at or very close to the land surface. They are covered by a veneer of Middle- and Young-Pleistocene sediments.

In the Pleistocene basin the Tertiary deposits are found at great depth and they are overlain by relatively thick layers of Lower- and especially Upper-Pleistocene sediments. There is clear evidence that during the Pliocene the sea gradually retreated from the investigated area. In the early Pleistocene, more specifically during the Icenian, east of the river IJssel the sea covered only a 5 to 10 km wide strip, as was proved in a boring near the village of Steenderen.

The white and light grey coarse and fine sands, overlying the sediments of the continental Pliocene in the western and south-western part of the investigated area, most likely belong to the Lower-Pleistocene Harderwijk Formation, rather than to the Pliocene.

On the East-Netherlands Plateau thin layers of the Sterksel/Enschede Formation are present as the remainder of a terrace and as a fill of relatively deep gullies.

Before the area was covered by the Scandinavian land ice, in the early Saalian or late Holsteinian, a rather narrow Rhine valley was present, running from Dinxperlo in the south to Ruurlo and Borculo in the north. The coarse gravel-bearing sands which filled this valley belong to the Urk Formation, which was unknown to occur in East Gelderland.

With the advancing ice tongues the initial drainage pattern was disturbed completely and new channels, draining off the melt waters, were formed. These channels were chiefly directed southwestward, almost perpendicular to the older as well as the present drainage systems.

Of the many buried glacial channels found in East Gelderland, the most impressive one extends from Vreden, via Winterswijk and Aalten toward Dinxperlo, where it crosses

the Netherlands-German border. A remarkable feature of this channel is its depth which increases rapidly in southwesterly direction. Geo-electrical measurements and borings have shown that near Aalten and Dinxperlo the bottom of this buried channel, as well as the bottom of one located near Zelhem, lies deeper than 70 m below the present sea level, indicating that during the Saalian the sea level was at least 100 m lower than at present.

It would be of interest to investigate the location and depth of the buried channel in the adjacent regions.

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