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GEOMORPHOLOGICAL AND PALEOHYDROGRAPHICAL RESEARCH BASED ON GEOELECTRICIAL PROSPECTING (SOUTH CAMPINE, BELGIUM)

by J. VANDENBERGHE (*)

INTRODUCTION.

The study was carried out to examine the usefulness and to determine the contribution of the geoelectrical method in certain areas of recent geological history. The elaboration of field data was kept as objective as possible by using a direct interpretation technique.

Electrical resistivity soundings in geomorphological research can be used to determine the structural and lithological effects to the subsoil upon the form of the relief. It is also necessary to know the variations in depth of the recent cover sediments. From a paleogeographical point of view special attention was paid to the reconstruction of fossil river patterns. Therefore fluviatile sediments were also examined by geoelectrical means. In the course of the research program the advantages of the use of geoelectrical measurements in mapping unconsolidated geological strata were clearly shown.

MEASURING AND INTERPRETATION SYSTEM.

The apparatus was compiled by separate measuring and DC feeding circuit. A maximum output of 500 volt at 1 Amp could be generated. The measuring circuit contained a microvoltmeter and a compensation connection to cancel constant stray voltage noise.

Mainly electrical soundings were performed because of the necessity for precise measurements of the specific resistivities and depth determinations. As the investigated space was rather shallow the maximum half electrode distance was kept at 100 m (Schlumberger array).

(*) Compiled at the Instituut voor Aardwetenschappen, Katholieke Universiteit Leuven in 1975.
Present address :
Instituut voor Aardwetenschappen, Vrije Universiteit,
De Boelelaan 1085, NL-1081 HV Amsterdam.

The field sounding curve was constructed by calculating the most probable curve between the apparent resistivity values at each measuring point. Therefore the backward interpolation formula of Gauss was used.

The interpretation technique then involves two main steps. The first is the calculation of the Resistivity Transform ($T_{(\lambda)}$) from the field data. This function was introduced by KOEFOED (1970) as a modification of the original kernel function ($K_{(\lambda)}$) :

$$T_{(\lambda)} = 2.\rho_1.H_{(\lambda)} = 2.\rho_1.(K_{(\lambda)} + \frac{1}{2})$$

$$\text{and } T_{(\lambda)} = \int_0^{\infty} \rho_s . J_{1(\lambda s)} . \frac{ds}{s} \quad \text{(in a Schlumberger array).}$$

The calculation of the kernel function (KOEFOED, 1968) was a rather laborious task. GHOSH (1971) introduced another calculation method, based on a "sampling" and "filtering" procedure adapted to the geoelectrical method. In this method 2 or 3 "sample values" (apparent resistivity values) in an interval 10^{n-1}-10^{n} of the logarithmic scale are sufficient. We have increased however this number to 8 in order to obtain a greater reliability in the field curve. Filtering enables one to represent the Resistivity Transform on a sample point m as :

$T_m = a_j.R_{m-j}$ (with R_m : apparent resistivity on the sample point m
and a_j : filtercoefficient).

The only difficulty is that 5 extra ρ_s-values are needed on the lefthand side of the field curve and 2 on the right (short filter). If the values of ρ_1 and ρ_n are visible in the field curve there is no problem, but otherwise extrapolations must be made.

In the second step the interpretation of the resistivity stratification from the kernel function was made formerly by Pekeris (1940). According to KOEFOED (1970) the Resistivity Transform curve was used. By this method the number of layers was progressively reduced until the parameters of all the layers were found. At this point the situation was reserved and construction of the theoretical sounding curve was made from the resulting solution. For these calculations the linear filter method was also used (GHOSH, 1971). Field curve and calculated curve were compared and interpretation was adjusted. This cycle was repeated until the difference between the field curve and the calculated curve differed less than 3 % on all the measuring points. Then the corresponding resistivity stratification was assumed to be correct. In all cases however, the ultimate solution remained susceptible to a certain variation originating from the equivalence and caused by small observation errors (KOEFOED, 1969 and 1974).

All calculations and drawings were performed on a desk calculator.

SITUATION.

The geoelectrical investigations were performed in the "Zuiderkempen", Belgium (fig. 1). The geological and geomorphological study first of all examined the possible relationship between residual relief forms and their lithological subsoil. The landscape is characterized by a series of hill tops and ridges, rising

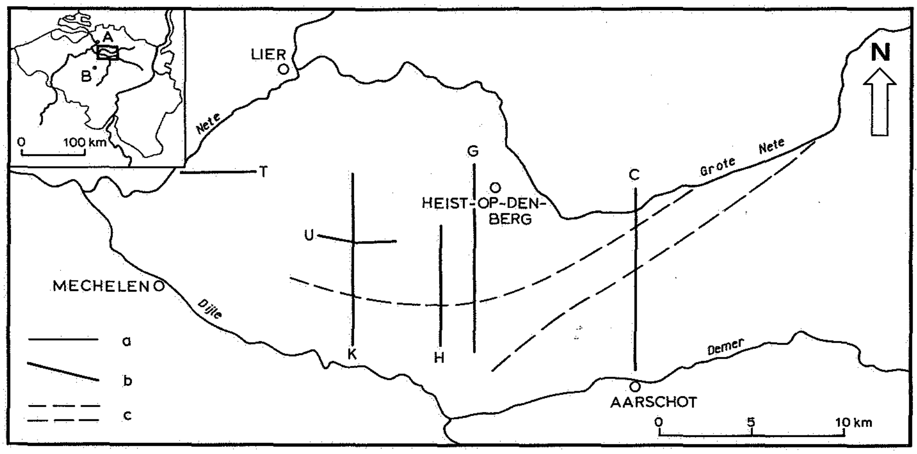

Fig. 1 - Situation map : a. electrical profiling;
b. geoelectric sounding;
c. limits of the "Houtvenne gully".

abruptly from the surrounding plains. Some of these hills consist of resistant Diest sands (GULLENTOPS, 1954), others show structures that must be envisaged more precisely. Between the hills very flat plains occur over large areas.

The principal phenomenon, however, is found in the hydrographical pattern, more precisely in the stream directions. The main river, the Grote Nete, shows in its upper course a regular ENE-WSW direction. This changes suddenly to a northerly direction at Heist. Other tributaries show the same abrupt changes in their stream directions. These irregularities can be explained by the paleohydrographical situation and by a morphological and geological study of the region.

The subsoil is formed by slightly northward dipping Tertiary sands and clays :
- rather coarse, glauconitic Diest sands (Miocene)
- dark finer glauconitic Antwerp sands (Miocene)
- Boom clay (Rupelian)
- grey silty fine Berg sands (Tongrian)
- calcareous Lede sands (Eocene).

Thus the electrical soundings were carried out on one hand to determine the depth and composition of the Quaternary sediments and, on the other, to investigate the stratigraphy, occurrence and geometry of the Tertiary subsoil.

RESULTS.

The soundings were brought together in NS-oriented sections, thus perpendicular to the strike of the Tertiary layers. Only one electrical profiling was performed as an experiment. Using all the results, the top of the Boom clay was reconstructed and a new geological map was designed.

The first correlations of the specific resistivities with the geological formations were made on the basis of borings. The Boom clay was found to have the smallest specific resistivities (6-16 Ωm) while the underlying and overlying Tertiary sands showed higher resistivities. For the Antwerp sands values of 17-33 Ωm were found, the Diest and Berg sands were less conductive (32-49 Ωm). At the base of the Diest sands lower resistivity values were found. In the Antwerp and Diest sands as well as in the Boom Clay a vertical variation was observed in several places.

The specific resistivities of the Quaternary sediments occur over a wide range : the clayey or silty alluvial sediments showed small resistivities while the high resistivities (> 150 Ωm) below the groundwater level indicate the presence of fluviatile sands and gravels. The conductive clays and loams can occur near the surface as recent alluvial sediments or at greater depths as silt layers in fluviatile sediments.

a. SOUNDINGS.

The principal results from a few geoelectrical sections are discussed below.

SECTION C (fig. 2)

In this rather detailed section the top and the base* of the Boom clay are frequently observed. The regular slope of the base was slightly steeper than the top, so that the thickness of the Boom clay increased towards the north. The erosive character of the Diest sands was proved in two places : first, in the extreme south of the section where the incision was so deep that both the Boom clay and the Berg sands were fully eroded; and secondly in the middle of the section where another gully was eroded at the Ramsel berg which rises out of the flat plains. Here the resistant character of the Diest sands was very obvious.

In this section 5 buried valleys which are in no way visible in the present landscape were discovered. The principal incisions occurred under the Calsterloop, Oevelse loop and Steentjesloop brooks. The first two were eroded to a depth of +4m, the third to +1 m. The specific resistivities of the filling sediments were clearly higher than those of the Tertiary subsoil. The greater part is considered to be medium grained sand (54 à 84 Ωm), but at the base of the gullies sandy gravels and coarse sands occur (145 Ωm).

Between the different gullies the Tertiary surface remained at a constant level over a great distance (+9 m between the Calsterloop and Oevelseloop gullies and +10,5 m north of the Ramsel berg).

About 2 m Quaternary coversands overly the Tertiary subsoil (except at the Ramsel berg) and locally this layer could be

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* see VANDENBERGHE, N. and VANDENBERGHE, J. (1979).

even greater and form small hills (e.g. at Westmeerbeek).

It is quite remarkable that the actual Grote Nete seemed to have only a 3 m deep incision. Thus the principal river of the basin is not appreciably incised, although important gullies were detected under actual brooks.

SECTIONS G and H (fig. 3-4)

An asymmetric but deep eroding Diest gully was found under the hill of Heist-op-den-berg (G). The resistant character of the Diest sands was striking. The small hills (Goor-Munksbossen) could consist of other Tertiary sediments or by an accumulation of Quaternary coversands (e.g. Langveld).

South of Goor-Munksbossen the top of the Tertiary subsoil reached a constant altitude (+8 à 9 m). It was covered by 2-3 m Quaternary sands. South of this first level, a second level was developed at an altitude of +3 m. In the extreme south of the sections a deep Quaternary incision occurs to a depth of -2 m. Low specific resistivities (29-32 Ωm) in the filling sediments suggest the presence of loam layers. This Quaternary gully is the continuation of the gully under the Steentjesloop in section C and is called the "Houtvenne gully". It has a NE-SW direction between the sections C and H. The gullies of the Casterloop and Oevelse loop have debouched into it.

SECTIONS K and U (fig. 5-6)

The most important feature of these sections is the clay elevation at the Niksenheuvel, showing the resistant character of the Boom clay. This clay hill was steeply bordered on all sides and partly covered by Antwerp sands. North of Putte a depression of 3-4 m existed at the top of the Boom clay, while the top of the Boom clay at the Niksenheuvel occurred 3-4 m above its normal level. A tidal current gully in the Antwerpian sea could be the explanation for the depression, but not for the clay top.

Therefore a movement in the clay itself can be assumed. In this hypothesis depression and elevation are complementary. Such structures are not unique in the Boom clay : a diapire structure was found at Antwerp (LAGA, 1966) and deformations occur at the north side of the Ramsel berg (N. and J. VANDENBERGHE, 1974 *). In other sections irregularities in the Boom clay also appear.

A small ridge at O. L. V. Waver consists of clayey Antwerp sands. The highest planation level occurs at +16 m between this ridge and the Niksenheuvel at Putte.

The level at +8 à 9 m in sections H and G was also found here south of the Niksenheuvel but was lowered to +6,5 à 7 m. The "Houtvenne gully" was incised up to -5,8 m and was mainly filled with coarse sands and gravels (ρ = 71 à 156 Ωm). There is a change from the NE-SW direction in the previous sections to a W-E direction here ** .

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[*] in : Geol. Survey of Belgium, Profess. Paper, 1979/4, n°160, 8 p. + figs.

[**] Afterwards, this section has been prolongated southward (section Sint-Adriaan in : VANDENBERGHE, J. & DE SMEDT, P., 1979). In this region the Demer valley is coming together with the Houtvenne gully. Hence a 6.5 km wide incision has been formed.

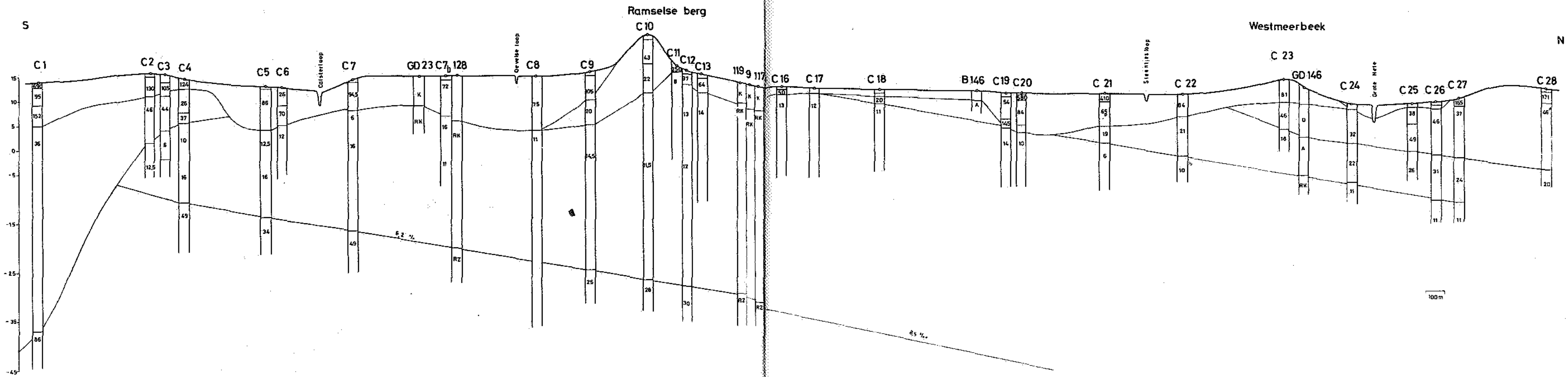

Fig. 2 - Geoelectric section C ocation on Figs. 1 and 9)

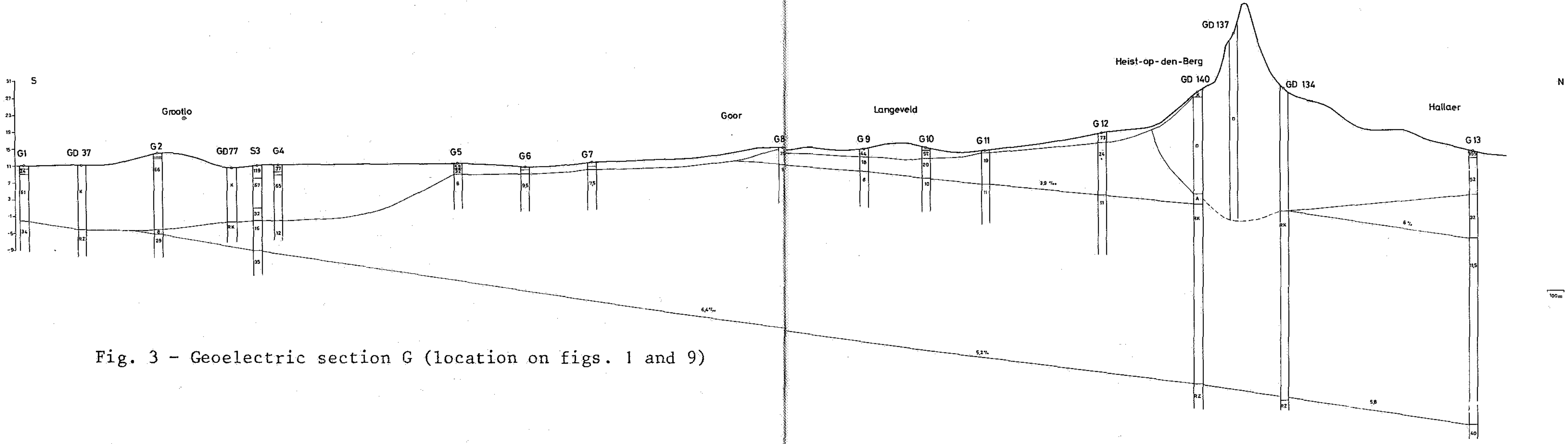

Fig. 3 - Geoelectric section G (location on figs. 1 and 9)

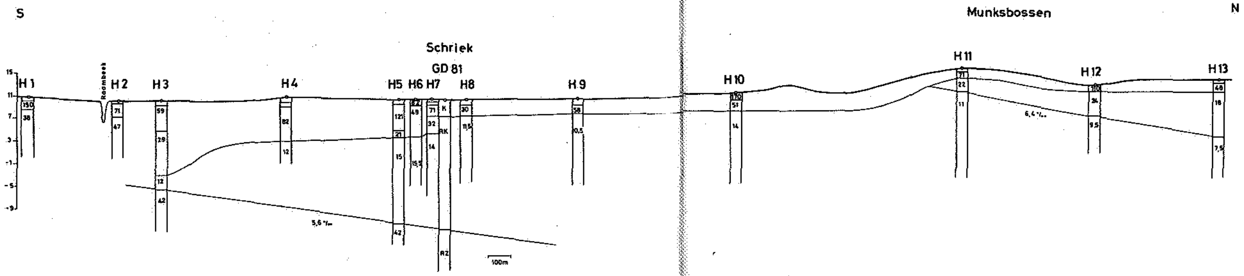

Fig. 4 - Geoelectric section H (location on figs. 1 and 9)

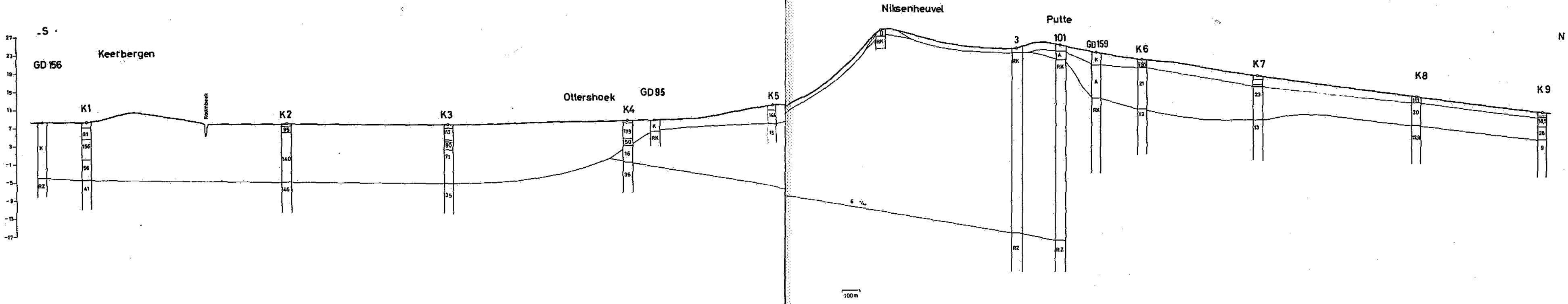

Fig. 5 - Geoelectric section K (location on figs. 1 and 9)

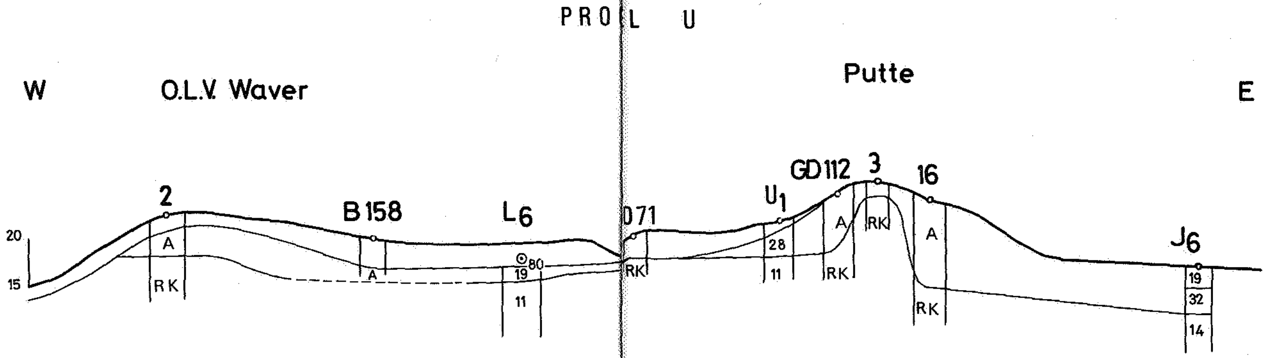

Fig. 6 - Geoelectric secti U (location on figs. 1 and 9)

SECTION T (fig. 7)

In the western part of the region the "Houtvenne gully" and the Nete valley come together. The W-E section T was constructed at the east side of the Nete for comparison with the sections over the "Houtvenne gully". The specific resistivities of the various layers of course remain the same. The Boom clay seemed to be divided into 2 parts - an upper part characterized by higher specific resistivities (13-16 Ωm) and a lower part with lower resistivities (7-13 Ωm).

The 2 levels found in the eastern sections appear in this section too and were confirmed by other data north and south of the section T. They occurred at +2,5 m and at +6,5-7 m. The Nete valley itself was incised until at least -4 m (T_1) and is filled with coarse sands and gravels (110-330 Ωm). The cover sediments in the west were significantly more conductive (37-46 Ωm), indicating the transition from the "coversands region" in the north (and east) to the "coverloam region" in the southeast.

It could be concluded therefore that in section T, perpendicular to the Nete valley, an identical fossil river bed and the same 2 levels along the gully occur as in the eastern sections. In the western gully, the river Nete is still flowing, while the "Houtvenne gully" is a fossil bed.

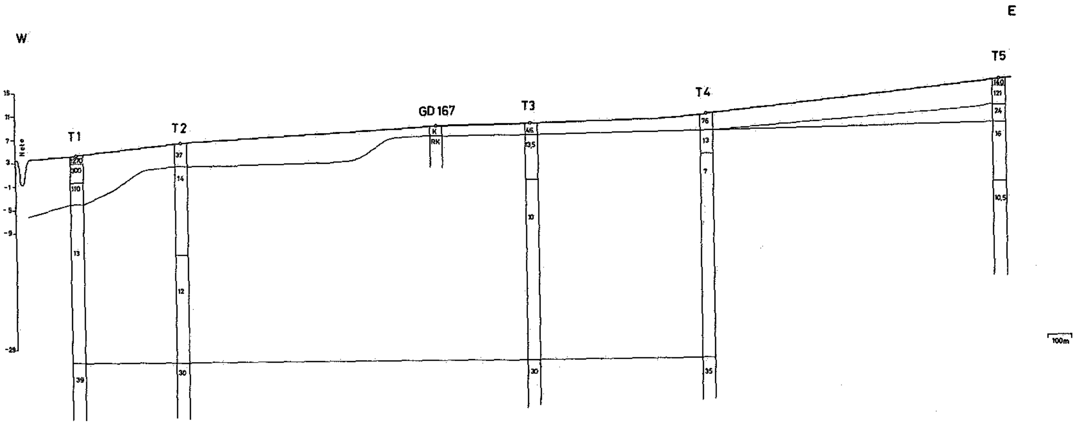

Fig. 7 - Geoelectric section T (location on figs. 1 and 9).

b. PROFILING (Fig. 8)

The utility and limitations of a geoelectrical profiling in such problems were illustrated by an example. The profile is situated 500 east of section H. Measurements were made with AB/2 = 16.7 m and also with AB/2 = 2.15 m in order to obtain information about the surface resistivities.

In the profiling curve 3 parts can be distinguished. A discontinuity is clearly present between point 2 and 3. The limit between the 2 southern parts is less clear, but it can be observed that from point 6 the resistivity curve rises slightly to the south apart from the surface resistivity.

These 3 phases are caused by the Boom clay acting as a conductive layer at different depths. The influence of the clay decreases from north to south in 2 stages : in the northern part the top of the Boom clay occurs at +8m (upper level), in the medium part at +3 m (lower level) and in the southern part the clay has practically disappeared due to the incision of the "Houtvenne gully". The discontinuity between the medium and southern part is not so clear, partly because the discontinuity in the buried relief itself is poorly defined and partly because it occurs at a greater depth.

As was shown, important results can be obtained by electrical profiling but they always remain qualitative.

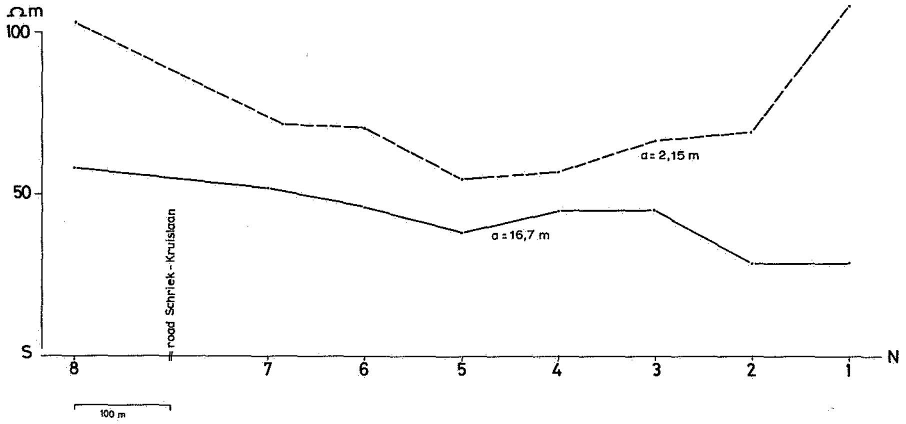

Fig. 8 - Electric profiling curve over the northern border of the Houtvenne gully, the Begijnendijk level (+3 m) and the southern part of the Sint-Katelijne-Waver level (+8 m). Location see figs. 1 and 9.

c. MODEL EXPERIMENTS.

The very pure Antwerp sands are characterized by a surprizingly low specific resistivity. The coarser Diest sands also show a rather low specific resistivity. To find the cause, detailed measurements were made on the formations in situ and laboratory model proofs using sediments with various composition were performed.

1. Model proofs.

These were used to determine the different resistivity values of glauconite free and practically pure glauconite sands. The grain size and water content were about the same and before the measurement the sediment was homogenized. The proofs were made in a wooden box (35x27x12 cm) with a simple resistivity meter. Fine copper wires were used as electrodes in both a Schlumberger and

Wenner array. On such a scale it was necessary to introduce several correction factors. The penetration depth of the electrodes was corrected by using KROLIKOWSKI's (1966) method and the influence of the vertical walls was eliminated by a correction determined from HEILAND's (1940) calculations. The bottom of the box could be considered as a second layer with $\rho = +\infty$. In this way a sounding curve was obtained that showed - after corrections - the situation of a 2-layer case. With AB = 17.5 cm (half the length of the box) the corrections for the vertical walls are still negligeable (0.54 %), so that calculations for AB < 17.5 cm remain straightforward. Because of the high contact resistances, measurements were only made for water satured sands :

Results :		
	- glauconite sand :	12 Ωm
	- glauconiteless sand :	42 Ωm

Thus the former sands are 3.5 x more conductive than the latter.

2. Detailed measurements on the formation in situ.

Advantage is taken of the fact that the sediment could be examined in its natural surroundings without having to make corrections for vertical and horizontal discontinuities. Experience led us to make measurements with a constant electrode distance in different directions. The electrodes were attached to a small plank and a Wenner array was used (a = 10 cm), with electrode penetration of 3 cm.

Results :			
	- Boom clay	12 Ωm	
	- Antwerp sands	18 Ωm	
	- Diest sands :	main sediment	32.9 Ωm
		limonite bank	18.8 Ωm
		base	26.9 Ωm

The specific resistivity for the Boom clay was equal to the average value resulting from the soundings. The specific resistivity for the Antwerp sands was a minimal value, because the measurements were made in the clayey base. The values found in the Diest sands were higher than in the Antwerp sands, but seemed rather variable. Thus grain size, glauconite content and clay content were determined. The grain size was the same for the 3 Diest sands but was coarser than the Antwerp sands. The base of the Diest sands contained more glauconite (60 %) than the overlying sediments (40 %). The clay, as a result of glauconite weathering, was practically absent (5 %) in the bottom layer, while the upper part contained 47 % clay. Thus the glauconite content is very important for its conductive character and in this sense exceeds the influence of the clay content. Iron (limonite) precipitation lowers the resistivity still further. The Antwerp sands contained about as much glauconite as the base of the Diest sands. The smaller grain size and the higher clay content however lower the specific resistivity slightly.

Conclusion.

The higher the glauconite and clay content, the higher the conductivity. The glauconite content, however, has the greatest influence in affecting the conductivity. Variations of grain size are less important. However, one should be cautious and more experiments are necessary.

GEOMORPHOLOGICAL, GEOLOGICAL AND PALEOGEOGRAPHICAL RESULTS.

Using all the results a reconstruction was made of the top of the Boom clay. Thus the structure of the Tertiary formations and the Quaternary phenomena became visible (fig. 9).

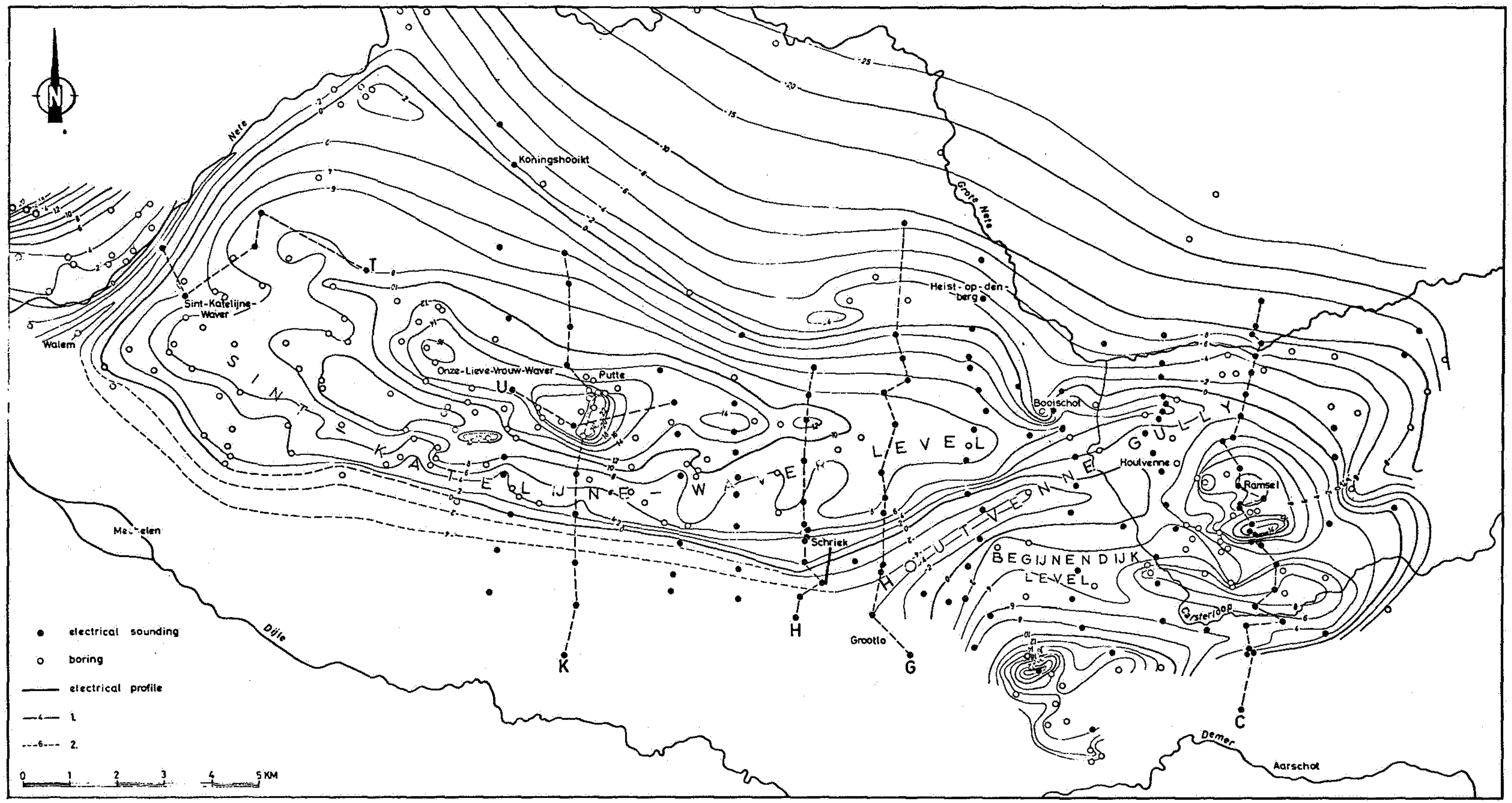

Fig. 9 - Hypsometric map of the top of the Oligocene subsoil with countour lines of the top of the Boom clay (1) and the lower Rupelian or Tongrian sands (2).

1. Tertiary structures.

The Boom clay occurs now as a basin with slopes to the north and the east (STAINIER, 1929). The basin structure however shows a few irregularities. In a zone from north of OLV-Waver to Booischot the gradual slopes of the contact Boom clay-Antwerp sands is interrupted by one or two planations. Other irregularities were observed north-west of Koningshooikt and near Booischot.

The steeper slopes in the top of the Boom clay were caused by the Diestian incisions. Erosion could be so deep that the Boom clay had disappeared completely (eastern part of the region). The resistant Diest hills still remain where the Diest sands are thicker as a result of the gully incisions in the underlying Tertiary formations (Heist-Ramsel berg).

2. Quaternary erosion.

This was most striking near the development of the two planation levels and the deep river incisions.

A first planation was formed on the Boom clay from Sint-Katelijne-Waver at +6m, over Schriek (+8 m) to Booischot (+9 m). East of Booischot this level was formed on the Antwerp sands. It occurred also between the gullies of the Calsterloop and Oevelse loop and proceeds along the Nete north of Sint-Katelijne-Waver. It is called the "Sint-Katelijne-Water level".

A lower planation level rose also from W to E (+2.5 to 5 m). Generally it was less extended than the upper one. The greatest development occurred near Sint-Katelijne-Waver and OLV-Waver. It was also found along the Nete. It is called the "Begijnendijk level".

The Nete and "Houtvenne" gullies are the deepest Quaternary incisions : +2 m at Westmeerbeek, -4.5 m at Grootlo, -7 m at Walem. The Calsterloop and Oevelse loop gullies have stopped their erosion at the level of the lower planation and both debouch in the "Houtvenne gully" with a steep slope. The actual Grote Nete however is incised only over 3 m. At Westerlo the "Houtvenne gully" and the Grote Nete come together. Thus we arrive at an important paleogeographical conclusion that the "Houtvenne gully" is the fossil bed of the Grote Nete. In the same way the Calsterloop and Oevelse loop gullies extend further eastward together with the Demer river which actually flows towards the south. These gullies are thus the fossil bed of the Demer.

The lower Begijnendijk planation must be considered as a river terrace; the upper Sint-Katelijne-Waver planation can be considered as a greatly extended terrace level.

CONCLUSIONS.

In the region between the Grote Nete and Dijle-Demer rivers most of the hills consist of resistant Diest sands and Boom clay, while the plains were formed by Quaternary erosion.

The geoelectrical soundings have revealed a whole new river pattern which has now disappeared leaving no evidence in the present landscape. Moreover these buried channels are the old valleys of the Grote Nete and the Demer piercing the resistant Boom clay. Nowadays both rivers have changed their course following easier routes north and south of the Boom clay. The paleo-incisions are mainly filled with sands and gravels and form ideal water-reservoirs.

The extension of these buried valley systems determined by the electrical resistivity method, corresponds very well with the results by the refraction-seismic and gravimetric methods (VANDENBERGHE, 1976). However the physical contrasts between the subsoil and the valley deposits are more pronounced in the electric soundings than in the seismic and gravimetric measurements. It has been shown that the different lithological and mineralogical compositions of the unconsolidated Tertiary and Quaternary sediments result in a clearly established resistivity stratification. In particular the important role of the glauconite content was demonstrated by the model experiments.

The direct interpretation method using the linear filter theory has proved its importance mainly by the greater accuracy that could be maintained in comparing field and theoretical curves. It is therefore obvious from this study that geoelectrical measurements are a useful aid in geomorphological research, drinking water exploration and paleogeographical investigations in such regions.

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