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The Feldbiss fault in the Maas valley bottom (Limburg, Belgium)

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Abstract

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An intensive geoelectric campaign in the Maas valley (Rotem area, Limburg, Belgium) allowed the location of the *Bichterweert scarp*, a (buried) scarp at the base of the Maas valley bottom gravels. This scarp, tectonic in origin, is attributed to the Feldbiss fault system at the southern border of the Central Graben. The Bichterweert scarp is the result of Saalian and Weichselian movements. Due to this activity the thickness of the Maas gravel beds suddenly increases north of the scarp. The electric specific resistivities are a measure for the gravel quality.

Introduction

The fault zone forming the southern limit of the Central Graben, the western prolongation of the Rhine Graben, has been the object of many contributions. In the Cenozoic sediments on the Dutch eastern Maas border this fault zone is mainly constituted by three NW-SE oriented faults (from north to south): the *Feldbiss*, the *Geleen* fault and the *Heerlerheide* fault (see Kuyl 1971, Van Montfrans 1975 - see fig. 1). In Belgium, basic knowledge of the southern Graben border was for a long time based on the coal borings of early this century. A structural reconnaissance survey of the Upper Carboniferous deposits has been effectuated recently in the Neeroeteren - Rotem concession (Bouckaert et al. 1981, Dusar 1982). The NE-border of the Kempen (Campine) Plateau has been recognized as a Quaternary fault scarp already by Stainer (1907) and Briquet (1907). It has generally been attributed to the Rotem - Heerlerheide fault since Grosjean (1942). The existing borings in the Maas valley bottom reveal a zone of sudden increase in gravel thickness (Paulissen 1973, pp. 208-212). This zone occurs between the NE-border of Campine Plateau and the Feldbiss fault near Sittard.

This paper contributes to the knowledge of the shallow fault pattern as far as it influences the Maas valley gravel deposits, by detailing the zone of sudden gravel increase, an economically important limit, and by supplying more information on the recent tectonic activity at the southern graben border. This paper is part of an evaluation project on the regional gravel resources. The base, top and thickness of the fluvial gravel deposits are defined in the Neeroeteren - Rotem area, a surface of about 20 km^2. The contour map of the base of the gravel deposits is supported by the results of 63 electric soundings and by borings. The map of the top of

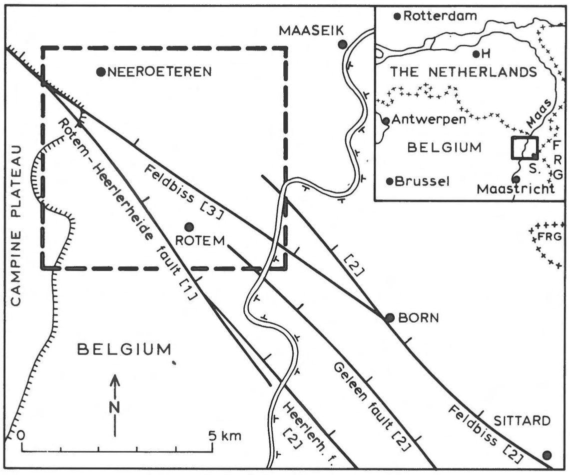

Fig. 1. Location map. Fault pattern according to Grosjean (1942) [1], Kuyl (1971) and Van Montfrans (1975) [2] and Paulissen (1973) [3].

the gravel deposits has been compiled from the same electric soundings and from about 270 manual borings through the thin cover layer. The altitude of the observation points is taken from the Belgian topographical map 1:20.000 (contour interval: 1m). All heights are expressed according to the Belgian Ordnance Datum (which is 2.33 m lower than the Dutch Ordnance Datum).

Geoelectric results

Since a detailed study of thick gravel deposits by borings is very expensive, the need for a geophysical investigation method was obvious. Resistivity measurements were thought to be useful in determining the top and the base of the gravel deposits. Gravel layers are generally characterized by relatively high specific resistivities with regard to the overlying and underlying finer strata. Geoelectric research in gravel exploration was applied by, among others, Homilius (1969), Monjoie (1969), Serres (1969), Flathe (1970), Homilius et al. (1973), but was always intended for the exploration of water reservoirs. In this study the Schlumberger configuration was used with a maximum half-electrode distance of 100 m. The resistivity curves were interpreted with a numerical method (Koefoed 1970; Ghosh 1971 a,b; Vandenberghe 1977).

In accordance to the bore hole data mainly three geological units may be distinguished in the geoelectric soundings: a fine-textured top layer, the gravel body and the Tertiary sandy subsoil. Due to a relatively shallow water table at a relatively small depth in the top layer or in the top of the gravel body, the most simple resistivity curves correspond to a four-layered ground (a surficial dry layer overlying three saturated layers). However, sandy and loamy intercalations in the gravel body involve geoelectrical models consisting of seven or eight layers. The lateral heterogeneity of the three main geological units is another complicating factor. At the top dry dune sands (with very high specific resistivities) alternate with loamy coversands and alluvial loams (with low specific resistivities). The gravel layer shows large variations in grain size and contains varying amounts of fine-grained lenses. Information on the nature of the underlying, also heterogeneous subsoil is rather scarce.

In nearly all cases the specific resistivity of the gravel body is higher than the overlying and underlying sediments to such a degree that most of the soundings curves show a bell-shaped form (Fig. 2,A,B,C). This bell shape may be masked in some soundings by a rather small thickness of the intermediate unit (gravel layer) and/or a somewhat high resistivity of the subsoil (Fig. 2,A). A few curves are of the double descending type because of the extremely high superficial resistivities (Fig. 2,D). Table 1 shows the electric specific resistivities of the cover layer, the gravel deposits and the underlying sediments. They were checked by reference soundings at four boring sites. However, due to the heterogeneity of the sediment series a relatively large range of electric specific resistivities is maintained for each unit. From Table 1 it is obvious that a major resistivity contrast exists between watersaturated and dry sediments. Therefore it was necessary to measure for each sounding the depth of the water table by manual borings. These boring data were also used to determine the nature and thickness of the cover deposits. Finally, in the interpretation some ambiguity always remains, due to the 'equivalence' principle, e.g.

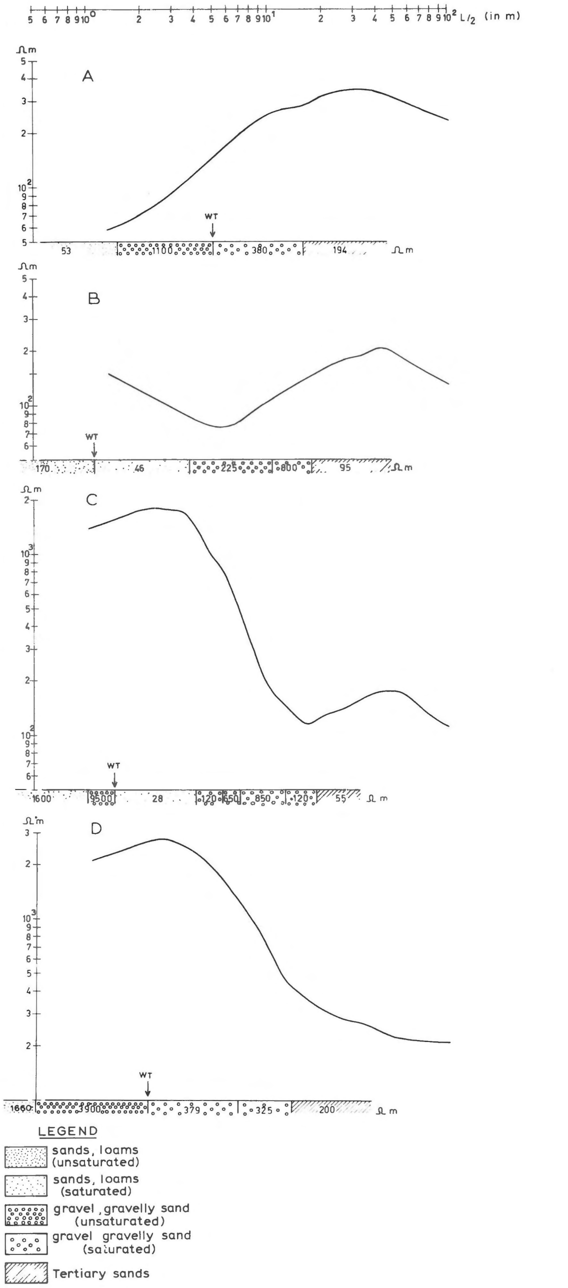

Fig. 2. Typical geoelectric curves with their interpretation. The apparent resistivity is plotted against the half electrode spacings (L/2). WT = water table.

that, between well-defined limits, the specific resistivity of the gravel deposits can be decreased (increased) a little when the thickness of this layer is proportionally increased (decreased).

The interpretation of the geoelectric curves provides a model giving the distribution of specific resistivities. The latter are -in saturated conditions- a function of the specific conductivity of the pore water and the sediment characteristics of the concerned layer expressed by the 'formation factor'. It is not unreasonable to suppose that, in such a small area, the electric conductivity of the pore water is relatively constant. On the other hand, the 'formation factor' of coarse sediments is mainly determined by the porosity which is in turn generally proportional to sorting. The sorting of sand and gravel deposits is mostly inversely proportional to the main grain size. Consequently the electric specific resistivities, derived from the geoelectric interpretations, may be transposed – in the present circumstances and within certain limits – the mean grain size of the saturated gravel or sand layers.

Table 1. Resistivity stratification. The elective specific resistivities between parentheses are exceptional values.

	water saturated	dry
cover sediments	90 Ωm	> 350Ωm
gravel deposits	(90) 190-800 (1100) Ωm	> 650Ωm
Tertiary subsoil	5-160 (240) Ωm	

Apart from the determination of the thicknesses of the gravel layer and its overburden, the geoelectrical prospection has also resulted in an estimation of the gravel quality. The specific resistivity of a gravel bed is lowered by weathering, smaller grain size and the presence of sand, loam or clay. Gravel of good quality is thus characterized by high specific resistivities. According to some authors gravel beds with specific resistivities higher than 300 Ωm (watersaturated) are suitable for exploitation, according to others a specific resistivity of 140 Ωm is sufficient. However, these values may vary considerably from one region to another due to variations in the specific conductivity of the pore water. In dry conditions specific resistivities lower than 600 Ωm point to rather high quantities of impurities in the gravel body. In the studied area the saturated gravel layers show a man specific resistivity of approximately 350 Ωm. The values are slightly higher near the Maas river while to the west locally more intercalated sandy or loamy beds occur.

Geometrical characteristics of the gravel deposits

A. The gravel base (Fig. 3)

The most striking feature of this map is the significant and sharp discontinuity in the gravel base, named *The Bichterweert Scarp*. This scarp crosses the Maas valley diagonally and has a general direction identical to the main fault lines on the southern border of the Central Graben. Other discontinuities with an analogous direction do not occur in the gravel base of this area. Remarkable is the curved pattern of this scarp: from nearly E-W between the Maas and Rotem, to SE-NW between Rotem and the Kempen Plateau at Neeroeteren.

North of the Bichterweert scarp, the gravel base, lies 7-11 m lower than south of the scarp, is subhorizontal and dips gently from the SW (17-19 m) to the varying altitude of the gravel top and base. In the area south of the Bichterweert scarp, the gravel base is subdivided by a N-S boundary in an eastern part at an altitude of 24-26 m and a western part at 29-31 m. The gravel thickness varies between 5 and 11 m.

B. The gravel top (Fig. 4)

The cover deposits are thin for most of the area. The surface morphology generally reflects therefore the surface of the gravel top. The characteristics of the gravel top will be discussed in relation to the three geomorphological units in this part of the Maas valley bottom (fig. 4):

The *alluvial plain*, situated east of the Tongeren-Maaseik road, is separated from the terraces by a series of abandoned meander bends. The altitude of the gravel top varies between 30 and 33 m. The thickness of the fine alluvium is generally 1-2 m, but increases in the abandoned channels (2-4 m).

The *Mechelen-aan-de-Maas* terrace, of Weichse-

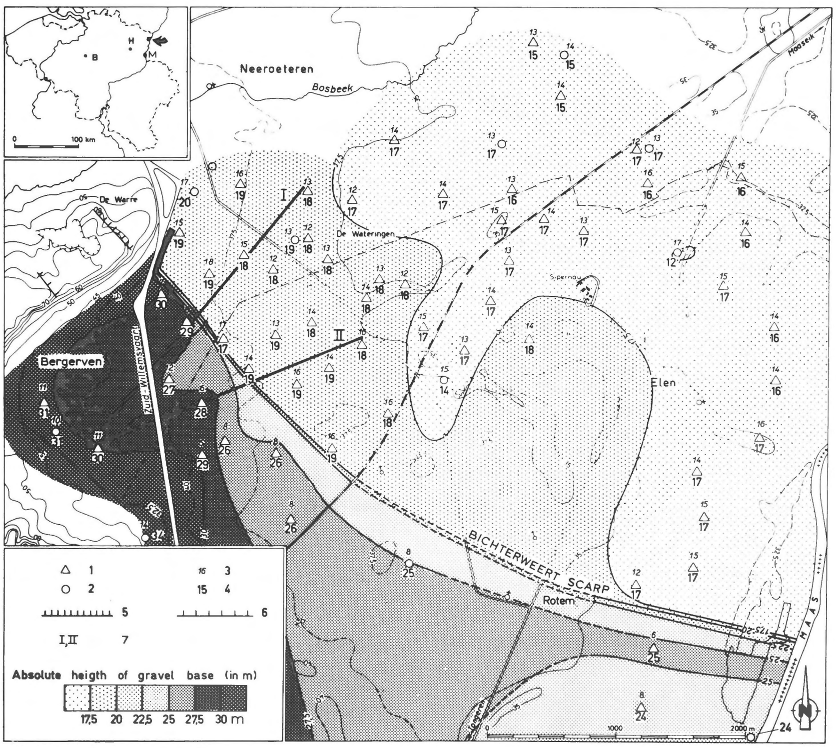

Fig. 3. Map of the gravel base of the Rotem-Neeroeteren area.
1. Electric sounding
2. Boring
3. Gravel thickness in metres
4. Altitude of the gravel base in metres
5. Main tectonic scarp on the Kempen Plateau
6. Secondary tectonic scarp on the Kempen Plateau
7. Cross section (Fig. 6)

(on inset) B = Brussel, H = Hasselt, M = Maastricht

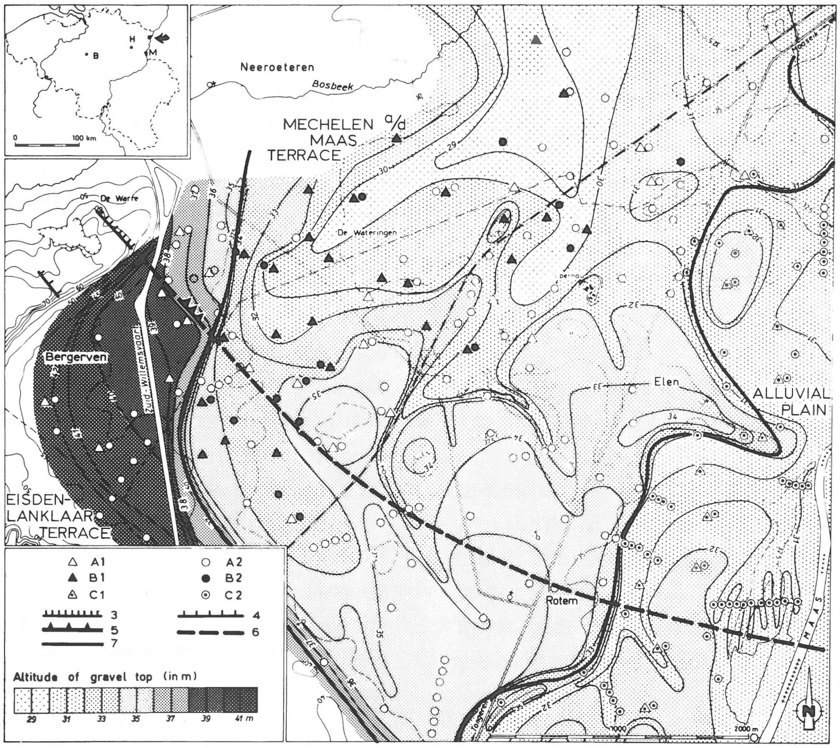

Fig. 4. Map of the gravel top of the Rotem-Neeroeteren area.

A. Overburden: exclusively coversands
   A1.: Electric sounding; A2: Boring
B. Overburden: grey silt and sandy silt covered with coversands
   B1: Electric sounding; B2: Boring
C. Overburden: fine deposits of the Holocene Maas
   C1: Electric sounding; C2: Boring

3. Main tectonic scarp on the Kempen Plateau
4. Secondary tectonic scarp on the Kempen Plateau
5. Denivellation in the top of the Eisden-Lanklaar terrace
6. Position of the Bichterweert scarp
7. Terrace scarps

lian age and always overlain by coversands, is situated between the alluvial plain and a 5m high escarpment in the gravel top (fig.4). This scarp is still partly visible in the relief. In the Rotem-Elen area, the eastern part of this terrace, the gravel top forms a flat surface dipping from 35 m in the south to 31 m in the north. In the NW-zone of this terrace, two wide depressions occur in the gravel top. They are completely filled, mainly by eolian sediments. They form the southern onset of the considerable eolian aggradations in the Central Graben.

The Elen area forms the southern zone of relief inversion between the alluvial plain and the Late Glacial Geistingen terrace on the one hand and the Mechelen-aan-de-Maas terrace on the other hand. Near Rotem the terrace top is at 35 m and the gravel top of the alluvial plain at 32 m, whereas some 5 km to the north their position are inversed (Paulissen 1973, p. 188).

The large meander bend of Bergerven forms the highest gravel level of the valley bottom in this area and is, according to Paulissen (1973) the continuation of the *Eisden-Lanklaar terrace*, the youngest of the Saalian terraces.

It is important to note that the Bichterweert scarp, clearly expressed in the gravel base throughout the valley, is missing in the gravel top of the alluvial plain and the Mechelen-aan-de-Maas terrace. A slight NW-SE denivellation is apparent in the gravel top of the Eisden-Lanklaar terrace (fig. 4, ref. 5). It coincides with the Bichterweert scarp in the gravel base.

Discussion

The Bichterweert scarp: part of the Feldbiss fault system

The Bichterweert scarp, represented by a sudden increase in gravel thickness, is clearly a fault scarp while it is unrelated to the fluvial system and crosses the Maas terrace. The Bichterweert scarp is situated in the exact continuation of the De Warre scarp (Fig. 4), part of the NE-border of the Kempen Plateau. This fault is not a straight line, but is is curved towards the south between Born and Neeroeteren (Fig. 5).

The Bichterweert scarp cannot be connected with the shallow fault pattern on the Dutch surveys maps (Fig. 1 and 5) as traced by Kuyl (1971) and Van Montfrans (1975). Indeed, at the crossing of the Maas, the Bichterweert scarp is situated about half-way between the Feldbiss and the Geleen Fault. East of the Maas, however, the exact position of a recent fault is known just north of the lock at Born along the Juliana Canal and considered as the Feldbiss fault (Ten Berghe 1959). Moreover, boring logs in the area between the Maas and the Juliana Canal exclude a sudden displacement of the gravel base at the position of the Feldbiss as supposed on the Dutch survey maps. These borings show, on the contrary, an E-W discontinuity in the base of the Maas gravels, connecting the Bichterweert scarp in Belgium with the shallow fault at Born. The connection of the latter fault with the Feldbiss fault at Sittard is obvious according to all existing data as expressed on the Dutch survey maps.

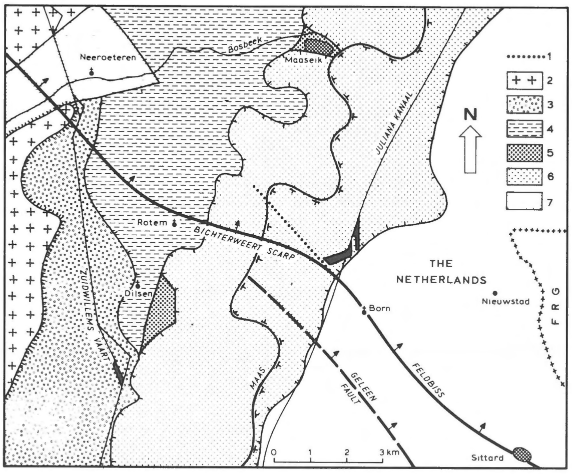

fig. 5. Shallow fault pattern and terrace morphology in the Maas valley. The fault pattern in the Netherlands is according to Kuyl (1971) and Van Montfrans (1975); terraces in the Belgian part according to Paulissen (1973); the Bichterweert scarp (this study).
1. Feldbiss pattern not recorded in this study
2. Main terrace deposits
3. Eisden-Lanklaar terrace
4. Mechelen-aan-de-Maas terrace
5. Geistingen terrace
6. Alluvial plain of the Maas
7. Deposits of the Bosbeek

Although the Feldbiss is only 40-45 m wide in the Dutch Carboniferous rocks (Heybroek 1947a) and shows a steep 'hade' angle between fault plane and the vertical (Rutten 1943, Heybroek 1947b), it is a well-known fact that the complexity of a fault may increase considerably in the upper unconsolidated deposits. The Feldbiss fault, for instance, shows several steps in the Lower and Middle Pleistocene deposits north of the Dutch-Belgian border (a.o. Van Montfrans 1975, Vandenberghe 1982). On the other hand the individual faults of such a system may be active at different times. As the Bichterweert scarp represents the only fault activity in the Maas valley gravels between Neeroeteren and Born and may be connected with the Feldbiss near Sittard, it is interpreted as being part of the shallow Feldbiss *fault system* in this region.

The late Pleistocene Feldbiss activity

The Maas terraces are excellent reference levels for dating Quaternary faulting on the southern graben border. A tectonic scarp at the base, respectively on the non-eroded top of the same terrace deposit, represents indeed the toal amount of downfaulting since the onset, respectively the end of the terrace formation. A sudden increase in thickness of the fluviatile deposits due to faulting, is a measure for tectonic activity during their formation.

Two geological sections (Fig. 6) illustrate the combined observations on the Eisden-Lanklaar and Mechelen-aan-de-Maas terraces which are

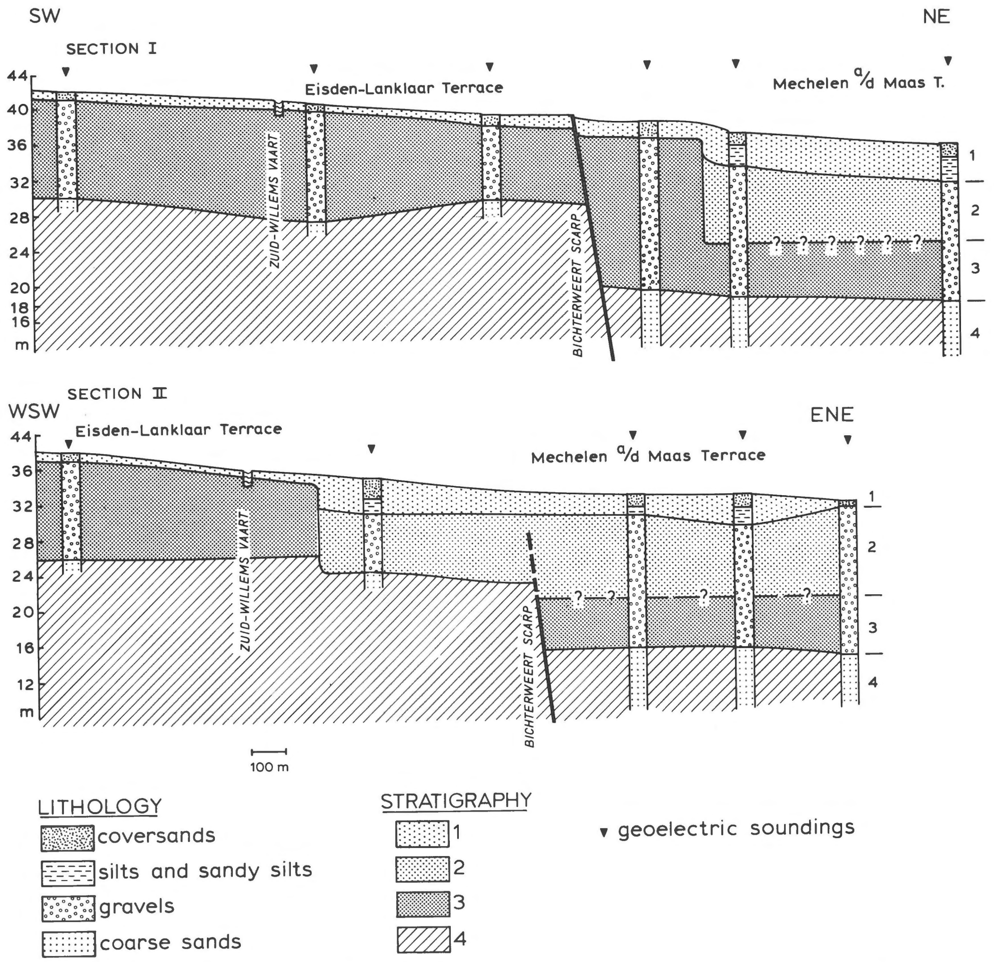

Fig. 6. Geological sections through the Bichterweert scarp based on geoelectric soundings. For situation see Figure 3.
1. Eolian deposits (Weichselian Middle/Upper Pleniglacial)
2. Deposits of the Mechelen-aan-de-Maas terrace (Weichselian)
3. Deposits of the Eisden-Lanklaar terrace (Saalian)
4. Tertiary subsoil

clearly separated by a scarp in the gravel top (fig. 4). In section 1, the fault scarp is situated in the deposits of the Eisden-Lanklaar terrace and is characterized by a 10 m escarpment at the base and a mean increase in gravel thickness of about 7-8 m. A little scarp occurs at the surface where the gravel top moves up 2-3 m. These observations show that the most important Late Pleistocene Feldbiss activity is synchronous with the aggradiation of the Eisden-Lanklaar terrace, the youngest of the Saalian terraces. Posterior faulting is of the order of a few metres and is related to the 2-3 m height difference at the top of the Eisden-Lanklaar terrace. In section II the Bichterweert scarp is situated below the Mechelen-aan-de-Maas terrace with a throw of about 8 m causing an equivalent thickening of the gravel deposits. The top of this terrace is not affected by tectonic activity.

From Fig. 4 it may be observed that the western scarp of the Mechelen-aan-de-Maas terrace is related to lateral erosion when (part of) the Maas river was situated in the 'Wateringen' depression. This depression has been abandoned by the Maas river system which continued to deposit gravels in the eastern part of the Mechelen-aan-de-Maas terrace. This eastward shift is assumed to be related to tectonic activity which is also reflected in the 2-3 m denivellation at the top of the Eisden-Lanklaar terrace (Fig. 6). In this hypothesis, the onset of the accumulation in the 'Wateringen'-depression post-dates this minor tectonic activity. The 'Wateringen'-depression is filled with eolian loams up to 4,5 m thick overlain by a gravel bed and 0,5 m of yellow coversands. These sediments are of Weichselian Upper and Middle Pleniglacial age, according to lithostratigraphical correlations (Vandenberghe & Krook 1981). As the Mechelen-aan-de-Maas gravels are of Weichselian age, it means that the minor tectonic activity along the Bichterweert scarp may be situated in Weichselian times prior to the Upper Pleniglacial. There are no evidences of Upper Pleniglacial, Late Glacial and Holocene faulting in the Maas valley. This conclusion is in contradiction to Kuyl (1980, p. 131), who assumes a more recent throw of 5 m along the Feldbiss near Sittard.

Conclusions

The occurence of an 8-10 m NW-SE scarp, the Bichterweert scarp, in the Maas valley bottom gravels was demonstrated by electric soundings. This scarp, tectonis in origin, is the westward prolongation of the Feldbiss fault in the Netherlands. The accurately localised fault line in the Maas valley is curved near Rotem and deviates from NW to ESE. The most important younger Pleistocene fault activity is synchronous with the aggradation of the Eisden-Lanklaar terrace, the youngest of the Saalian terraces. A minor posterior faulting is dated between Eemian and Weichselian Upper Pleniglacial.

The specific resistivities of the gravel unit give an indication of the quantities of fines within the gravel unit and provide an estimation of the gravel quality.

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