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EXPLORATION FOR COAL IN THE NEEROETEREN-ROTEM AREA (CAMPINE COALFIELD OF THE CAMPINE-BRABANT BASIN NE. BELGIUM) PRELIMINARY RESULTS OF A SEISMIC SURVEY CARRIED OUT IN DECEMBER 1980 - JANUARY 1981 (1)

by

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(3 figures)

RESUME.- Une prospection sismique par "vibroseis reflection" d'une longueur totale de 83,7 km a été effectuée dans la concession de Neeroeteren-Rotem située dans le bassin charbonnier de Campine du nord du district minier et limitée vers le nord-est par le graben central des Pays-Bas.

Cette prospection avait pour objectif une reconnaissance structurale des dépôts du Carbonifère supérieur tronqués par une surface d'abrasion à la base du Crétacé supérieur à des profondeurs s'étageant de - 500 m dans le sud à - 650 m dans le nord. Un bassin synclinal dans la partie sud-ouest de l'aire prospectée, a conservé une partie des dépôts Permo-Triasiques de couleur rouge, en-dessous de la surface d'abrasion Crétacé supérieur.

Le fait structural le plus remarquable est une structure plissée, parallèle à l'orientation NW-SE des failles principales et qui est très différente de la structure monoclinale du bassin charbonnier où des pentes vers le Sud sont rares. Dans l'extrême nord de l'aire prospectée, la prolongation de l'axe anticlinal principal a la forme d'un dôme d'une importance telle que le Carbonifère pourrait bien se trouver immédiatement sous le Tertiaire. Il est possible que cette structure s'élargisse vers l'ouest et qu'elle coïncide avec une anomalie gravimétrique positive dans l'aire de Meeuwen-Bree.

SUMMARY.- A vibroseis reflection seismic survey with a total length of 83,7 km has been carried out over the Neeroeteren-Rotem concession, situated in the Campine coal basin north of the mining district and limited towards the northeast by the Netherlands Central Graben.

This survey was aimed at a structural reconnaissance of the Upper Carboniferous deposits truncated by an abrasion surface at the base of the Upper Cretaceous at depths ranging from - 500 m in the south to - 650 m in the north. A synclinal basin in the southwestern part of the survey area has preserved part of the red-coloured Permo-Triassic deposits below the Upper Cretaceous abrasion surface.

The most striking structural feature observed is a fold structure, parallel to the NW-SE trending major faults, which is very different from the monoclinal structure in the coal field where dips to the south are rare. In the extreme north of the survey area the prolongation of the main anticlinal axis is doming to such an extent that the Carboniferous may directly underlie the Tertiary. It is possible that this structure widens westwards and that it coincides with a positive gravimetric anomaly in the Meeuwen-Bree area.

1.- INTRODUCTION

1.1.- JUSTIFICATION

At the first stage of a five year coal exploration programme (1979-1984) by the Belgian Geological Survey in the Belgian Campine region, the Neeroeteren-Rotem area has been selected because of its known coal reserves (boreholes 110-113-117) at relatively shallow depths (top Coal Measures at around 600 m). The exploration programme encompassed a reflection seismic survey and a cored borehole drilled at Neerglabbeek (Dusar & Houlleberghs, in press).

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1.2.- GEOLOGICAL SITUATION

This seismic survey covers the unexploited Neeroeteren–Rotem concession which is located towards the northeast of the Campine coal mining field. The latter forms the southern part of the larger Campine–Brabant Basin which extends over northeastern Belgium and the southeastern Netherlands and lies in the paralic belt of NW-Europe during the Upper Carboniferous (Bless et al., 1977) (Fig. 1). In the Neeroeteren–Rotem area the Upper Carboniferous Coal Measures are locally overlain by a red - coloured Permo - Triassic sequence which is, in turn, unconformably overlain by a calcareous Upper Cretaceous sequence. Below the major unconformity at the base of the Upper Cretaceous all older Mesozoic, Permian and Carboniferous sediments have been progressively eroded towards the Brabant Massif in the south. Along the northeastern part of the seismic

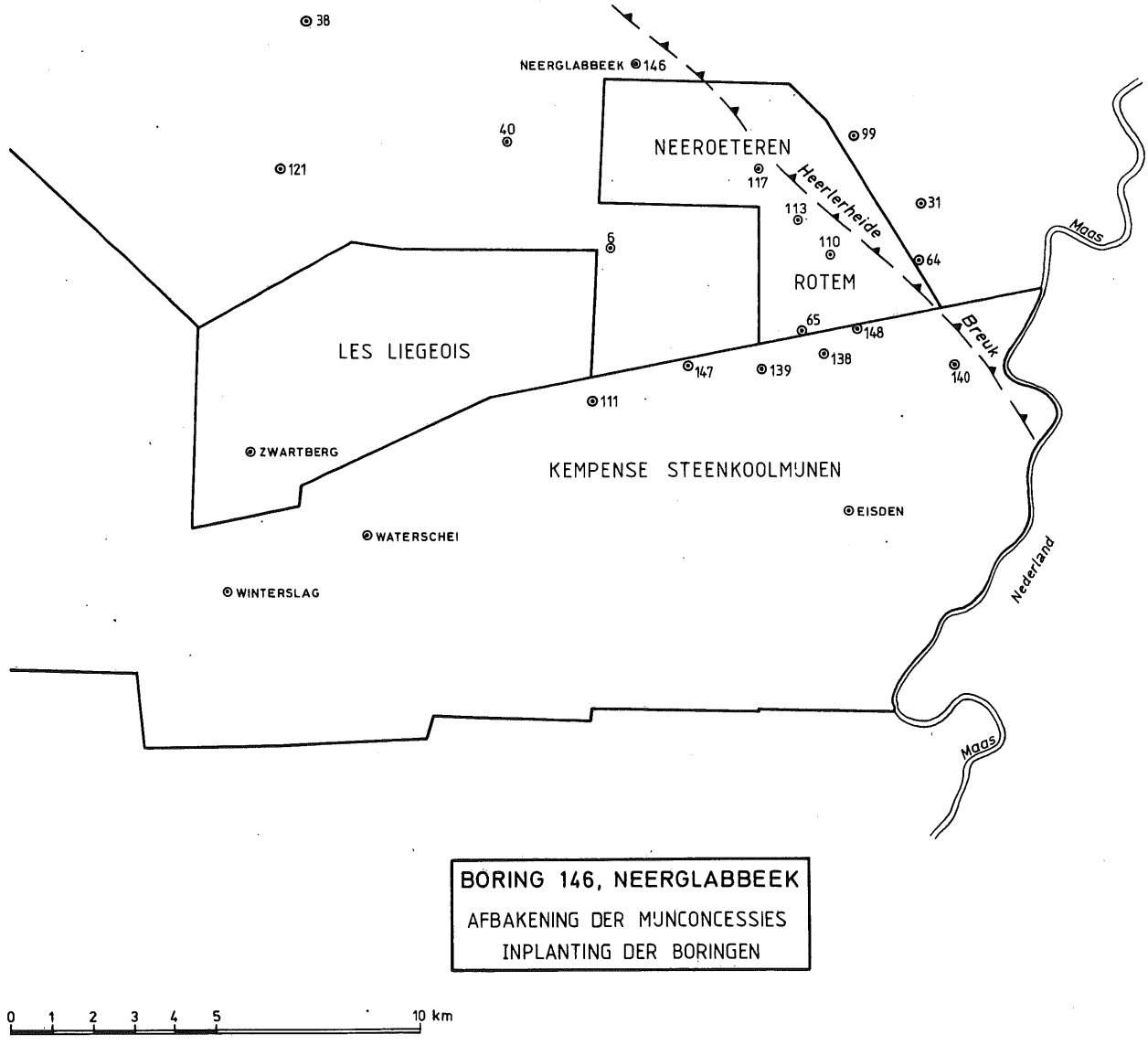

Figure 1.- Situation map showing borehole locations and concession boundaries.

survey area the Heerlerheide and Feldbis Faults cause a downwarp of the Carboniferous under a more complete post-Paleozoic cover in the Netherlands Central Graben (Legrand, 1961, 1968).

1.3.- PREVIOUS WORK

Previous seismic investigations including the Neeroeteren-Rotem area have been carried out by Seismos in 1953-1956 on behalf of the Belgian Geological Survey and in 1961-1963 on behalf of the Société Campinoise de Recherches et d'Exploitations Minérales (SCREM). Well seismic velocities and synthetic seismograms were available from the following boreholes : Meeuwen (Cretaceous/Permo-Triassic/Upper Westphalian), Turnhout (Cretaceous/Lower Westphalian) and Neerglabbeek (Upper Westphalian).

No map of the area under consideration has been produced although important information has been obtained on the general NW-SE trend of major structural features and on the location of the Heerlerheide and Dorne faults.

Fifteen boreholes have explored the pre-Cretaceous deposits in the survey area (Fig. 1). Boreholes 6, 31, 40, 64 and 65 were drilled shortly after the discovery of the Campine coal field. Borehole 99 was drilled in an exploration campaign for rock salt. Borehole 111 was drilled in an exploration campaign starting during the second world war, to investigate the coal reserves in the eastern part of the worked André Dumont (Waterschei) and Les Liégeois (Zwartberg) concessions. Boreholes 110, 113 and 117 drilled between 1939 and 1946, on the "Horst of Neeroeteren - Rotem" (Grosjean, 1939) lay at the origin of the establishment of the Neeroeteren-Rotem concession. Stratigraphic correlations between all these boreholes were proposed in Delmer (1963) but a Westphalian D age for the uppermost sections in boreholes 113 and 117 was only ascertained in 1975 (Stockmans and Williere, 1975) and confirmed by borehole 146 (Dusar and Houlleberghs, in press). Increasing energy prices and a concern for the future of the Campine coal mining industry instigated a new exploration campaign starting at the end of 1979. This led to the series of boreholes 147-139-138-148 drilled by the Kempense Steenkoolmijnen (KS) along the northern margin of their concession and to borehole 146 drilled north of the Neeroeteren-Rotem concession by the Geological Survey of Belgium (Fig. 1).

2.- DATA ACQUISITION

2.1.- PURPOSE OF THE SURVEY

Exploration objectives for the seismic survey were :

- a structural reconnaissance of the upper part of the Carboniferous deposits, down to a depth of ± 1500 m. These deposits consist of a cyclic coal-bearing shale-sandstone sequence of Westphalian C-D age terminated by a coarse grained highly porous sandstone unit with a minimum thickness of 300 m, named the Neeroeteren Sandstone.
- a map of the Cretaceous unconformity truncating the underlying Carboniferous and Permo-Triassic deposits at different stratigraphic levels.
- the distinction between the grey-coloured Carboniferous deposits and the red-coloured Permo-Triassic deposits with a maximum known thickness of 575 m and which are overlying the Carboniferous deposits in the southwestern part of the surveyed area (boreholes 6 and 40).
- the location, age and composition of the Heerlerheide Fault which constitutes the northeastern limit of the Neeroeteren-Rotem coalfield.
- the reconnaissance of the major faults which intersect the Carboniferous and partly affect the overlying formations as well.

2.2.- GRID OUTLINE AND SURVEY METHOD

The survey was carried out from December 4, 1980 to January 22, 1981 by a Vibroseis telemetry crew from Prakla-Seismos, Hannover. The investigated area measures ± 65 km^2, covered by the following topographic mapsheets (scale 1 : 10.000) : Bree 18/6, Maaseik 18/7, Opoeteren 26/2 and Stokkem 26/3.

Although the area is generally flat, the elevation difference ranges from 35 m in the eastern part to 88 m in the western part. This is partly due to a NW-SE oriented scarp along the Feldbiss Fault.

The grid was composed of 13 practically rectilinear profile lines with a total length of 83.7 km. These lines were NW-SE/NE-SW oriented in function of the main structural directions. Most exploration boreholes within the survey area were intersected by the profile-lines (Fig. 2).

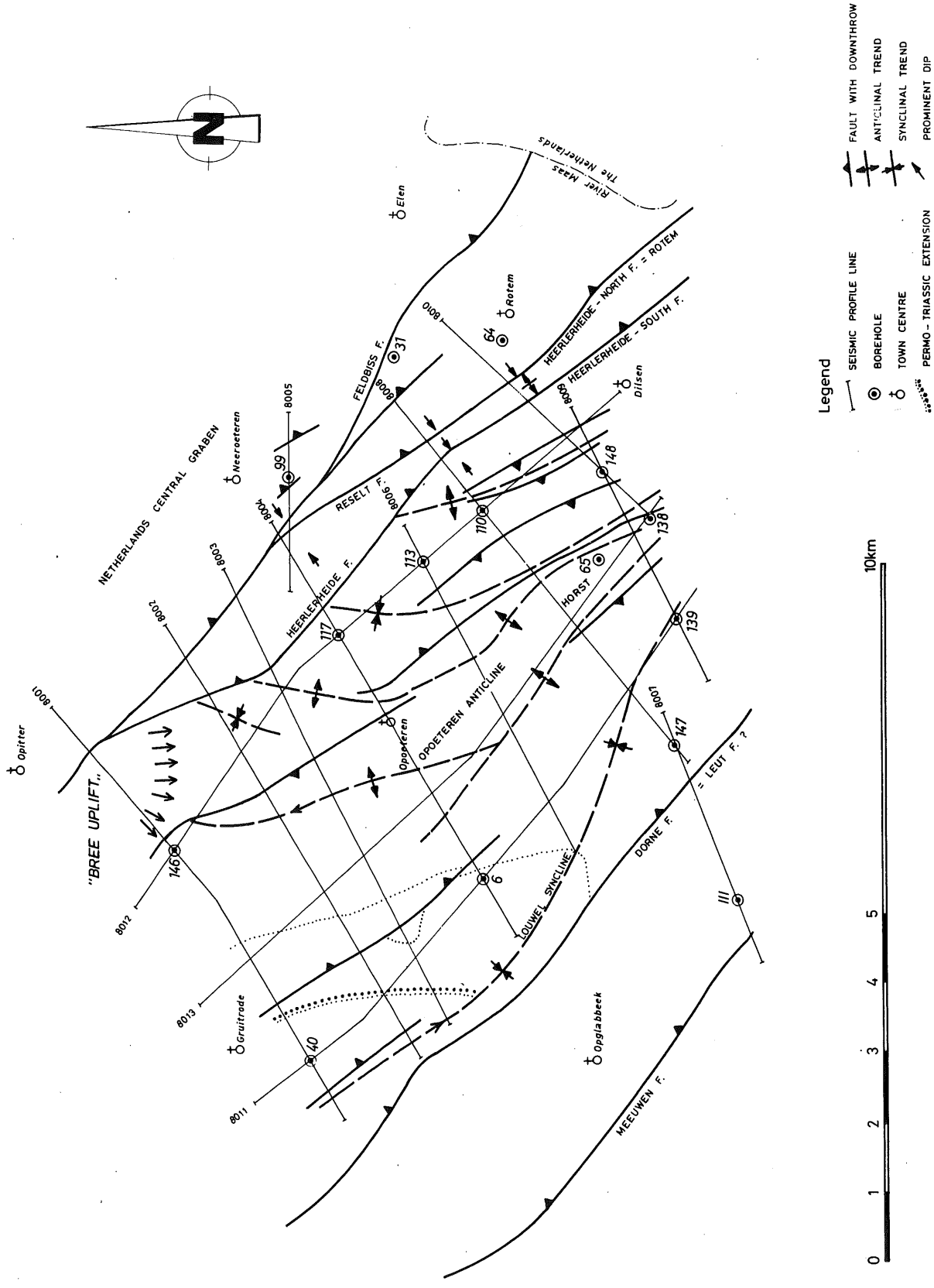

Figure 2.- Neeroeteren-Rotem coal exploration. Preliminary geological interpretation.

3.- INTERPRETATION

3.1.- THE FOLD STRUCTURE

Compared to the Campine coal mining district to the south the appearance of gentle folds forms the most striking structural feature in the Neeroeteren-Rotem area. Except for a small dome, named the Kuilen Anticline, in the Winterslag mining field (Renier, 1925) this characteristic is unknown elsewhere in the mining district so that the widespread southward dips, demonstrated first in the 146 (Neerglabbeek) borehole were really unexpected.

Nevertheless folding has played a far less important part than faulting (normal and reverse) to produce the final geological situation. This part of the Campine basin closely resembles the northwestern part (Niederrhein) of the Rhein-Ruhr Coal District (Breddin, 1929).

The tilted strata are gently dipping with an average dip of 10^{o} similar to the one observed in the Campine mining district. The folds are elongated in a NW-SE direction and generally plunging towards the northwest. Near the Heerlerheide Fault the fold trends may bend towards the NNE and thus may intersect this fault (Fig. 2).

A transition to the more monoclinally folded southern part of the Campine basin was observed on profile-lines 8009 and 8010 in the southeastern part of the survey area where these folds are serrated and at an incipient stage of formation.

The largest and centrally located anticlinal fold which has been named the Opoeteren Anticline, rapidly widens and splits into several undulation secondary folds.

North of borehole 146 the Opoeteren Anticline is prolongated by a dome rising under the post-Paleozoic cover and virtually devoid of any Cretaceous deposits. Consequently one can expect the first Carboniferous beds directly underneath the Tertiary or uppermost Cretaceous at a depth of - 400 m (Ostend level) on top of the dome. Unfortunately this uplift was intersected for only 1.5 km on profile-line 8001 where as a result of the northbent of the anticlinal axis exclusively south-dipping paleozoic and triassic strata were encountered on the entire length of the profile-line south of the Heerlerheide - Feldbiss Fault.

It is suggested that the uplift of the Carboniferous strata observed on profile-line 8001 extends towards the northwest in the direction of Bree (hence the name Bree Uplift) and enlarges towards the west in the direction of Meeuwen, at least if there exists a relation between this uplift and the Meeuwen - Bree positive gravimetric anomaly (Fig. 3). Furthermore a peculiar increase in coalification has been noticed from borehole 110 to borehole 146, in the direction of the Bree Uplift: in stratigraphically equivalent Upper Westphalian C deposits the volatile matter content increases by 3.5 % on 6600 m distance (Dusar and Houlleberghs, in press).

The hypothetical " Horst of Neeroeteren - Rotem" postulated by Grosjean (1939) cannot be retained as the tectonic structure in this area is not simply fault-controlled. Nevertheless the area obviously forms a structural high composed of a series of NNW-SSE folds. Furthermore the Neeroeteren (110-113-117) and Neerglabbeek (146) boreholes aligned in a N40W direction donot belong to a singular internally undisturbed structure as shown on a cross-section in Delmer, 1958 and Dusar and Houlleberghs, in press.

Similarly the Louwel Graben also postulated by Grosjean (1939) cannot be retained as the strata are folded into a syncline and the main surrounding faults are all donwthrown towards the north.

Contrary to the mining map of the Campine coal basin (Delmer, 1963) Westphalian D strata may subcrop over the largest part of the Neeroeteren - Rotem area. Westphalian D strata were identified in boreholes 113, 117 and 146 (Stockmans and Willière, 1975 ; Dusar and Houlleberghs, in press).

3.2.- THE MAJOR FAULTS

All major faults encountered in the Neeroeteren - Rotem area are normal and roughly parallel, striking northwest-southeast. Many smaller faults not affecting the Cretaceous cover probably strike in a north-south to NNE-SSW direction perpendicular to the main trend. The fault system probably originated at the end of the Carboniferous and had new periods of activity, not always in the same direction, on the late kimmerian phase of Stille, between the Lower Jurassic and the Cretaceous, and in the younger Tertiary. The overlying post-Carboniferous strata are thus partly affected by the faults which dislocated the unconformity at the base of the Upper Cretaceous (Patijn, 1963 ; Tys, 1980).

In the adjoining South Limburg coalfield the measured hade of small normal fault planes varied around 60^{o} (Sax, 1946). Patijn and Dikkers (1944) measured angles varying between 50^{o} and 65^{o} along the Heerlerheide fault.

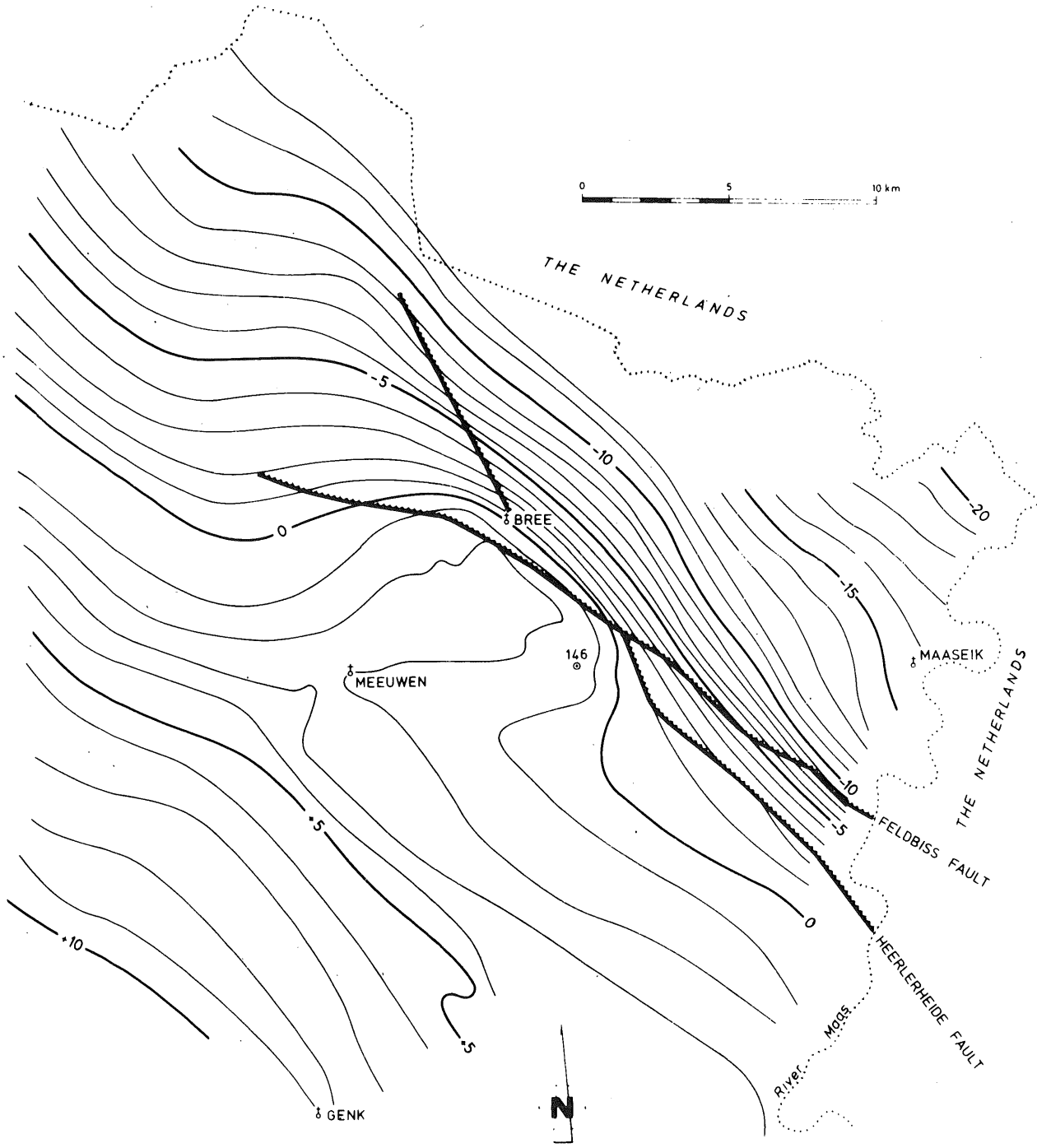

Figure 3.- Bouguer Anomaly map N.E. Limburg (B) (after Geological Survey of Belgium, 1953).

The major faults occurring in the survey area can be subdivided into three groups according to their geographical position : northern - central - southern.

The most important fault group including the Heerlerheide and Feldbiss Faults, marks the southwestern limit of the Central Graben (cf. 3.3.).

In the central part of the Neeroeterem - Rotem area fold structures are very conspicuous, contrary to the fault-controlled monoclinal deformation in the Campine coal mining district.

Fault structures do not necessarily enhance the fold structure : the Opoeteren Anticline is downthrown in a broad graben in the northwest (profile-lines 8001 and 8004), whereas in the southeast, this incipient fold is located in a narrow horst (profile-line 8009). The faults delimitating these horst and graben structures apparently do not cross each other (Fig. 2).

Borehole 138 was located - prior to the seismic survey - in the fault zone on the north flank of the anticline. Anticlinal curvatures also are prone to more small-scale vertical tectonic dislocation.

The Bree Uplift, marked by a considerable thickness reduction of the Upper Cretaceous beds may be limited to the south by a reverse fault, similar to the "Umkehrverwerfungen" in the Nordrhein-Westfalen coal basin which resulted from an uplift of the downfaulted blocks during the Laramide (Cretaceous) phase of orogenic deformation (Breddin, 1929 ; Wolansky, 1960).

In the Eisden mining field, further towards the southeast, several reverse faults are also known (Delmer, 1963).

A third group of faults characterised by an unidirectional downthrow to the north and occurring in the southwestern part of the survey area, is still associated with the gradual deepening of the Campine basin towards the north. The laterally continuous Meeuwen and Dorne (= Leut ?) Faults, intersected on profile-line 8007, were traced according to the structural interpretation of a previous seismic survey in 1956.

The youngest Carboniferous strata to be found in the Campine coal basin will eventually subcrop on the southern flank of the Opoeteren Anticline, on the hanging wall of the normal faults occurring near Gruitrode. They may be overlain by a thin cover of Permo-Triassic strata as postulated by Tys (1980).

3.3.- THE BOUNDARY OF THE CENTRAL GRABEN

The southern boundary of the Netherlands Central Graben (or Roer Valley Rift) is formed by the Heerlerheide and Feldbiss Faults, striking NW-SE and continuing into the South Limburg and Aachen coalfields (de Sitter, 1949). These faults have ever marked the northern limit of the accessible coal deposits in the Campine coal field. The recent exploration for coal in the Neeroeteren - Rotem area is limited by these faults as well. However, the NE-SW striking seismic profile-lines have been extended sufficiently towards the northeast to allow an unequivocal identification of the step faults limiting the Central Graben (Fig. 2). Steep gravity gradients, probably associated with faulting, also mark the southern boundary of the Central Graben (Fig. 3).

The movement of sinking of the rift valley and tilting of the flanking blocks occurred in several successive phases : a first Asturian phase of down-faulting and tilting, a second Kimmeric (Jurassic) phase in the same sense as the first movement, a third Laramide (Cretaceous) phase of uplift of the formerly down- faulted blocks and a fourth Tertiary phase which is probably still active in the same sense as the first movement (de Sitter, 1949).

Successive movements along these faults did not necessarily occur within the same fault plane but formed faulted zones up to one kilometer wide (Patijn, 1961).

The vertical downthrow of the top Carboniferous along the Heerlerheide Fault is estimated at 400 metres. No information exists on the stratigraphic level of the topmost Carboniferous strata inside the Central Graben, e.g. in borehole 64 where the Carboniferous has been reached at - 1147 m (Delmer, 1963).

A fault north of the Heerlerheide Fault and roughly parallel to it has been named provisionally the Reselt Fault (Fig. 2). In the survey area the vertical downthrow along this fault is less important but laterally in a southeasterly direction, due to the rotational movement along these en echelon faults, the major displacement attributed to the Heerlerheide Fault is probably associated with the southeastern prolongation of the Reselt Fault, whereas the displacement along the Heerlerheide Fault as identified in the survey area is rapidly diminishing in the same direction.

In proximity of borehole 99, the Reselt or Heer-

lerheide - North Fault joins the Feldbiss Fault the eastern trace of which is based on the structural interpretation of previous seismic surveys.

The Feldbiss Fault is responsible for the conspicious scarp marking the boundary between the Campine Plateau to the south and the Central Graben to the north. The fault scarp has been rejuvenated by a vertical displacement of about 10 metres in the near-surface Quaternary beds (Paulissen, 1973). Along the Feldbiss Fault the top of the Carboniferous is assumed to be downthrown for another 400 metres. Between borehole 117, south of the border faults and borehole 99, north of these at 2400 m distance the top of the Carboniferous thus has been downthrown for 950 metres (from - 606 m to - 1560 m) (Delmer, 1963).

In the Central Graben, epeirogenic movements have resulted in the deposition and preservation of a more complete Mesozoic succession. Up to Lower Jurassic rocks were encountered in borehole 99. During the Upper Cretaceous this Jurassic basin was the site of a structural reversal and was characterised by a non-deposition or denudation of a major part of the Cretaceous cover (Legrand, 1961).

The Carboniferous uplift in the Bree area is probably older than the graben formation and the Cretaceous strata are apparently not involved in this uplift. The geometry of the Heerlerheide Fault is influenced by the location of the Bree uplift. In fact where the Carboniferous is doming, the Heerlerheide Fault bends towards the north as to circumscribe a more rigid mass and finally joins the Feldbiss Fault (Fig. 3).

3.4.- THE PERMO-TRIASSIC

The pre-Cretaceous post-Carboniferous succession in the area south of the Heerlerheide Fault is limited to a red coloured Permo-Triassic sequence. In the survey area these deposits are preserved underneath the Cretaceous abrasion surface in the central part of the Louwel Syncline only. Triassic Buntsandstein deposits have been intersected at boreholes 6 (42 m without attaining the base) and 40 (227 m without attaining the base). The complete Buntsandstein sequence recognised in borehole 64 attains a thickness of 575 m whereas the underlying Permian is restricted to a marginal Zechstein formation, maximum 30 m thick (boreholes 121 and 64) (Delmer, 1963).

Mapping of the areal distribution and thickness estimations of the Permo-Triassic deposits are complicated by the fact that they cannot be easily distinguished from the underlying Carboniferous on seismic sections. A small angular disconformity near the base of the Permo-Triassic sequence (as postulated by Tys, 1980), discernible on profile-lines 8001 and 8011 has allowed the sketchy reconstruction shown on Fig. 2 : at the centre of the Louwel Syncline the Permo-Triassic deposits attain a thickness in excess of 250 m but along the double-dotted line they rapidly wedge out. In the surrounding area, enclosed by the single-dotted line and including the site of borehole 6, only a thin veneer of Permo-Triassic deposits has been preserved. At the intersection of profile-lines 8003 and 8011 these may have even been removed below the Cretaceous unconformity.

3.5.- THE CRETACEOUS UNCONFORMITY

The major unconformity at the base of the Upper Cretaceous forms a plane leveling down from - 500 m in the south of the survey area to - 650 m in the north. This plane dips with an average dip of 1.75 °/o towards the north, conformable to the average value for the Campine basin (Legrand, 1968).

The Bree Uplift (cf. supra) has created a large anomaly on this abrasion surface (max. elevation difference estimated at 250 m).

On the NE-SW striking seismic profile-lines (traversing the NW-SE striking large normal faults) the dip rather greatly varies from 0.5 °/o on profile-line 8006 to 2.7 °/o on profile-line 8008, resulting in an average dip of 1.5 °/o in a north-easterly direction. On the NW-SE striking profile-lines a much more regular dip of 1.15 °/o in a northwesterly direction was noted. On these lines a fairly regular but slightly greater plunge of the Carboniferous beds in the same northwesterly direction was also observed.

Most faults (as indicated on Fig. 2) affecting the Cretaceous overburden enforce the general northerly dip of the Cretaceous unconformity. Except for some faults in the eastern part of the survey area the displacement of the basal Cretaceous beds normally does not exceed 40 metres. The downwarp of this unconformity in the Central Graben is already discussed in 2.3.

One should bear in mind that the surface of the Carboniferous is an abrasion surface which was formed locally by more than one erosion period. The Cretaceous peneplation has eroded away the older Permo-Triassic sediments, in some places partly, in others entirely down to the Carboniferous.

4.- CONCLUSIONS

A preliminary structural interpretation of a recent seismic survey for coal exploration in the Neeroeteren-Rotem area has led to the reconnaissance of gentle NW-SE to N-S trending folds previously unknown in the Carboniferous of the Campine coal basin.

In the extreme north of the survey area, close to the boundary of the Netherlands Central Graben, the Carboniferous is doming and practically devoid of a Cretaceous cover. It is possible that this feature, raising the top of the Carboniferous by almost 250 metres to - 400 m, extends over the Meeuwen - Bree area.

A further investigation of the Meeuwen - Bree area by means of a new seismic survey and a borehole in the uplift zone is imperative to provide a clearer picture of this structure which is potentially of the highest economical significance.

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