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GRAVIMETRIC EXPLORATION APPLIED TO THE DETECTION OF FAULTS IN THE AREA OF MOL-TURNHOUT (BELGIUM)

by

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(10 figures)

ABSTRACT.- A gravimetrical exploration has been realized in the area of Mol and Turnhout (province of Antwerp, Belgium) to localize steep dipping faults in the Paleozoic bed rock and the meso- to cenozoic overburden. With a 600 to 1000 m thick overburden consisting of sand and clay, 10 m high steps in the bed rock result in significant gravimetrical anomalies.

The interpretation is based upon comparison with theoretical anomalies computed for various density contrasts and depths.

After the classical corrections, the Bouguer anomaly has been smoothed and horizontal derivatives computed to reduce the effect of shallow heterogeneities and regional gradients.

The results confirm the presence of several faults already detected by other methods and enable a more accurate positionning.

RESUME.- Une prospection gravimétrique a été réalisée dans les régions de Mol et de Turnhout dans le but de mettre en évidence et/ou de confirmer la présence de failles subverticales décalant le sommet du substratum paléozoïque et ayant pu rejouer dans les dépôts secondaires et tertiaires de couverture. Sous une épaisseur de 600 à 1000 m de terrains sablo-argileux, les dénivellées de plus de 10 m des terrains plus denses du Primaire sont décelables en termes d'anomalies gravimétriques.

L'interprétation est menée par comparaison avec différents cas théoriques correspondant à diverses géométries, plusieurs profondeurs et plusieurs contrastes de densité.

Après les corrections habituelles, l'anomalie de Bouguer a été traitée par lissage et dérivations horizontales successives afin de s'affranchir des variations régionales et des influences superficielles.

Les résultats obtenus ont permis de confirmer et préciser le tracé des failles connues par observations directes ou déduites de la présence de linéaments en photos aériennes.

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INTRODUCTION

In the area of Mol and Turnhout, the paleozoic bed rock, consisting of quartzite, sandstone, siltstone, shale and coal is overlain by an overburden consisting of clay, silt and sand layers of Cretaceous to Quaternary age. The thickness of the overburden increases from about 600 meters in Mol to about 1.000 meters in Turnhout.

A gravimetrical exploration has been carried out to localize steep dipping faults in the bed rock and overburden. If the step in the top of the bed rock exceeds 10 meters, a significant gravimetric anomaly may be measured on the surface; if the throw is less than 10 meters it is nearly impossible to distinguish between a steplike structure and a gently dipping structure.

15 gravimetric profiles have been realized: 4 close to Turnhout in the North and 11 in an area limited by Geel in the South-West, Kasterlee in the North-West, Postel in the North-East and Lommel in the South-East (fig. 1). The profiles are directed WSW - ENE or W-E in order to investigate NNW - SSE or N-S striking faults. One profile, along the Geel-Retie road, is directed NNE - SSW to investigate a possibly E-W striking fault (Profile XI).

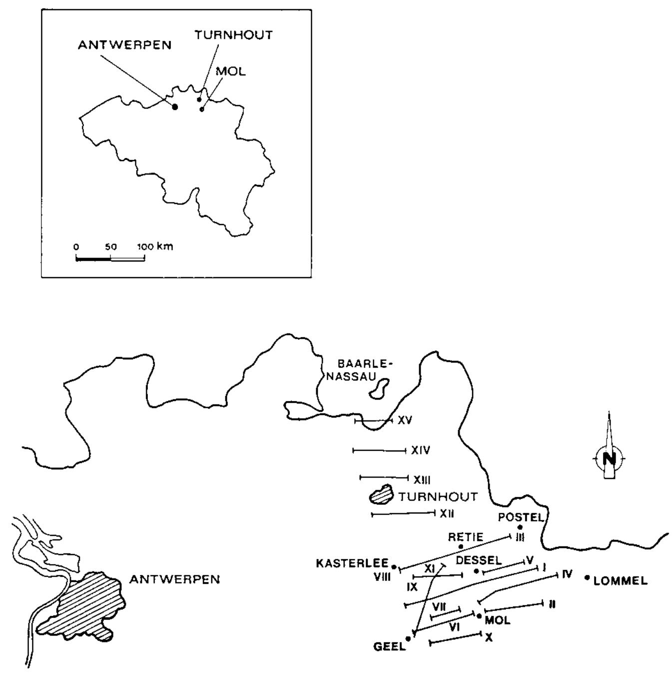


Fig. 1.- Situation of the gravimetrical profiles

PRINCIPLE OF THE METHOD

The principle of gravimetrical exploration is classical and will be only briefly summarized hereafter.

The units commonly used to express the gravitational acceleration are derived from the cgs system: the «gal» (= 1 cm/sec^2), the milligal and the microgal. The value of the acceleration on earth is about 980 gals. The measurements for this survey are expressed in 10^{-5} gal.

The variations of the gravitational attraction from one point to the other can be related to density changes in the underlying rocks but other parameters affect the value of g: gravitational attraction of the sun and the moon (tides), latitude and elevation of the point, masses around the point (topography). Field measurements must be corrected to eliminate the effect of these parameters.

The effect of tides and of instrumental drift are corrected for by linear adjustment deduced from the measurements at a base station at the beginning and the end of each loop of stations.

The correction of elevation is obtained adding the free air (Fay) and Bouguer corrections:

$$g'p = (30{,}86 - 4{,}19\,\sigma)\,Z$$

with g' p: correction at point P (10^{-5} gal)

σ: density of surficial layers (T/m^3)

Z: elevation difference between point P and datum plane (meters)

For $\sigma = 1.8$ T/m^3 we have $g'p = 23.32\,Z$ (10^{-5} gal).

The latitude correction is obtained by derivation of the International Formula expressing g as a function of the latitude. The correction is approximately equal to $81{,}21 \sin 2\Phi . 10^{-5}$ gal/km which means that a distance of 12.5 m in the N-S direction results in a 10^{-5} gal gravity change in the surveyed area.

The topographic correction can usually be neglected in this area, because of the very low relief. Only in some cases like measurements along the canal or railway embankment is a topographic correction necessary. It is computed by modeling the topographic surface by vertical prisms and adding the effect of each prism at the measuring point.

All measurements and corrections are given with reference to an arbitrary base station since we are only interested in gravity variations, not in absolute values. After correction, gravity variations with reference to the base station are called Bouguer anomalies. They may be due to:

1) Superficial density contrasts.

2) Changes in the thickness of the overburden related to the horst and graben structure of the bed rock.

3) Very deep or distant density contrasts (Rhine graben, earth crust...).

Only point 2 is relevant to our investigation.

FIELD PROCEDURE

The gravity measurements have been carried out with a Lacoste and Romberg model D gravity meter with an accuracy in the microgal (10^{-6} gal) range. In this case however a 10^{-5} gal accuracy was more than sufficient and a faster reading procedure could be used.

The spacing between stations along a profile is 250 m, each station consisting of 4 measuring points on the edges of a 20 x 20 meters square centered on the station (fig. 2).

The length of the profiles ranges from 4 to 20 km with a total length of 110 km (450 stations, 1800 measuring points).

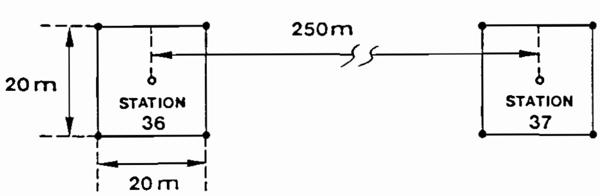


Fig. 2.- Four measures realized for each station

INTERPRETATION

The interpretation is based upon comparison with theoretical anomalies due to steps in a 600 to 1000 m deep rock. The anomaly may be computed using the horizontal semi infinite slab formula (BARANOV, 1975)

$$B(x,o) = 2.10^{10}\, K\, \sigma\, h\, (\quad + \text{atan} \quad)\, (10^{-5}\ \text{gal})$$

with:

B (x,o) : surface anomaly at horizontal distance x (m) to the step

K : gravitational constant ($6{,}7.10^{-11}\ m^3\ kg^{-1}\ S^{-2}$)

σ : density contrast ($T.m^{-3}$)

h : thickness of the slab (m)

Z : depth to the center of the slab (m).

The density contrast is known from borehole data: 2.5 (bed rock) - 1.8 (overburden) = 0.7 T/m^3 (= 700 kg/m^3).

Figure 4 shows some examples above 10 to 40 m high steps in the bed rock. Steps smaller than 10 m cannot be detected.

To reduce the effect of shallow heterogeneities a simple smoothing has been used, each value being replaced by the mean of 5 measures:

$$B(i) = \quad (B(i-2) + B(i-1) + B(i) + B(i+1) + B(i+2))$$

First and second order horizontal derivation with smoothing has also been used because the effect of very deep and distant density contrasts which are not relevant to this study will modify the overall slope of the anomalies, will shift the gradient (first derivative) by a nearly constant value but will not change the second derivative significantly.

Figure 3 shows the anomaly and the derivatives in the 40 m step case: the gradient is maximum or minimum above the step while the second derivative equals o.

It must be stressed that a single fault, closely spaced faults or steep slopes result in a nearly identical anomaly.

RESULTS

A. Area of Mol

On the isanomalic map (showing lines that connect points of equal Bouguer anomaly), appears a clear decrease of the gravity towards the North-East. This decrease is important near Rouw and it becomes rather slow to the West. In the western area, we notice that isanomalic contours show large inflections in the North and in the South (fig. 5).

For the purpose of this survey, the isanomalic map is not very useful. The maps showing the contours of iso first and second derivatives allow a better analysis (fig. 6 and 7).

1. In the East, (Stevensvennen) a main fault is detected, striking N-S to NNW-SSE. This fault clearly appears on the profiles «I» and «IV» (fig. 8 and 9):

   - negative anomaly of the gradient
   - zero of the second derivative at station 71 of profile «I» and at station 33 of profile «IV».

   Computation of a theoretical case with a density contrast of 0.7 T/m^3 shows that the anomaly may be explained by a fault shifting down the eastern block by about 40 meters on the profile «I» and about 80 meters on the profile «IV».

   This fault had been previously detected by several other methods:

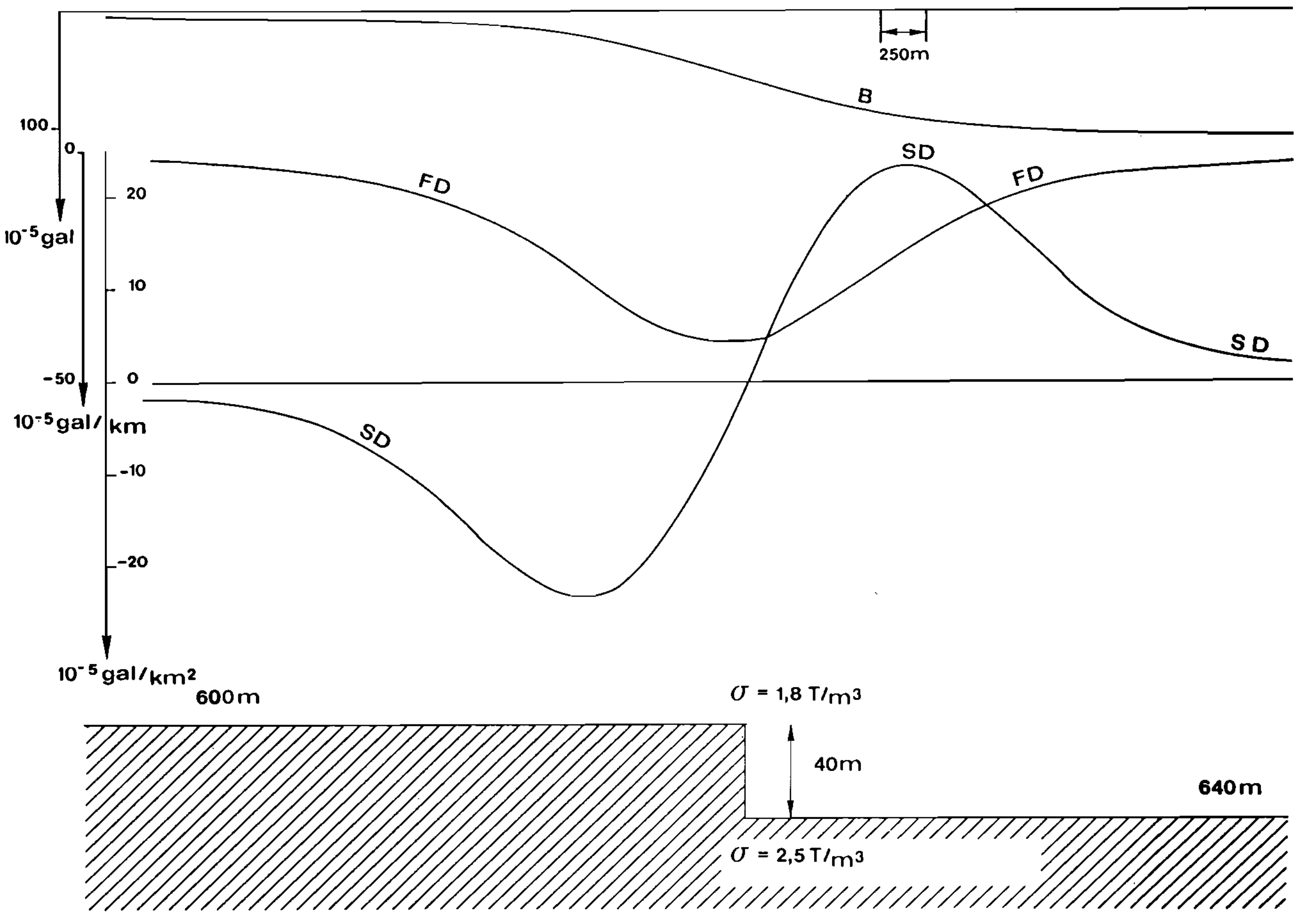
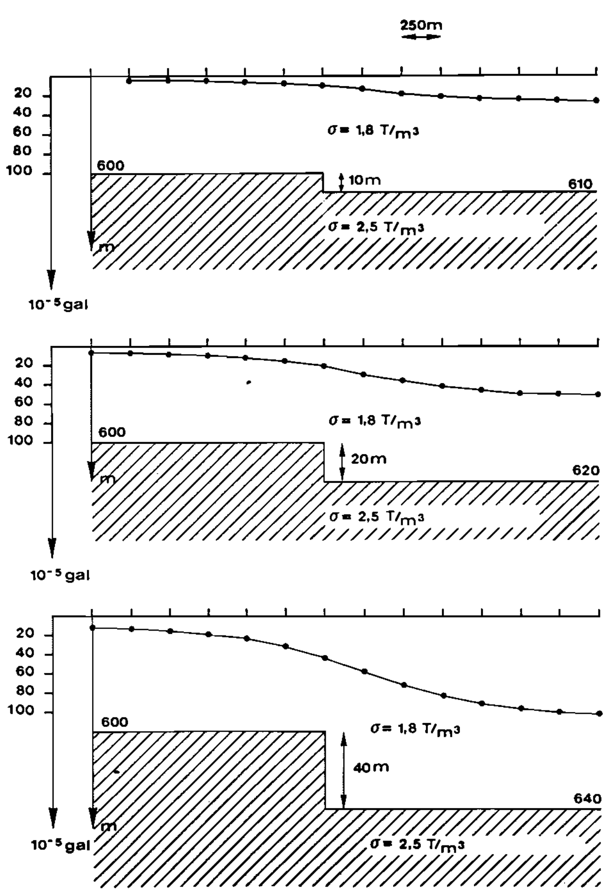


Fig. 3.- Bouguer anomaly (B), first (FD) and second (SD) horizontal derivative for a 40 m throw of the bed rock at a depth of 600 m.



- in open pit mining: interruption of a lignite bed because of a 25 meters throw
- detailed study of boreholes
- seismic campaigns of 1953 - 1956 and 1984.

2. Close to the «provinciaal domein» of Zilvermeer, two faults with less throw are noticed on the profiles «I», «IV» and «V» at Plaasbeemden and Harde Putten, striking NNW - SSE. They form a little «graben» under the «provinciaal domein». The limits of the «graben» are shown by minimum and maximum values of the gradient and a zero of the second derivatives: on profile «I» at stations 50 and 57, and on profile «IV» close to stations number 13 and 20. The computed depth of the depression is 20 m at the profile «IV» and 10 m at the profile «I». On profile «V», the second derivative curve, shows a shape very similar to that on profile «I» but the amplitude of the variations is much smaller.

Fig. 4.- Bouguer anomaly for a 10, 20 or 40 m throw of the bed rock at a depth of 600 m.

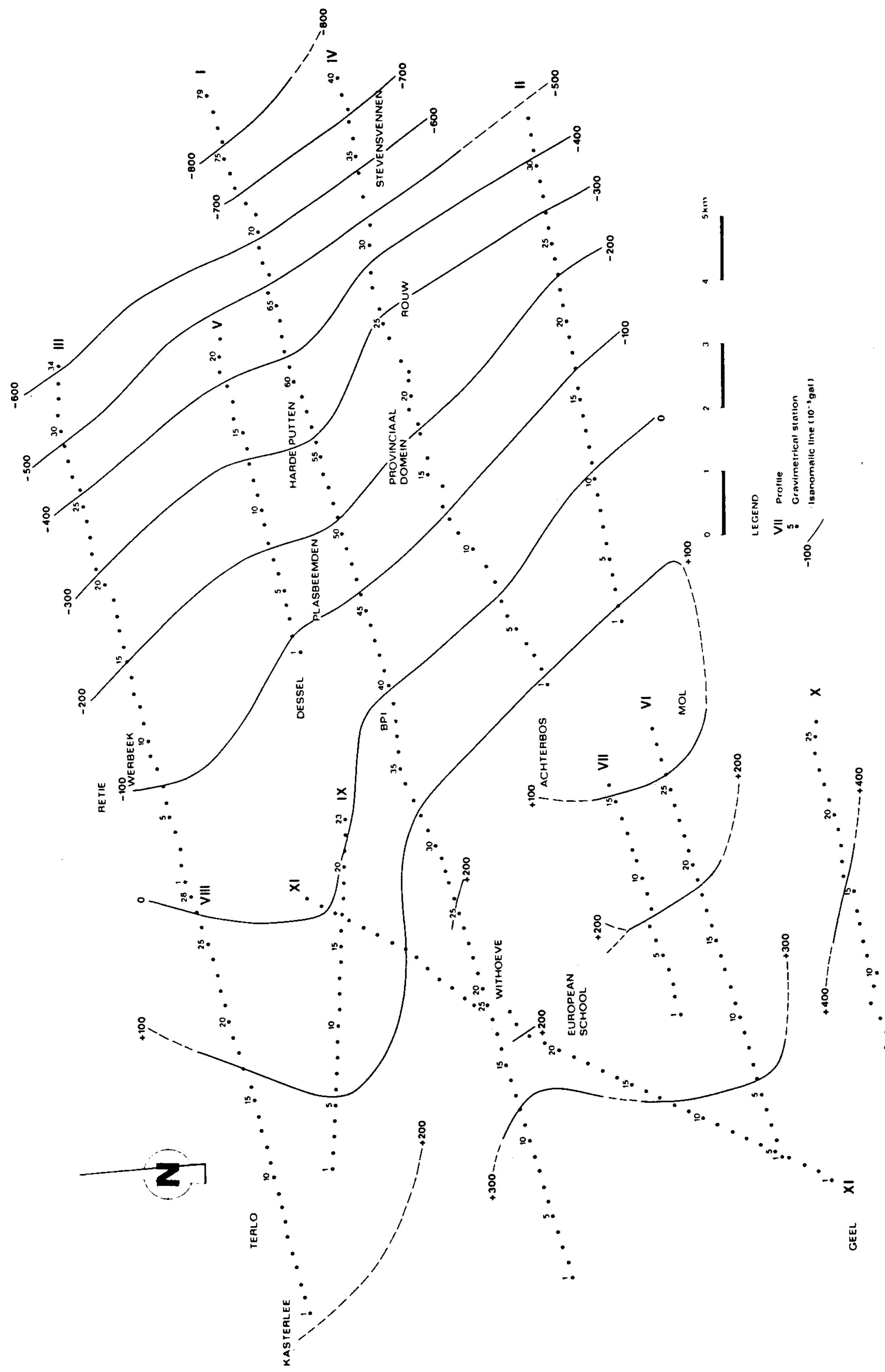


Fig. 5.- Isanomalic map in the area of Mol.

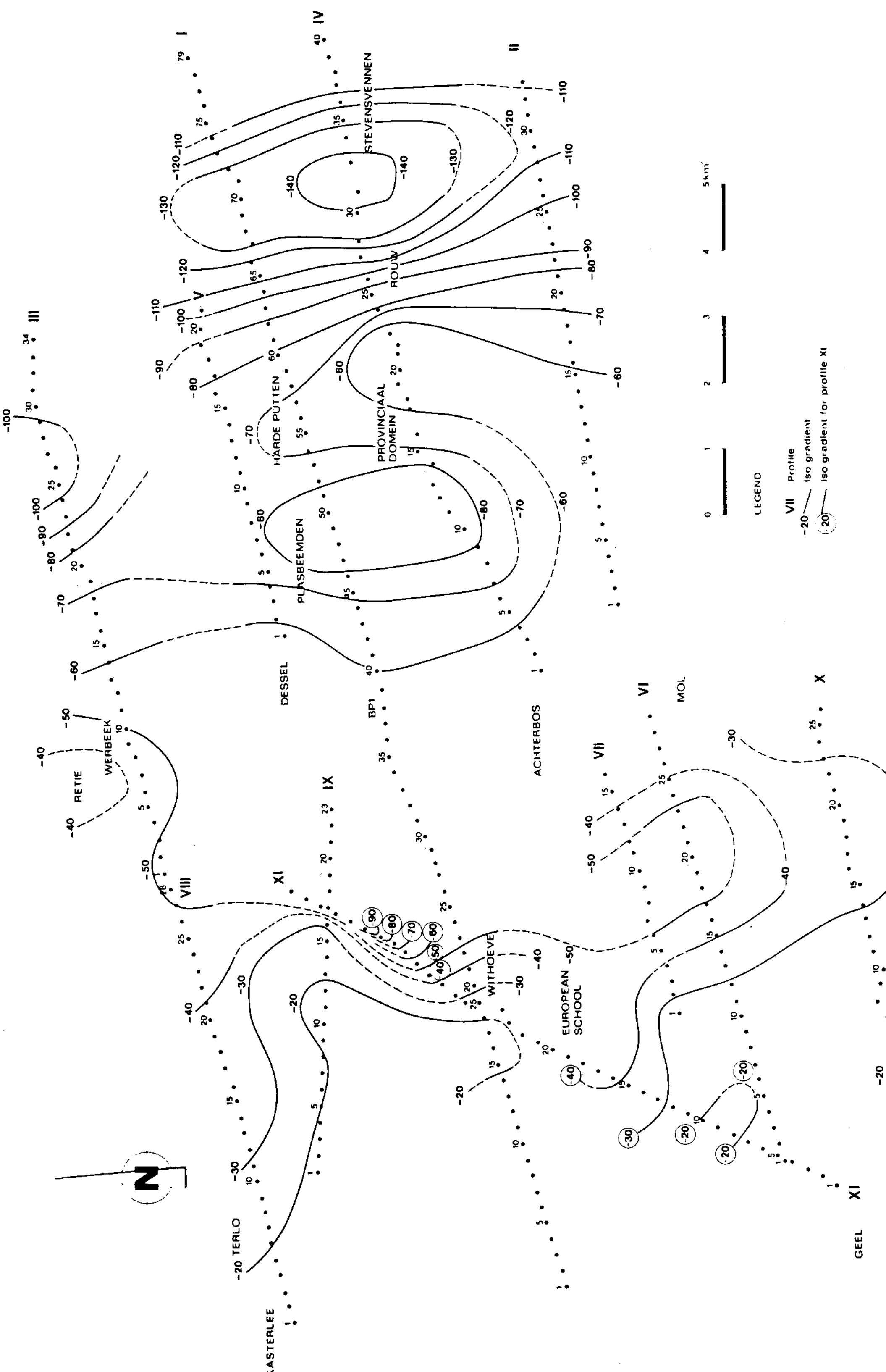


Fig. 6.- Iso gradient map in the area of Mol.

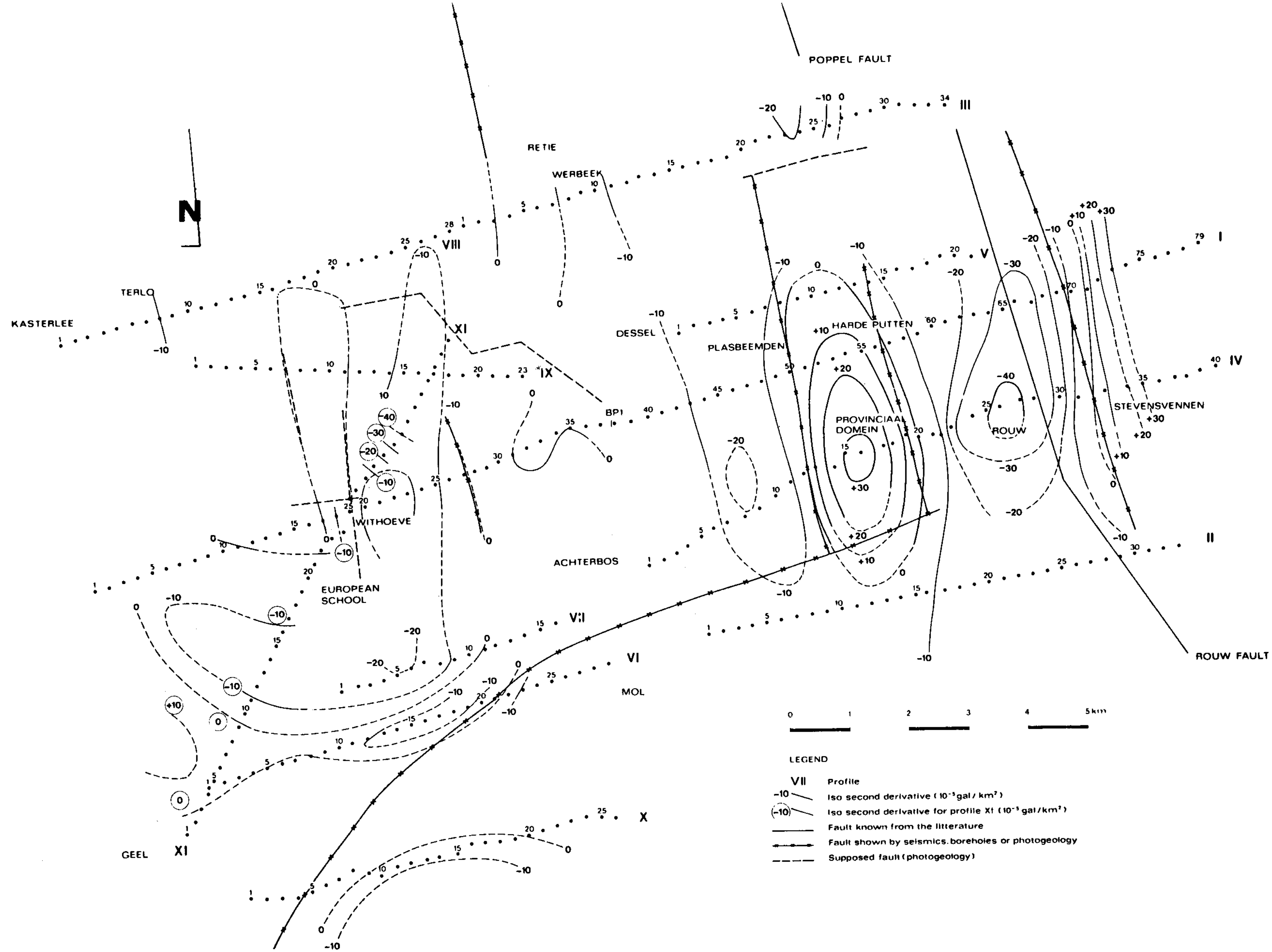


Fig. 7.- Iso second horizontal derivative map in the area of Mol, indicating the faults known from other investigations.

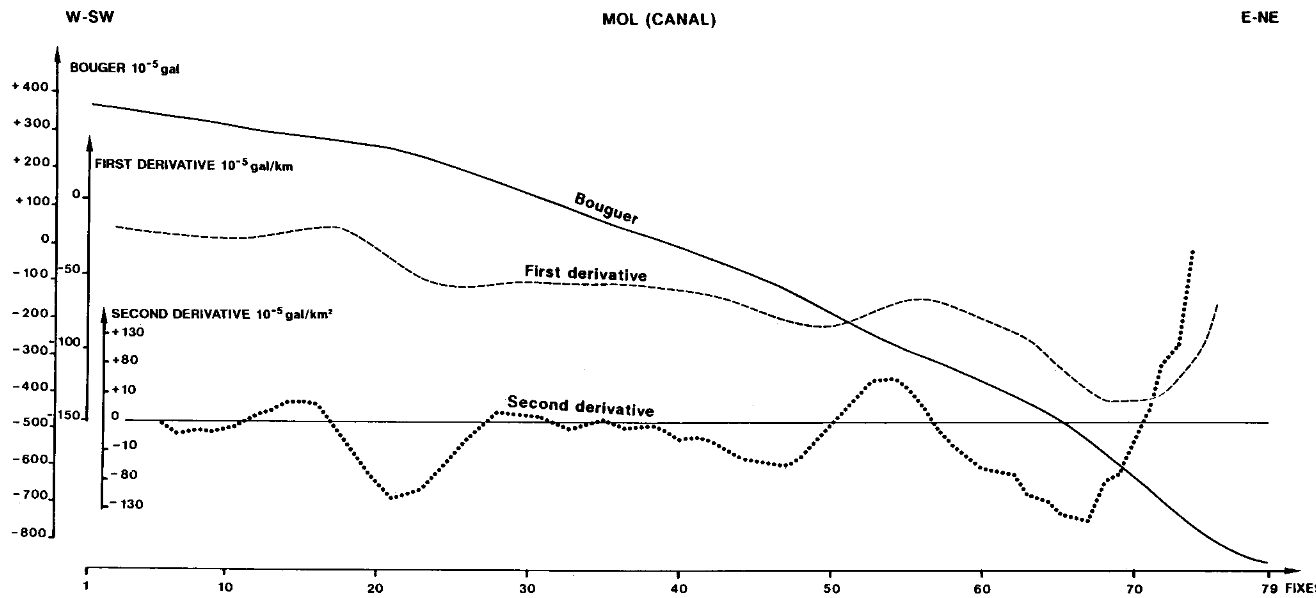


Fig. 8.- Profile I: smoothed Bouguer anomaly and smoothed first and second derivatives.

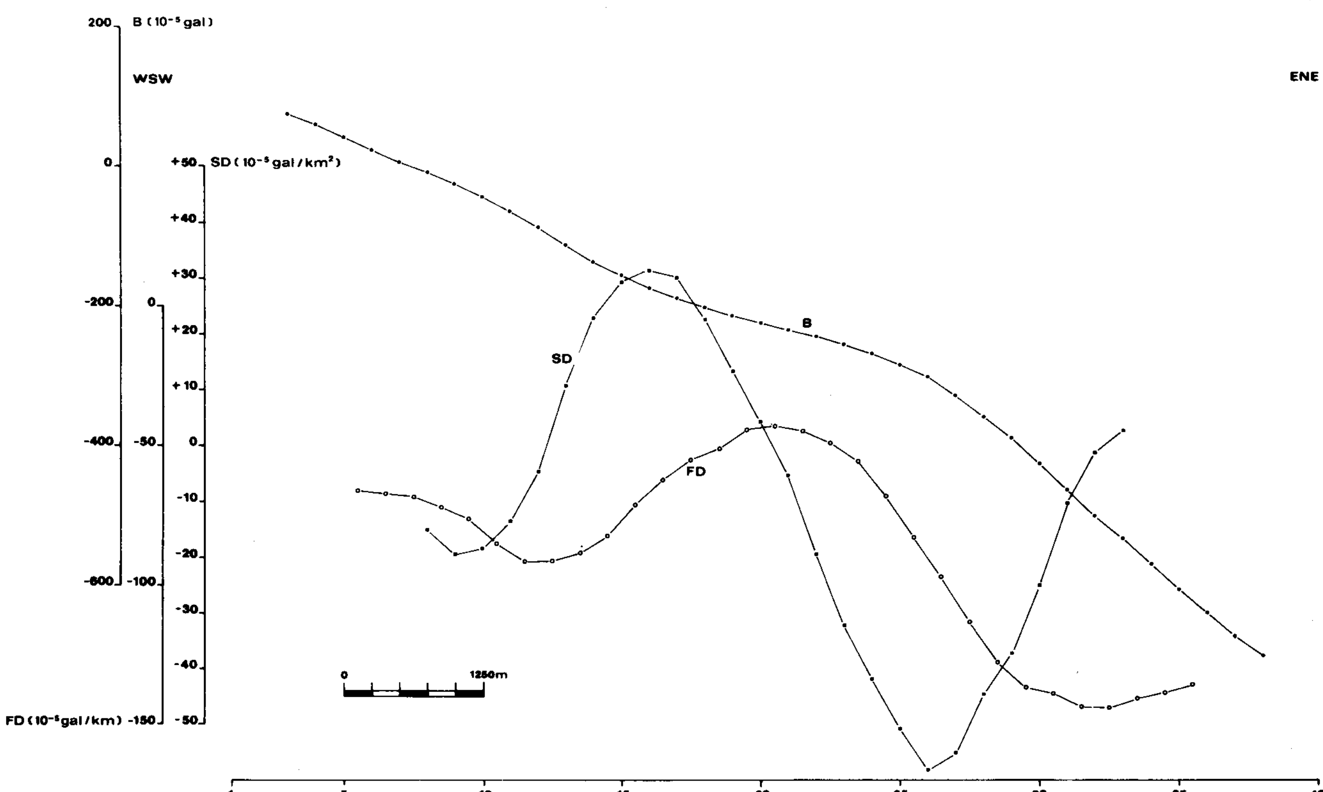


Fig. 9.- Profile IV: Bouguer anomaly (B), first (FD) and second (SD) horizontal derivative

So, the influence of the graben doesn't seem to extend very much beyond the three central profiles. On the profiles «II» and «III», the gradient does not show such variations. These two faults under the «provinciaal domein» are confirmed by following observations:

For the western fault:

- in sand-pits, the glauconiferous sand below the Mol sands are shifted 10 meters down on the eastern side;
- borehole studies show a Tertiary fault shifting down the eastern block;
- the seismic exploration of 1984 indicated a fault.

For the eastern fault:

- the boreholes show that the bed rock in the eastern block is higher than in the western block;
- the seismic explorations of 1953 - 1956 indicated a fault.

The western fault is related to the fault of Poppel through an E-W striking transversal fault.

3. In the area situated between Werbeek in the North, Achterbos in the South and the Retie-Withoeve road in the West, a nearly constant gradient and a nearly nul second derivative are observed (fig. 6 and 7). The gradient may be due to the continuous or steplike shifting down of the Paleozoic bed rock towards the North-East.
Small anomalies at the East of Withoeve and at the West of Retie are due to N-S striking faults already indicated by the seismic exploration of 1984.
4. In the area situated between Retie in the North, the European School in the South and Terlo in the West, the profile «XI» directed SSW - NNE shows that the iso gradient contours are closely spaced along the Geel-Retie road in the North. These values may indicate the presence of an imporatant depression of the northern block beyond the station number 39, that could be correlated with lineaments seen on aerial photographs. This anomaly could also be due to a continuous slope of the bed rock (5 percents) going down towards the NE. In the hypothesis of a fault, its evaluated throw would be more than 40 meters. The presence of transversal faults is common in this area. The horizontal derivatives along profile XI are of course different from those along the other profiles since the direction is not the same.
5. In the southern area, isanomalic coutours, first and second derivatives contours show an overall West - East direction which indicates that the northern compartment is shifted by successive faults. These observations are confirmed by a fault located during the seismic campaigns of 1953 - 1956.
6. Close to the Withoeve lock, North-South faults are located and confirmed by aerophotogeology, WE faults are not confirmed but are usual in the area.

B. Area of Turnhout

The same kind of interpretation is possible (fig. 10):

1. In the East a straight line connects the nul second derivatives at station 20 on profile «XII», at station 18 on profile «XIII» and at station 21 on profile «XIV». This straight line is due to a NNW - SSE striking fault passing through Oud-Turnhout and Oosthoven and shifting down the eastern block. The throw is estimated to 40 - 50 meters at the profiles «XII» and «XIII». It seems to decrease towards the North (about 20 m at the profile «XIV») and is not detected on profile «XV». A transversal fault between profile «XV» and profile «XIV» is assumed.

   These observations are in good agreement with the results of the seismic campaigns of 1953 - 1956 which had detected these two faults.
2. In the West, we notice a less important fault, indicated by the zero value of the second derivative at station 7 of profile «XII», at station 4 of profile «XIII» and at station number 8 of profile «XIV». It shifts down the western part of the bed rock.

CONCLUSION

Steep dipping or vertical faults creating a horst and graben structure of the top of the bed rock have been detected by gravimetrical exploration under an overburden of 600 to 1000 meters in the area of Mol and Turnhout (Belgium).

A very simple smoothing of the Bouguer anomaly, its first and second horizontal derivatives was sufficient for an accurate mapping of the investigated faults.
For a density contrast of 0.7 T/m^3 a minimum throw of 10 meters is necessary to allow detection.

The results are clearly confirmed by other methods: geology, photogeology, seismics and boreholes.

A more elaborate treatment of the data would probably allow the method to be used for the

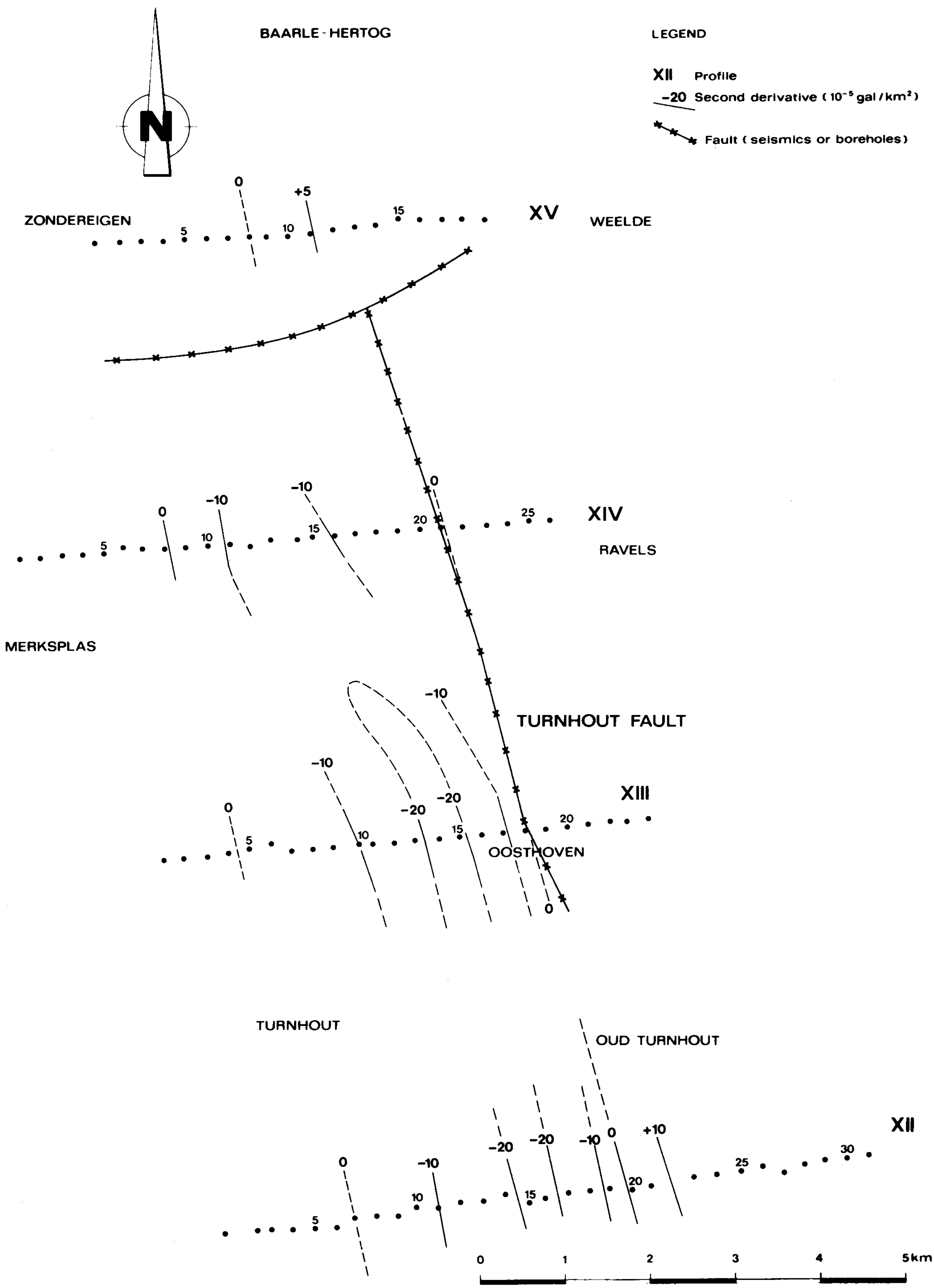


Fig. 10.- Iso second derivative map in the area of Turnhout also showing the faults located by boreholes and seismic explorations.

investigation of more complex structures under a thick overburden.

The method has proved itself very useful, and for similar structural investigations it should be considered as an interesting alternative to seismics, at a much lower cost.

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