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ANOMALOUS TOPOGRAPHY OF THE LOWER PALAEOZOIC BASEMENT IN THE BRUSSELS REGION, BELGIUM

Johan MATTHIJS[1], Timothy DEBACKER[2], Kris PIESSENS[3] & Manuel SINTUBIN[2]

(11 figures, 1 table)

1. Geological Service Company, Houwaartstraat 31, B-3210 Linden, Belgium, E-mail: gsc_mb@skynet.be.

2. Geodynamics & Geofluids Research Group, Katholieke Universiteit Leuven, Celestijnenlaan 200E, B-3001 Leuven, Belgium.

3. Royal Belgian Institute of Natural Sciences, Geological Survey of Belgium, Jennerstraat 13, B-1000 Brussels, Belgium.

ABSTRACT. A detailed reconstruction has been made of the topography of the top of the Lower Palaeozoic basement in the Brussels Region (Brabant Massif). The model of the palaeotopography reveals a series of SE-NW-elongated anomalous structures with differences in height, relative to the overall topography, up to 35 m. A clear correlation was found between the anomalies and the lithological composition of the Lower Palaeozoic substrate. Furthermore, a remarkable coincidence was observed between the palaeorelief and the aeromagnetic map, showing that the positive anomalous structures correspond to aeromagnetic lows and the negative anomalous structures to aeromagnetic highs. Lithological and aeromagnetic data seem closely interrelated with the palaeotopography and thus form an important contribution to the current palaeotopographical model. Conversely, the palaeotopographical model can be a major clue in unraveling the geological structure of the Lower Palaeozoic basement.

KEYWORDS. palaeotopography, Brabant Massif, lithology, aeromagnetism

1. Introduction

Since 1989 the Ministry of the Flemish Community runs a program to remap the geology of the Flemish Region. This is done in collaboration with the Geological Survey of Belgium, which has kept and maintained an inventory of geological observations since early 19^{th} century. Two types of maps were commissioned at scale 1/50,000, one depicting the Quaternary strata and another depicting the Pre-Quaternary strata.

In 2000 the mapsheet of the Brussels Region and its immediate surroundings was compiled (Buffel & Matthijs, 2002) (Fig. 1). This subsurface map (800 km^2) was based on approximately 9000 observation points with various kinds of geological information (lithological, structural, stratigraphical, palaeontological, …) obtained from boreholes, outcrops, geophysical logs, geotechnical logs and literature. A 3D-model was constructed for the base of each Tertiary formation and the same was done for the base of the Quaternary and the top of the Cretaceous. The intersection of the base of the Quaternary with the base of the different Tertiary units resulted in the subsurface map. With the exception of the Brussels and Diest formations, all Tertiary strata in the mapped area have a smooth, flat, gently north-dipping base related to the Southern North Sea Basin. However, during the construction of the 3D-models a great number of palaeotopographical anomalies was observed in the base of several Tertiary formations. These anomalies are mainly positive, i.e. the paleotopographical level of the base is locally higher than might be expected from neighbouring observation points. Although a small portion of the anomalies in the southeastern part of the map could be explained as the result of faulting, a likely cause for the majority of the anomalies was less evident at first.

However, looking deeper than the Tertiary deposits, it was observed that underneath the positive anomalies the Cretaceous sediments are strongly reduced or even absent. This phenomenon is very pronounced in the central part of the map, right below the centre of Brussels. Within the anomalous zones, the Tertiary strata are immediately overlying the Lower Palaeozoic substrate, whereas in between the anomalies they are resting on the Cretaceous deposits. It thus seems that the anomalous behaviour of the base of the Tertiary formations is the result of local topographical variations in the top of the Lower Palaeozoic basement.

Figure 1. Location of the mapped area.

2. Methodology

2.1. Data

An attempt was made to reconstruct the topography of the top of the Lower Palaeozoic basement. This reconstruction is based on 650 observation points of Lower Palaeozoic rocks, 585 of which are situated within and 65 immediately outside the mapped area. These data points are not evenly distributed throughout the mapped area. There is a marked concentration of observations in a NNE-SSW-trending zone, from Vilvoorde (NNE) over Brussels to Halle (SSW), that is approximately

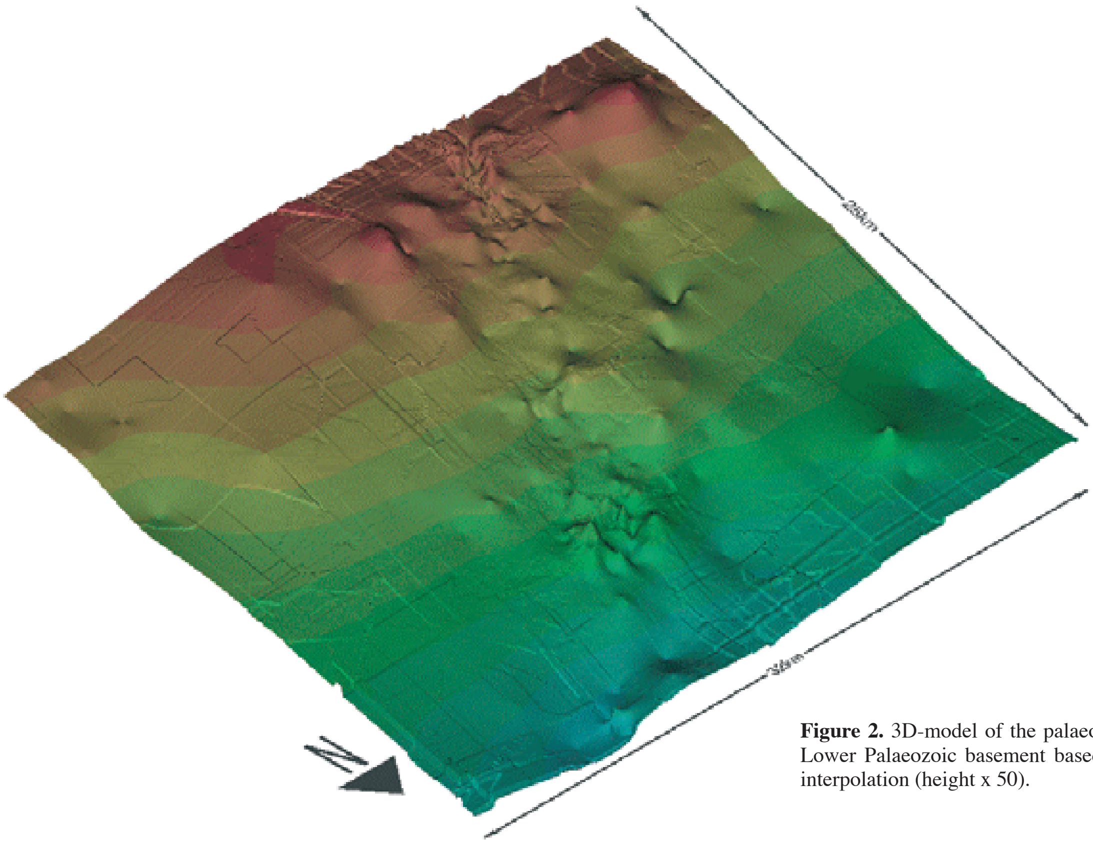

Figure 2. 3D-model of the palaeorelief of the top of the Lower Palaeozoic basement based on a fully automated interpolation (height x 50).

3.5km wide and largely coincides with the Senne valley. The remainder of the map is characterised by a relatively low data density, especially in the northwestern and the southeastern corner. This uneven spread of data points will lead to significant bias in any fully automated interpolation procedure.

For each data point the elevation, with respect to the mean sea level, of the top of the basement was determined from the altitude of the ground level (m TAW) and the depth (m) at which the Lower Palaeozoic rocks were encountered in drill holes and outcrops. As the topographical position of the observation is crucial in this process, great care was taken to determine the coordinates (X, Y and Z) as accurately as possible, using old and new topographical maps, literature, street names, etc… For further processing of the data, it is necessary to distinguish between observations with seemingly normal palaeotopographical heights and observations with seemingly anomalous palaeotopographical heights. This was done by assuming that the top of the Lower Palaeozoic basement is an overall gently north-dipping surface (Legrand, 1968; De Vos *et al*., 1992a). A manual screening of the data showed that about half of the observations could be considered normal with respect to the absolute height of this surface, while the remaining points yielded significantly higher or lower values, i.e. the difference in height is at least 5 m. This results in an anomalous to normal ratio of 1. However, when there are no observations in the immediate vicinity, it is hard to distinguish between normal and anomalous data points and one tends to classify these observations as normal rather than as anomalous. A more scientific approach to make a distinction between normal and anomalous data points is by creating a surface through all observation points using a polynomial regression and then looking at the difference between the calculated height and the observed height. Nevertheless, in areas with few observations each point will have a significant influence on the position of the created surface and as a result there will be little or no difference between the calculated and the observed height for these data points. This will also affect the result of the reconstruction.

Both problems, the unequal distribution of data points and the distinction between normal and anomalous observations, could partially be resolved. Firstly, there are about 250 observations from drillings and outcrops that do not reach the Lower Paleozoic basement, but that come sufficiently close to attribute a meaningful depth to the top of the Lower Paleozoic basement. Two types of observations may be distinguished: 1) Observations that reach the basal gravel of the Quaternary (southern part of the map), the Tertiary (centre of the map) or the Cretaceous (northern part of the map) deposits. From a lithostratigraphical point of view the base of these observations is very near to the Lower Palaeozoic substrate. 2) Observations that reach a palaeotopographical level similar to or deeper than that of the top of the basement in neighbouring data points, but remain within the overlying strata. Both types of observations are helpful in reconstructing the palaeorelief, as they provide a minimum depth at which the Lower Palaeozoic rocks may occur. Furthermore, they can be a guide in making a better distinction between normal and anomalous data points. Secondly, the presence or absence of anomalies in the top of the Cretaceous and in the base of the Tertiary strata is considered. The topography of the base of these deposits reflects the palaeorelief of the top of the underlying Lower Palaeozoic substrate. As the 3D-models of the top of the Cretaceous and base of the Tertiary sediments are based on more data points than there are available for the Lower Palaeozoic deposits, it is possible to better classify normal and anomalous observations and to enhance the model of the palaeotopography of the top of the basement.

2.2. Interpolation

In a first attempt to reconstruct the palaeorelief a fully automated interpolation was used. As a result, Figs 2 & 3 show a rather chaotic surface with irregularly spaced bumps and holes, clearly indicating the existence of a large amount of anomalous observations. The top of the Lower Palaeozoic basement seems to be a gently north-dipping surface with

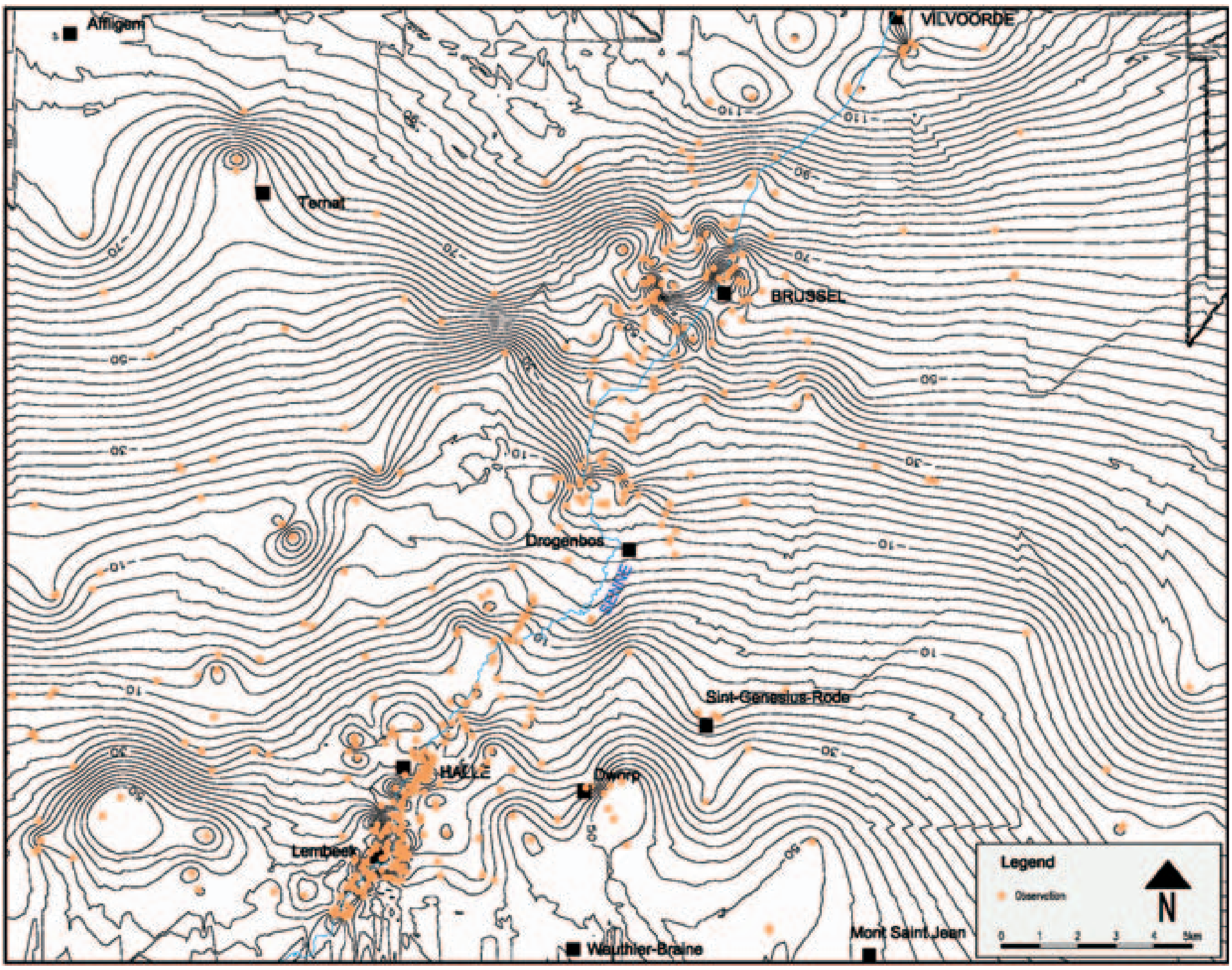

Figure 3. Reconstruction of the subcrop-topography of the top of the Lower Palaeozoic basement using an automatic interpolation method.

"circular" anomalies superposed upon. The anomalous behaviour of the top of the Lower Palaeozoic basement appears to have a different nature in the southeastern part of the map, as the surface there is dipping to the NE rather than to the North.

In a second attempt the reconstruction was done semi-automatically, using two interpolation methods: 1) A radial basis multiquadric function and 2) Kriging with a linear variogram. Both methods resulted in nearly identical surfaces. In a first step, the overall trend of the topography of the top of the Lower Palaeozoic basement was constructed using an automatic interpolation of the normal observation points only. In a second step, the anomalous data points were added to this surface. Fig. 4 shows the subcrop-area right below the centre of Brussels. The green dots are normal observation points, whereas the blue (negative) and red (positive) dots are the anomalous ones. It is clear that the interpolation between anomalous data points should not cross normal data points. So an automatic interpolation was done using a search ellipse and an anisotropy factor, both obtained from the distribution of the anomalous data points within the mapped area, by means of a trial and error procedure. Within certain limits, dictated by the observations, it is possible to draw different search ellipses with ratios varying from 0.06 to 0.19 and orientations varying from N30W to N45W, incorporating as much anomalous data points as possible and leaving out all or nearly all normal observations. The best results for the entire map, however, are obtained by using a search ellipse with a ratio of 0.13 and a preferred orientation of N38W and an anisotropy factor with the same ratio and orientation. In a third step the observation points that nearly reached the Lower Palaeozoic substrate were introduced, using the depth of drilling or the height of the outcrop as minimum depth. Again an automatic interpolation was done, but this time without defining a search ellipse or an anisotropy factor. In a fourth step, the newly created surface was manually corrected according to the presence or absence of anomalies observed in the overlying Cretaceous and Tertiary strata. This finally resulted

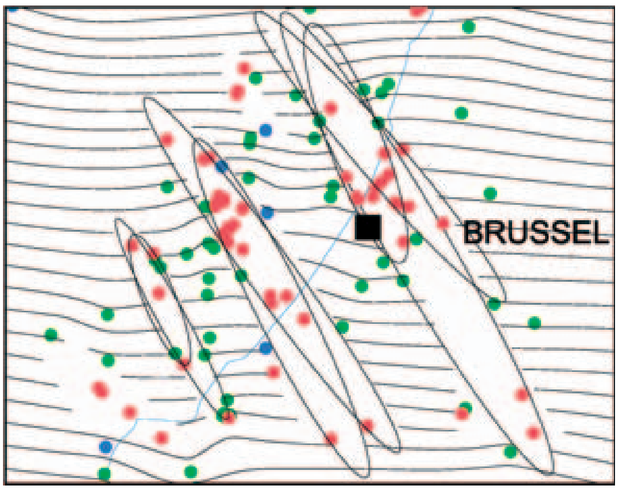

Figure 4. Determination of the search ellips and the anisotropy factor.

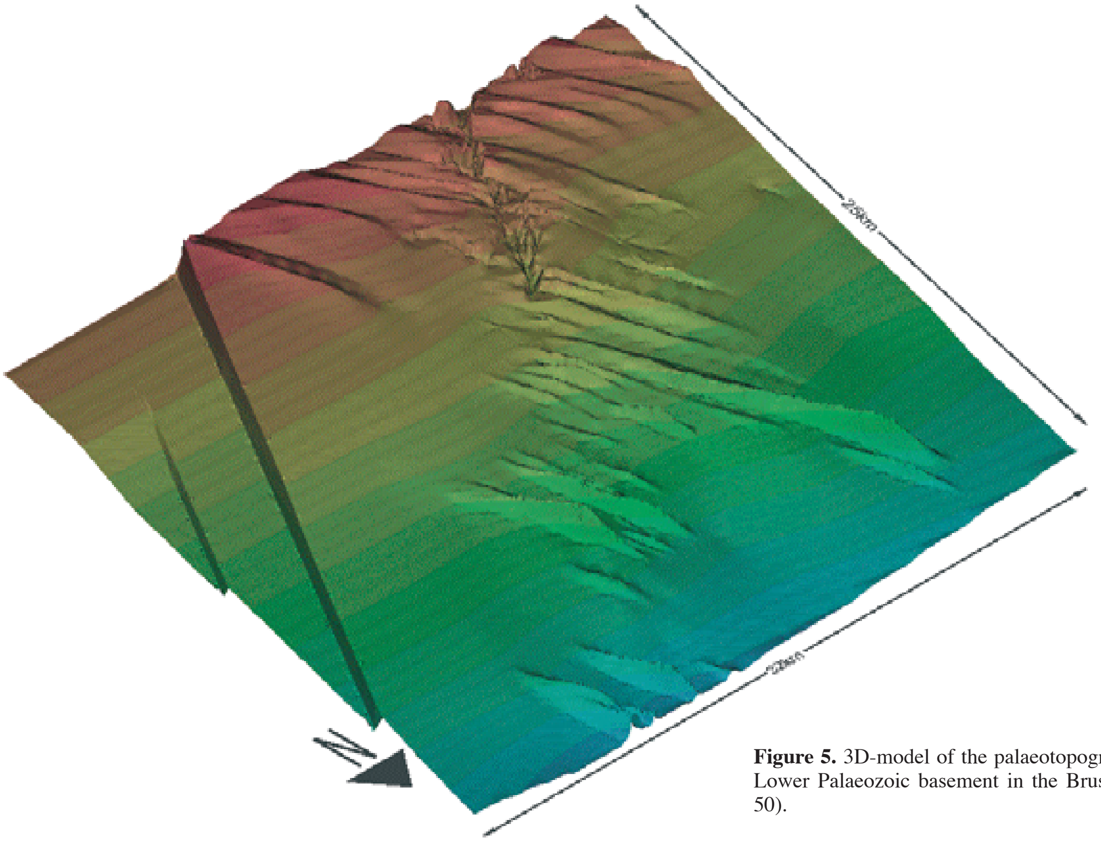

Figure 5. 3D-model of the palaeotopography of the top of the Lower Palaeozoic basement in the Brussels Region (height x 50).

in a 3D-model of the palaeotopgraphy of the top of the Lower Palaeozoic basement (Fig. 5).

3. Description

The reconstruction reveals an accidented landscape (Fig. 6). The overall trend of the subcrop-topography is a smooth north-dipping surface (0.8%) from near-outcrop (+60 m) in the South to depths of more than –200 m in the North, which complies with the overall trend of the entire top of the Lower Palaeozoic basement as shown by Legrand (1968) and De Vos *et al.* (1992a). The more detailed analysis, however, indicates the presence of significant anomalies in a NNE-SSW-trending zone, from Vilvoorde (NNE) over Brussels to Halle (SSW), largely coinciding with the Senne valley. In this area the subcrop-topography consists of a chain of SE-NW trending ridges and depressions that gradually become more pronounced to the NW, respectively to the SE, with regard to the overall relief. The ridges and depressions have a width that ranges from 0.5 to 1 km and a spacing of 1 to 1.5 km. They have a longitudinal extension up to 15 km and reach a maximum relative height or depth of 35 m.

The ridge-dominated topography is particularly apparent in the Brussels-Vilvoorde area. Right below the centre of Brussels two large and three small ridges occur. The larger ones have a length of 7.5 km, a width of 0.75 km and a maximum relative height of 25 m. They start off in the SE at the same topographical level as that defined by the overall trend of the top of Lower Palaeozoic substrate. Whereas the basement as a whole keeps dipping gently to the North, the absolute height of the ridges remains more constant as their relative height increases northwards. Contrary to their southeastern parts, to the NW the ridges seem to end rather abruptly and the basement becomes flat again. A similar configuration is present South of Vilvoorde. Here the ridges extend beyond the borders of the map, as shown by the data of the adjacent area in the North (observations 073W0218, 073W0227, 073W0248, 073W0249, 073W0266,… on the mapsheet of Mechelen).

A very large ridge is situated below the commune of Ternat. This ridge has a length of 15 km and a maximum relative height of 35 m. Together with the ridges below Brussels it determines partly the southern limit of the continuous subcrop of the Cretaceous deposits in the mapped area (Fig. 10). The ridge of Ternat can be tentatively linked to the ridge of Drogenbos, where it blends into the overall trend of the palaeorelief to the SE. It may even be linked to the ridge of Mont Saint Jean, making it twice as long, as it reappears South of Sint-Genesius-Rode.

To the SW of this ridge, in the Halle-Lembeek area, fewer and less pronounced ridges are found. Their height relative to the surrounding basement does not exceed 15 m. The subcrop-topography in this area is characterised by the presence of pronounced depressions with relative depths up to 30 m. The deepest depressions recorded are situated near Halle and have a length of approximately 8 km. Contrary to the ridges in the Brussels-Vilvoorde area, the depressions start off rather abruptly in the SE and tend to lose (relative) depth gradually to the NW, where they end at the same topographic level as the rest of the basement. Due to the effect of additional Quaternary erosion, the topography of the Lower Palaeozoic basement becomes more complex in the Halle-Lembeek area and the pre-Quaternary and Quaternary topography of the basement are easily confounded.

Away from the NNE-SSW-trending chain of anomalies the palaeorelief seems to become smooth. Apart from two fault zones in the southeastern part of the mapped area, the topography of the top of the Lower Palaeozoic basement remains flat. Enhancement of the 3D-model of the subcrop-topography of the Lower Palaeozoic substrate using Tertiary data was not possible for the eastern part of the map, as it is entirely covered by the Brussels Sands, a formation with a highly irregular base itself. On the basis of the present knowledge it is not possible to determine whether the top of the Lower Palaeozoic basement really is less accidented in both the NW and the SE or if this is due to insufficient

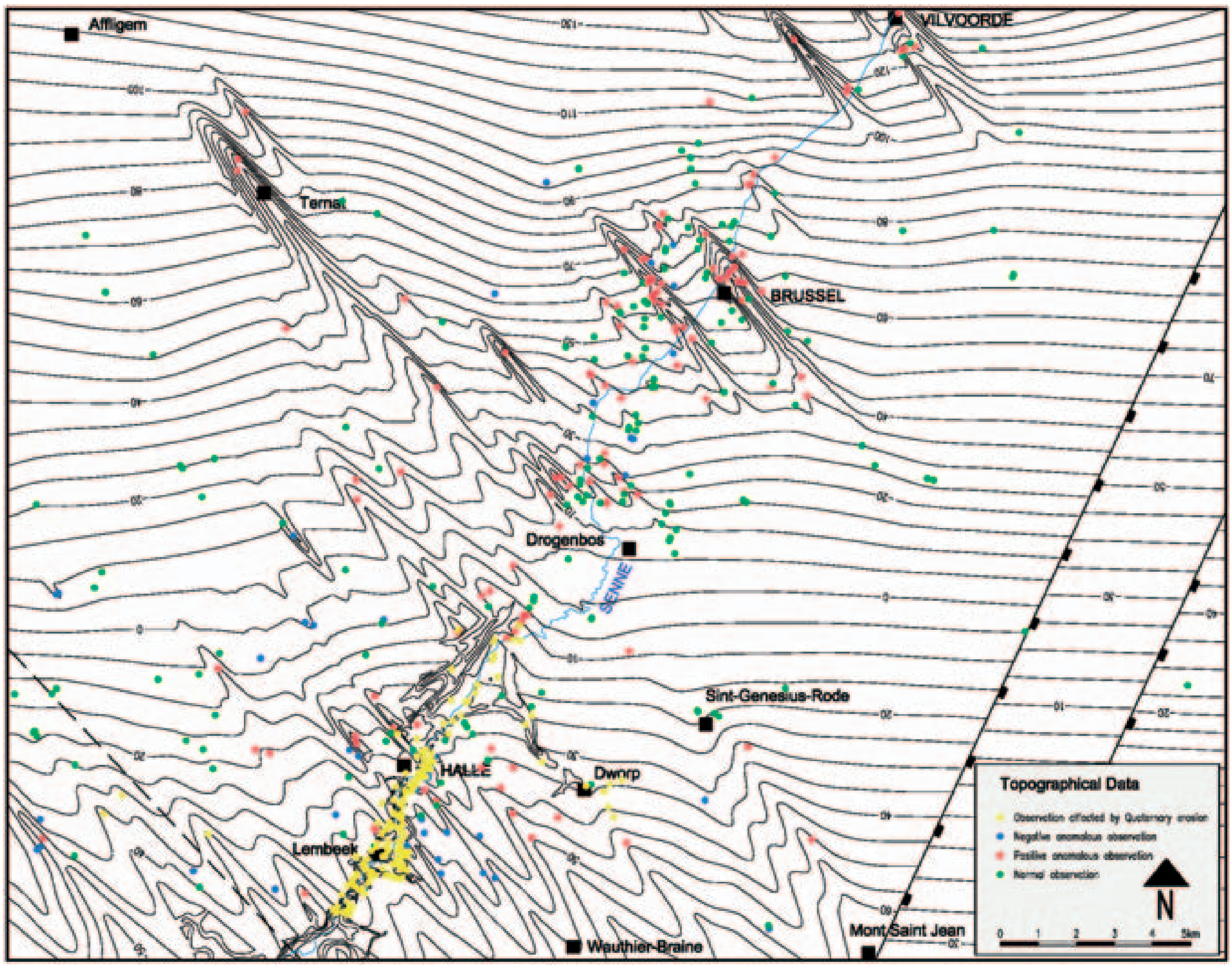

Figure 6. Subcrop-topography of the top of the Lower Palaeozoic basement in the Brussels Region.

observations and the impossibility to distinguish between normal and anomalous data points.

4. Lithology

In the mapped area a relation exists between the palaeotopography and the lithology of the Lower Palaeozoic substrate. Such a relation was already observed during the early 20th century as demonstrated in a drawing of a temporary outcrop at Rodenem, South of Halle, by Leriche (1927). The outcrop shows the top of the Lower Palaeozoic basement covered by Cenozoic deposits. The Lower Palaeozoic rocks consist of quartzites and shales, the latter being profoundly altered to clay. The top of the basement forms a palaeorelief with approximately 8 m difference in height. The highest point of the palaeotopography is dominated by quartzites, whereas the lowest point is completely made up of weathered shales (Fig. 7).

The steeply dipping Lower Palaeozoic deposits that occur in subcrop in the mapped area belong to the Blanmont, Tubize and Oisquercq formation (Legrand, 1968; De Vos *et al*. 1993) (Figs 8 & 9). The Blanmont Formation is rather homogeneous and consists mainly of pale-coloured quartzites, though intercalations of shaly parts may occur. From a stratigraphical point of view it is covered by the Tubize Formation, composed of mostly green-coloured high-density turbidite sequences. Hence, the latter is lithologically more heterogeneous than the Blanmont Formation ad contains sediments ranging from shales and claystones over siltstones and greywackes to arkoses and coarse-grained sandstones, with a predominance of fine-grained deposits (Verniers *et al*., 2001). The Oisquercq Formation covers the Tubize Formation and consists of purplish, greenish and gray claystones and siltstones.

Looking at the map of Legrand (1968) and emanations from his unpublished work (Piessens *et al*., 2004) it becomes obvious that he did not know how to connect the different occurrences of the Blanmont Formation. In the Western part of his map a SE-NW-trending elongated structure, assigned to the Blanmont Formation, is present that seems to be in accordance with the preferential orientation of the palaeotopography. Underneath the centre of Brussels, however, Legrand uses Rutot's concept (Rutot & Van Den Broeck, 1883, 1889a, 1889b) of a SW-NE-trending

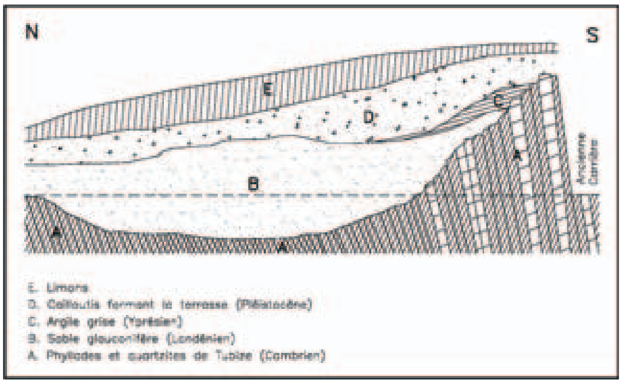

Figure 7. Outcrop section at Rodenem according to Leriche (1927).

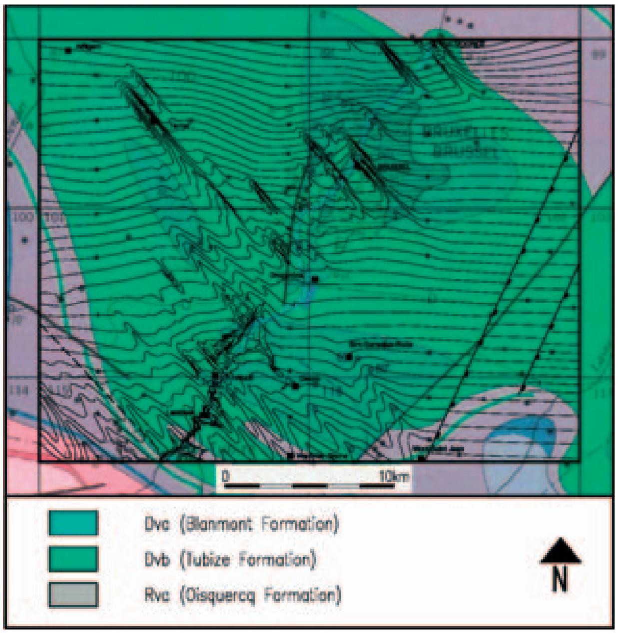

Figure 8. The geological map of the Lower Palaeozoic subcrop according to Legrand (1968) with an overlay of the palaeotopography as presented in this paper.

palaeovalley and palaeocrest to delineate the subcrop of the Blanmont Formation, thus transecting the palaeotopographical trend. The same can be said of the occurrence of the Blanmont Formation in an E-W-oriented structure in the South. In the centre of the map a N-S-fault is needed to explain the sudden variations in depth at which the Lower Palaeozoic basement occurs. The map of De Vos *et al.* (1993) on the other hand, shows a structural direction that is compatible with the palaeotopographical trend (SE-NW), but does not make the distinction between the Blanmont and Tubize formations. Contrary to Legrand's original map (Piessens *et al.*, 2004), but in accordance with Legrand's published map (1968), it shows the Oisquercq Formation occurring in subcrop in the South.

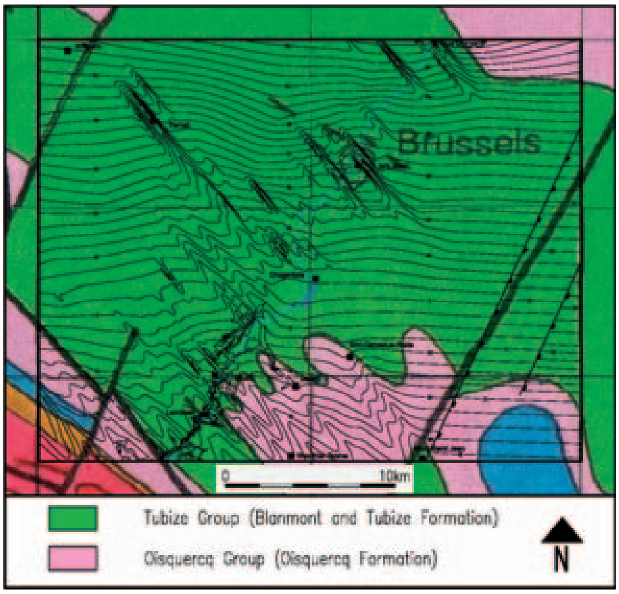

Figure 9. The geological map of the Lower Palaeozoic subcrop according to De Vos *et al.* (1993) with an overlay of the palaeotopography as presented in this paper.

The distribution of the different Lower Palaeozoic lithologies is represented in Fig. 10. Each symbol is divided into an upper and a lower half, indicating the first (upper) and the second (lower) lithology that was encountered in every observation point. From the picture it appears that sandstones and mudstones are most abundant in the Halle-Lembeek area. Quartzites and shales on the contrary, are most abundant in the Brussels-Vilvoorde area. Whereas sandstones, mudstones and shales occur throughout the mapped area, quartzites seem to be present only in the northeastern half of the map. With the exception of the outcrops at Rodenem and Berendries, the southwestern boundary of the occurrence of quartzites coincides approximately with the line Affligem - Wauthier-Braine.

In the Brussels-Vilvoorde area it is observed that the relative abundance of quartzites is greater within the ridges than in between the ridges and the opposite can be said about shales and mudstones. Samples that can unequivocally be assigned to the Blanmont Formation are situated at palaeotopographical ridges. The different lithologies in between the ridges belong to the Tubize Formation. The quartzites of the Blanmont Formation have proved more resistant to erosion than the heterogeneous deposits of the Tubize Formation. In the Halle-Lembeek area on the other hand, it is observed that shales and mudstones are more abundant within the depressions, whereas sandstones are more abundant within the ridges and in between the depressions. The distribution of ridges and depressions in this area can be related to lithological differences within the Tubize Formation itself. The fine-grained shales and mudstones seem to be more subject to erosion than the coarse-grained sandstones. This phenomenon of differential erosion is even present on top of the ridges below Brussels. Here small depressions exist filled with Cretaceous sediments. The Lower Palaeozoic substrate underneath these Cretaceous sediments consists of shales and mudstones, whereas aside of these pockets, underneath the Cenozoic deposits, it is composed of quartzites and sandstones (observations 088W0003, 088W0103, 088W0752, 088W0947,...).

Table 1 gives a numeric overview of the relation between lithology and topography. The lithology was taken from the outcrop and drilling descriptions of the Belgian Geological Survey. Only minor modifications were made: Hard Rock = *(zeer) harde rots, roche (très) dure*; Quartzite = *kwartsiet, quartzite*; Sandstone = *zandsteen, arkose, grès*; Mudstone = *siltsteen, schiefer, shiste*; Shale = *schalie, leisteen, phyllade*; Soft Rock = *zachte rots, malse rots, roche tendre*. Descriptions such as rock, *rots, roche, primaire, sokkel,…* are not incorporated in the table as they give no information on the lithology. They are marked as unspecified lithology in Fig. 10. The table shows that 35% of all the observations are positive anomalies, 53% are normal observations and only 12% are negative anomalies. Approximately 44% of hard rock, quartzites and sandstones are positive anomalies, 42% are normal observations and 14% are negative anomalies. About 31% of mudstones and shales are positive anomalies, approximately 52% are normal

	Hard Rock	Quartzites	Sandstones	Mudstones	Shales	Soft Rock	Total
+ Anomaly	47%	40%	44%	28%	34%	49%	35%
Normal	33%	48%	46%	54%	50%	38%	53%
- Anomaly	20%	12%	10%	18%	16%	13%	12%

Table 1. Numeric overview of the relation between the lithology and the palaeotopography.

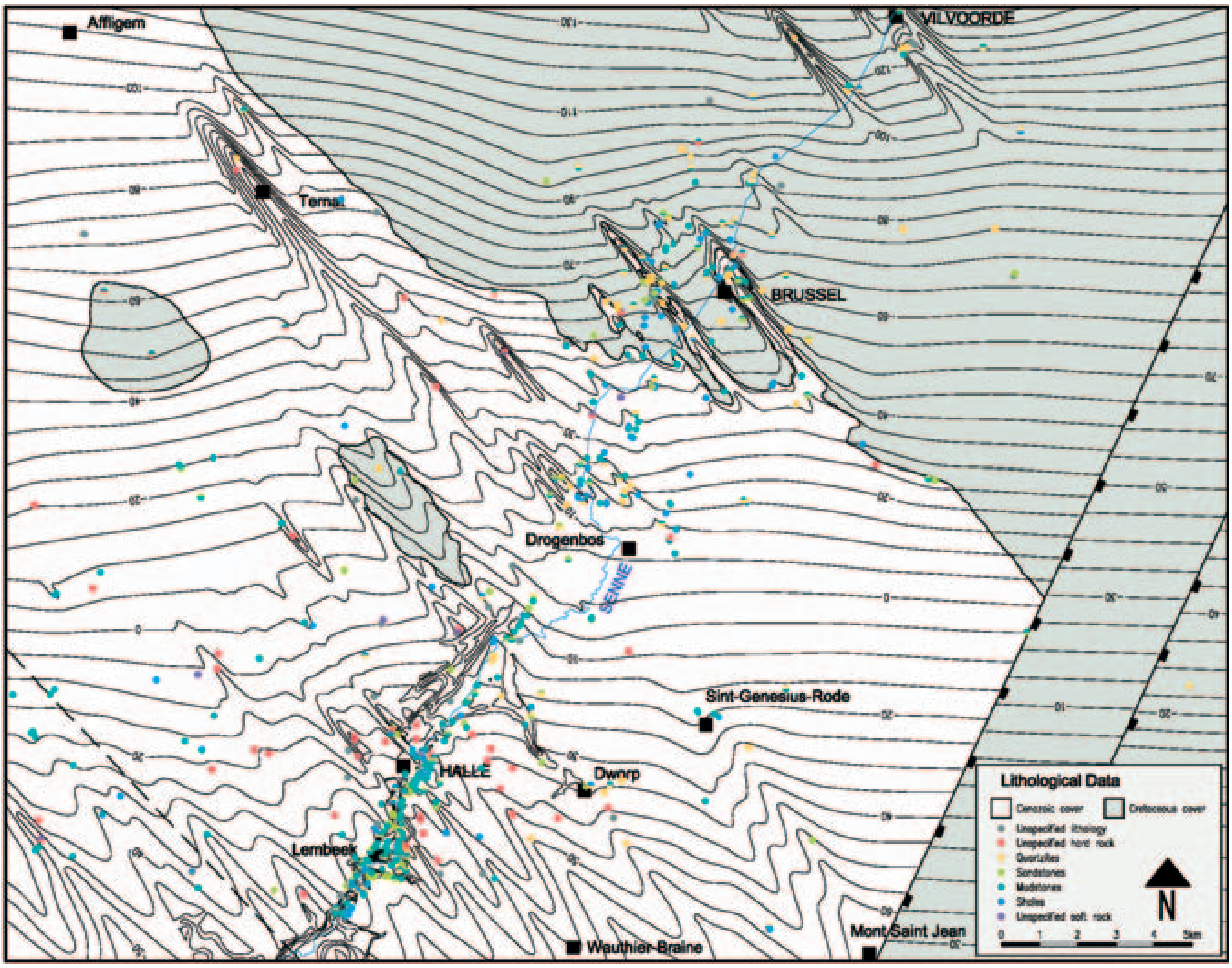

Figure 10. Distribution of the different Lower Palaeozoic lithologies in relation to the palaeotopography.

observations and 17% are negative anomalies. As the positive and negative anomalies and the normal observations are not equally represented (total), it is not the absolute percentage of lithology that is important, but the difference in percentage. This difference in percentage between hard rock, quartzites and sandstones on the one hand, and mudstones and shales on the other hand, is in agreement with the differential erosion hypotheses. Only soft rock does not fit the picture. This is due to the low number of records of this type of lithological description (8 out of 650), because of which this category should be disregarded.

5. Aeromagnetic map

A remarkable coincidence exists between the topography of the top of the Lower Palaeozoic basement and the aeromagnetic map (Fig. 11). As there are no aeromagnetic data available for the larger part of the Brussels-Vilvoorde area, the aeromagnetic map presented here is the result of an automatic interpolation using a search ellipse with a ratio of 0.50 (16000 m/32000 m) and a preferred orientation of N38W and an anisotropy factor with the same ratio and orientation. The width and the length of the search ellipse are dictated by the dimensions of the area without data. The orientation was the result of a trial and error procedure between orientations varying from N35W to N40W based on the original aeromagnetic data. The preferred orientation of N38W resulted in the most continuous structures, i.e. not an alignment of circular structures as seen on the original aeromagnetic map (Belgian Geological Survey, 1994). For the largest part of the map the aeromagnetic data are very detailed, with flight lines being 0.5 or 1 km apart. For the Brussels-Vilvoorde area (hatched area in Fig. 11) the map only shows the most likely extent of the larger aeromagnetic highs and lows.

In the area studied, the aeromagnetic map shows two SE-NW-trending zones of 15 to 20 km width. The Brussels-Vilvoorde area, characterised by its pronounced palaeotopographical ridges, is thought to be situated in a zone with an overall aeromagnetic low, whereas the Halle-Lembeek area, characterised by its pronounced palaeotopographical depressions, is situated in a zone with an overall aeromagnetic high. Within both zones, smaller SE-NW-trending aeromagnetic features can be observed or inferred (hatched area). The aeromagnetic lows coincide with the ridges, whereas the aeromagnetic highs coincide with the depressions and the areas in between the ridges. This apparent relationship between the aeromagnetic and palaeotopographical data is in agreement with the correlation between lithology and palaeotopography. The Tubize Formation regularly contains magnetite, whereas this mineral is extremely rare in the Blanmont Formation, resulting in clearly different magnetic susceptibilities for both formations (De Vos *et al.*, 1992b). In the Halle-Lembeek area, Piessens *et al.* (2004) demonstrated that the aeromagnetic highs correspond to the Tubize Formation (outcropping along the Senne valley), whereas the aeromagnetic lows correspond to the Blanmont Formation (East of the Senne valley near Dworp). Based on drillings and core material similar conclusions as in the Halle-Lembeek area can be drawn for

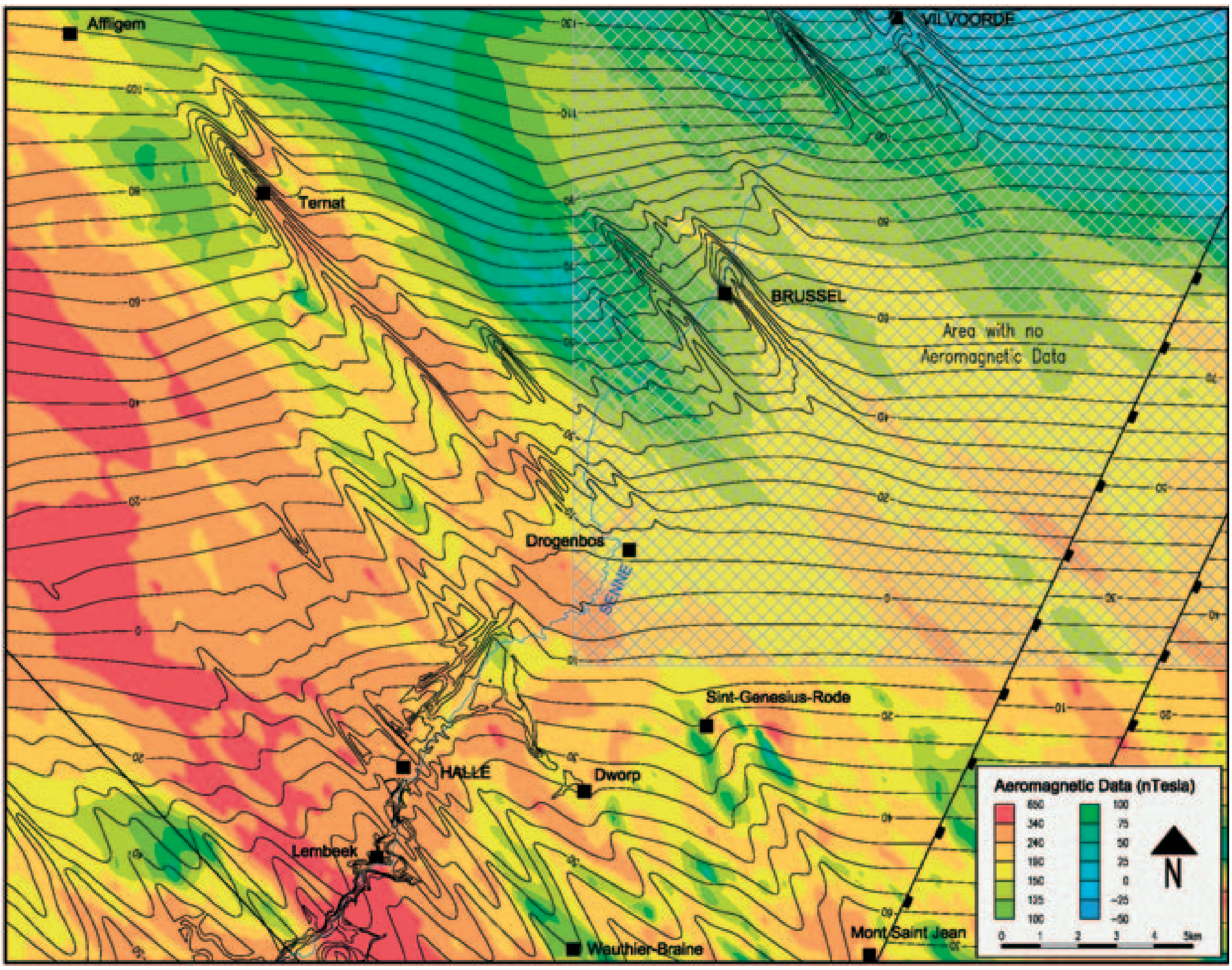

Figure 11. The relation between the aeromagnetic map and the palaeotopography of the top of the Lower Palaeozoic basement. Hatched area: no observations, the map is drawn on the basis of extrapolation (see text).

the area North of the line Affligem - Wauthier-Braine, as far as aeromagnetic data are available. This is best demonstrated by the ridge of Ternat which is composed of quartzites belonging to the Blanmont Formation. It corresponds to an aeromagnetic low being flanked on both sides by elongated zones with a relatively higher aeromagnetic response, indicating the presence of the Tubize Formation. Moreover, the aeromagnetic high near Drogenbos and the aeromagnetic low South of Sint-Genesius-Rode are in agreement with the disappearance of the Ternat ridge South of Drogenbos and its reappearance near Sint-Genesius-Rode.

6. Geological Structure

Through the years different models have been proposed for the geological structure of the Lower Palaeozoic Brabant Massif as a whole or for parts of it (Legrand, 1968; De Vos *et al.*, 1993; Sintubin, 1997, 1999; Sintubin *et al.*, 1998; Sintubin & Everaerts, 2002; Debacker *et al.*, 2004; Piessens *et al.*, 2004). These models were based on field observations, lithology, palaeontology, aeromagnetism, gravimetry or on a combination of these. The palaeotopography and its correlation with lithology and the aeromagnetic map in the Brussels Region, however, seemingly suggests a fold train of gently NW-plunging folds, causing the Blanmont Formation to subcrop at regular distances as anticlinal cores in between depressions of the overlying Tubize Formation. In this hypothesis, this fold train is superposed on a large-scale fold with an antiform in the Brussels-Vilvoorde area and a synform in the Halle-Lembeek area. This model would explain the presence of the ridges and the overall aeromagnetic low in the Brussels-Vilvoorde area and the presence of the depressions and the overall aeromagnetic high in the Halle-Lembeek area. Both aeromagnetic data and the disappearance and reappearance of the Ternat ridge near Drogenbos may even suggest the existence of transverse undulations.

7. Conclusions

A detailed reconstruction of the relief of the top of the Lower Palaeozoic basement in the Brussels Region reveals a series of SE-NW-trending ridges and depressions. A first correlation could be made between the palaeotopography and the lithological composition of the Lower Palaeozoic substrate. A second correlation was observed between the palaeorelief and the aeromagnetic map of the area. On the basis of these correlations, a gently NW-plunging fold train may be proposed, superposed on a large-scale fold with an antiform in the Brussels-Vilvoorde area and a synform in the Halle-Lembeek area. However, outcrop observations within the (scarce) exposed parts of the Cambrian core have revealed the common occurrence of steeply plunging folds (e.g. Sintubin *et al.*, 1998; Sintubin, 1999; Debacker *et al.*, 2004, in press; Piessens *et al.*, 2004). Future work will have to reconcile these observations with the image resulting from the palaeotopography and aeromagnetic data (cf. Piessens *et al.*, 2004).

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