Fault Distribution Inferred from Gravity Anomalies in the Northern France and Its Adjacent Areas

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Abstract. Using Bouguer gravity data, the information on faults has been obtained by means of horizontal directional derivative processing, vertical derivative and wavelet analysis. And according to synthetic analysis with geological data, fault zones distribution map of Northern France and its adjacent areas is presented. We have not the exact depth of the three wavelets details map, but we still can determine the relative spatial relations among faults of different scale and different depth. The northwest trending fault and the northeast trending fault control the structure in the study area. There are also a few south-north trending faults. The structure is quite complicated. The faults with different direction cut each other. The faults outline the boundaries of the basins, grabens and intrusive bodies.

Introduction

The study area includes northern France, Belgium, southern North Sea, southwestern Netherlands and western Germany (Figure 1).

![Location map and the faults from other papers.](image)

Many authors have discussed the deep structure in this area by means of seismic data [1-4], gravity and magnetic data [5-10], paleomagnetic and seismic data [11], or various geological data [12,13], or integrated seismic data and gravity and magnetic data [14,15].

The central Netherlands Basin and the west Netherlands Basin locate in the northeast part. It is separated from the London-Brabant Massif by the South Hewett fault [16]. The major trend of these faults is northwest, which are same with the South Hewett fault.

From the southern North Sea to Belgium is the London-Brabant Massif, which is between the
Midi fault and the South Hewett fault. Northwest and northeast trending faults coexist in this part. The west Midi fault is northwest trending and the east Midi fault is west-east trending.

Between the Midi fault and the Bray fault is the Ardenne-Brabant Terrane [7]. This part can be divided into two parts, most of the faults are in the east part, and they are northeast trending.

The Central Terrane is to the south of the Bray fault.

Generally the boundary of different tectonic units is fault, and fault related with the development of tectonic formation, here we present the three dimensional variation of the major fault zones by means of horizontal directional derivative processing, vertical derivative and wavelet analysis of gravity data.

**General Outline of Bouguer Gravity Anomaly Map**

The complete Bouguer gravity anomaly map of the study area (Figure 2) was prepared using the gravity database of the Royal Observatory of Belgium. The main characteristics of the gravity anomaly in the study area are close to the known geological data.

On the Bouguer gravity anomaly map (Figure 2), the regional variation of the gravity anomaly values is decreasing from southwest to northeast, which reflected the deeper variation of density beneath basement. But the variation of local anomalies in this area is the result of the thickness of the sedimentary materials in the basins and of the density variation of the intrusive bodies.

The London-Brabant Massif stands out as a positive area. The maximal value is up to 15mGal in its southeastern part, this is attributed to high density pelitic sediments of the Ordovician-Silurian sedimentation cycle. To the northeast, the west and the south of the London-Brabant Massif gravity high, the gravity decrease, the negative gravity is its main feature. The minima gravity value is -40mGal near Paris.

Some of the gravity low has been interpreted. Within the southern part of the Brabant Massif, an elongated gravity low, trending WNW in the western part and roughly east-west more to the east, was partly modeled by Everaerts et al. [8] as deep-seated granite. Near Paris there are two gravity lows (GL5 and GL6, Figure 2), which are interpreted as Cadomian/Hercynian granites by Lefort [7]. To the northeast of Bray fault there are two gravity lows (GL4, Figure 2), they are related with the Permian basin. To the southeast of Metz fault, one gravity low (GL7, Figure 2) corresponds to the Rhine graben. In the English Channel, there is a gravity low (GL3, Figure 2) which can be divided into two gravity lows, it is possible due to large Old Red Sandstone deposits of relatively low density. From GL3 to the northeast, another one gravity low (GL2) has been interpreted as magmatic body by Rijkers et al. according to the seismic data of MPNI-9101 [16]. To the northeast of Brabant Massif, the gravity lows are related with the Central Netherlands basin and the West Netherlands basin and with the Roermond graben.

The most prominent feature of the Bouguer anomaly map (Figure 2) is the gravity gradient zone. All the gravity gradient zones are related with fault, which define the sharp boundary between different structural zone or represent lateral lithological contrasts.

In the southern part there are three gravity gradients (GG1, GG2 and GG3, Figure 2). GG1 is northwest trending, which is identical with the Bray fault. GG2 (Figure 2) is related with Metz fault, which is northeast trending. GG3 is to the southeast of Metz fault, it corresponds to the southeast boundary of Rhine graben.

GG4 (Figure 2) is in the middle part of the study area. It is an east-west trending gradient defined a sharp boundary between the Brabant Massif and the southern Ardennees area. It is steeper along the northern border of the Mons basin. East of Namur, the boundary turns to a northeasterly direction; it stops near Vise, where it joins the north-west oriented boundary of the Roermond graben (the Feldbiss fault, GG5 in Figure 2). At the western extremity, the gravity gradient turns to a northwesterly direction to the west of St. Amand, and gradually loses its sharp character. The boundary curves further to the north, and becomes a gentle gradient when it reaches the coast line between Dunkerque and Nieuwpoort.

GG6 is to the northeast of GG5, it is related with the northeast border of Roermond graben.

GG7 is within the southern part of Brabant Massif. It is the effect of Nieuwpoort-Asquenpont.
fault zone. This fault zone is also the southern border of GL1, so it should be related with the granite intrusive GL1.

Gravity Data Analysis and Interpretation

The Bouguer gravity anomaly values shown on Figure 2 reflect the combined gravitational effect of all rocks in the study area. In order to highlight the fault at different depth and in different direction, here we calculated the horizontal directional derivates, vertical derivates and wavelet details.

Gravity Derivative Anomaly

The gravity derivative anomalies can improve the resolution of gravity anomalies, and highlight the position of the boundaries between different density bodies. The anomaly of the special object can be extracted and the regional anomaly can be removed from the combined anomalies by means of derivative anomaly. Using horizontal derivatives in different direction may stress the information of the faults in different directions [17]. This method is in common to interpret the variation of the fault’s direction.

We calculated the horizontal directional derivative in two directions, one of 135° (Figure 3) highlights the northeast trending faults, and the another one of 45° (Figure 4) highlights the northeast trending faults. Figure 5 is the vertical derivative anomaly map, which is effective for deciphering local and shallow features, and stresses the direction and range of the anomalous density bodies.

In Figure 3 the major maximal value circle locate in the middle and the southeast part of the study area. It is not evident in the northwest and southwest part. The Metz fault is highlighted.

In Figure 4 the northeast trending maximal value circle are situated mainly in the southwest and northeast part and within the Brabant Massif. The Bray fault, Midi fault and the South Hewett fault are highlighted. The South Hewett fault is clearer comparing with that in the complete Bouguer anomaly map (Figure 2).

There are two northwest trending faults in both Figure 3 and Figure 4. The first one is near Mohon, and the second one is to the northeast of Rochefort. They are separated from the Brabant Massif by Midi fault, and stretch to the southeast to cut the Metz fault. Besides these two faults above, more than one other northwest trending faults also cut Metz fault.

Compared with Figure 2 the location of the basin, graben and intrusive body are clearer in the vertical derivative anomaly map (blanket in Figure 5). The two northwest trending faults near Mohon and Rochefort still exist in Figure 5.

Gravity Wavelet Analysis

The wavelet analysis is a new branch of mathematical method. It has been used extensively in
signal and image processing and oil seismic exploration. And the multi-resolution wavelet analysis has been used in the separation and inversion of gravity data [18-25]. The wavelet details have the same characteristics as the one order horizontal derivative. The wavelet details with different order reflect the direction and range of the anomaly object at different depth or in different scale. It can overcome anomaly ambiguity in upward continuation, and enable fault analysis in gravity field more accurate and reliable.

Figure 3. Horizontal directional derivative (highlights the northeast trending faults).

Figure 4. Horizontal directional derivative (highlights the northwest trending faults).
Figure 6 is the first order wavelet details map, Figure 7 is the second order wavelet details map, and Figure 8 is the third order wavelet details map.

The higher the wavelet order, the deeper is the origin of the density bodies. The depth of the anomaly increase from Figure 6 to Figure 8, and the effect of the small faults disappear gradually. Here we haven’t the exact depth, but we can learn the relative variation of the fault’s shape at different depth.

From the first order wavelet details map to third order wavelet details map (Figure 6 to Figure 8), we can get the same information that the Metz fault has been cut by more than one northwest trending faults. It has been cut into four main parts form southwest to northeast in the study area (the southwest end – northeast of Metz – Saarouis – Obersein). The anomaly for Metz fault in the 1st and the 2nd order wavelet details maps are almost in the same position, but in the 3rd order wavelet map the gradient of the anomaly moves to the southeast, which means that the dip of the Metz fault is very steep in the shallower part and is to the southeast in the deeper part.
In complete Bouguer anomaly map (Figure 2) and the first order wavelet details map (Figure 6), the location of Bray fault is identical with the anomaly. But in the second order wavelet details map (Figure 7) and the third order wavelet details map (Figure 8), there are two anomalies besides the location of Bray fault, so the Bray fault on surface becomes two faults underground, and they dip to the southeast and to the northeast separately. Or there is one deeper fault to the north of Bray fault and its direction of dip is northeast. Near Dieppe the Bray fault is cut by one northeast trending fault and moves to the southeast.

The location of the maximal values moves to north and leave the Midi fault near Denain with the depth increasing. The northern maximal values are not the effect of Midi fault, because the Midi fault is not too deep [11]. The sharpest gravity gradient to the north of the Midi fault should associate with the Bordiere fault.
Outline of the Fault Distribution and Conclusion

Figure 9 is the distribution of the density boundaries (fault and contact belt between different density bodies) based on Bouguer anomalies, horizontal derivatives, vertical derivative and wavelet details. The locations of the major faults (such as Bray fault, Midi fault, Dowsing fault, and Nieuwpoort-Asquenpont fault zone) are identical with that from the geological map of France, and other papers [1-3, 6].

In the study area, the main direction of structure is northwest. The major northeast trending faults are situated in the southeast and northeast part. One obvious west to east trending fault locates in the southern border of the Brabant Massif, which is the east part of the Midi fault. There is one clear south to north trending fault in the west part and cross the English Channel. Between the Midi fault and the Bray fault there are also some small south to north trending fault.

The relations between different trending faults are very complicated. The northeast trending and the northwest trending faults cut each other. The Bray fault is cut by one northeast fault near Dieppe, and it is even cut by the northwest trending fault near Meaux and one south-east trending fault near Rouen. The Nieuwpoort-Asquenpont fault zone is perpendicular to many northeastward faults and is cut by them. The South Hewett fault and Dowsing fault are cut by more than one northeast faults, and seem not to be continuous. The Metz fault is cut by two northwest trending faults and one south-north ward fault.

Figure 9. The distribution of the density boundaries (fault and borders between different density bodies) based on Bouguer anomalies, horizontal derivatives, vertical derivative and wavelet details.

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References


