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# Interpretation of Gravity, Magnetic Data and Contribution to the Structural Study of the Congo Basin: A Case Study of the Southern Part of the Province of Sankuru in D.R. Congo

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## ABSTRACT

*This study is focused on the recognition of the geological structure of the southern part of the province of Sankuru in the D.R. Congo which covers the oil blocks 18 and 18b. Gravity and magnetic data were processed using the horizontal derivative and upward continuation methods. Note also that the Reduction yo Pole (RTP) was previously applied to the magnetic data in order to eliminate the distortions of the anomalies. Thus, we found that the region was affected by several tectonic phenomena, the most important of which was the rifting phenomenon that shaped this region by establishing a large collapsed central zone forming an NW-SE direction graben and raised peripheral reliefs forming horsts to the northeast and southwest. This study also revealed several faults, some of which, which are of the normal type, are parallel to the central graben and others are perpendicular to it. It should also be noted that the large negative gravity anomalies result from the salt domes located for the most part in the central graben. The integration of all the geological information from the interpretation of gravity and magnetic maps has enabled us to develop a structural map that improves our knowledge of the geological structures of major oil interests in this region.*

**Keywords:** Geological structure, Gravity, Magnetic data, Oil Blocks, Salt domes.

## 1.INTRODUCTION

The exploration of the Cuvette Centrale sedimentary basin began in the 1950s. The first exploration project was carried out between 1952 and 1956 by the 'Société de Recherche Minière en Afrique (REMINA)' and consisted of a geological prospecting, a combined gravity and magnetic campaign, the acquisition of 600 km of seismic refraction profiles and 131 km of seismic reflection profiles as well as the drilling of two stratigraphic wells approximately 2,000 m deep (Samba-1 and Dekese-1) (Delvaux and al., 2015 [1]). Then several additional studies based on the geochemistry, geology, geophysics and the drilling of two new exploration wells (Mbandaka-1 and Gilson-1), were carried out with the aim of improving the understanding of the geology and the petroleum system of this basin (ECL, 1988 [2]). These made it possible to retain that this gigantic sedimentary basin would have a major petroleum interest by highlighting potential source rocks, migration routes, reservoir rocks and possible traps (Mello, 2006 [3]; ENI, 2011 [ 4]). As part of this study, we will deepen our knowledge of the structural geology of blocks 18a and 18b of the Cuvette Centrale in order to guide future oil prospecting in the region.

## 2. MATERIAL AND METHOD

### 2.1. Material

We used a gravity database as well as an aeromagnetic database of the Congo Basin which were provided to us by the the National Hydrocarbons Company of Congo (SONAHYDROC) in Excel format. A variety of earth science modeling software was essential for this work.

### 2.2. Method

Several data processing methods have been applied. A pole reduction filter was previously applied to the magnetic data in order to remove distortions of the anomalies. The data was then mapped using the Minimum Curvature interpolation method. These gravity and magnetic data were transformed into horizontal derivatives and upward continued at several altitudes to better identify geological structures. Finally, all the results obtained have been presented on a structural map which improves our knowledge of the geological structures of major petroleum interest in this region.

## 3. GENERAL OVERVIEW OF THE STUDY AREA

### 3.1. Location

The study area is located in the southeast of the Congo Basin. The province of Sankuru occupies about 80% of the area while the remaining part is occupied by the provinces of Kasaï and Kasaï central. The area is located between 22° and 24° East longitude and 3° and 5.17° South latitude. It corresponds to oil blocks 18 and 18b, with an area of approximately 25,000 km² each (fig. 1).

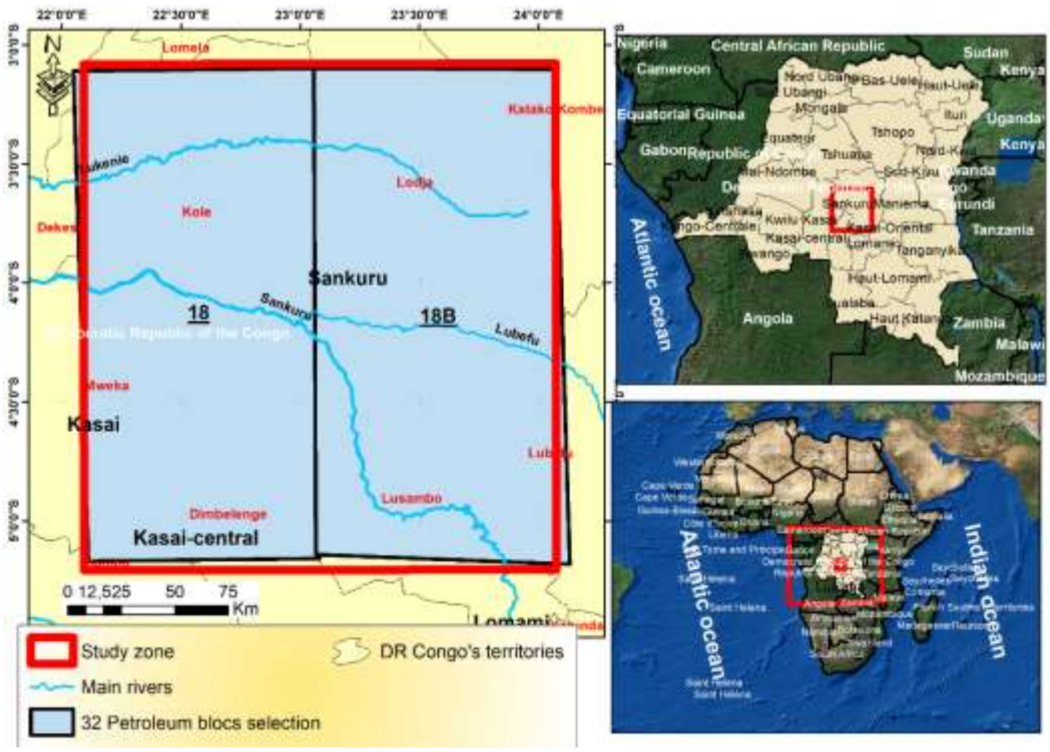


**Figure 1: Map of the location of the study area.**

Table 1 presents the coordinates of the tops of the two oil blocks.

**Table 1: coordinates of the tops of the oil blocks 18 et 18b.**

| Bloc 18 | | |
|---|---|---|
| **Tops** | **Longitude (D°M'S'')** | **Latitude (D°M'S'')** |
| **1** | 22°3'16"E | 3°5'41"S |
| **2** | 23°3'31"E | 3°5'41"S |
| **3** | 23°3'31"E | 5°9'30"S |
| **4** | 22°3'16"E | 5°9'30"S |
| **Bloc 18b** | | |
| **1** | 23°3'31"E | 3°5'41"S |
| **2** | 24°4'46"E | 3°5'41"S |
| **3** | 24°4'46"E | 5°9'30"S |
| **4** | 23°3'31"E | 5°9'30"S |



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### 3.2. Geographic Framework

From an administrative point of view, our study area is occupied by the territories of Kole and Lodja in the north, Dimbelenge, Lusambo and Demba in the south, Mweka in the south-west, Lubefu in the south-east and Katakokombe north-east. The area is characterized by a type Am climate in the Koppen classification. Average annual precipitation varies between 1,900 mm in the northern part and 1,400 mm in the southern part. The climate is therefore of the equatorial type in the north. On the other hand, the further south one moves from the Equator, the more the climate becomes of the Sudanese type marked by a dry season of 3 to 4 months. Rainfall peaks in November and April. While a third of its surface is covered by savannah, the remaining two thirds are occupied by forest formations. Its altitude varies between 370 m to 680 m. The area has an important network of rivers, the most important of which are the Lukenie rivers in the north and Sankuru in the center plunging towards the South-East.

### 3.3. Geological Framework

Geological, geophysical and geochemical studies as well as the drilling of exploration and stratigraphic wells have contributed to the understanding of the surface and deep geology of the Congo Basin. A simplified geological map of our study area was therefore drawn up at the end of these studies (fig. 2).

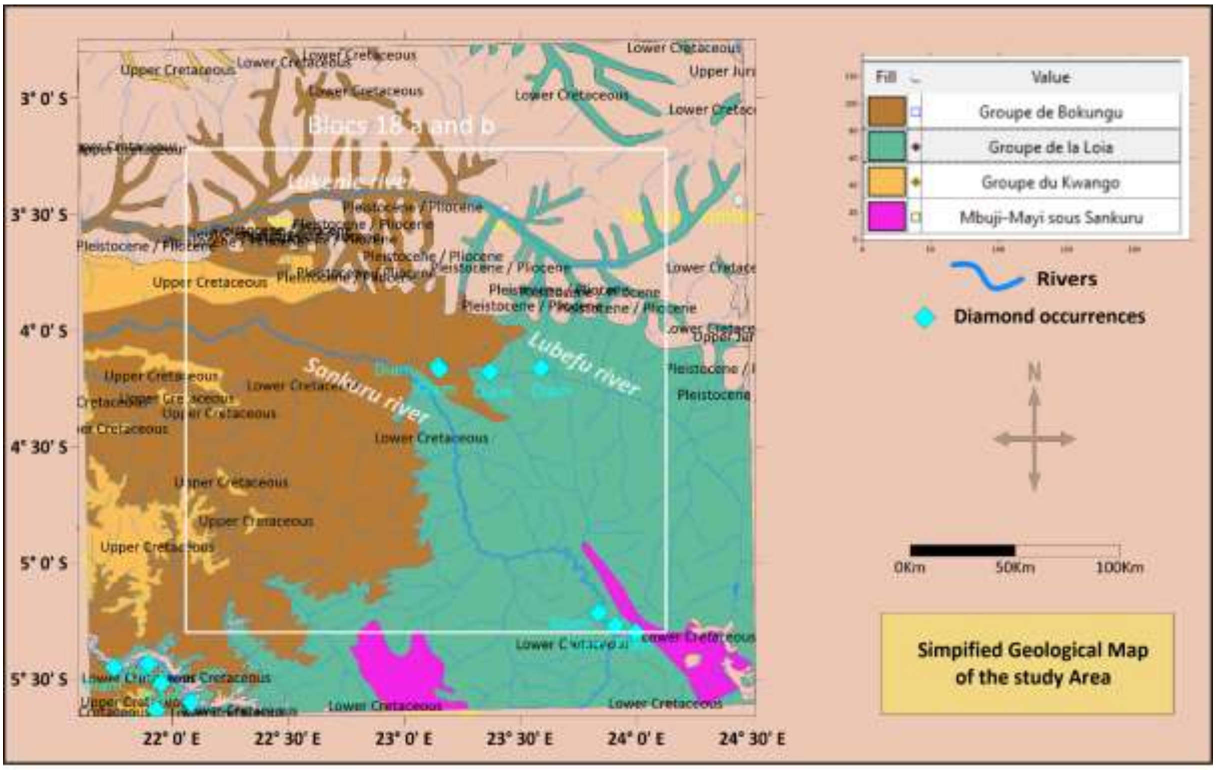


**Figure 2: Simplified geological map of the study area.**

On this map, we notice that the western part of the area is occupied by the geological formations of the Kwango groups (Upper Cretaceous) and Bokungu (Lower Cretaceous) while its eastern part contains sediments of the Loia groups (Lower Cretaceous) and Mbuji-mayi which are much older. In this zone, the soils are directly related to the vegetation: they are of the sandy to sandy-clayey type in the forest region, while in the savannah region they are of the very sandy type, succeeding each other in the South by clayey-to-clayey soils.

Although no wells have been drilled in the area, the regional stratigraphy has been studied by the Dekese-1 stratigraphic well (3°27'26"S; 21°24'28"E). This well crossed a 755 m thick series composed mainly of red sandstone, then a 955 m thick series composed mainly of dark shales and diamictites (Bastien Linol and al., 2015 [5]). From the tectonic point of view, this basin was marked by a crustal extension during its initial development in the Neoproterozoic which certainly initiated the development of other peripheral Neoproterozoic basins such as the basins of Sembe-Ouesso, Fouroumbala-Bakouma and Bangui (Kadima and al., 2015 [6]). It should be noted that the lithostatigraphy, the structural aspect and the paleo-environment confirm this hypothesis (Delpomdor et al., 2015 [7]). The sediments were later affected by Pan-African and Permo-Triassic (Hercynian) compressive events, phenomena that will form the basis of tectonic imprints in the Congo Basin. The involvement of saliferous tectonics observed on most seismic profiles has also contributed to the structural evolution of this basin. It should be noted that currently this basin is tectonically active along the margin of the East African Rift (Delvaux and al., 2010 [8]).



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## 4. DATA PRESENTATION AND PROCESSING

### 4.1. Data Presentation

The gravity data used in this work were acquired during the first mining surveys carried out in the Congo Basin by the "African Mining Research Company" (REMINA) between the years 1952 and 1956. On this, we added a source of gravity data acquired airborne by the CGG in 1986. As for the magnetic data, they come from a compilation made by the African Magnetic Mapping Project (AMMP). This project, carried out by Paterson, Grant & Watson Limited (PGW) in collaboration with GETECH and ITC, brought together all the airborne and marine magnetic surveys (approximately 800) carried out in the African continent. The compilation of these data was the work of the National Hydrocarbons Company of Congo (SONAHYDROC). A sample is shown in Tables 2 and 3 below.

**Table 2: Sample of gravity data used**

| Station n° | Longitude (˚) | Latitude (˚) | Elevation (m) | Gravity (mGal) | Free-Air Anom. (mGal) | Bouguer Anom. (mGal) |
|---|---|---|---|---|---|---|
| **01** | 22.0117 | -3.88 | 552.5 | 977870.9 | -13.8 | -75.7 |
| **02** | 22.0567 | -3.9133 | 560 | 977868.4 | -14.5 | -77.1 |
| **03** | 22.0617 | -3.91 | 553.5 | 977869.5 | -15.3 | -77.2 |
| **04** | 22.0767 | -3.8917 | 619.5 | 977851.9 | -12.3 | -81.6 |
| **05** | 22.0917 | -3.88 | 555.5 | 977866.3 | -17.5 | -79.7 |

**Table 3: Sample of aeromagnetic data used**

| Line n° | Longitude (˚) | Latitude (˚) | Flying Height (m) | Magnetic Field intensity (nT) |
|---|---|---|---|---|
| **A1** | 22.10576 | -3.109787 | 1372 | -96.17 |
| **A1** | 22.1057 | -3.110475 | 1372 | -96.24 |
| **A1** | 22.10567 | -3.111163 | 1372 | -96.28 |
| **A1** | 22.10565 | -3.11185 | 1372 | -96.4 |
| **A1** | 22.10561 | -3.112519 | 1372 | -96.44 |

### 4.2. Data Processing

#### 4.2.1. Reduction To The Pole (Rtp)

Unlike the gravitational field, which is vertical and always directed downward, the magnetization field vector and the inducing vector are generally tilted, causing asymmetry in the shape of anomalies. Thus, in order to facilitate the interpretation of these data, they were first reduced to the pole by taking into account the local parameters of the Earth's magnetic field, namely, an intensity of 33,225 nT, an inclination of -36.4 ° and a declination of –2.8 °, determined using the 1985 IGRF (International Geomagnetic Reference Field) geomagnetic model. The objective of this treatment is to eliminate the distortions of the anomalies generated by the inclination of the Earth's magnetic field. It allows anomalies to be obtained, the maximum of which is centered on magnetic sources (M. Jaffal et al., 2010 [9]). That is, these new anomalies would be those that would be observed if the field were vertical in the study area. This then simplifies the modeling because we are in a situation identical to that encountered in gravimetry (J. Dubois and al., 2011 [10]).

#### 4.2.2.The Upward Continuation Method

This filtering is equivalent to the application of a powerful low-pass filter to study and monitor the variation of large regional anomalies as a function of depth. The maps upward continued make it possible to highlight the anomalies of long wavelengths (Yvette H. Poudjoum, 1993 [11]). The upward continuation method has the effect of bringing out deep regional anomalies to the detriment of superficial anomalies. Therefore, the degree of smoothing is a function of the continuation altitude. In this study, we upward continued the Bouguer and magnetic RTP anomalies to altitudes of 5, 10, 15 and 20 km.

#### 4.2.3. The Horizontal Derivative Method

In geophysical imaging, more specifically in gravity and magnetic surveys, the application of horizontal derivative filters is the most effective method in the detection of faults and other geological contacts. These directional filters calculate the horizontal



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gradients of the anomalies. Indeed, above a vertical contact, the anomaly is materialized by a curve having a minimum on the side of low-density rocks and a maximum on the side of high-density rocks. The inflection point of the curve is directly above this contact. However, after calculating the horizontal gradient, this anomaly becomes a maximum. This is what makes it easier and better to identify and map these contacts. So, to try to highlight a maximum number of lineaments in our study area, we filtered in four directions: N-S; E-W; NW-SE and NE-SW. The maps resulting from all the processing methods mentioned above will be presented and interpreted in point 5 of this work.

## 5. RESULTS AND INTERPRETATION

### 5.1. Digital Elevetion Model (DEM)

To make a DEM of our study area, we used an SRTM image with a spatial resolution of 90 m downloaded from the earthexplorer.usgs.gov site. The following figure 3 shows us the SRTM image uploaded to the ArcGIS software environment.

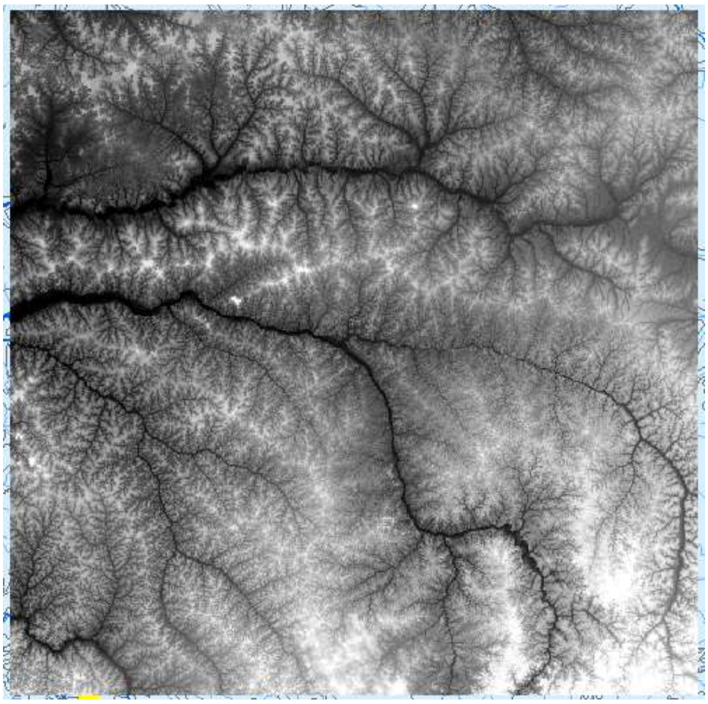

**Figure 3: Raw SRTM image of the study area downloaded via earthexplorer.usgs.gov**

Indeed, a DEM corresponds to a representation in digital form of the relief of a geographical area. The model can be composed of point vector entities, linear (level curves), surface or represented in raster mode (cells). In our case, from the SRTM satellite image above, we carried out an unsupervised classification of the image based on the variation in altitude as a function of longitude and latitude. This allowed us to generate a DEM to have a fairly precise image of the geomorphology of the study area (fig. 4).



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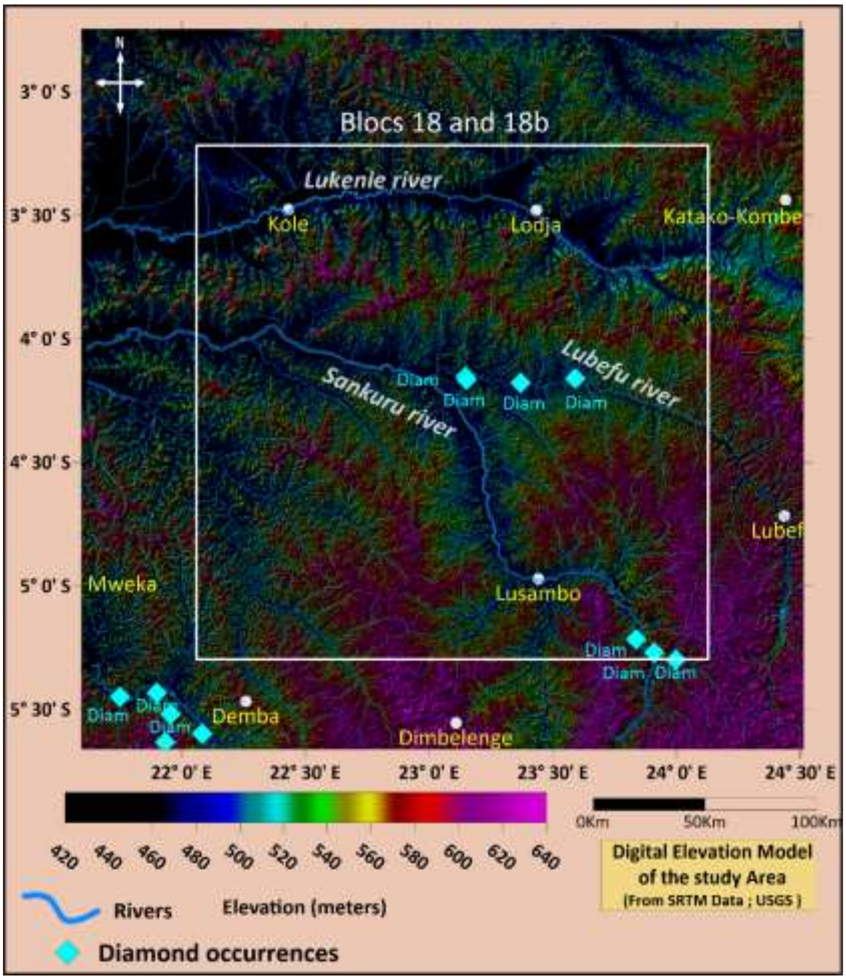


**Figure 4: DEM of the study area.**

This DEM shows us that the geomorphological variability observed is representative of the relief observed in this region. The altitudes vary in decreasing ways from the South, an area corresponding to the edge of the Congo Basin, to the North, an area approaching the alluvial plain of the Congo River. The lowest altitudes (from 420 to 500 m) are observed in the North-East of this zone in the territory of Kole, as well as along the Lukenie, Lubefu and Sankuru rivers which are the main rivers that water this region. Using the superposition of data on mining occurrences in the D.R. Congo from the Royal Museum Central Africa (RMCA), this DEM also makes us discover that this region contains occurrences in particular in diamonds along the Lubefu and Sankuru rivers in its southern part.

### 5.2. Bouguer Anomaly Map

We represented the Bouguer anomaly maps in the form of the variation of their intensities on a shaded relief background in order to improve the visual analysis and the interpretation of the results. We have subdivided our study area into several gravity anomaly zones based on intensity:

a) The areas of high gravity intensity (-90 to -56 mGals) are Mweka high and Lusambo high;

b) The areas of low gravity intensity (from -120.5 to -97 mGals) are Kole depression and Lusambo depression (fig. 5).



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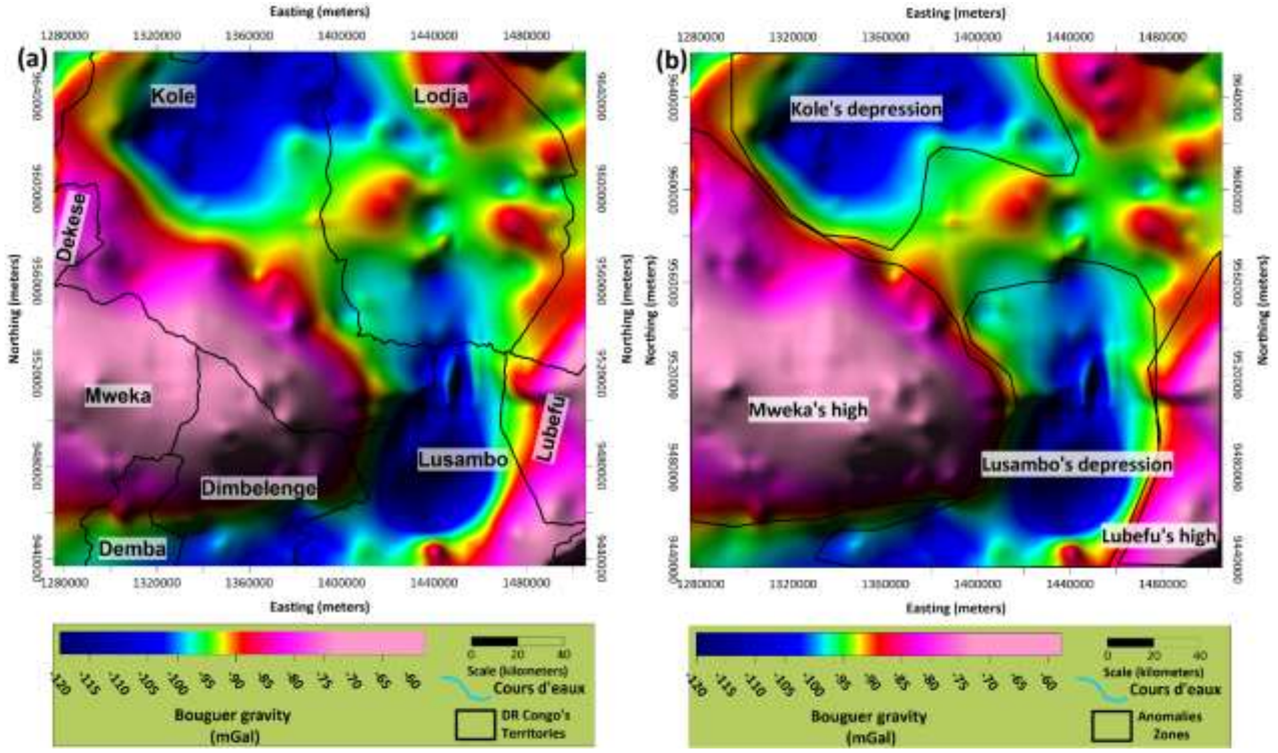


**Figure 5: Bouguer anomaly map: (a) map of the territories of the study area; (b): map subdivided into anomaly zones.**

Figure 4.a shows us the gravity map of the territories in the study area. In Figure 4.b we have made a subdivision of the gravity map into anomaly zones. Our study area consists of two large horsts located to the east (Mweka high) and west (Lusambo high) surrounding a central depression having the gravity signature of a graben (Kole and Lusambo depressions)

The Mweka high, which covers much of the west of our study area, is characterized by a large uplift of dense basement oriented E-W. This area covers the territories of Mweka (eastern part), the entire northern part of the territory of Dimbelenge as well as the entire southern part of the territory of Kole in the province of Sankuru. The uplift of the basement observed in the Lubefu high area causing high gravity intensities is located in the territories of Lubefu and Lodja.

The Kole and Lusambo depressions, which are bounded by the different gravity highs that we have just described, are part of the central graben with very low anomaly intensity values. It should also be noted that the presence of salt in the Congo Basin was attested by the Mbandaka-1 well in the central part of the Basin. The study by Tondozi K. and al., 2018 [12] showed from seismic and gravity profiles that this saliferous layer thickened in the depressions of the Congo basin. Large negative anomaly values in these areas may also indicate the presence of a very thick salt layer. Indeed, salt being a lighter substance (2.22 g/cm3 average density) than the other surrounding sedimentary rocks (2.35 to 2.70 g/cm3) (H.O Seigel, 1995 [13]), it there will be a negative density contrast which will have the effect of locally reducing the intensity of the anomalies. This is how a negative gravimetric anomaly is observed above the salt uplifts. The Bouguer anomaly map therefore reveals that our study area has the shape of a rift consisting of a central graben oriented mainly in the NW-SE direction surrounded by horsts.

### 5.3. The Magnetic Map Reduced to Pole (RTP)

Total Magnetic Field (TMF) anomalies have been reduced to the pole (RTP) using the 1985 International Geomagnetic Reference Field (IGRF) geomagnetic model in an effort to bring them back plumb to their sources. We have also subdivided our study area into several RTP magnetic anomaly zones based on intensity:

a) High intensity (-90 to 100 nT) RTP magnetic anomaly zones are the southwest and northeast Magnetic high zones.
b) The zone of low-intensity RTP magnetic anomalies (from -140 to -100 nT) is called Magnetic Depression (fig. 6).



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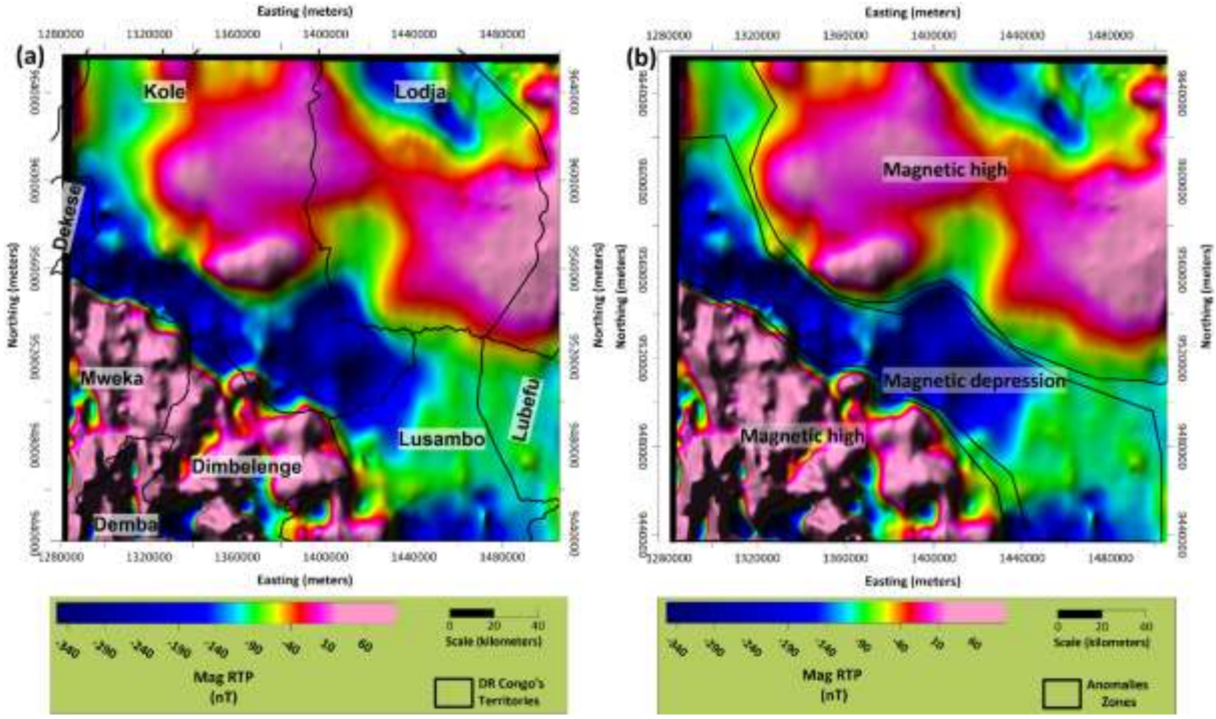


**Figure 6: RTP magnetic map; (a) map of the territories of the study area; (b) map subdivided into anomaly zones.**

The RTP map shows us significant positive anomalies in the North-East and South-West which surround a zone of negative anomalies in the center, thus confirming the presence of a geological structure in rift consisting of a central graben oriented NW-SE surrounded by horsts on either side.

We observe positive uplifts in the Southwest (250 nT) and Northeast (90 nT) of the chart. The large negative anomaly covers the entire central part of the map with values that reach around -350 nT.

### 5.4. The Upward Continued Maps

The upward continued maps allow us to highlight the long wavelength anomalies in order to study the deep structure of our study area. This is how we upward continued the Bouguer and magnetic RTP anomalies to 5, 10, 15 and 20 kilometers (fig. 7 and fig. 8).



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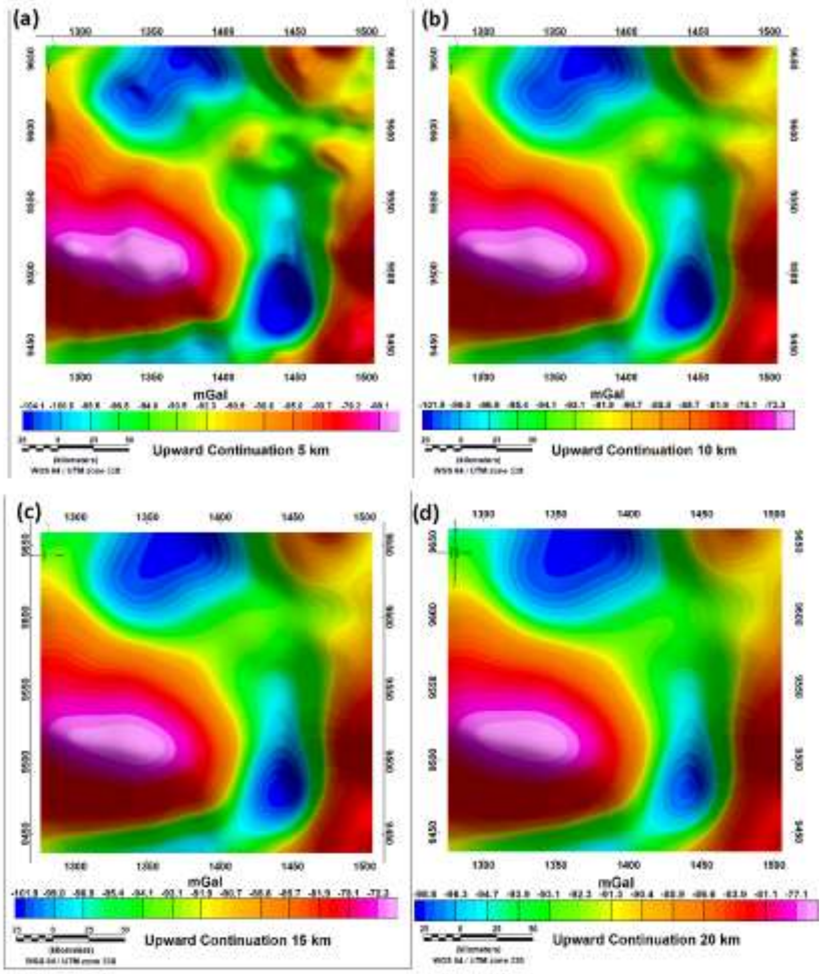


**Figure 7: Bouguer anomaly upward continued maps: (a) 5 kilometers; (b) 10 kilometers; (c) 15 kilometers and (d) 20 kilometers.**



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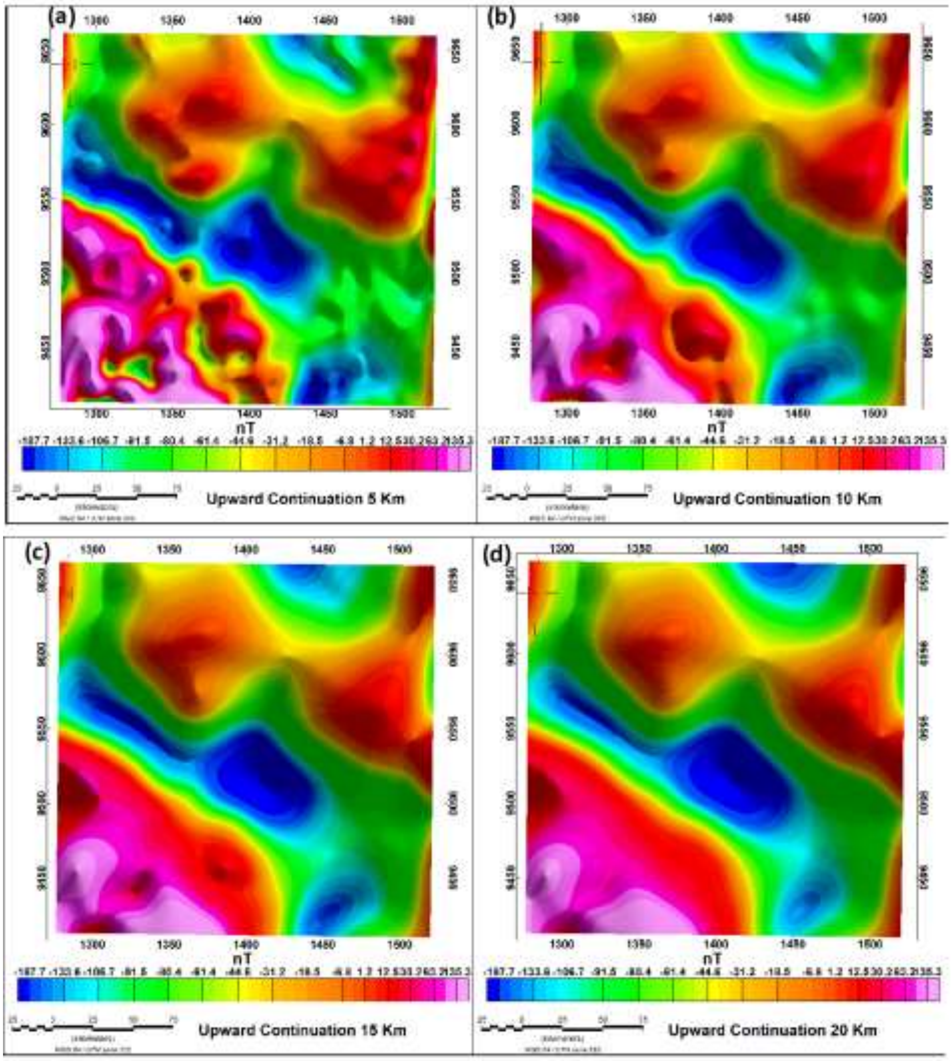


**Figure 8: Magnetic RTP upward continued maps: (a) 5 kilometers; (b) 10 kilometers; (c) 15 kilometers and (d) 20 kilometers.**

The 5 km upward continuation of the Bouguer (fig. 7a) and RTP (fig. 8a) anomalies closely resembles the initial maps. We still find the anomalies described above but with a slight smoothing. Compared to previous maps, we notice that the small anomalies of short wavelengths disappear giving way to the anomalies of long wavelengths on the maps upward continued to 10 km (fig. 7b and fig. 8b). At altitudes of 15 km (fig. 7c and fig. 8c) and 20 km (fig. 7d and fig. 8d), only the sets of long wavelength anomalies remain which are linked to very deep sources. The separation of high intensity anomalies representing horsts and low intensities related to central graben is felt as the height of the continuation increases. The demarcation of anomalies revealing the presence of huge fracture zones around the central graben becomes clearly visible.

## 5.5. HORIZONTAL DERIVATIVE MAPS

Horizontal derivative filters in the N-S, E-W, NW-SE and NE-SW directions were applied to the Bouguer anomalies in order to enhance the maximum number of faults present in the area (fig. 9).



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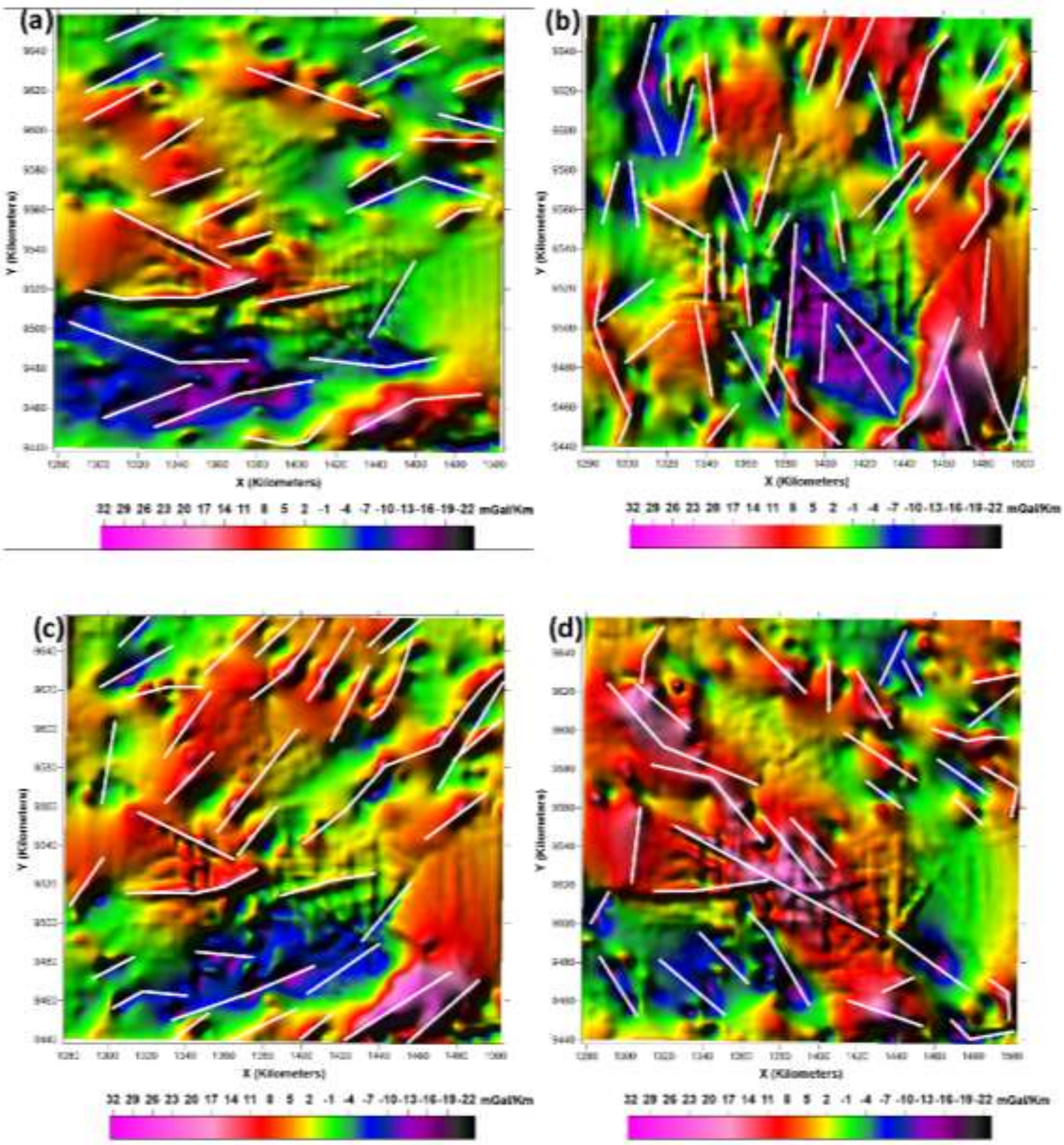


**Figure 9: Gravity horizontal derivative maps: (a) N-S; (b) E-W; (c) NW-SE and (d) NE-SW.**

We notice on the four maps presented in the figure above that the majority of the highlighted faults is perpendicular to the direction of the applied filter. Figure 9a, for example, shows the map filtered in the N-S direction and the preferred direction of orientation of the faults is E-W.

The interpretation of the various gravity and magnetic maps allowed us to better understand the geological structure of the study area. The gravity anomaly maps reveal that our study area is a rift characterized by a central graben oriented mainly in the NW-SE direction surrounded by horsts. The negative circular anomalies in the trench could well indicate the presence of a large salt uplift. The magnetic anomaly maps also show us large positive anomalies surrounding a zone of negative anomalies in the center. This arrangement is in line with that observed on the Bouguer anomaly map, thus confirming the presence of a geological rift structure consisting of a central graben oriented NW-SE and surrounded by horsts on either side. Nevertheless, we find that the magnetic depression seems narrower than the gravity one. In the following figure, we have clearly indicated the location of these geological structures on the gravity and RTP magnetic maps (fig. 10).



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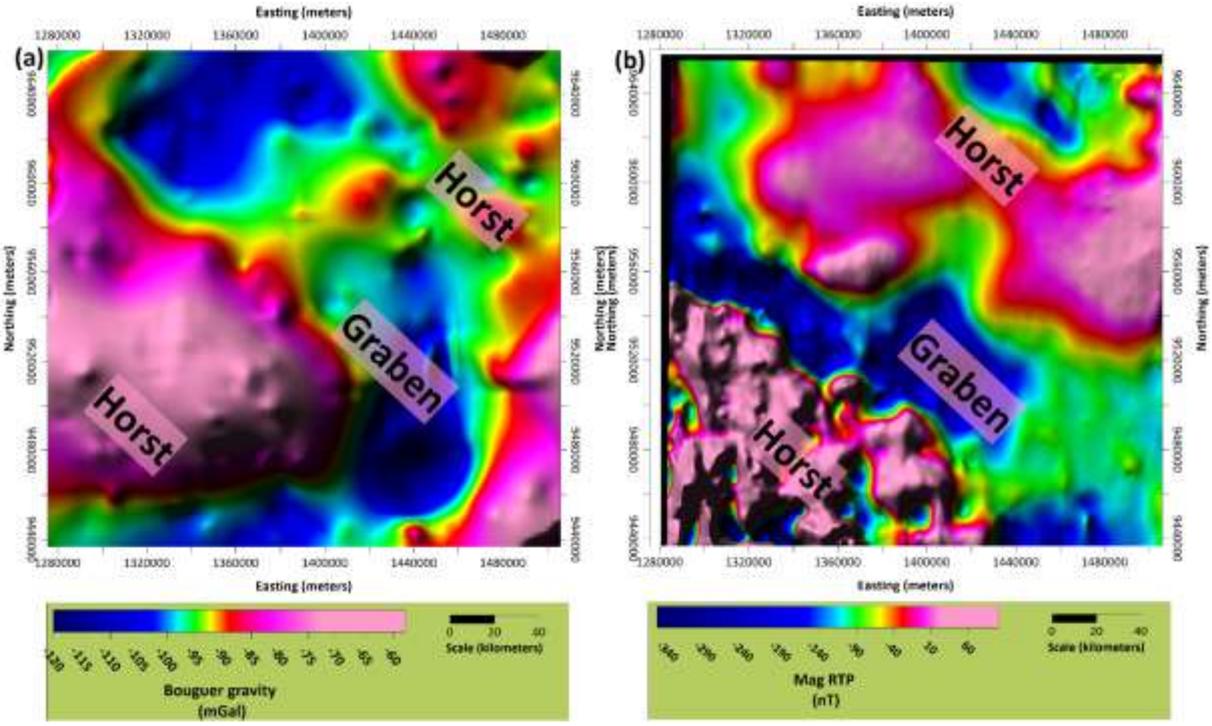


**Figure 10: Identification of horst and graben structures in the study area; (a) on the Bouguer anomaly map; (b) on the RTP magnetic anomaly map.**

Note that the very high magnetic anomalies in the Southwest zone correlate perfectly with the high intensities of gravity anomalies in this same zone. The geophysical signature of this place tells us that the uplift of the basement would most certainly be accompanied by a mafic intrusion because, for igneous rocks, the density and the magnetic susceptibility generally increase according to the basicity. This is how basic and ultrabasic rocks are generally denser and more magnetic than acid rocks. The presence of mafic rocks in the basement therefore generates significant magnetic and gravity anomalies at this location.

The upward continued maps at 5, 10, 15 and 20 km altitude showed us a degree of smoothing of gravity and magnetic anomalies depending on the continuation altitude. However, the arrangement of the anomalies remains the same as on the Bouguer and RTP maps. The horizontal derivative maps have highlighted several faults in this area which is located near the southeastern edge of the Cuvette Centrale sedimentary basin. Indeed, the latter has experienced several tectonic phenomena during its structural evolution. Pan-African (Neoproterozoic) rifting phenomena, pan-African (Neoproterozoic-Paleozoic) and Hercynian (Permo-Triassic) compressive events, compression due to the opening of the East African Rift (Cenozoic-present) as well as the intense saliferous tectonics which has been highlighted by several studies (Kadima and al., 2011 [14]; Tondozi K. and al., 2018 [12]) have largely contributed to the generation of several faults enhanced by the horizontal derivative filters.

### 5.6. 3D Modeling of Anomalies

One of the benefits of converting gravity and magnetic data into a three-dimensional model of the subsurface is that the highly visual end product allows explorers to better see and understand the distribution of density and magnetic susceptibility of geological formations. In figure 11 below, a 3D model has been generated by integrating the regional and residual gravity anomalies as well as the RTP magnetic anomalies.



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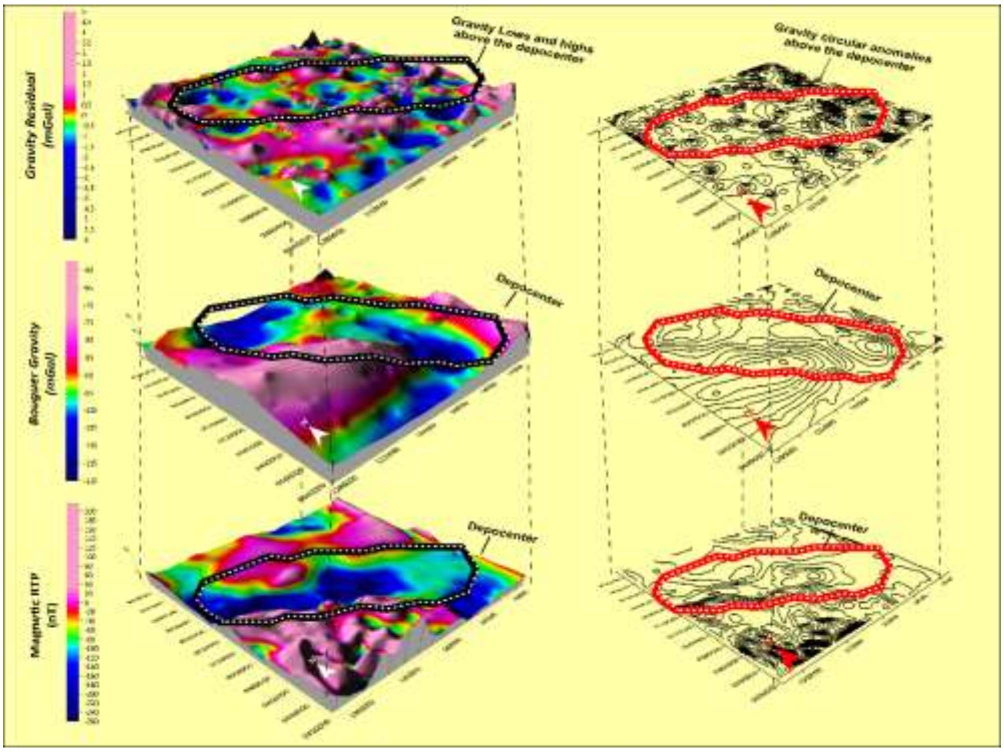


**Figure 11: 3D model of anomalies.**

This model allows us at the same time to:

- Visualize the topography of the crystalline basement and have a first idea of its composition using the analysis of variations in regional gravity anomalies and magnetic anomalies;
- Have a much clearer overview of the various oil targets that could be the subject of much more advanced exploration such as seismic and/or exploration drilling.

The low anomalies in the graben correlate perfectly with the high intensities of regional gravity anomalies. We therefore confirm the hypothesis of a basement depression at this location. Through this model we also notice that the positive residual anomalies in the form of circular bulging reveal the presence of antiform structures in the sedimentary cover are strongly linked to the uplift of the crystalline basement due to tectonic movements of compression.

The integration of all the geological information resulting from the interpretation of the gravity and magnetic anomaly maps has enabled us to draw up a structural map which improves our knowledge of the geological structures of petroleum interest which have played a major role both in the process of formation and migration of hydrocarbons than in their trapping (fig. 12).



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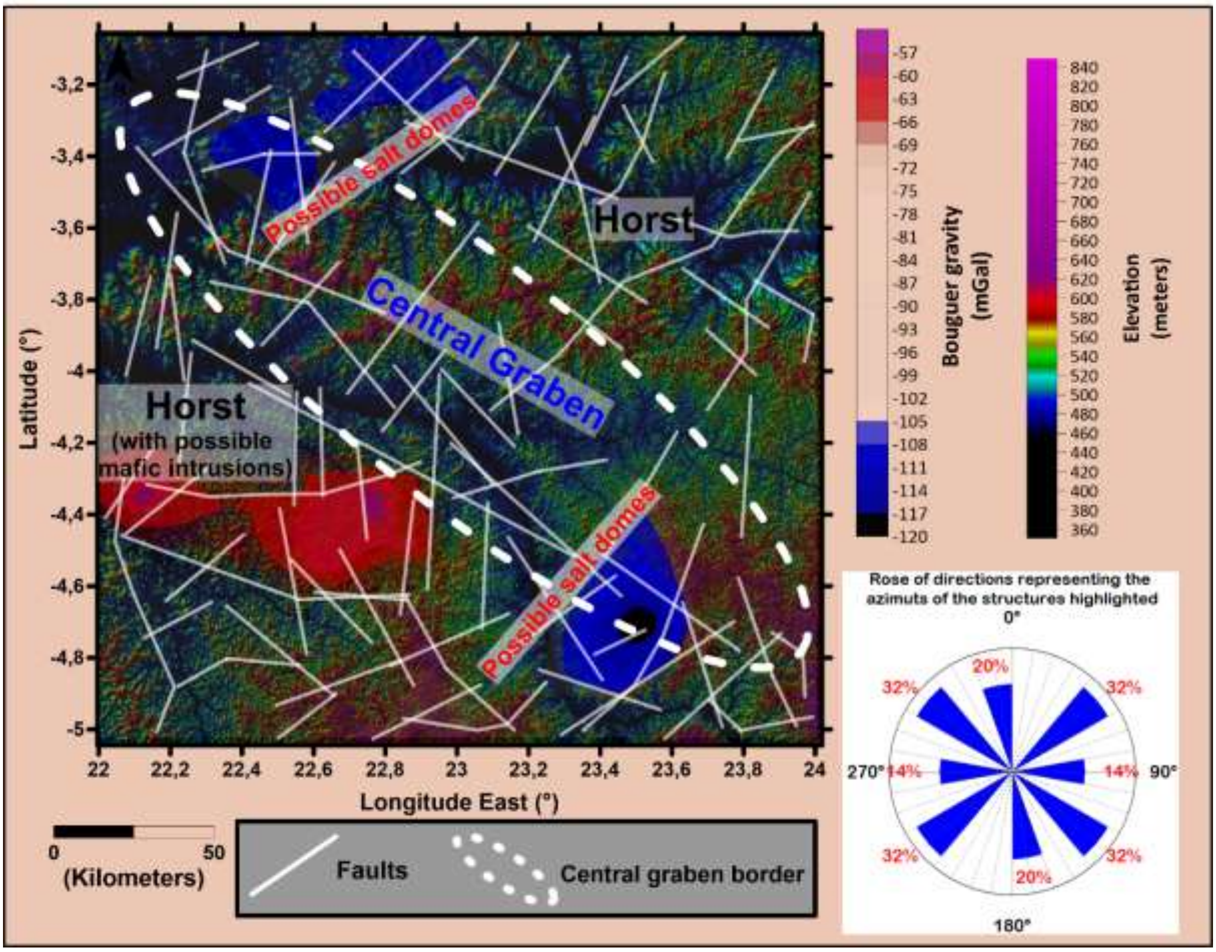


**Figure 12: Structural map of the study area.**

This map was produced by superimposing the results obtained on a background of altitude variations produced by the DEM. We therefore make the following observations:

- An important rifting event has shaped this zone by establishing a large central collapsed zone forming a NW-SE graben and raised peripheral reliefs forming horsts to the north-east and south-west;
- Several faults of large extension oriented parallel to the central graben are strongly linked to this crust stretching event at this location. These NW-SE faults are therefore of the normal type and the directional rose indicates that they represent 33% of all the faults detected in this region;
- Some major faults (also 33%) line up in the NE-SW direction which is perpendicular to the graben while other faults are oriented in the E-W (14%) and N-S (20%) directions;
- The horst of the south-western part is characterized by high intensities of both gravity and magnetic anomalies, which leads us to believe that the basement uplift would most certainly be accompanied by mafic intrusions at this location;
- The large negative gravity anomalies of almost circular shape reveal the geophysical signature of the salt domes resulting from halokinesis due to salt uplift in the graben.

All the geological structures identified on this structural map are of petroleum interest. The central graben represents an area of major petroleum interest because, in general, the petroleum-bearing sedimentary basins are filled with several kilometers of sediment. These great thicknesses of sediments called "depocenters" are favorable places for the generation of hydrocarbons because the maturation conditions of the source rocks are proportional to their depth of burial. The multiple faults highlighted can constitute traps (faults-traps) but they can also promote the migration of hydrocarbons towards the salt domes which are excellent oil traps but also towards raised areas above the horsts.

## 6. CONCLUSION

This structural study was based on the interpretation of gravity and magnetic data from oil blocks 18 and 18b located in the south-east of the Cuvette Centrale sedimentary basin in DR Congo. Sankuru province occupies about 80% of the area while the remaining part is occupied by Kasai and Kasai Central provinces. Through this study, we noted that the region was affected by



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several tectonic events, the most important of which was the rifting stage which shaped the area into horst and graben. On gravity and magnetic maps, the horsts are characterized by high anomaly intensities and the central graben is an area of low anomaly intensities. This structural configuration confers great petroleum interest on the central graben in which the organic matter contained in the source rocks has a high probability of reaching maturity. The oil thus formed could be trapped along faults to form fault-traps or migrate to be trapped on the flanks of salt domes or on raised areas above the horsts. For a better understanding of these two blocks, we estimate that by multiplying the field campaigns (geological and geochemical surveys) and by reducing the mesh of gravity and magnetic surveys in the areas of interest, we would succeed in locating the zones to carry out a seismic survey on which the location of a first exploration drilling would depend.

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