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Interpretation of Gravity Data and Contribution in the Structural Study of the Southern Part of the Congo Basin: Case of the Kasaï Region in D.R. Congo

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Abstract:- The Kasai region is an area historically known for its wealth in minerals such as diamonds and gold. This study aims to study the structural geology of the northern part of the Kasai province in the D.R. Congo in order to guide future mining and oil prospecting. The analysis of the gravity data using the regional-residual separation method, the vertical and horizontal derivatives as well as the estimation of the depth of the sources of the anomalies by the Euler deconvolution method allowed us to identify and study several gravity signatures that can be associated with geological structures of economic interest. Thanks to the results obtained, we have produced structural maps in which all the identified geological structures have been well defined. The northern part of this zone is occupied by a gigantic high gravity while the southern part, for its part, is characterized by several gravity depressions. By analyzing the gravity maps of this area, we found that the structure of our study area is arranged in Horst (uplifted part in the north) and grabens (subsided part in the south). This interpretation is all the more supported by the fact that the anomaly contrast between these two structures is very clear, which could indicate the presence of a series of faults oriented in the NW-SE direction. Several gravimetric signatures representing structures that can promote the migration and trapping of hydrocarbons such as faults, antiform folds and salt domes have also been identified in this part. The southern part of the zone is located around the Archean rocks of the Kasaï craton which is very rich in minerals. Negative anomalies could be associated with diamondiferous kimberlite intrusions that are abundant in the region while positive anomalies could reveal the concentration of economically important metal ores.

Keywords:- *gravimetry, geology, structure, mine, oil, Kasai region.*

I. INTRODUCTION

The Kasai region in D.R. Congo is a poorly explored area despite its enormous mining and oil potential. According to the Technical Cell for Coordination and Mining Planning (CTCPM), 2003 [1], the main minerals found in this area are Diamond (in abundance) as well as several indices of minerals such as iron, gold, chromium, nickel, cobalt, platinum, copper, kaolin and lead. Although no economically exploitable oil discovery has taken place in this region, it has nevertheless always aroused great interest about its hydrocarbon potential. The only seismic reflection line (L59) as well as the only drilling (Dekese-1), which is of stratigraphic type, present in this zone revealed important structures and stratigraphic units which can be respectively considered as oil traps and rocks reservoirs. The present study therefore concerns the recognition of the geological structure of this area based on the analysis and interpretation of gravity data.

II. MATERIAL AND METHOD

A. MATERIAL

In addition to the gravity database of the study area, we used software that allowed data analysis, processing and modeling. This software has allowed us to produce 2D and 3D maps, to draw profiles, to perform various processing methods and to interpret the results obtained.

B. METHOD

The method used to carry out this study can be summed up in three stages:

- The first step is the data acquisition. It consisted in listing all the gravity measurement stations located in our study area in a database. These stations come mainly from the gravity campaign carried out by the “Société de Recherche Minière en Afrique (REMINA)” between 1952 and 1956 and the “Compagnie Générale de Géophysique” (CGG) (1986);
- In the second step, we proceeded to data processing and mapping of the results obtained. To do this, the regional-residual separation method, the vertical and horizontal derivatives, the upward continuation as well as the estimation of the depth of the sources of anomalies by the Euler deconvolution method allowed us to produce several maps identifying gravity signatures that may be associated to geological structures of economic interest;

- The third step was to interpret the results. At this stage, it was a question of giving a geological significance to the gravity signatures identified on the maps and profiles produced.

III. GENERAL OVERVIEW OF THE STUDY AREA

A. LOCATION

Our study area is located between 20°3’ and 22°11’ East longitude and 3°4’ and 5°9’ South latitude. Almost all of this area is located in the province of Kasai while a western part of the area is located in the neighboring province of Mai-Ndombe. It crosses the territories of Dekese, Mweka, Ilebo and Oshwe. Note that the area has an area of about 50,000 km² (fig. 1).

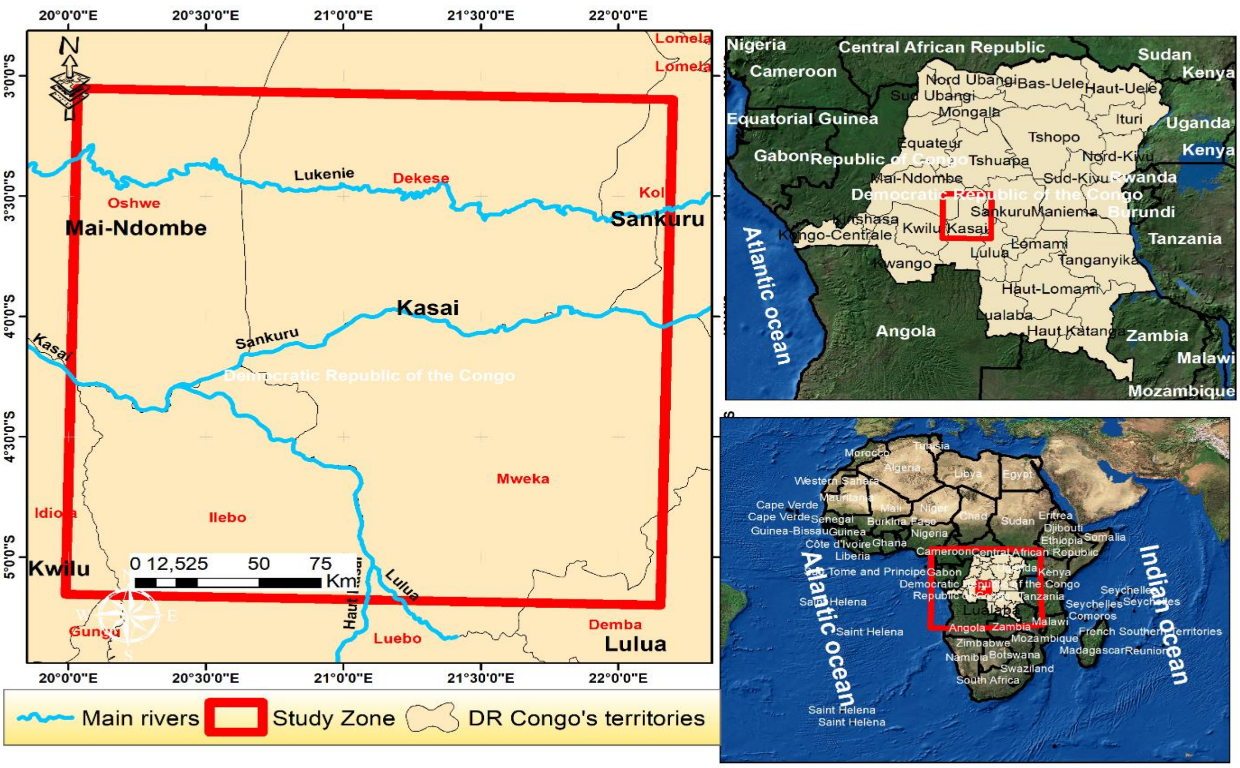

Fig. 1: Map of the location of the study area.

B. GEOGRAPHY OF THE STUDY AREA

According to the Koppen classification, the area is characterized by the climate type Am in which the average annual precipitation is 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 that can be grouped into 3 types from North to South (General Secretariat for the Environment, DRC, 1999 [2]):

- Equatorial evergreen rainforests;
- The semi-cadulated subequatorial and Guinean mesophilic forests, economically more important;
- The subequatorial and Periguinean semi-cadulated mesophilic forests.

Its altitude varies between 360 m to 680 m. The area has an important network of rivers, the most important of which are the Lukenie river in the north, Sankuru River in the center and Kasaï river in the south.

C. GEOLOGICAL FRAMEWORK OF THE STUDY AREA

The stratigraphic and structural geology of this zone was studied in the northern part by the seismic profile L59 and the stratigraphic well of Dekese-1 (3°27'26"S; 21°24'28"E) (fig. 2). 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. It stopped at a depth of 1,856 m, and did not reach the base of the quartzites. Therefore, the entire sequence from the Lower Paleozoic to the Neoproterozoic was therefore not crossed by this well.

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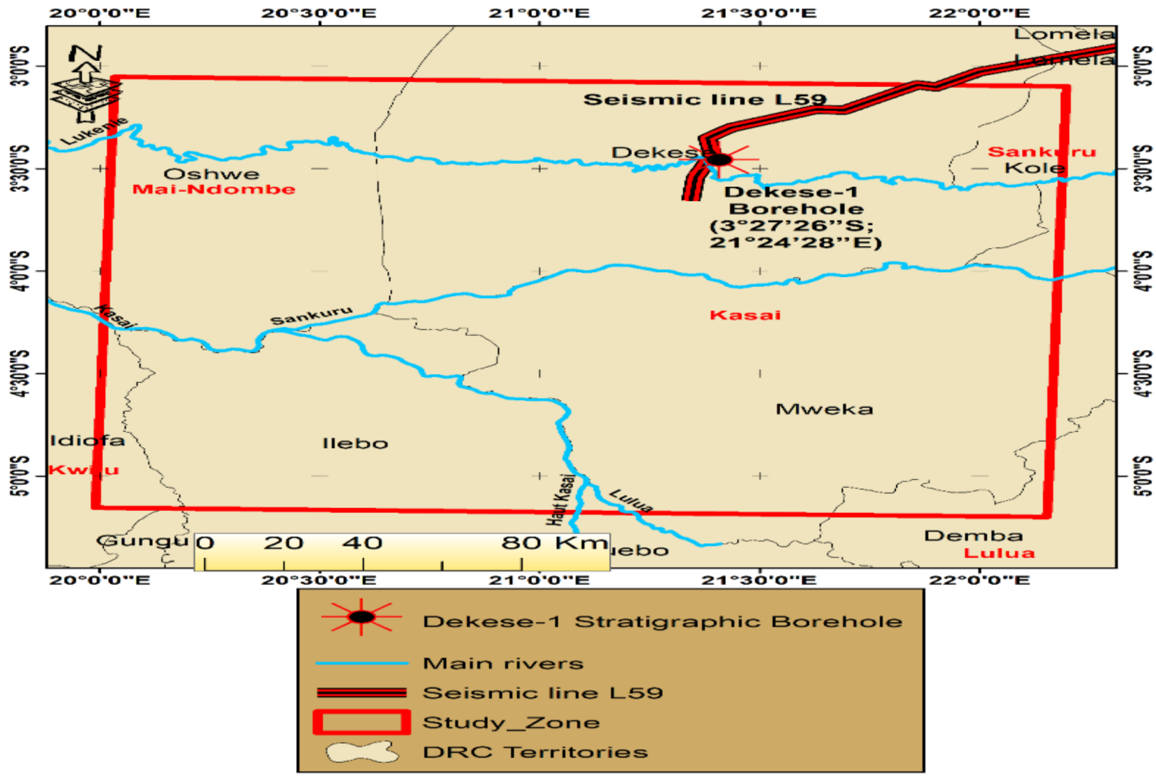

Fig. 2: Location map of the seismic profile L59 and the stratigraphic well of Dekese-1.

However, the geochronology of Archean and Proterozoic rocks in this area has been studied by several authors including Cahen and al., 1984 [4] and is presented as follows:

a) Archean rocks:
They are composed from bottom to top of:
- The complex of gneisses and granulites from Haute-Luanyi dated at 3.5 Ga;
- The gabbro-noritic and charnockitic complex of Kasaï-Lomami;
- The complex of migmatites and migmatitic granites of Dibaya dated to 2.6-2.7 Ga.

b) Lower Proterozoic rocks:
they are represented by the Luiza metasedimentary complex and the Lukochien complex.

c) Middle Proterozoic rocks:
this is the volcano-sedimentary complex of Lulua made up of feldspathic sandstones, arkoses, conglomerates, limestones and some basaltic lavas. The lavas have been dated to 1.4 Ga.

d) Upper Proterozoic rocks:
they are represented by the Bushimay Supergroup which is about 1,600 m thick, and which includes from top to bottom:
- The schisto-limestone group (more than 1,030 m of power): it includes amygdaloid basalts at the top and a powerful calcoro-dolomitic group with past schist rocks (dark schists, dolo-schists, ...) as well as quartzites towards the base;
- The schisto-sandstone group (more or less 450 m of power): It includes conglomerates, red clayey schists and psammites, psammites and psammitic sandstones as well as cherto-dolomitic intercalations.

IV. PRESENTATION OF DATA

The gravity data used in this work were acquired by the 'Société de Recherche Minière en Afrique' (REMINA) which collected approximately 6,550 stations in the Congo Basin between the years 1952 and 1956 (P. Evrard, 1957 [4]). On this, we added a source of gravity data acquired by airborne by the CGG in 1986. These data were provided to us by the National Hydrocarbons Company of Congo (SONAHYDROC). They were then reduced using the classic Bouguer anomaly formula for a reduction density of 2.67 g/cm^3 in which a series of corrections are applied to the raw measurements in order to eliminate non-geological causes of variations in gravity, including topographic correction. Note that it is not easy to represent all of these data in this work due to their multitude, which justifies the choice of the first 10 stations for illustrative purposes (tab. 1).

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N° Station	Longitude (°)	Latitude (°)	Elevation (m)	Gravity (mGal)	Free-Air Anom. (mGal)	Bouguer Anom. (mGal)
001	20.0117	-3.0233	393	977889.4	-35.3	-79.3
002	20.0433	-3.4133	358.5	977895.6	-43.7	-83.8
003	20.045	-3.45	431	977877.3	-40	-88.3
004	20.0517	-2.9717	398	977884.8	-37.9	-82.5
005	20.0533	-3.3783	363.5	977896.1	-41.3	-82
006	20.0633	-3.4867	425	977885.3	-34.3	-81.8
007	20.0783	-3.5083	400.5	977895.2	-32.2	-77
008	20.09	-3.3767	342	977899.3	-44.7	-83
009	20.1067	-3.5433	434	977890.3	-27.1	-75.7
010	20.13	-3.5617	449	977891.3	-21.7	-72

Table 1: Sample of gravity data used

V. DATA PROCESSING METHOD

The geological interpretation of gravity data is facilitated by filtering the data through various mathematical filters. The various operations that we used for the realization of this study are described in the following points

A. THE REGIONAL-RESIDUAL SEPARATION

We performed this processing in order to attenuate the regional field coming from the deep structures in order to enhance the residual anomalies for the identification of the structures generally located more or less close to the surface. In our case, two types of frequency filters were applied to the Bouguer anomaly data. These are the low pass and high pass filters.

a) The low pass filter performed two operations at the same time because it attenuated the high frequencies and it highlighted only the low frequencies. This kind of filter produces a map of regional anomalies that is smoother than that of Bouguer anomalies. The difference between the total signal (Bouguer) and the low-pass filtered signal (Regional) is shown by the graph below (fig. 3).

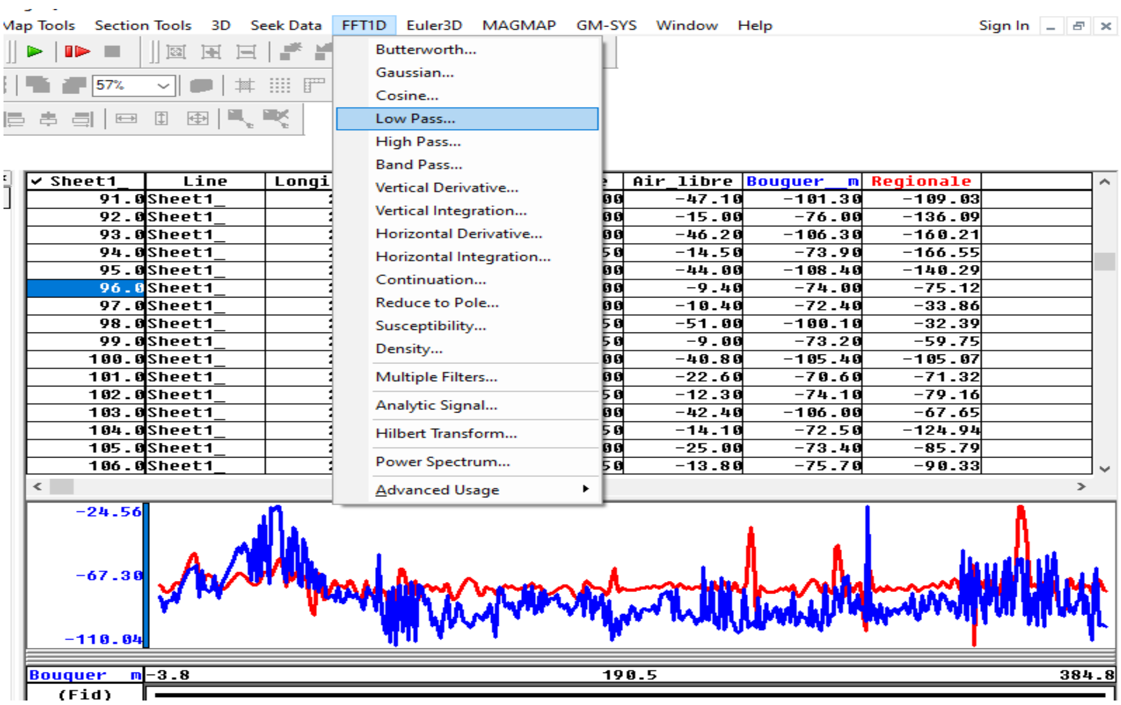

Fig. 3: Application of the low-pass frequency filter in the Geosoft Oasis Montaj software.

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In the figure above, we can see that the curve of the total signal (in blue) has several roughness related to the high frequencies still present in the signal, while the curve of the low-pass filtered signal (in red) is smoother. This smoothing proves that the disturbing noises of the high frequencies related to the residual anomalies have been extracted from the total signal.

b) The high pass filter attenuated the low frequency anomalies and enhanced the high frequency anomalies. The difference between the total signal (Bouguer) and the high-pass filtered signal (Residual) is shown by the graph below (fig. 4).

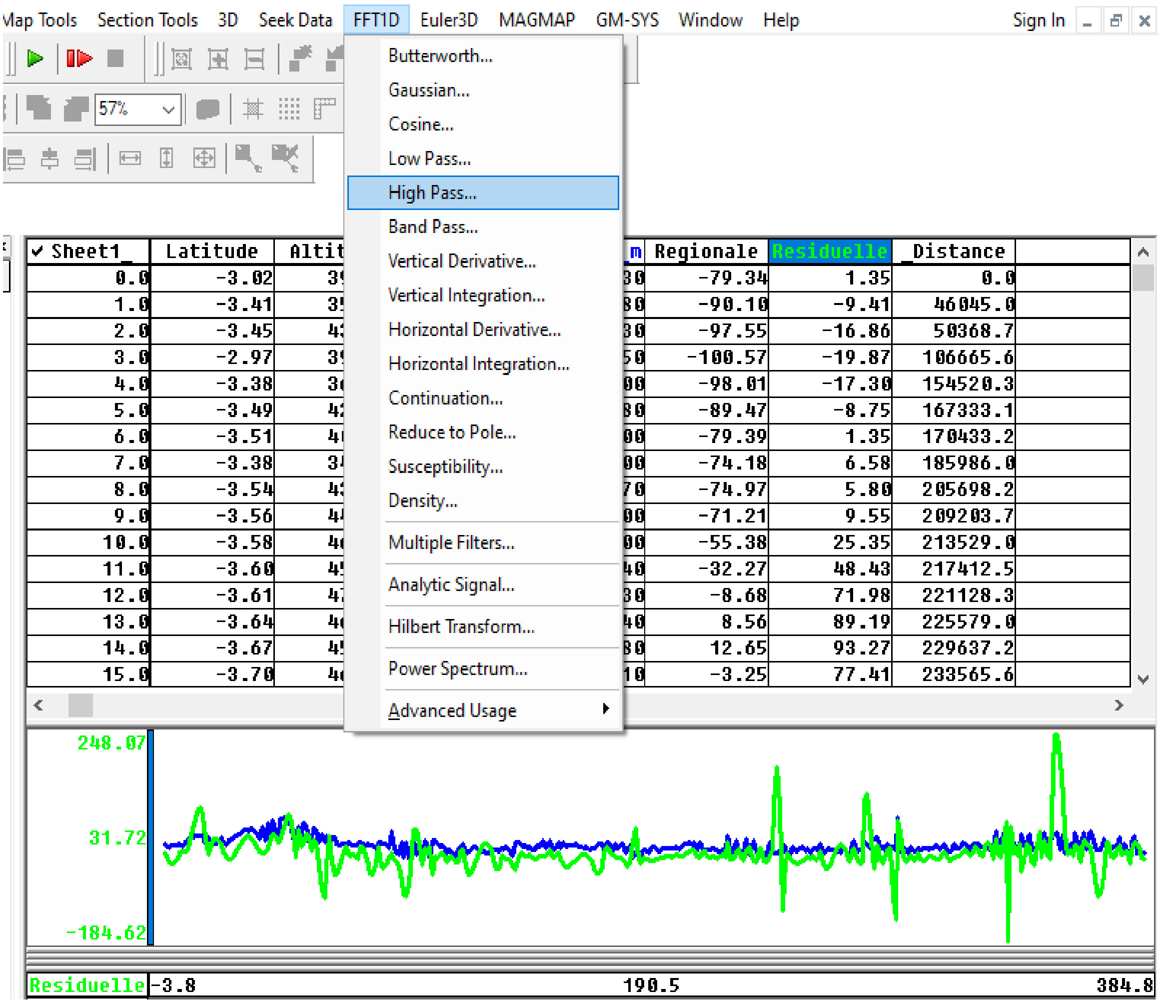

Fig. 4: Application of the high-pass frequency filter in the Geosoft Oasis Montaj software.

Here we notice that the curve of the high-pass filtered signal (in green) retained only the anomalies of weak extension while attenuating the large regional variations. Thus, based on this method of regional-residual separation, we have developed maps of regional and residual anomalies in our study area.

B. THE TOTAL HORIZONTAL GRADIENT (THG)

The Total Horizontal Gradient filter is used to locate the areas of maximum gradient of the variation of the gravitational field. Indeed, above a vertical contact the anomaly is materialized by a curve having a minimum on the low-density rock side and a maximum on the high-density rock side (N. El Goumi and al., 2010 [5]). The point of inflection of the curve is directly above this contact. However, after calculating the Total Horizontal Gradient, this anomaly becomes a maximum. This is what facilitates and improves the identification and mapping of lineaments. For example, figure 5 below shows the anomaly created by a contact and the corresponding horizontal gradient on a profile perpendicular to this contact.

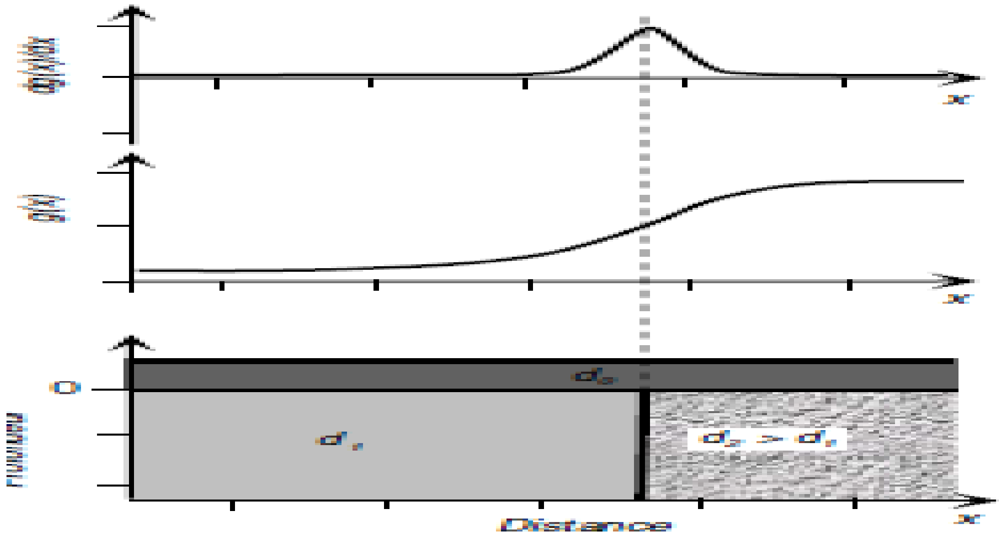

Fig. 5: Difference between the curves of the horizontal gradient and the Bouguer anomaly above a contact (Jacques Dubois, 2011 [6]).

This figure shows us that the Total Horizontal Gradient calculation can therefore make it possible to better identify a contact between two rocks of different density, hence the importance of the application of these horizontal derivatives in the detection of faults in our study area. This filter was applied as follows (fig. 6).

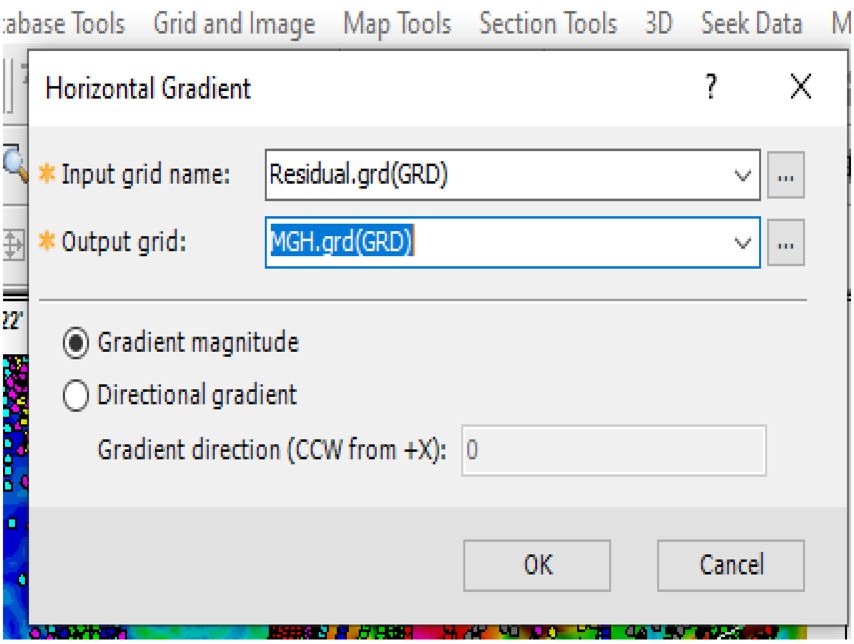

Fig. 6: THG application window in Geosoft Oasis Montaj software

C. EULER DECONVOLUTION METHOD

Euler deconvolution is an analytical filtering method that allows the localization of sources of anomalies. The application of the Euler deconvolution to the gravity data map uses the three derivatives along X, Y and Z. For this method, the correct estimation of the source depths depends on the appropriate choice of three parameters The structural index N, the step of the calculation window W and the tolerance T. The Euler3D extension of the Geosoft Oasis Montag software allowed us to carry out this operation in the following way. Figure 7 below shows us the command window (Euler3D_ Standard eulerdecon...) to do the Euler deconvolution. In this example, we have chosen a Structural Index N = 1 (location of faults or contacts), a calculation window W = 10 and a tolerance T = 5% (fig. 7).

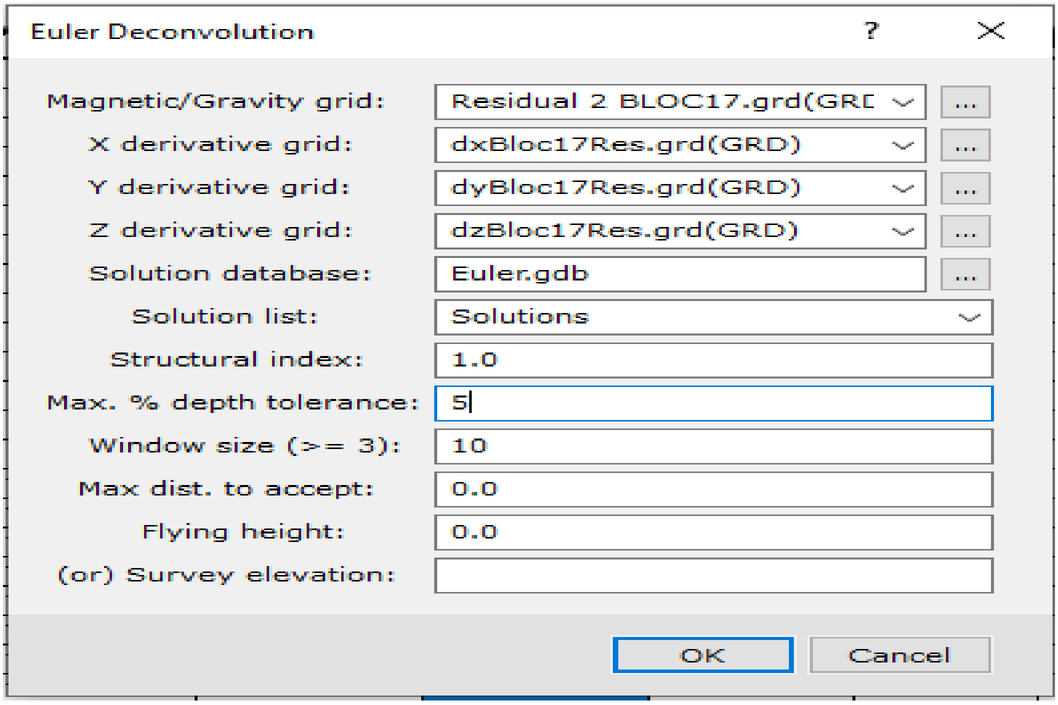

Fig. 7: Calculation of Euler deconvolution in Geosoft Oasis Montag software

VI. RESULTS AND INTERPRETATIONS

A. BOUGUER ANOMALY MAP

On the Bouguer anomaly map below (fig. 8), we observe quasi-circular shaped anomalies and linear anomalies that allow us to better understand the geometry of the geological masses that create the anomalies. We also note that all Bouguer anomaly values are negative. This indicates the predominance of low-density geological substances resting on a dense crystalline basement.

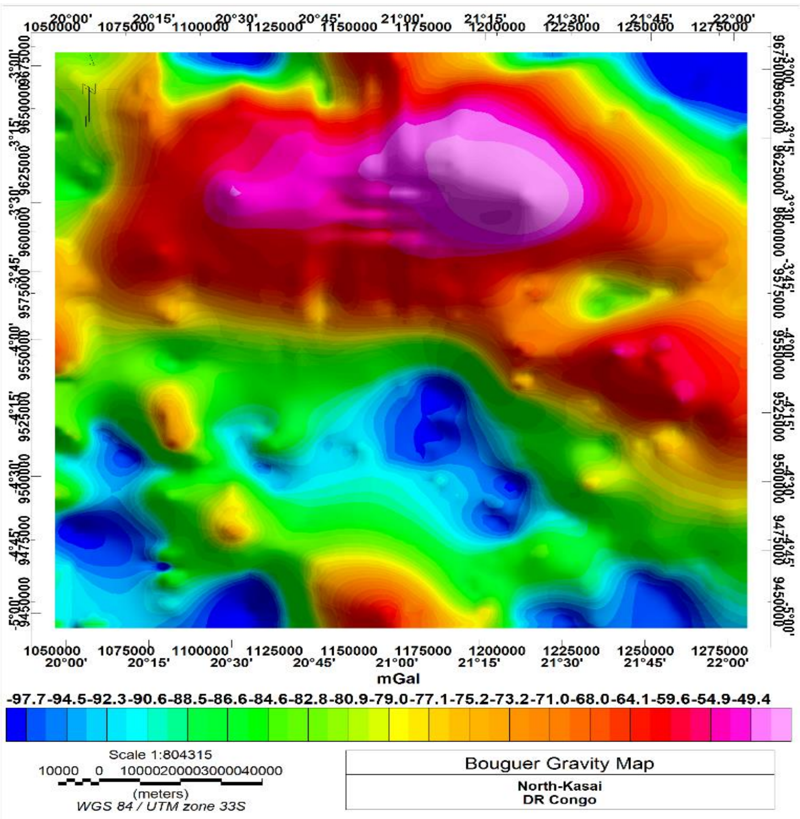

Fig. 8: Bouguer anomaly map

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In the northern part of the map, we see the presence of a large anomaly oriented in the E-W direction. This large structure is characterized by weak anomalies on the outside towards the high values of anomalies on the inside could indicate an uplift of the basement due to compressive events. The anomaly peak of this gravity high reaches the value of -26.2 mGals which is the highest in this area. This uplift would have led to the formation of anticlines: this is the great dome of the Dekese region. Other high anomalies vary in the same direction and tend to indicate the presence of a basement uplift of low amplitude and extension than that of the northern part. We speculated that this would have led to the formation of our second group of anticlines. Note also that amagmatic intrusion in sedimentary rocks can also cause this kind of anomalies.

Low-intensity anomalies (around -97 to -92 mGal) are mostly located south of our study area. These are the lowest anomalies in this area, this indicates that the density of geological formations is low, indicating significant subsidence at this location. Geologically speaking, these series of negative anomalies indicate the depressions where the presence of mature source rocks can be detected. The sharp contrast of anomalies located between high values of anomalies in the north and weak values in the south, could indicate the presence of a series of faults oriented in the NW-SE direction separating the uplifted northern part (horst) and the southern part depression (graben).

On this map, we also notice that the Dekese dome belongs to a more regional uplift trending NW-SE. The limits of this structure are characterized by strong anomaly gradients (-90 to -65 mGals). The southern part, in particular the territories of Ilebo and Mweka, is occupied by very low anomaly intensity values (-80 to -110 mGals). In this part, we notice a zone having the shape of a corridor with average quasi-circular anomalies ranging from -80 mgals to -55 mgals.

B. THE RESIDUAL ANOMALY MAP

The map of residual anomalies shows us small local disturbances of the gravitational field which are secondary in size but essential in the study of geological structures (fig. 9). The generating sources of this type of anomalies are generally shallow geological structures (mineral deposits, surface faults, folds, salt domes, cavities, etc.).

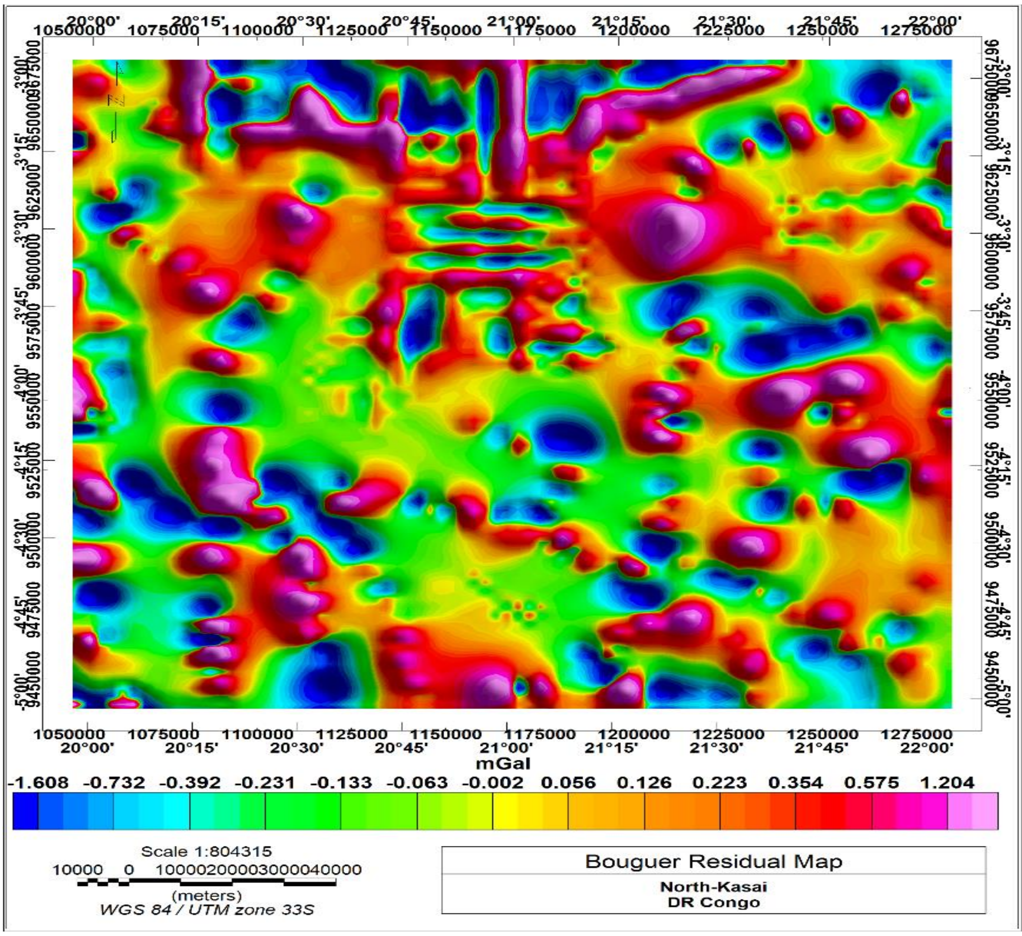

Fig. 9: Residual anomaly map

On this map we notice the presence of positive and negative anomalies of quasi-circular shape. Note also the attenuation of the dome-shaped anomaly to the north of the study area and of the gravity depressions to the south of this area. The shape and intensity of these anomalies tell us about the type of structures present in this area:

- Positive anomalies indicate the presence of anticlinal folds affecting the sedimentary cover. Indeed, an anticline produces a positive and symmetrical gravity anomaly. This is how we observe several positive residual anomalies in the North which would be antiform structures generated by the compression and uplift of the basement at this location.

It should also be noted that this type of anomaly can also indicate the presence of high-density mineral substances such as most of the metallic ore deposits found in the southern part of this zone. Magmatic intrusion in the sedimentary column could generate similar positive anomalies.

- Negative anomalies indicate the presence of syncline structures or salt domes. Indeed, several studies (ECL, 1988 [7]; Kadima and al. 2011 [8]) have attested to the presence of evaporites in the deep strata of the Congo Basin. Since the salt is a lighter substance than the surrounding rocks, there will be a negative density contrast which will have the effect of locally reducing the intensity of the anomalies. This is how negative gravity anomalies are generally observed above salt domes. A few examples such as the "Way dome" in the Gulf of Mexico and the "Grand Saline dome" in Texas should be noted (G. R. Foulger et al., 2002 [9]).

C. THE TOTAL HORIZONTAL GRADIENT (THG) MAP

The map of the Total Horizontal Gradient allowed us to locate the zones of maximum variations of the Bouguer anomaly corresponding to lineaments representing faults, fold axes or lithological contacts (fig. 10)

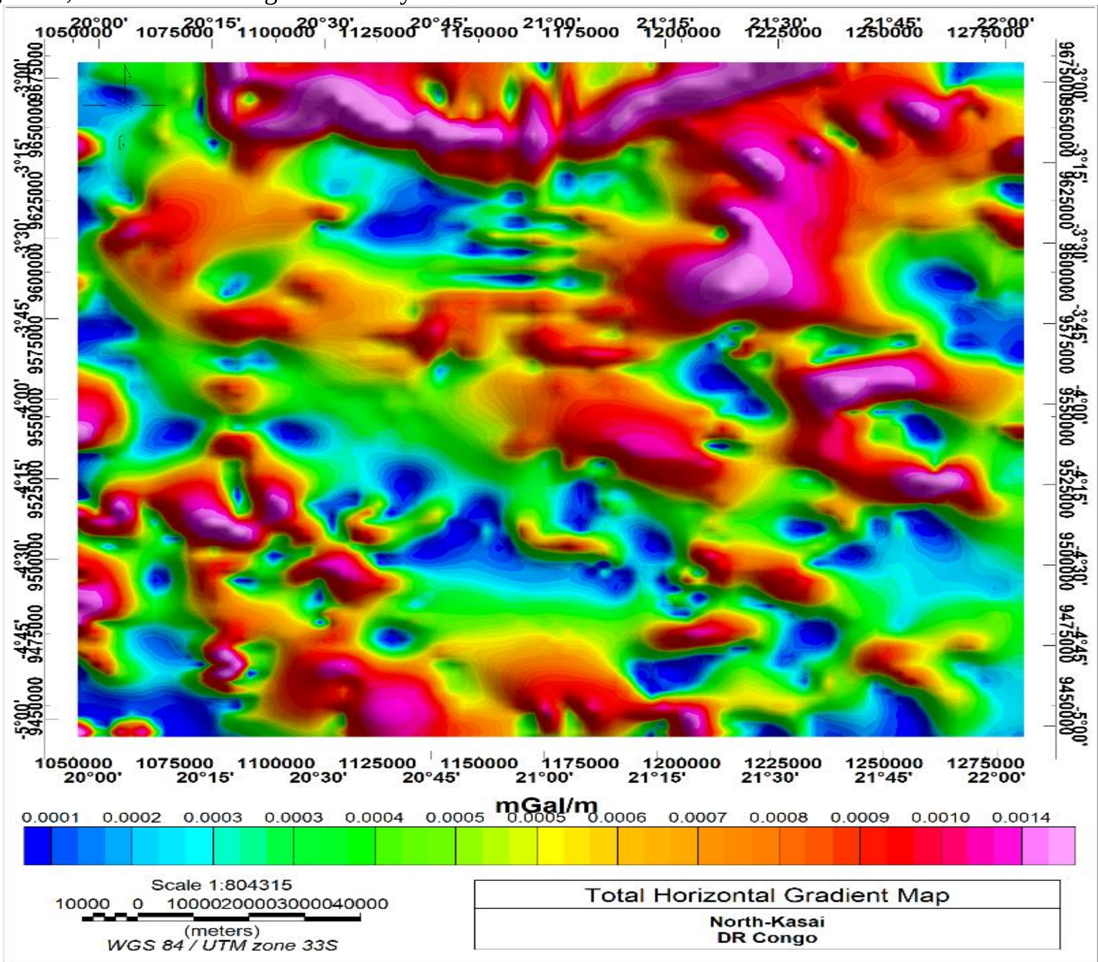

Fig. 10: Map of the Total Horizontal Gradient of the Bouguer anomaly

On this map, the maxima of the horizontal gradient represent the zones of sudden variations of the Bouguer anomaly. These areas which have the reddish color represent faults, contacts and/or fold axes. We notice that these areas are more extensive in the northern part compared to the southern part of the study area, more precisely around the large dome of Dekese. This shows that the flanks of this dome are surrounded by several faults as the variations of the Bouguer anomalies are very important.

D. ENHANCEMENT OF LINEAMENTS AND ESTABLISHMENT OF THE STRUCTURAL MAP OF THE STUDY AREA

The study of lineaments is very important for the lithostructural characterization of a region. Indeed, these lineaments can represent faults, fold axes or lithological contacts. Lineament extraction was performed as follows:

- Applying the Total Horizontal Gradient (THG) filter;
- Automatic location of THG maxima and vectorization of the latter using the "CET Grid Analysis" extension of the Geosoft Oasis Montaj software (fig. 11).

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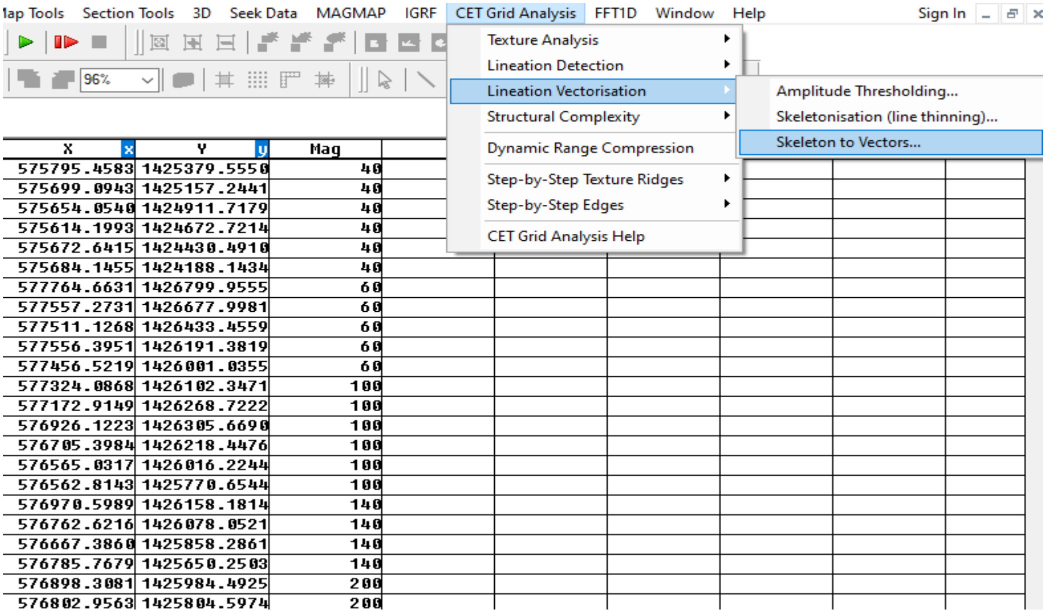

Fig. 11: Lineament vectorization in Geosoft Oasis Montaj software.

This lineament enhancement operation enabled us to produce the lineament map of the study area as well as the directional rose of these lineaments (fig. 12).

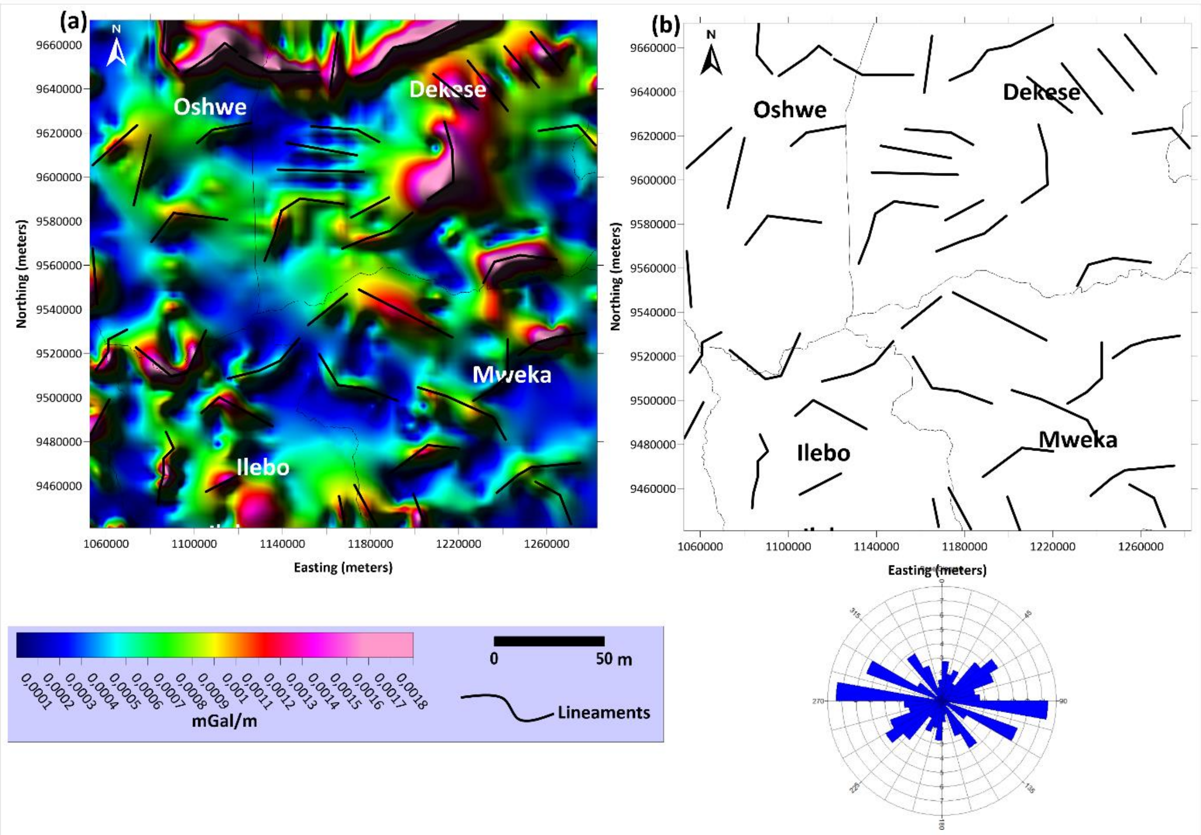

Fig. 12: (a) Lineament map superimposed on the THG map; (b) Lineament map with the directional rose

The northern part of the area (Dekese dome region) approaches the center of the Congo Basin, where the sedimentary cover is important. The lineaments found there would therefore be important oil and gas targets because these structures can respectively represent faults constituting hydrocarbon migration routes, or axes of antiform folds constituting oil traps. The southern part of this area is located around the Archean rocks of the Kasai craton in which several ores such as diamondiferous kimberlite (Michiel C.J. de Wit and al., 2015 [10]; Maarten J. de Wit and al, 2015 [11]) as well as iron (Royal Museum of Central Africa, RMCA, 2005 [12]) have been discovered. Gravity anomalies of kimberlites are generally negative (eg kimberlite intrusions in Quebec) (Michel Chouteau and al., 2006 [13]) while most metallic ores have very high densities compared to other geological substances in their

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environment (H.O. Seigel, 1995 [14]). Gravity method is therefore very often used to detect the presence of this type of mineral. Thus, the multiple lineaments of the southern part of this zone are of significant mining interest and will have to be the subject of several detailed geological, geochemical and geophysical surveys with the aim of discovering new ore deposits in this zone.

The automatic localization of the sources by the method of the deconvolution of Euler, for a structural index of N = 1 for the identification of the faults or contacts, made it possible to have a better outline on the depth of the sources. Figure 13 below shows the depth map obtained.

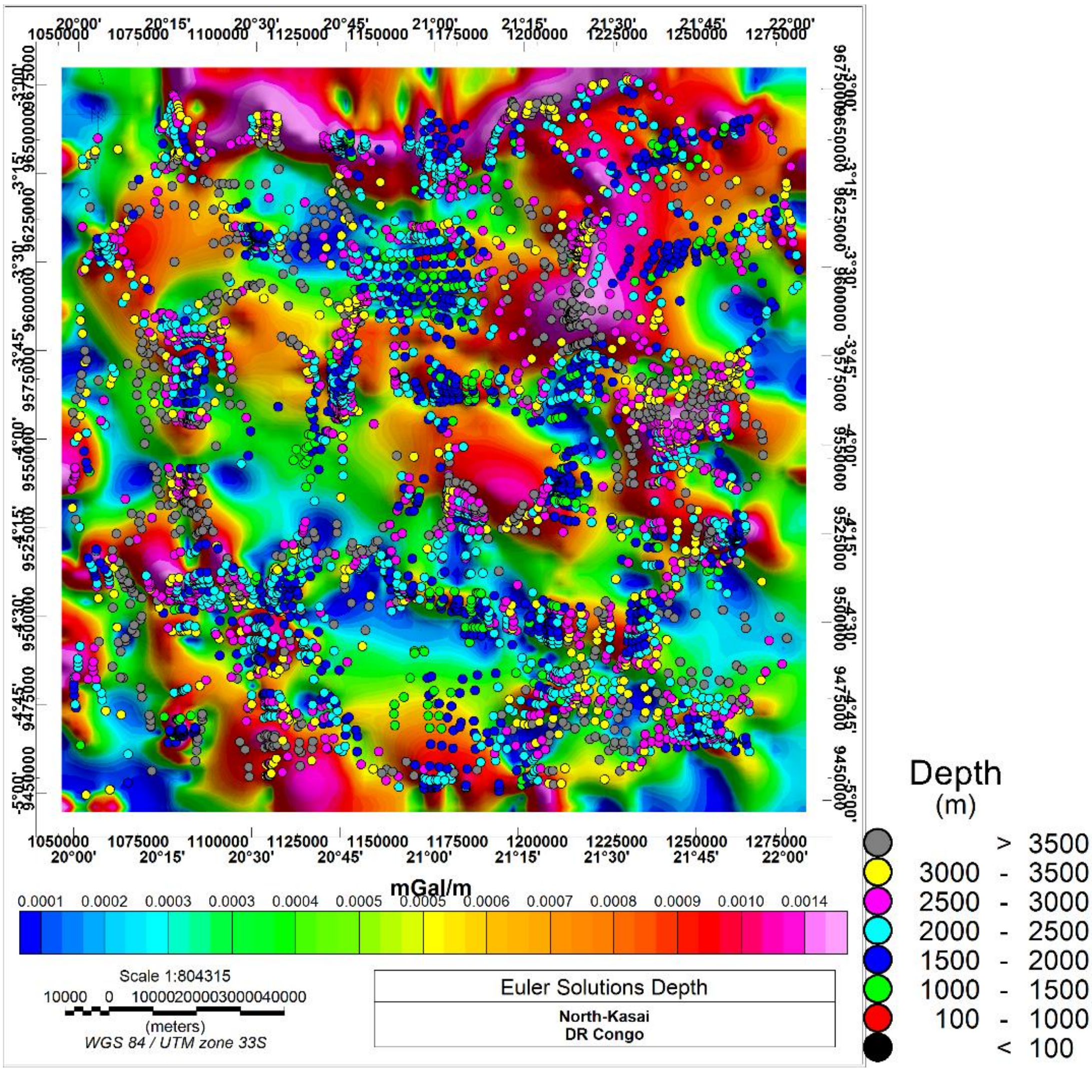
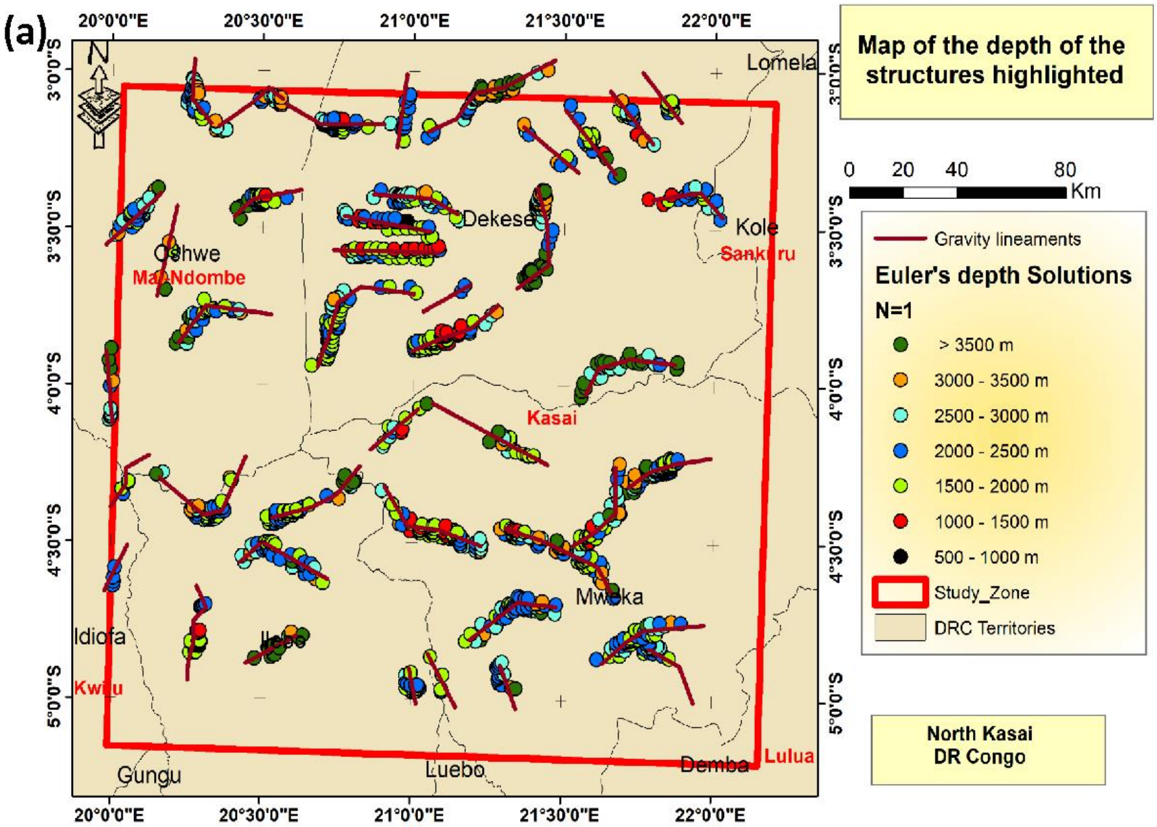


Fig. 13: Map of Euler solutions obtained with a structural index N=1

On the map above, the solutions found are, for the most part, located at depths ranging from 1500 m to 3000 m, while few solutions have been found beyond this depth range. After processing these results, we only selected the solutions crossing with the lineaments in order to estimate the depth of the latter as well as the histogram representing the statistical distribution of the depth of the sources of the Euler solution (fig. 14).

(a)



(b)

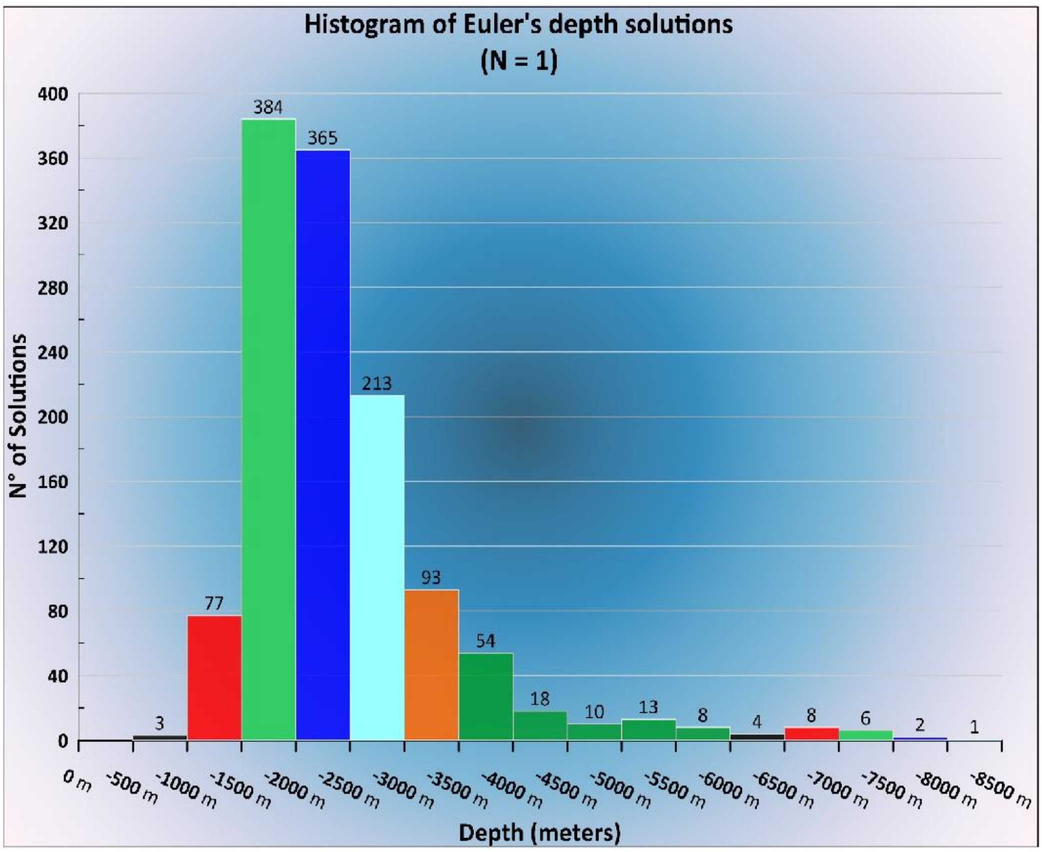


Fig. 14: (a) Lineament depth map; (b) Histogram of Euler solutions obtained with a structural index N=1

The processing of the Euler deconvolution with a structural index of 1 for the location of the structures and the histogram above show us a predominance of solutions located between 1500 and 3000 m. On the N=1 solution map, we see that the localized structures are oriented in several directions in our study area.

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VII. CONCLUSION

This study focuses on the recognition of the geological structure of the northern Kasai region based on gravity data interpretation. After the analysis and the interpretation of these data by using the several operations of transformation, we noted that the area was affected by several tectonic phenomena of which most important was the phenomenon of rifting having modeled the topography of the crystalline basement of this region by establishing a large uplifted area in the north forming a NW-SE trending horst and depressions in the southern part. The integration of all the geological information resulting from the interpretation of the gravity maps has enabled us to develop structural maps that improve our knowledge of the geological structures of petroleum and mining interest in this region. The processing of the Euler deconvolution with a structural index of 1 for the localization of the structures and the statistical analysis using the histogram show us a predominance of the depths of thehighlighted structures between 1500 and 3000 m.

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