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Study of the in-Depth Extension of Geophysical Lineaments Deduced from Magnetic Data in an Oil Block: Case of Block 10B in the Central Basin (Democratic Republic of the Congo)

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Abstract

This paper aims to study the magnetic data collected in block 10B of the central basin in the Democratic Republic of Congo. This block includes lineaments mainly of internal geodynamic origin. This is work that further deepens knowledge of the lineaments of the central basin, although analyzes and maps for oil research purposes remain complex (location, detection techniques, and enhancements). The lineaments play great importance in mining prospecting than in oil prospecting. Because often the lineaments are studied to know their relationship with the mineralization. This is why more or less objective interpretations by focusing on residual anomalies have been made in this paper. Indeed, the determination of the lineaments in blocks 10B is done to better understand the geological structures playing a petroleum interest. Thus, the interpretations of the various maps produced have revealed the prolongations of the lineaments in-depth, very useful for tracing the history of the migration of hydrocarbons and probable structures that could trap them. The particularity of this work is that it not only emerges from the groups of lineament and their extension in this area but also it is written among the rare works of interpretation of magnetic data in this region.

Subject Areas

Geophysics

Keywords

Lineaments, Geophysics, Central Basin, Geodynamic, Magnetic Data

1. Introduction

During geological evolution, the earth's crust has undergone complex shifts in various directions. The rocks of which it is composed have compressed into folds, the others have overlapped on each other, yet another one suffers from ruptures, etc. [1] [2]. As a result, the relief of the earth's surface has changed with the formation of mountains and deep depressions. Also, the most exhaustive information on the sign, duration, and speed of tectonic movements can be provided by analysis of geological data [3]. The most important among these are brought on the one hand, by lithology and on the other hand, by geological lineaments [4]. A lineament is a simple or compound line, detected on the surface, of which the different parts, aligned along a straight line or a curve, stand out distinctly from those around them and possibly reflect a phenomenon generated below the surface. These lineaments are associated with structural elements such as faults, fractures, fold axes and contacts lithological. They result in topographic depressions, by the network hydrographic and by vegetation anomalies [5] [6].

Several works on the study of lineaments have been carried out in the central basin much more on the basis of satellite imagery. The peculiarity of this work is that it emerges not only from the groups of lineaments and their extension in this area but also is written among the rare works' interpretation of magnetic data in this region. The study of lineament plays great importance in terms of knowledge of the tectonics of the sedimentary basin. Since the exploration is based on geological, geochemical, geophysical studies, drilling but especially on the interpretations of data from the aforementioned studies; the collection and interpretation of magnetic data explained in this paper enrich the existing data from the 1950s obtained by several foreign companies and organizations including the Brussels laboratories of TERVUREN, CGG, the Belgian firm REMINA, etc.

On one hand this paper aims to study the magnetic data collected in block 10B of the central basin in the Democratic Republic of Congo. This block includes lineaments mainly of internal geodynamic origin. When these forces come into activity in an intense way, movement tectonics is created between the asthenosphere and the lithosphere. And, according to the domain of their manifestation, we will distinguish the surface movements (from cover) associated with the processes that take place in the sedimentary sheath (for example, saliferous diapir folds), movements of the bark, which intervene practically in the whole volume of the solid bark, and the deep movements, conditioned by the processes that sit in the upper mantle. This results in plicative movements, blocks, massifs, earthquakes, fractures, all kinds of lineaments, and many more events according to Lepersonne, J. (1977); Kadima *et al.* (2011) [1] [7].

On other hand, this paper further deepens knowledge of lineaments of the central basin although analyzes and maps for oil exploration purposes remain complex (location, techniques of detection and enhancements).

In addition, this paper going to highlight some types of lineaments; distinguish the in-depth extension of these lineaments by establishing maps from residual and regional magnetic anomalies; show the petroleum interest of these lineaments in terms of migration and trapping. The main objective of this work is to analyze the magnetic data to contribute to the improvement of the existing geological information in this oil block, particularly by striking lineaments of internal geodynamic origin.

2. Presentation of the Study Area

Block 10B is located in the northern part of the Central Basin having as geographic coordinates 0˚10" to 1˚10" South latitude and 23˚ to 25˚ East longitude.

Its surface area is equivalent to 23,079.4 km^2 covers 5 territories namely:

- The territory of Opala occupies a large part of this Block; Ikela territory is located in the western part of Opala territory;
- The territory of Ubundu located in the eastern part of this Block;
- The territories of Djolu and Yahumu are located in the northwest part of Block 10B;
- Taking into account the oil blocks of the Central Basin, Block 10B is located:
- To the North by Block 5;
- To the south by Block 11;
- East by Block 12;
- West by Block 7;
- To the North-West, North-East, South-West, and South-East by Blocks 4B, 6, 9, and 13.

Relief

The topography of Oil Block 10B can be summarized as follows:

The low values of the altitude correspond to the areas of valleys or plains are located in the west, south-east part going towards the north; these low altitudes correspond a lot to stream alignments (thalweg zone); the plateaus corresponding to the high altitude zones (line of ridges) are located in the North-East, East, South-West, South, and a part located towards the North-West.

By observing the reliefs that exist in Block 10, it is observed that the type of relief that dominates is that of the plateaus and ridgelines also the ridge lines. The white-colored lines represent the thalwegs which by definition are lines that connect all the lowest points, and the black lines represent crest lines connecting all the high point [2].

3. Methology and Materials

After reading several scientific articles [8] [9] [10] [11] [12] [13] the authors adopt the following methodology:

- Data collection;
- Data acquisition;
- Data processing and interpretation;
- Result.

The dataset used in this study is collected from the aeromagnetic survey in the Democratic Republic of Congo by the Geophysical Research Center (CRG). Moreover, the treatment and interpretation of acquired magnetic data were done using appropriate software allowing 2D and 3D visualization, so it is about:

Geosoft Oasis montaj software (Core software of the Geosoft platform to process and map magnetic anomalies; Arc Gis 10.3 software (Geographic Information Systems Software, in acronym SIG); the Adobe family with lightroom 5 software for card saturation; microsoft offices including Word and Excel for word processing.

4. Magnetic Data Processing

The objective is to search for geophysical lineaments and to know the depth extensions that exist in Block 10B of the Central Basin. The magnetic data treatment done in this paper is similar to those used by [1] [4] [5] [14] [15] [16] [17] [18]. Thus, the treatment methods used are those which give us information on superficial anomalies, and on deep anomalies. This is why the use of the method of separation of anomalies; we were thus interested in residual, regional anomalies, the derivative tilt angle filter, analytical signal, vertical first and horizontal derivatives. Indeed, it has emerged from the residual anomalies of the Magnetic field from some filters that are mentioned above. To bring out the geophysical lineaments and to see the extension, the same filters were used as those applied to the regional anomalies.

4.1. Residual Magnetic Field Anomaly

The residual anomalies correspond to the high frequencies of the total signal; they are analyzed to study shallow geological structures (geophysical lineaments) generally located in the sediment cover [19]. It should therefore be understood that it can reason in terms of frequency and submit the data of the variation of the Magnetic Field to an analysis which will look for the high frequencies belonging to the residual anomalies in order to put in evidence the geophysical lineaments existing in Block 10B. In our case, the application of the high-pass frequency filters on the data of the variation of the magnetic field. These frequency filters show a precise distinction in the frequency domain for a given input signal [20]. High-pass filters remove background variations and enhance certain shallow details [21]. Based on these methods, develop the map of residual anomalies for the study area (**Figure 1**).

4.2. First Vertical and Horizontal Derivative from the Residual Magnetic Field

After obtaining the Residual Magnetic Field data, it is possible to calculate numerically, using a mathematical algorithm, the first and second vertical ($\mathrm{d}T/\mathrm{d}z$)

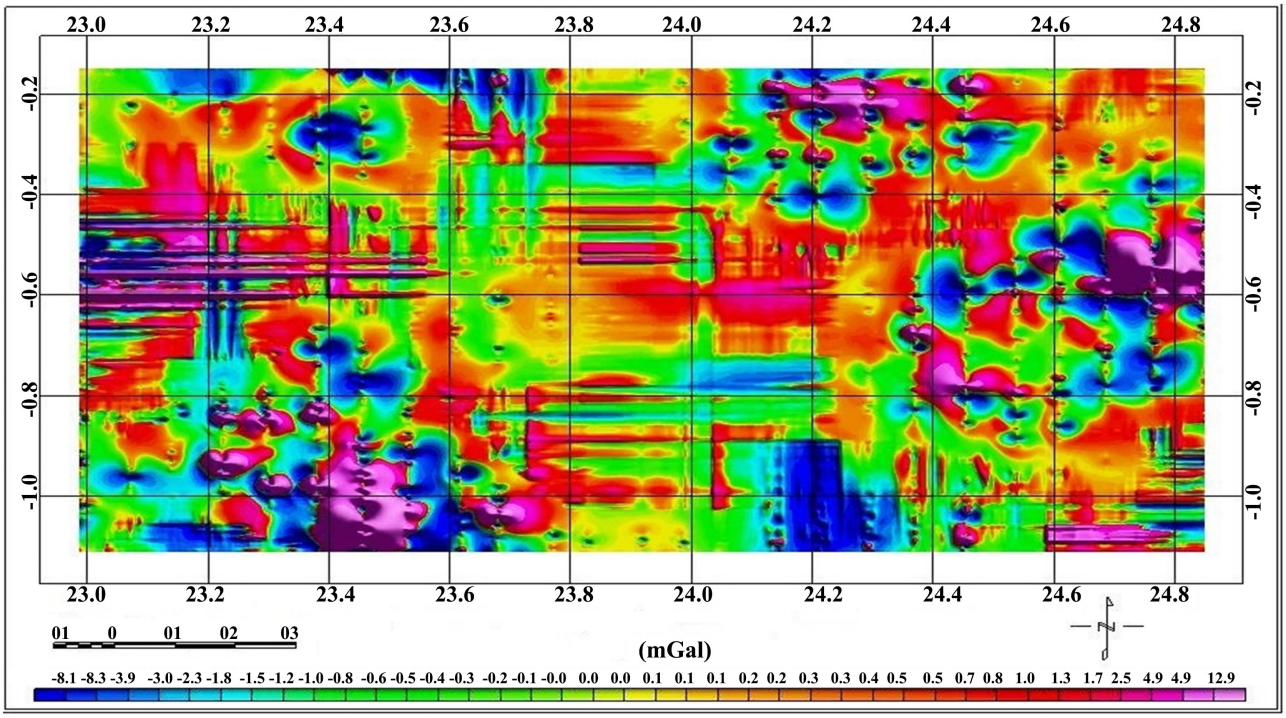

Figure 1. Map of residual magnetic field anomalies of block 10B.

and (d2 T/dz2) and horizontal (d T/dx and d T/dy). The first vertical derivative is often referred to as the vertical gradient of the Magnetic Field. Calculating the first and second vertical derivatives reduces the contribution from long wavelengths and significantly improves the resolution of weak, close-knit, or overlapping anomalies located closer to the surface. On the other hand, the horizontal derivative makes it easier to identify faults and geological contacts [22].

The first derivative identifies the presence of deeper regional anomalies, while the second derivative identifies and accentuates the presence of anomalies related to shallow sources [14]. **Figure 2** and **Figure 3** show the map of the first vertical and horizontal derivative of the variation of the Magnetic Field in Block 10B of the Central Basin.

4.3. Tilt Derivative

This operator is defined as the tangent arc of the ratio of the vertical derivative of the total field anomaly to the modulus of its horizontal gradient [18] [23] [24]. The derivative tilt technique is a data transformation method applicable to potential field data. It allows, among other things, to highlight relatively shallow bedrock structures. This transformation relates the ratio between the first vertical derivative (Z) and the total of the horizontal derivatives (X and Y). This value, therefore, represents the angle between the total horizontal derivative (X, Y) and the first vertical derivative (Z). This transformation reduces the amplitude variations between different anomalies while eliminating the regional gradient [20]. This filter allows underlining the secant lineaments and the Dykes.

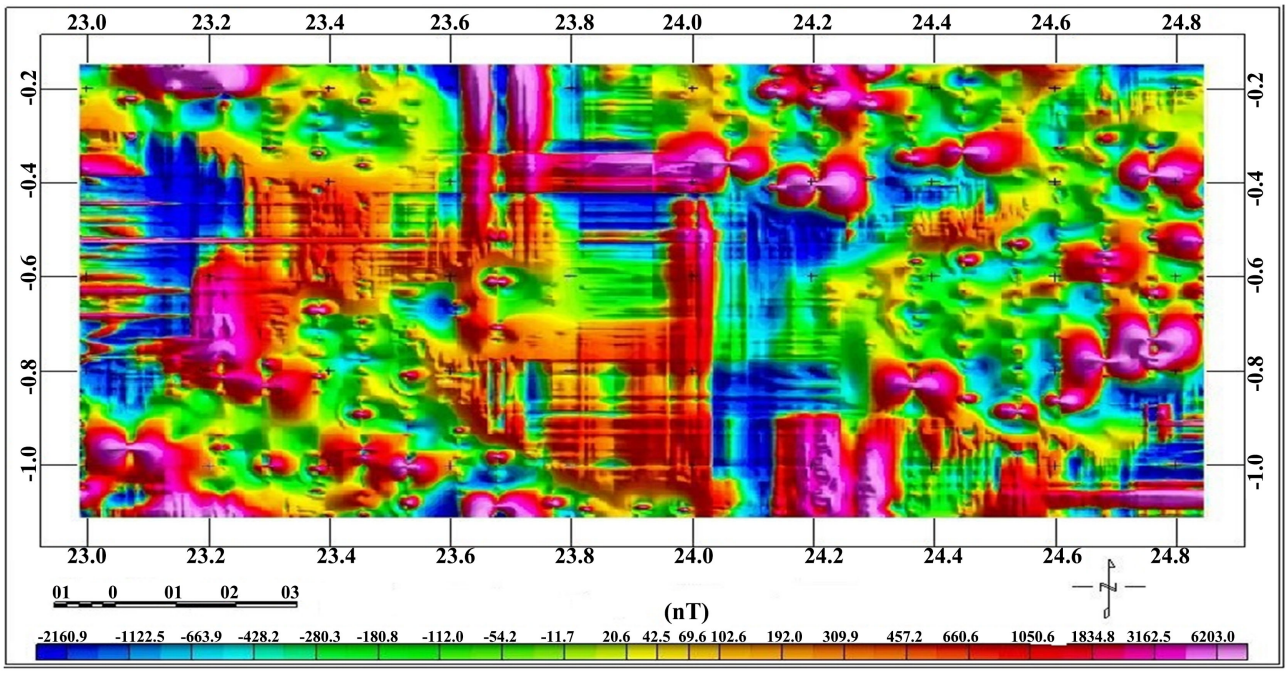

Figure 2. Map of the first vertical derivative of the residual magnetic field in block 10B of the central basin.

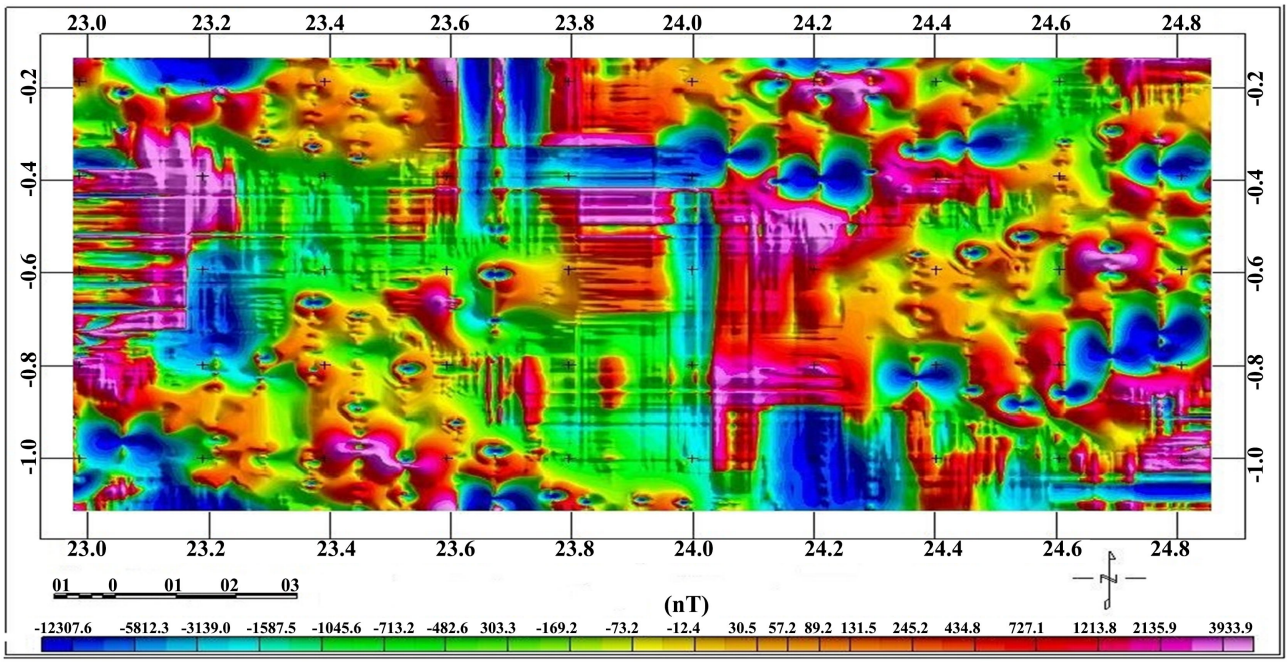

Figure 3. Map of the horizontal derivative of the residual magnetic field in block 10B.

4.4. Analytical Signal

Using another digital filter it is also possible to calculate what is referred to as the analytical signal. It is therefore the sum of the vertical and horizontal gradients of the residual magnetic field. Its properties are quite exceptional [17] [22] [25] [26]. It, therefore, combines the horizontal and vertical derivatives. Create peaks above the edges of large anomalies or in the center of small ones. Put in

evidence the entrainment lineaments [27].

4.5. Regional Anomalies

To find geophysical lineaments from great depths, it is important to develop regional magnetic field maps and filters to obtain these geophysical lineaments. Regular and continuous variations of the magnetic field over great distances called "regional anomalies" are produced by heterogeneities at great depths. Figure 4 illustrates the regional magnetic field map of Oil Block 10B of the Central Basin of the DRC.

To bring out the geophysical lineaments at great depths, it is important to use other filters like those are used in the previous pages on Residual Magnetic Field. The identification of geophysical lineaments located at great depths will allow knowing the in-depth extension of the lineaments highlighted from the various maps from the residual magnetic field [14] [28]. The different maps issued from the regional Magnetic Field map correspond to the same types of maps issued from the Residual Magnetic Field.

4.6. Enhancement of Geophysical Lineaments

The enhancement of the magnetic lineaments is structured under two main parts, the first of which is based on the enhancement of the lineaments from the different maps resulting from the residual anomalies of the total magnetic field and the second, on the highlighting of the lineaments from different maps since regional magnetic field anomalies (Figure 5). The enhancements of these lineaments from different maps since residual and regional anomalies will make it possible to mark some arguments about the oil interest of Block 10B.

From the map of the variation of the Residual Magnetic Field, two important types of lineaments were revealed:

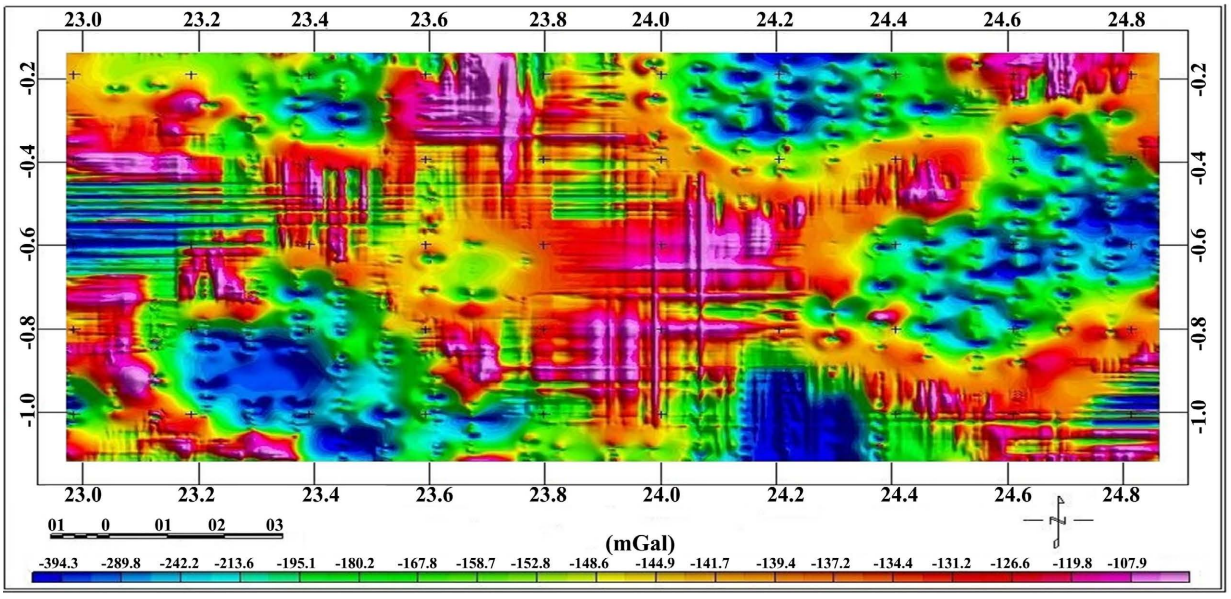

Figure 4. Regional magnetic field map of block 10B of the central basin of the DRC.

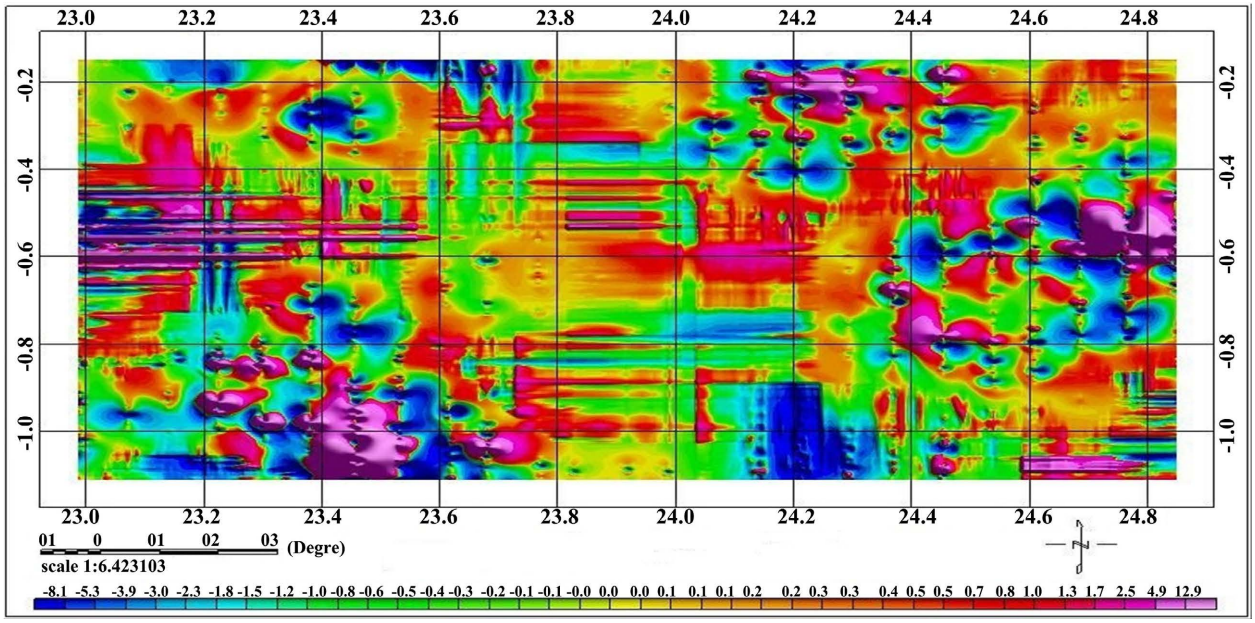

Figure 5. Map of residual anomalies of block 10B.

- The secant lineaments are located at the ends of the study area, the western part to the north; these secant lineaments are oriented West-East and are interpreted as brittle faults; they allow horizontal movements of the dexter and sinister compartments. These lineaments cut across the geological formations of the Pleistocene, the Pliocene, and certain veins of the Upper Jurassic and the Lower Cretaceous;
- The concordant lineaments are located in the western part towards the Center and the South; these lineaments are often interpreted as Dyke. The Dyke is a blade a few tens or hundreds of meters thick of igneous rock intersecting the surrounding structures. Due to erosion, it can give relief in the form of a wall (V), vein, and volcanic relief [1] [7] [29]. The westerly lineaments cut across the Albian and/or Aptian, Lower Cretaceous, and Pleistocene, and Pliocene geological formations. And those located towards the Center by going to the South intersect the geological formations of the Lower Cretaceous and the Pleistocene and/or the Pliocene.

4.6.1. First Vertical Derivative of the Residual Magnetic Field

The map of the first vertical derivative locates the secant lineaments in the same places as that of the map of residual anomalies of the Field Magnetic. These lineaments are also interpreted as in the previous case brittle faults and having created the horizontal movement of the compartments from the North-South direction therefore in dextral and sinister. The entrainment lineaments find their place in this interpretations by which we had located that one located in the southwestern part. The concordant lineaments of which it is either dykes or the veins of others minerals with high magnetic susceptibilities are located in the West, towards the Center going south. **Figure 6** illustrates the interpretations made through the map of the first vertical derivative of the Magnetic Field.

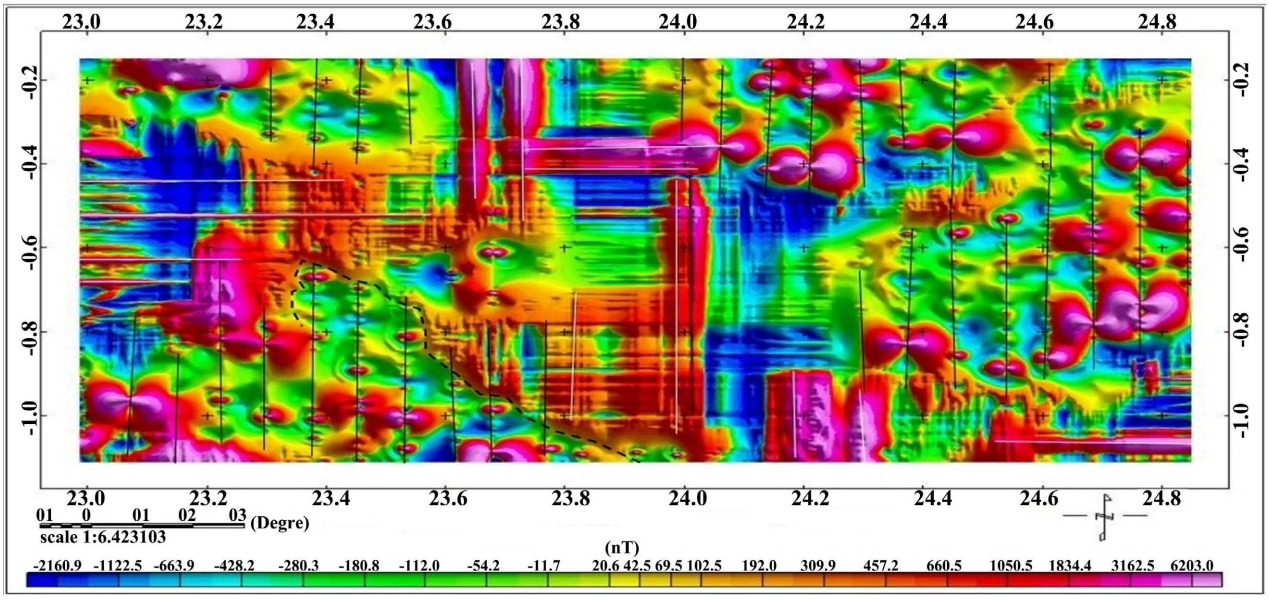

Figure 6. Map of the first vertical derivative resulting from the residual anomalies of the magnetic field with the traces of the identified lineaments.

4.6.2. Horizontal Derivative from the Residual Magnetic Field

Interpretations from the figure below (**Figure 7**) showing the Derivative map horizontal Magnetic Field give almost the same results to interpretations made on the previous map concerning secant lineaments. The different that exists is that the secant lineaments that were interpreted like brittle faults are clearly visible and confirm the location and direction granted. It was also observe the horizontal movements in dexter and sinister of the compartments. Apart from the secant lineaments, it is also found two entrainment lineaments located towards the North-West and South-West of the study area. These lineaments intersect the geological formations of the Lower Cretaceous and the Pleistocene and/or the Pliocene. There are also concordant lineaments but their lengths are not important. They are located in the western part and the Center.

4.6.3. Derivative Tilt

The filter of the Tilt derivative put in evidence the concordant lineaments [23]. After interpretations of this map, the results obtained are:

- The majority part of block 10B is dominated by concordant lineaments;
- There are also some entrainment lineaments located in the North-West and South-West part and a part located in the North-East;
- Besides these two lineaments, the secant lineaments spread in a region where the tectonic activity is intense or less intense as in the case of this block 10B where it is observed a lot of the secant lineaments in the parts of this block.

Figure 8 shows the Tilt Derivative map of the magnetic field variation in Block 10B.

4.6.4. Analytical Signal

The analytical signal filter put in evidence the entrainment lineaments [17] [22]

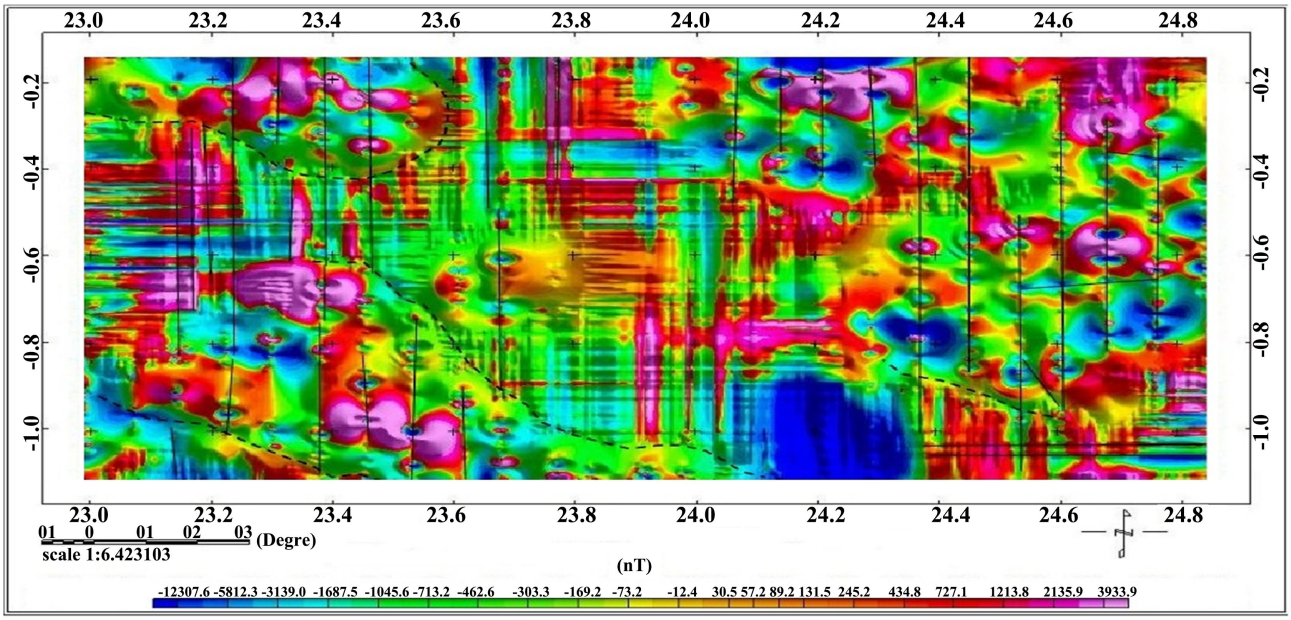

Figure 7. Map of the horizontal derivative of regional magnetic anomalies with the traces of the identified lineaments.

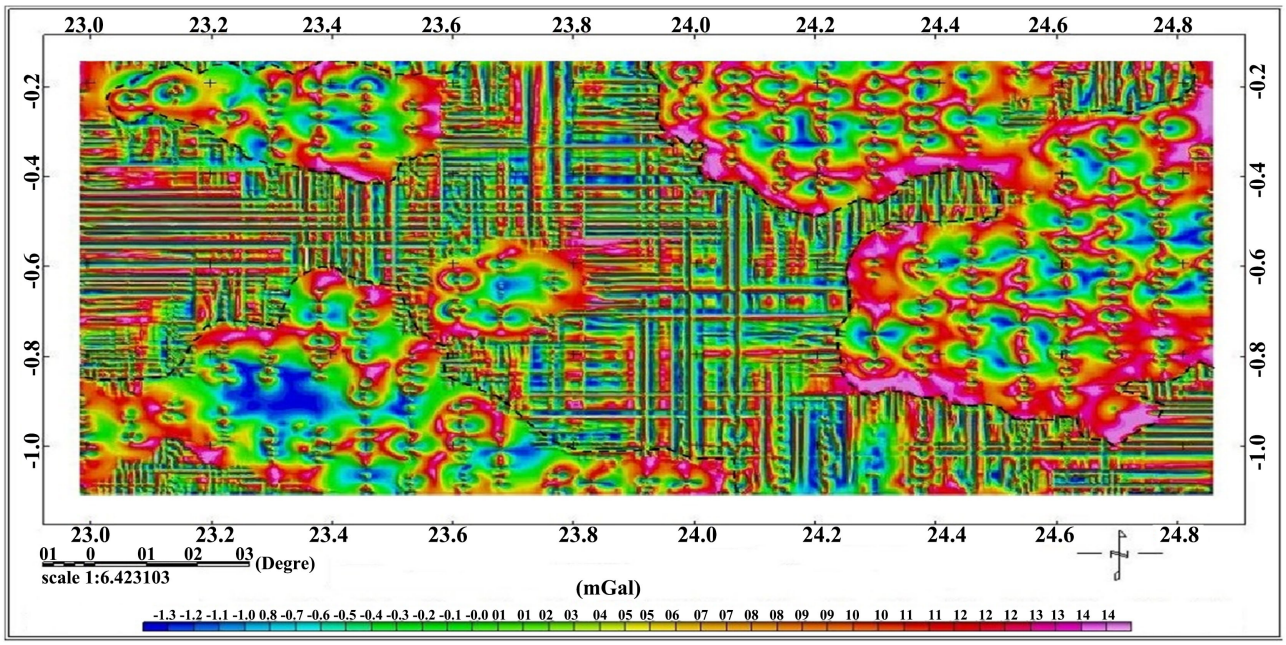

Figure 8. Map of the derivative tilt of regional magnetic anomalies with the tracings of the identified lineaments.

[26]. Thus, from the map of the analytical signal deduced through residual magnetic anomalies, it was found the following results:

- The entrainment lineaments are located in East, North-East, North-West, and Towards South-West; these lineaments cut the geological formations of the Lower Cretaceous and the Pleistocene and/or the Pliocene, the Lower Cretaceous, and the Upper Jurassic;
- The intersecting lineaments are also visible and located in the parts where we have located the entrainment lineaments. These lineaments showed the dis-

placements of the vertical compartments thus creating collapse faults (collapse lineaments); they intersect almost all the geological formations found in Block 10B;

- Apart from these two lineaments interpreted in this filter of the analytical signal of the residual anomalies, we quote the concordant lineaments that had highlighted and traced in the West, North, and South-East part. **Figure 9** below illustrates an analytical signal map of the Magnetic Field variation in Block 10B of the Central Basin.

4.6.5. Enhancement of Lineaments from Regional Anomalies of the Total Magnetic Field

The determination of the magnetic lineaments in block 10B from the map of magnetic anomalies made it possible to obtain the extensions of the magnetic lineaments deduced from previous interpretations of the maps of surface information (magnetic anomalies) and depths (regional anomalies). **Figure 10** presents a map of the regional magnetic anomalies with the traces of the identified lineaments. The regional magnetic field anomaly map shows us several types of lineaments:

- Secant lineaments; are more abundant in the southwest, northeast, northwest, and southwest. The secant lineaments are aligned in parallel in the East, South-West, North-East, and North-West part and thus create Horst and Graben structures;
- The concordant lineaments correspond to the dykes located in the western part, the center, and also towards the south-east;
- The entrainment lineaments: these lineaments are not visible but two could be identified, one is located towards the eastern part, and the other towards the southwest.

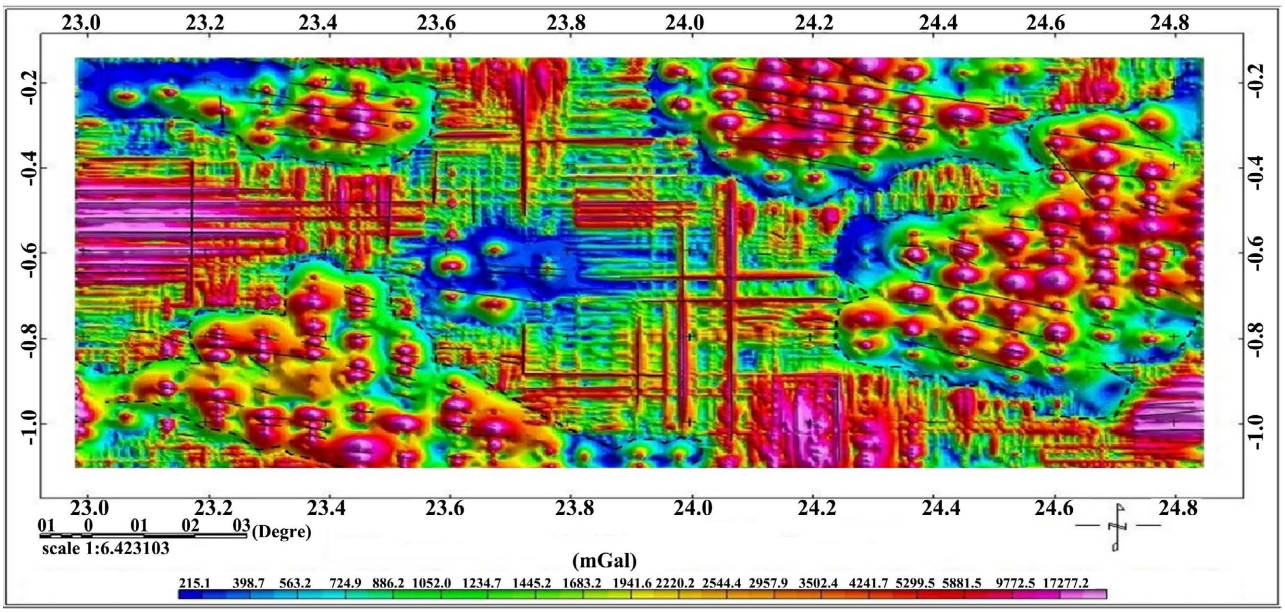

Figure 9. Map of the analytical signal of the residual anomalies with the tracings of the identified lineaments.

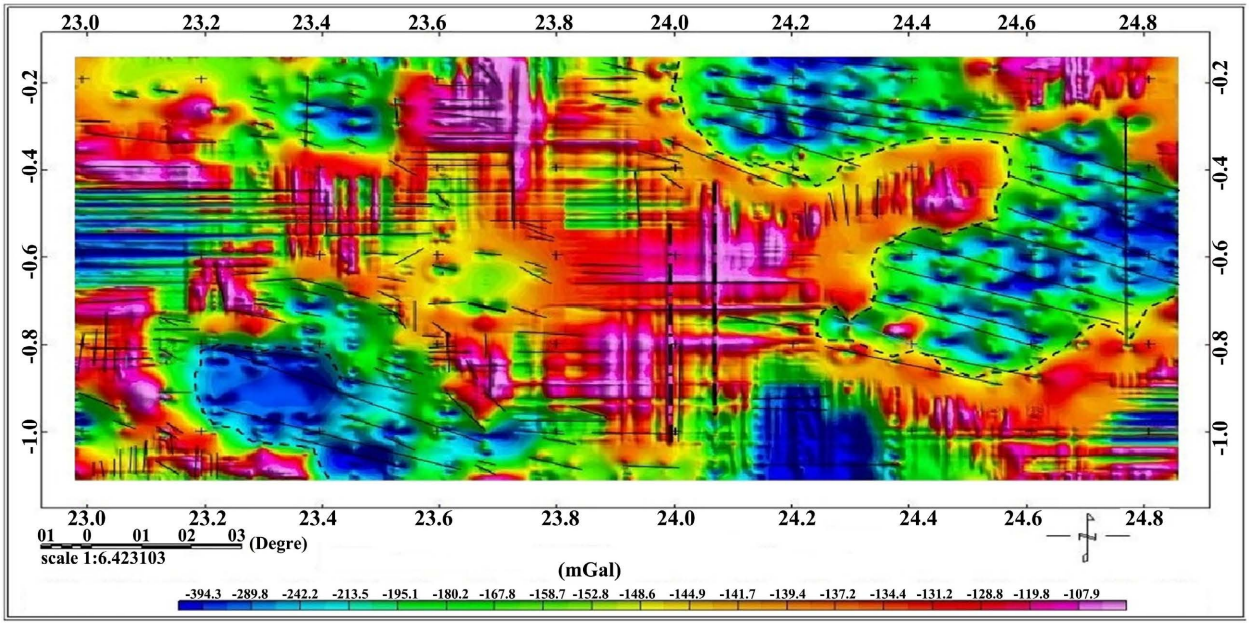

Figure 10. Map of regional magnetic anomalies with tracings of identified lineaments.

1) Vertical derivative

The first vertical derivative map of the Magnetic field deduced from regional magnetic anomalies reveals two very important lineaments. The parallel concordant lineaments located in the South-West, East, North-East, and towards the North-West part allow the movements of the dextral and sinister faults causing the formation of the detachment faults. There are also point out the presence of concordant lineaments such as those located in the central part oriented East-West having a great distance. The magnetic entrainment lineaments are almost invisible.

2) Horizontal derivative

The horizontal derivative map of the magnetic field deduced from the regional magnetic anomalies illustrated in Figure 11 shows the presence of three main types of lineaments of which are concordant, secant, and entrainment lineaments. The map in Figure 11 shows us several magnetic lineaments, namely:

- The parallel secant magnetic lineaments, of long-distance, are located in the East, North-East, South-West, and North-West parts. These lineaments are the basis for the horizontal displacement of the compartments, thus creating setback faults in dextral and sinister positions. We point out that the types of faults in the dextral position which dominate and these lineaments are oriented from North-South;
- The concordant magnetic lineaments are observable in the central parts, West to North-West and South-East.
- The magnetic entrainment lineaments are identified in the North-West, South-West, and South-East part.

4.6.6. Tilt Map Derivative and Deconvolution of Euler by Dykes Determination and Their Depths

As it was pointed out in the previous paragraphs that the importance of the

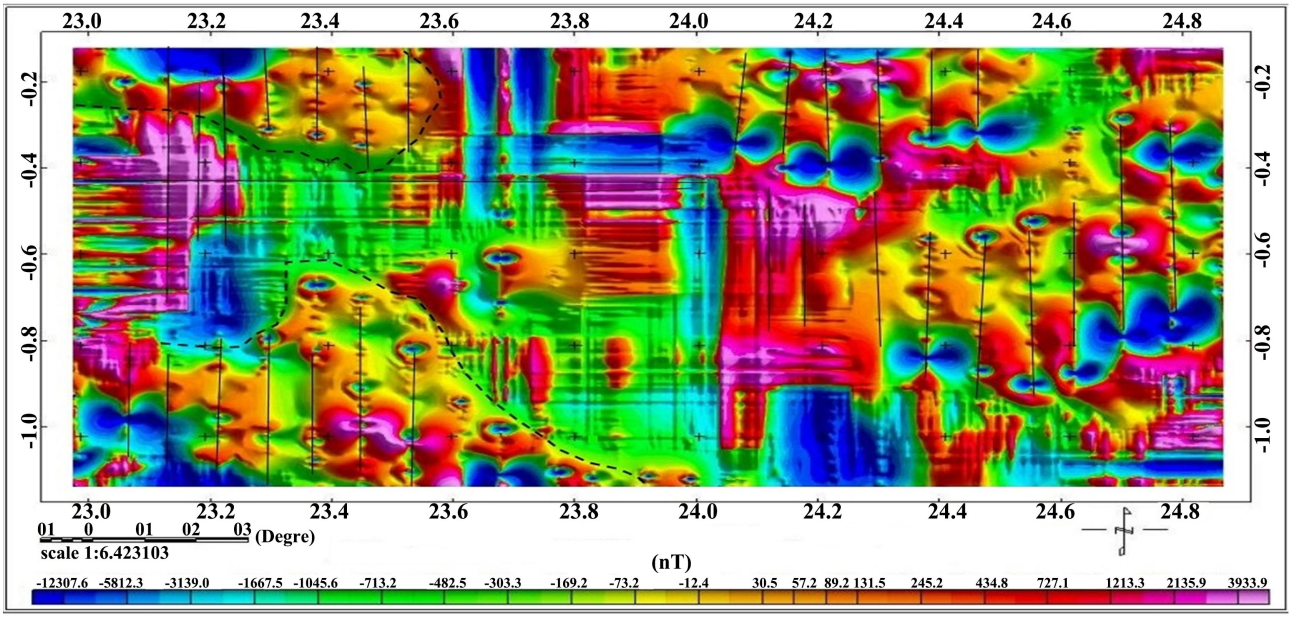

Figure 11. Map of the horizontal derivative resulting from the residual anomalies of the magnetic field with the traces of the identified lineaments.

Derivative Tilt Filter is to determine concordant lineaments like dykes. The figures below illustrate the different maps showing the presence of magnetic lineaments. Several concordant magnetic lineaments are visible in **Figure 8**. They are more located in the West, Central, South-East, and North. These concordant lineaments are oriented from north to south and from east to west. In addition to concordant lineaments, it notes the presence of secant and entrainment lineaments. Secant lineaments exist almost everywhere and even modify the structures of the Basin in Horst and Graben. Speaking of concordant lineaments, it was found especially in the North-East, East, South-West, and North-West.

Since there is a filter allowing concordant lineaments like dykes and even their depths, this is Euler's deconvolution while taking the structural index of 1; this index, therefore, makes it possible to identify the dykes. **Figure 12** shows the depth map of the dikes in Block 10B of the Central Basin. By observing the dike depth map in Block 10B, the depths go to distances greater than 2000 m. The peculiarity of this map is that some parts omit the dikes as in the South-West, North-East, North-West, and North-East. The dikes that are put in evidence through the depth variation map in Block 10B show that the concordant lineaments are in fact dikes and that they are oriented North-South and East-West. Most North-South facing dikes have depths between 100 - 500 m and 500 - 750 m. There are fewer East-West oriented lineaments with depth between 500 - 750 m.

Looking at the depth map in Block 10B, the depths go up to distances greater than 2000 m. the particularity of this map is that some parts omit the dykes as in the South-West, Northeast, Northwest, and Northeast. The dykes put in evidence through the map of the variation of depth in Block 10B shows that the

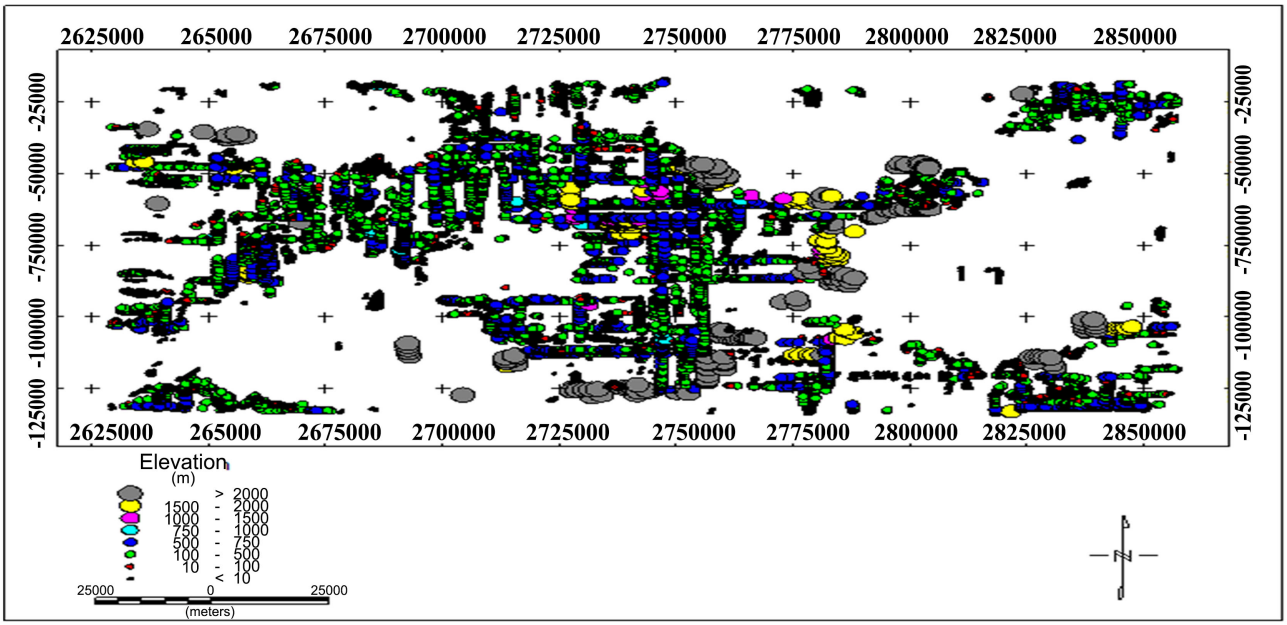

Figure 12. Map of the depths of in block 10B of the central basin.

concordant lineaments are dykes and that they are oriented North-South and East-West. Most dykes 64 oriented North-South have a depth between 100 - 500 m and 500 - 750 m. There are fewer East-West oriented lineaments with depth between 500 - 750 m.

The interpretations are as follows:

- The entrainment lineaments are located in the East, North-East, North-West, and South-West parts;
- The concordant lineaments are also visible and located in the parts where they were located the entrainment lineaments. These lineaments gave rise to the geological formations in Graben and Horst. These lineaments have shown the displacements of the vertical compartments thus creating the collapse faults (collapse lineaments) and others have displaced the compartments horizontally creating also movements of the faults in Dexter and Sinister (dropouts faults or lineaments of setbacks);
- Except for these two interpreted lineaments, the concordant lineaments that are highlighted and traced in the West, North, and South parts such as the previous map of the depth of the dykes showed the petroleum interest of the lineaments interpreted in the Block 10b.

After interpretation of the lineaments in Block 10B, the results show that these lineaments play great importance in terms of tectonic and petroleum knowledge, they are:

- Hydrocarbon migration path in Block 10B;
- Traps as in the case of entrainment and secant lineaments since they create vertical compartment movements thus determining fault traps and as for secant, lineaments move blocks or compartments in such a vertical and horizontal position. These two displacements then create collapse and horizontal

faults that can serve as oil traps;

- Conditions favorable to the genesis of hydrocarbons; the horst and the Graben are key elements of great importance in oil research. The Graben constitutes a deep zone favorable to the formation of hydrocarbons and the horst, a favorable place for the accumulation of hydrocarbons;
- Knowledge of tectonic movements as in the case of horizontal and vertical movements of compartments.

Figure 13 shows the map of geological formations in the study area.

5. Result

In all, 786 secant magnetic lineaments, 9 entrainment lineaments, and 114 concordant axes were traced. The statistics for these lineaments are shown in detail in Table 1.

5.1. Secant Magnetic Lineaments

The secant lineaments vary in length from a few kilometers to several thousandths of a meter (Table 1). Lineament width can be measured due to demagnetization (caused by weathering and deformation) or magnetic disturbance on either side of the lineament. The intersecting lineaments are preferably oriented North-South, East-West, North-West, South-East and also North-East towards South-West (Figure 14).

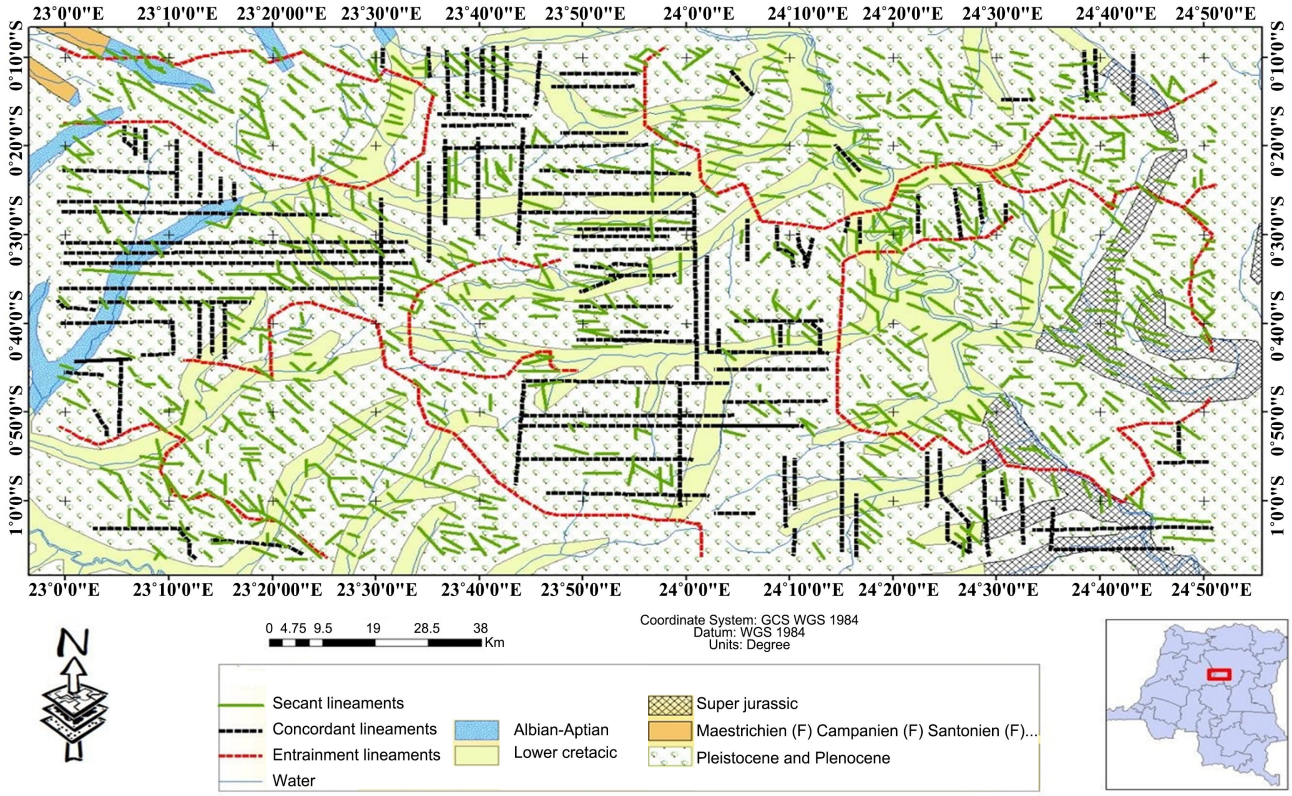

Figure 13. Geological map of the study area.

Table 1. Types of lineaments and statistics

Data	lineaments	Number	orientation	Length Average (m)	Length min (m)	Length max (m)	meaning
Magnetic	Secant	786	N-S E-W NW-SE NE-SW	3.74847279	1.13881091	24.9587028	Brittle fault
	Entrainment	9	NW-SE	62.3283094	2.64273291	169.213063	Corridor deformation
	concordant	114	NW-SE N-S E-W	13.4849424	3.07544514	63.9645382	Dyke

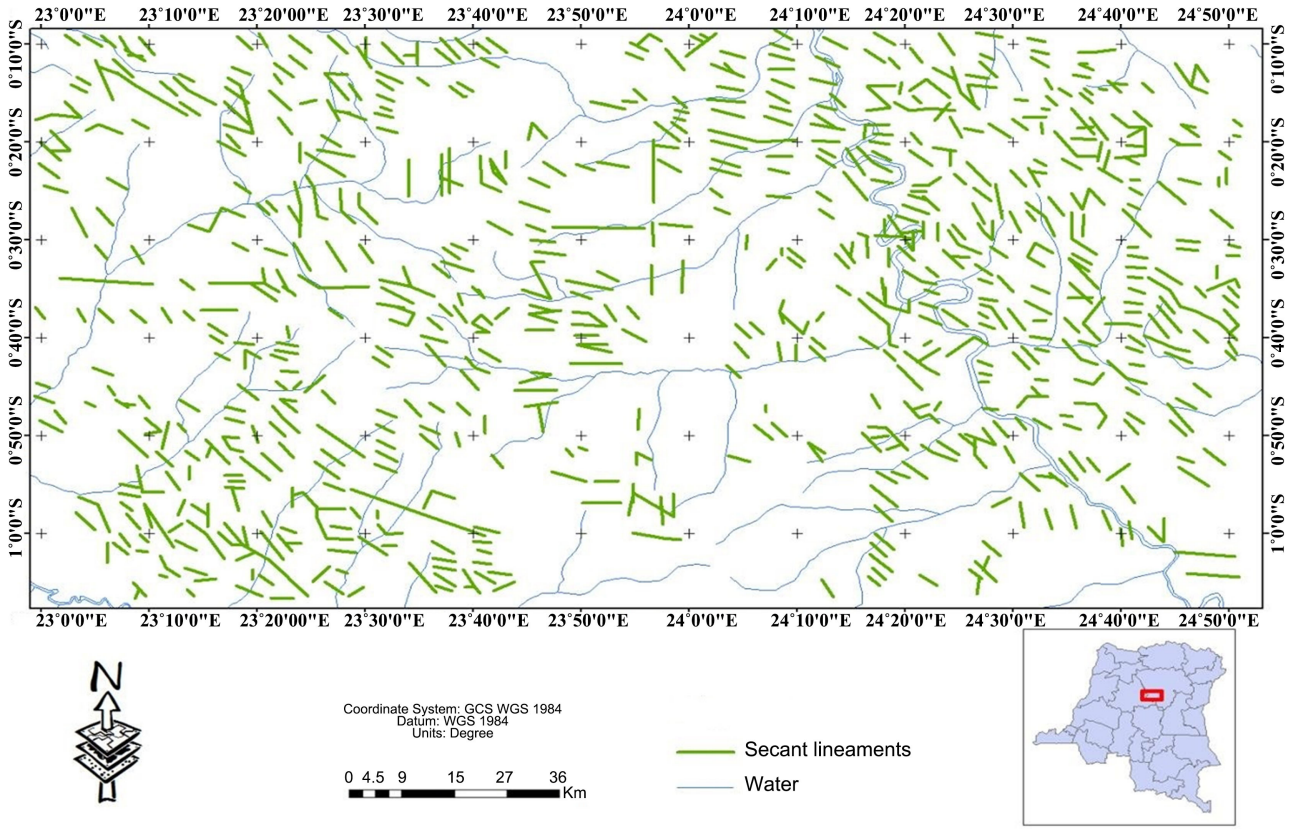

Figure 14. Secant magnetic lineaments interpreted on the whole of block 10B of the central basin.

5.2. The Entrainment Lineaments

The effect of entrainment magnetism along the edge of the entrainment lineaments is generally noticeable 6974 to 49,077 m from the center of the magnetic trough. Magnetic entrainment lineaments have average lengths of 62 km (min. 2642; max. 169,213 m) (**Figure 15**). Unlike secant lineaments, there is a dominant family-oriented North-West and South-East.

5.3. Concordant Magnetic Lineaments (Proterozoic Dykes)

The concordant magnetic lineaments which characterize the diaclase dykes have

lengths varying between 3 and 64 km, for an average of 13 km (Figure 16). The interpreted dykes are divided into three groups of preferential orientation, namely:

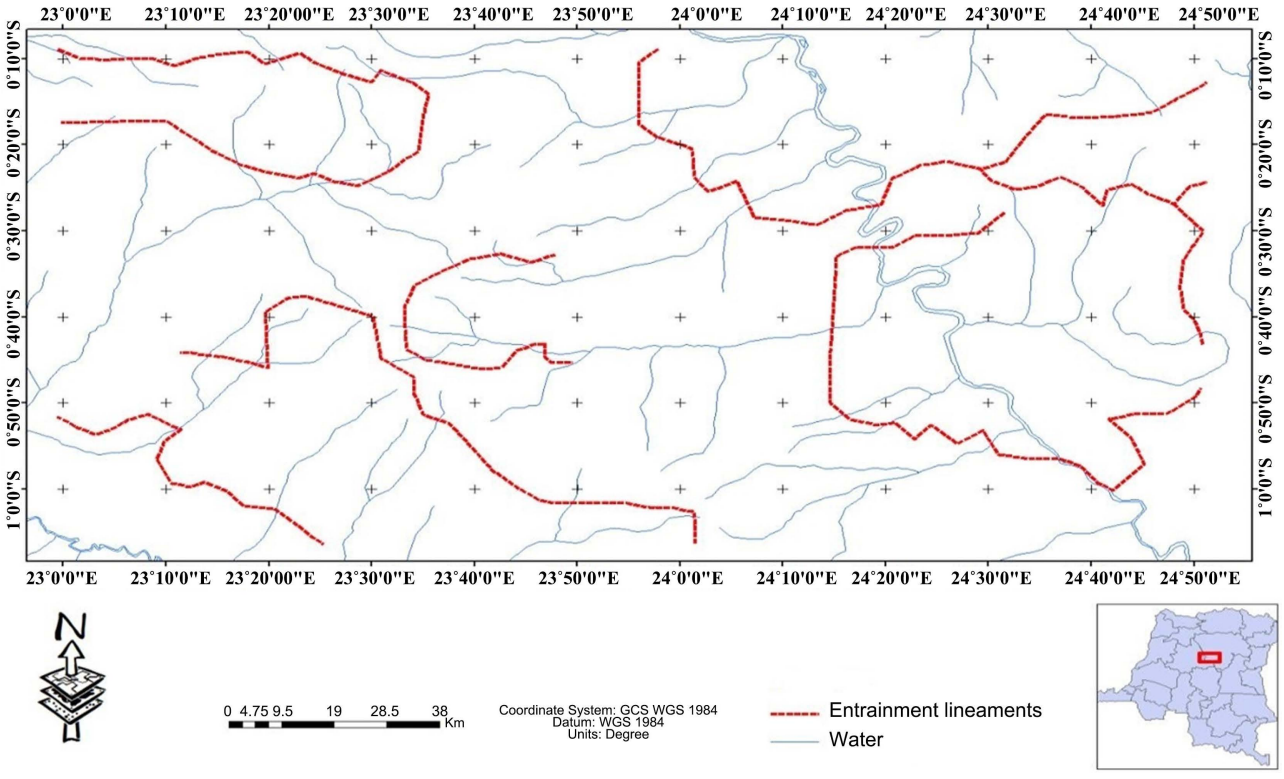

Figure 15. Entrainment lineaments.

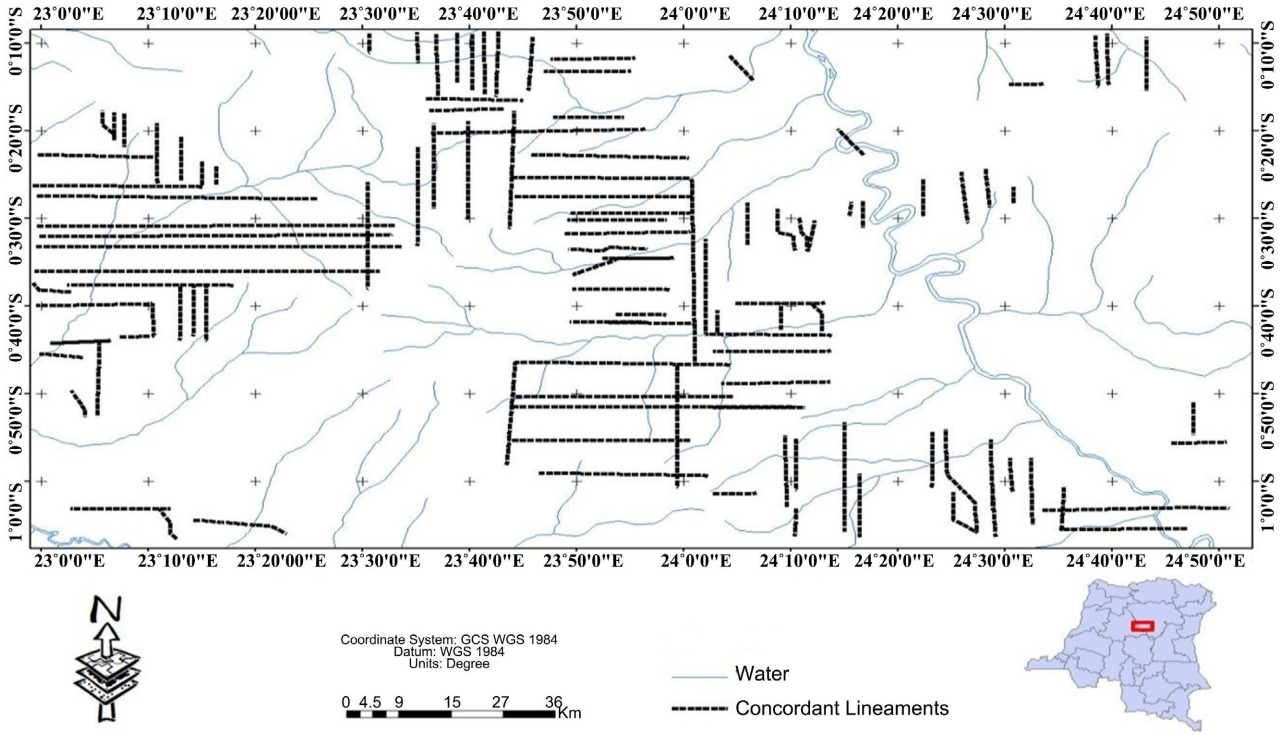

Figure 16. Concordant magnetic lineaments.

- East-West oriented dykes located in the South-West, North-East, and East part;
- The network of North-South oriented dykes located in the North-East part;
- The dykes oriented from North-West to South-East located towards the North-West, center, and South-East.

6. Conclusions

As has been said, a lineament is a structural alignment of varying dimensions. It corresponds to an accident in the earth's crust (usually a fault) the influence of which can be felt for a long time [3] [30] [31]. It can either correspond to faults, geological contacts, or alteration zones. Its determination can be done through several methods including the geophysical method. The magnetic method allowed us to know the different types of lineaments in this study area based on total magnetic field data. The lineaments play great importance in mining prospecting than in oil prospecting. Because the lineaments are often studied to know their relationship with the mineralization. This is why more or less objective interpretations by focusing on residual anomalies have been made in this paper. Indeed, the determination of the lineaments in blocks 10B is done to better understand the geological structures playing a petroleum interest. Thus, the interpretations of the various maps produced have revealed the prolongations of the lineaments in-depth, very useful for tracing the history of the migration of hydrocarbons and probable structures that could trap them.

As result, three main types of lineaments emerged; the secant, entrainments, and concordance lineaments, which lineaments derived from maps established by residual anomalies of the magnetic field that extend into depths as evidenced by the various maps developed from regional anomalies of the magnetic field. The extensions were more pronounced in the case of the entrainment and concordant lineaments and are associated with the geological formations in horst and grabens thus creating collapse faults. Moreover, from the petroleum approach, the lineaments serve as a path for the migration of hydrocarbons and hydrocarbon traps. And in addition, from a tectonic approach, these lineaments show vertical fault movements creating collapse faults and horizontal fault movements creating dextral and sinister faults.

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Conflicts of Interest

The authors declare no conflicts of interest.

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