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STRUCTURAL MODELLING OF THE OIL POTENTIAL OF THE WEST CONGOLIAN SUB-BASIN THROUGH THE IDENTIFICATION OF GEOLOGICAL STRUCTURES AND GRAVIMETRIC ANOMALIES

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ABSTRACT

The Democratic Republic of Congo has significant hydrocarbon reserves in its subsoil. The western Congo sub-basin is less explored in terms of oil potential. This study contributes to enriching the subsoil geological data by highlighting geological structures of major interest for oil exploration. This sedimentary basin is located in the Congo-Central province of the Democratic Republic of Congo and represents the main hope for oil prospects. With regard to the potential of this basin, it is worth mentioning that the presence of source rocks, oil showings, the presence of anticlines and faults identified in this study constitute potential traps for hydrocarbons. To date, the Western Congo sub-basin has been relatively unexplored. The satellite data have been compared with the tectonic field model in order to highlight the structural patterns of this vast basin. This research is crucial for informing future exploration initiatives and unlocking the hydrocarbon potential of the region, thus contributing to the country's economic development.

Keywords: gravimetric data, structural model, gravimetric anomalies, geological structures, oil potential

INTRODUCTION

The Democratic Republic of Congo has significant hydrocarbon reserves in its subsoil. It has three major sedimentary basins: The Coastal Basin, the Central Basin and the West Branch Basin of the East African East Rift. However, so far, only the Coastal Basin is in the exploitation phase. Indeed, the West Congo sub-basin is less explored in terms of oil potential. This study contributes to enriching the geooil data by highlighting geological structures of major interest for oil exploration [4], [5]. This is why our study focuses on the West Congo sub-basin, which is less known in terms of oil potential, especially with regard to underground resources. According to several authors [3], The West Congo is considered one of the seven sub-basins of the central basin, but it has distinct characteristics compared to the Neoproterozoic outcrops found in other regions of the central basin, such as the Indian, the Katanguian, and the West Congo itself. The West Congo sub-basin borders the Congo Craton to the west and extends along the Atlantic coast from Gabon to Angola [8], [11]. It underwent intense tectonic events, as well as a phase of cratonization estimated to be about 2,500 million years old, followed by the phase of oceanization. It is a valuable tool to guide future exploration campaigns in the field [13], [25].

Hence the knowledge of the geological structure of this sub-basin of West Congo is an effective way to better understand its oil potential. Thus, this study presents the analysis of geophysical and topographical data in order to highlight geological structures likely to be of petroleum interest.

The study aims to map geological structures, specifically faults and folds, including anticlines and synclines, which can influence the presence of oil reservoirs. We utilized gravimetric data to identify density variations in the subsurface, potentially indicating hydrocarbon accumulations at depth. By combining these different datasets, we created a detailed 3D model containing various geological structures in the West Congolese sub-basin. This model facilitates the exploration and exploitation of petroleum resources in the area [9],[14].

This study addresses several gaps by providing more precise information. Previous studies may have lacked detailed data on deep structures and gravimetric anomalies. Additionally, modeling methods used in the past might not have incorporated the latest technologies and analytical techniques. However, we employed more precise technologies, such as ArcGIS and Surfer software, to determine the exact numbers of anticlines, faults, and an anticline located in the Bangu region within our study area. These structures can serve as hydrocarbon traps, potentially storing and accumulating oil.

Our use of sophisticated cutting-edge technologies for analyzing gravimetric and geological data allowed us to offer new and more accurate perspectives. Furthermore, we combined three analysis methods (gravimetric, geological, and 3D modeling) within a single study, which is innovative. This approach enabled us to precisely determine the number of anticlines present in our study area, grouped by zones, along with their orientations. We also identified various faults and their directions. These structures enhance the overall understanding of petroleum potential. The study's results can directly influence oil exploration and exploitation strategies, making operations more efficient and profitable. In summary, this study represents a significant advancement in understanding and exploiting petroleum resources in the West Congolese sub-basin.

MATERIALS, METHODS AND TECHNIQUES

The methodology of this study includes several steps. First of all, by the acquisition of satellite gravity data of the Bouguer anomalies from the BGI site (International

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Gravimetric Bureau). Then the processing of gravimetric data. This step consisted of the development of the maps of the gravity anomalies by applying filters to extract information on the geological structures. Finally, the interpretation of the maps and the discussion of these maps. This part allows us to highlight the structural models resulting from the combined interpretation of these methods [15], [16].

The equipment used in this paper includes a laptop computer equipped with the following software:

- Surfer 19 used for gravity data processing;
- The Arc-GIS 10.8 software allowed us to develop the maps of the study area;
- The Oasis Montaj software used for the application of gravimetric filters.

PRESENTATION OF OUR STUDY AREA

Located in the heart of the Congo Central province in the Democratic Republic of Congo, the study area (Figure 1) is an integral part of the West Congo sub-basin between Mbanza-Ngungu and Songololo via Kasangulu and Madimba. The city of Kimpese is located between 5°12' and 5° 24' south latitude, 14°13' and 14°18' east longitude at an altitude of 337 m; in the territory of Songololo, district of cataracts.

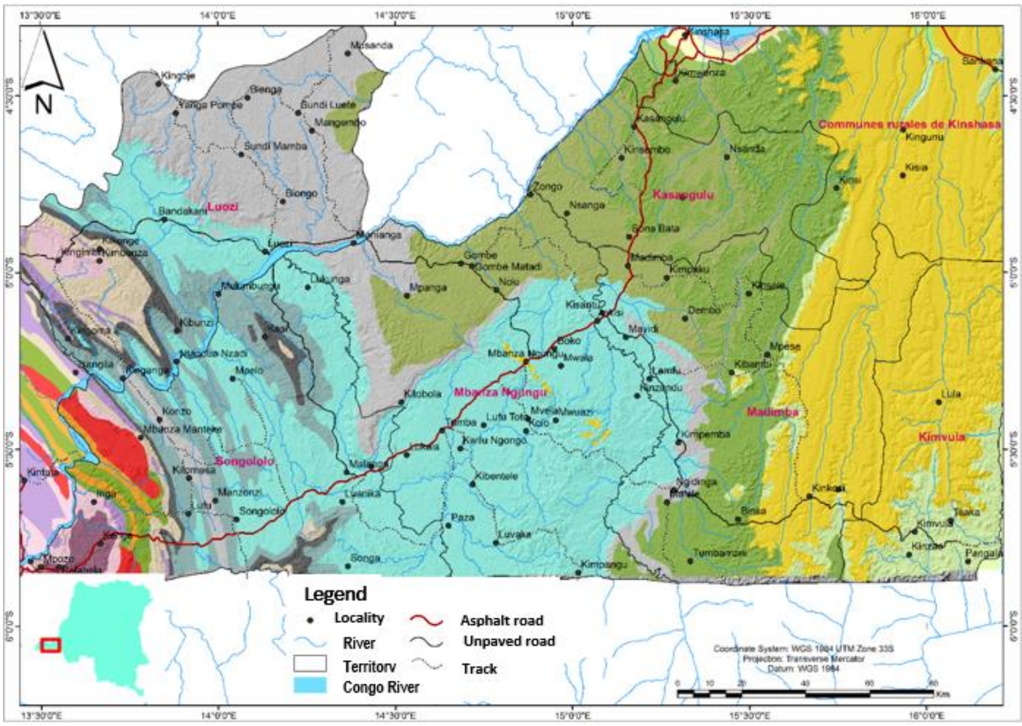

Figure 1. *Localization of West Congo sub-basin developed using Arc GIS software*

GEOLOGY OF THE WEST CONGOLIAN SUB-BASIN

In the studied area the West Congo Supergroup – (OC) includes: West-Congo Group – I, mp, sc, sh, ti, S; Mayombian Group – M; Zadinian Group – Z. The typical section of the West-Congo chain illustrates a general decrease in deformation and regional metamorphism from west to east. To the west, in the innermost part of the Pan-African chain of thrust and fold belts, the c.2.1 Ga Kimeza Supergroup, of eastern vergence, is straddled above the Zadinian Group, which in turn overlapped above the Mayombian Group. The latter was in contact with the West-Congolien Group, the youngest part of the chain [1], [6], [7].

The recent paper of [6] and then that of regional mapping of the Bas-Congo Province by the IRCGM [1] has led to a complete revision of the stratigraphy of the West Congolian chain. Tack L. redefined the lithostratigraphy of the West Congo Supergroup into three Groups, respectively from bottom to top: the Zadinian, Mayombian and West Congo Groups. [1], [8] for reasons of stratigraphic nomenclature rules and based on new field surveys, refined the Tack stratigraphy and defined a new formal terminology; From top to bottom: Cataract Group o (Inkisi Sub-Group); Mpioka Sub-Group; Lukala Sub-Group; Upper Shiloango Subgroup; Sansikwa Sub-Group; Tshela Group (west) / Seke-Banza Group (east); Matadi Group

The top unit of the Cataract Group, the Inkisi subgroup, is postulated by [1] in line with [7], [3], and [6] to be in fact of post-Precambrian age. This unit is a typical reddish arkose of relatively thick "red beds" appearance, showing sedimentary structures typical of siliciclastic sediments deposited relatively quickly in a shallow deltaic environment (Figure 2).

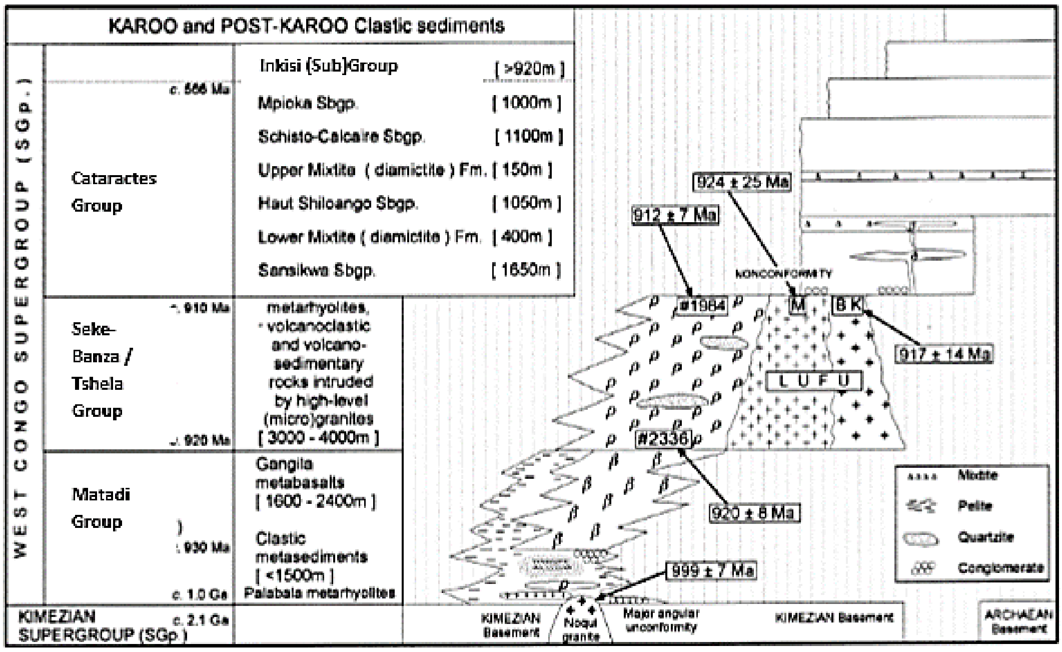

Figure 2*. Description of each lithostratigraphic unit* [6]

STRATIGRAPHY OF THE WEST CONGOLIAN SUB-BASIN

The West-Congo is one of the groups of the West-Congo super-group [12], [21]. From bottom to top, its stratigraphy consist of several subgroups: Sansikwa, Haut-Shiloango, Schisto-Calcaire, Schisto-Gréseux. The stratigraphic logs below (Figure 3) allow us to understand our remarks. It should be noted, however, that the stratigraphy of the West Congo is based on the paper of [2] and has been completed by [6].

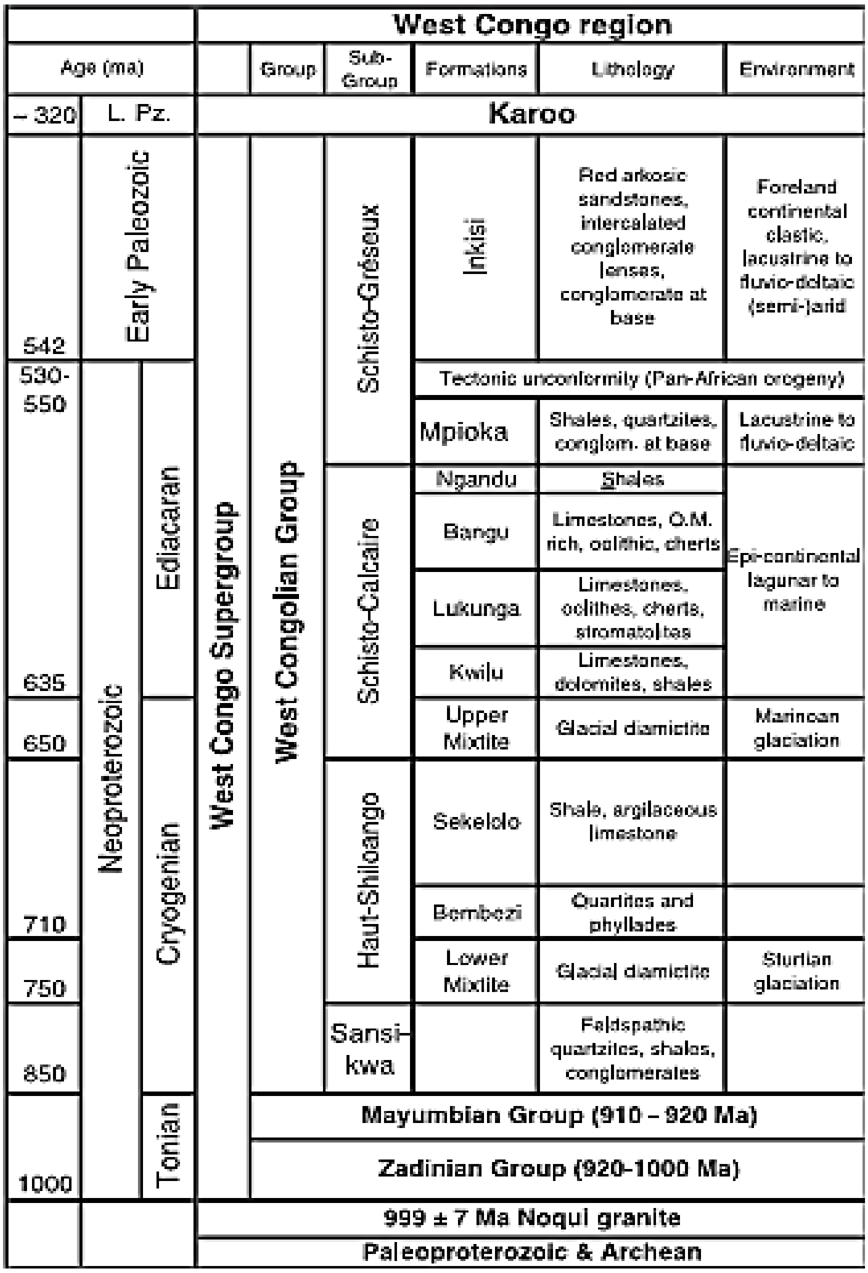

***Figure 3**. The stratigraphy of the western Congo sub-basin* [5].

PRESENTATION OF GRAVITY DATA

The Bouguer anomaly data used in this study are from the BGI (International Gravimetric Bureau) platform. They are provided in the form of grids and Excel files, which allows us to understand the spatial variability of acceleration or density in the West Congo sub-basin. These gravity data of the Bouguer anomalies include 3722 stations. Each station is characterized by three parameters: longitude, latitude and the Bouguer anomaly. We have selected a representative sample of these stations, as shown in the Table 1 below. It is important to note that these data will provide valuable information on the geological structure of the West Congo sub-basin, which will help to improve oil exploration works in this region. [26]

Table 1. Presentation of spatial Bouguer anomaly data

Longitude (Degree)	*Latitude (Degree)*	*Bouguer anomaly (mGal)*
13.00	*-4.00*	*77.04*
13.03	*-4.00*	*80.58*
13.06	*-4.00*	*83.13*
13.10	*-4.00*	*82.27*
13.13	*-4.00*	*81.43*
13.167	*-4.00*	*88.32*
13.20	*-4.00*	*85.88*
13.23	*-4.00*	*89.78*
13.26	*-4.00*	*85.50*
13.30	*-4.00*	*79.80*

DATA ANALYSIS

– Bouguer Anomaly

The map of Bouguer anomalies (Figure 4) in the study area reveals different intensities of gravity anomalies [17-20], [22]. To the north-west and the eastern part towards the centre, the anomalies are heavier, with an intensity between 67.9 and 80.5 mGal, depending on spatial data. The northern and southern parts also show heavy anomalies, but with a slightly lower intensity, ranging from 50.4 to 67.9 mGal. Overall, the Bouguer anomalies in the study area vary in intensity from 50.4 to 80.5 mGal.

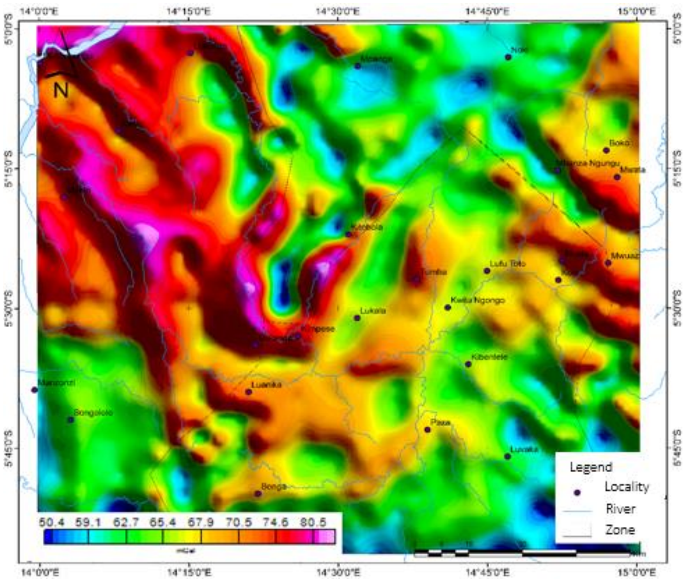

Figure 4. Bouguer Anomaly Map

The general appearance of the Bouguer anomalies shows three main directions: from north to south, from northeast to southwest, and from northwest to southeast. In the Songololo domain, the Bouguer anomalies are mainly oriented from the northwest to the southwest, with light anomalies in the northern part. In the Mbanzangungu area, the anomalies are moving in two directions, either from the northeast to the southwest or from the northwest to the southeast. Anomalies in this area are mostly weak. In the Kimpese domain, the anomalies show an orientation either from northeast to southwest or from northwest to southeast.

THE SPATIAL DERIVATIVE (RATE OF CHANGE) OF GRAVITY

– Spatial derivative with respect to X

The map of the horizontal derivative with respect to X (Figure 5) highlights the gradient maximums oriented from North to South. Some of these gradient maximums have a northwest-to-southeast orientation. In the Songololo domain, it is observed that these gradients are mainly directed from the North-West to the South-East. In the southern part of Songololo, the concordant lineaments (gradient maximums) are oriented from north to south. In the Mbanzangungu domain, the gradient maximums show two main directions. These are the direction from northeast to southwest and northwest to southeast. As for the Kimpese domain, the gradient maximums have a north-south orientation.

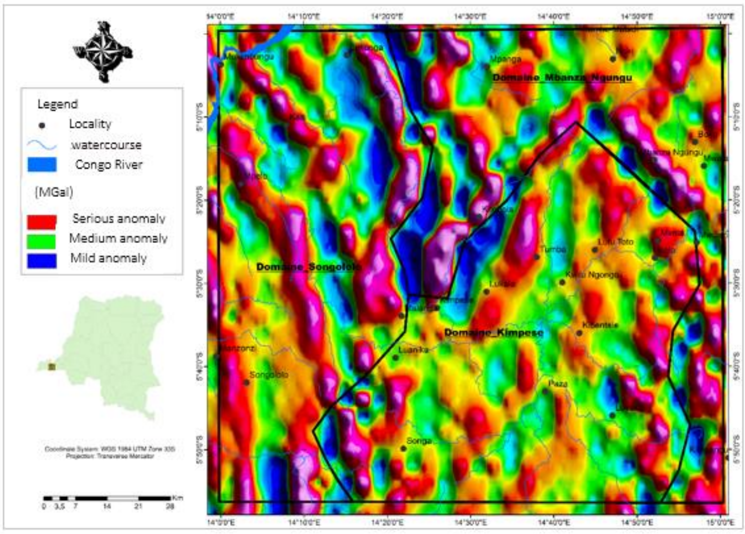

Figure 5. *Map of the first derivative with respect to X.*

- Spatial derivative with respect to Y

The results of the horizontal derivative map with respect to Y (Figure 6) in the three domains we selected below present the following results:

The Songololo domain has two directions of gradient maximums. On the northern part in the Songololo domain, the gradient maximums present North-West to South-East directions. The southern part shows maximum gradients oriented East-West;

In the Mbanzangungu Domain, the maximum gradient oriented northeast to southwest is observed towards the eastern part. Towards the west, maximum gradients are observed in the north-west to south-east direction. The northern part showed us east-west oriented maximums. The south-western part shows a NE-SW orientation of the gradient maxima.

The Kimpese domain shows us two orientations of the gradient maxima, one towards the east, which are oriented E-W, and the other towards the west, oriented NW-SE.

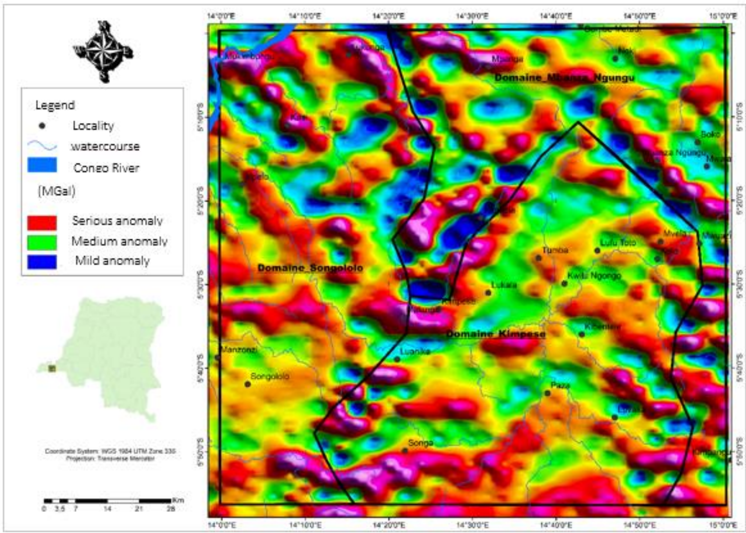

Figure 6. *Map of the first derivative with respect to Y*

– **Upward extension method**

The Bouguer anomaly extension map at a depth of 6500 m (Figure 7) reveals that heavy gravity anomalies are mainly present in the Songololo domain. On the other hand, in the Mbanzangungu and Kimpese domains, the gravity anomalies have low intensities. This means that in the Songololo domain, there are significant variations in the density of materials below the surface, resulting in more pronounced gravity anomalies.

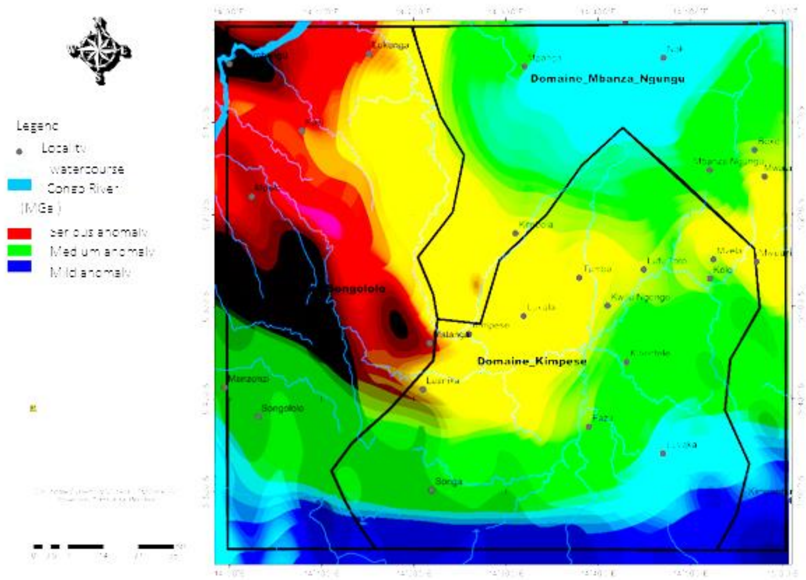

Figure 7. *Extension map to 6500m upwards*

In contrast, in the Mbanzangungu and Kimpese domains, density variations are less pronounced, which explains the low-intensity gravity anomalies. It is important to note that these observations are based on data from the Bouguer anomaly extension map at 6500 meters depth. More detailed geological studies are needed to fully understand the causes of these variations in density and intensity of gravity anomalies in each domain.

– Euler's deconvolution

The Euler deconvolution map (Figure 8) allowed us to highlight the geological structures called anticlines in the three domains studied. Anticlines are folds of rock that form when layers of rock are subjected to tectonic forces and bend into a dome shape.

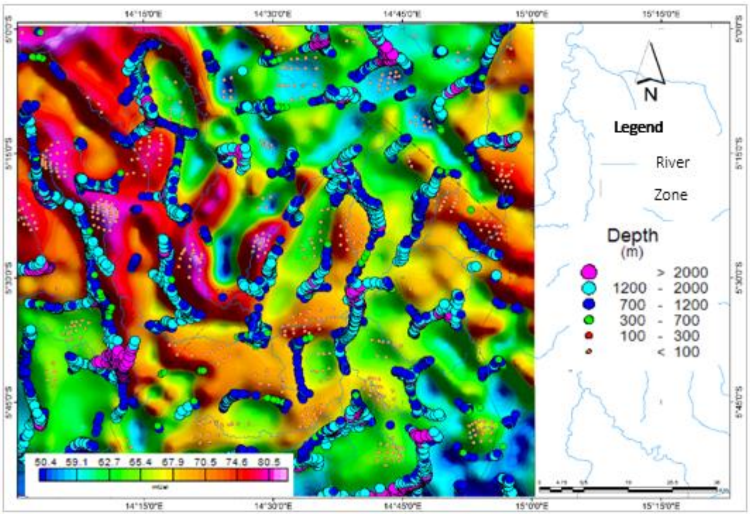

Figure 8. *Euler map of dykes and sills*

Based on the map of Euler's deconvolution, we had highlighted the anticlines in all the areas studied by doing the supervised classification. These anticlines (Figure 9) are distributed as follows:

- 10 anticlines in the Songololo domain, the majority of which are located towards the northern part;
- 13 anticlines located to the north by going east, in the Mbanzangungu domains;
- 14 Anticlines in the Kimpese domains.

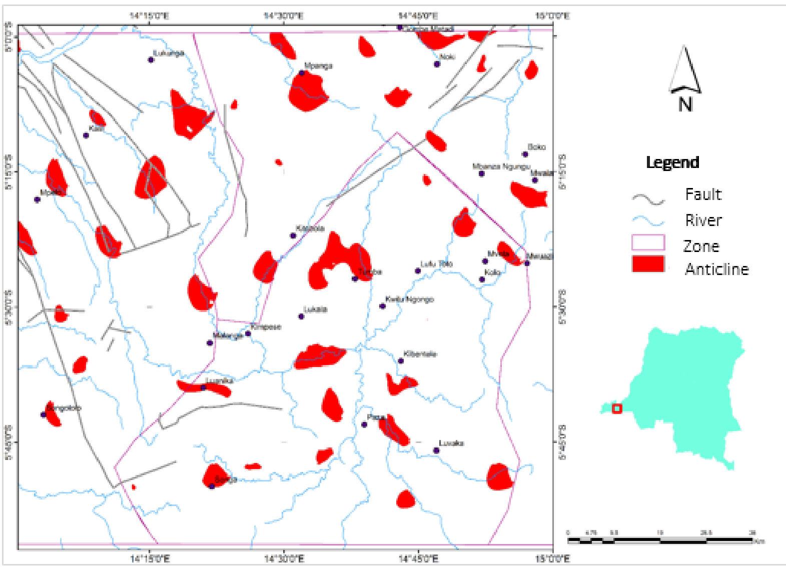

Figure 9. *Map location of anticlines*

3.2 INTERPRETATION STRUCTURAL MODEL

The structural map of the study area has been shown in the Figure 10. This map highlights the interpretations of the gravity data of the Bouguer anomalies after the application of several filters [23-24]. The information obtained is the anticlines and lineaments. The latter are either associated by faults or lithological contacts. Based on the oil interest, we had highlighted the structures that can promote the formation of hydrocarbons as in the Bangu area, the faults that promote the migration and trapping of hydrocarbons as well as the anticlines which are favorable and potential traps for the accumulation of hydrocarbons.

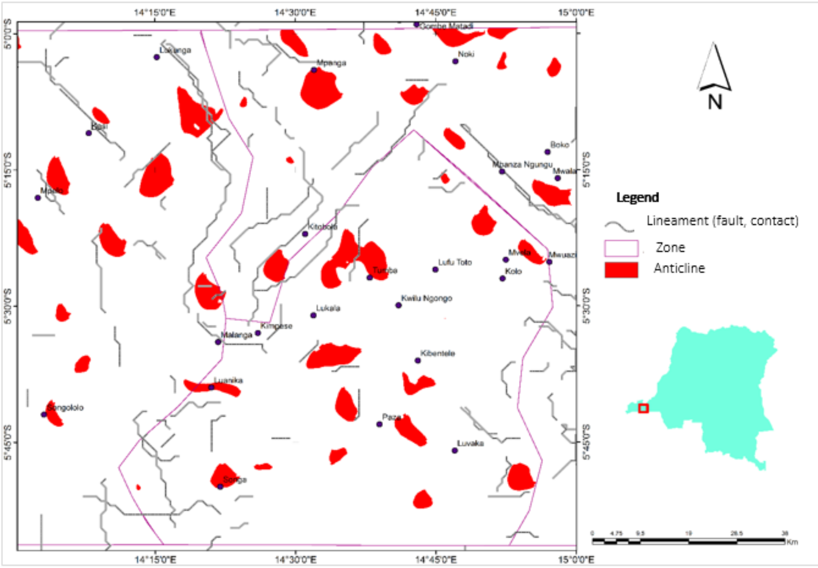

Figure 10. *Structural map of the study area*

CONCLUSIONS

This paper focused on the identification of geological structures and the highlighting of their oil potential in the West Congo sub-basin. This sedimentary basin is located in the Congo-Central province of the Democratic Republic of Congo and represents the main hope for the oil prospects. As far as the potential of this basin is concerned, it is worth mentioning the presence of source rocks and oil showings with a very good TOC.

So far, the West Congo sub-basin has been relatively little explored. Only surface geological studies, such as geological surveys, have made it possible to highlight the different existing potentialities. The deep geological structures of this sub-basin are less known due to the absence of seismic and/or geophysical campaigns.

We performed combined interpretations based on satellite data for gravity anomalies and topography. The gravity data comes from the Topex satellite, which provides the values of longitude, latitude and anomalies in the open air spaced every 1 km. These satellite data were compared with the terrain model caused by tectonics in order to highlight the structural models of this vast basin.

After processing and interpreting the data we have, the results obtained are:

- From the point of view of tectonic constraints, we observed the presence of compressive tectonic resulting from distinctive movement to the west and east.
- From a structural point of view, our study area is marked by the presence of anticlines to the north-west, oriented from north-west to south-west, synclines such as Mont Bangu, and faults, among others.

As far as oil interest is concerned, the West Congo sub-basin has significant oil potential. The presence of the anticlines and faults identified in this study constitute potential traps for hydrocarbons. The synclines identified demonstrate the existence of a zone favourable to the formation of hydrocarbons. In addition, the presence of the faults deduced in our interpretations indicates structures favorable to the migration of hydrocarbons. The research can be continued with other geophysical prospecting methods.

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