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DETERMINATION OF SEDIMENTARY THICKNESS FOR ASSESSING THE HYDROCARBON SOURCE ROCK POTENTIAL USING GRAVIMETRY: CASE OF MOUNT BANGU IN THE WEST CONGOLESE SUB-BASIN (DRC)

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ABSTRACT

This study focuses on determining sedimentary thickness to evaluate the hydrocarbon source rock potential using the gravimetric method, applied at Mount Bangu in the West Congolese sub-basin of the Democratic Republic of Congo (DRC). The main objective is to accurately estimate the thickness of sedimentary formations and their burial depth, parameters that are essential for understanding the thermal maturation conditions of potential source rocks. To achieve this objective, we applied the method developed by J. Goguel, whose approach is well adapted to environments composed of fine-grained rocks, typical of our study area. The gravimetric data were processed using a gravity profile superimposed on the topography of Mount Bangu, which is considered, from a geophysical perspective, as a graben-like collapse structure. The classical steps of gravimetric processing were carried out: calculation of the Bouguer anomaly, separation of residual and regional anomalies, and derivations along the X, Y, and Z axes. The results obtained show a sedimentary thickness of approximately 5 km, with a lateral extension estimated at 13 km. Considering the regional geothermal gradient as studied in the Central Cuvette – to which the West Congolese sub-basin is attached – this depth places the sediments within the window of full maturity for liquid hydrocarbons. This suggests significant petroleum potential, further supported by surface hydrocarbon indicators such as dysmigration phenomena observed in nearby regions including Kimpese, Kisantu, and their surroundings. Thus, the gravimetric results reinforce the hypothesis of an active petroleum system within the West Congolese sub-basin and open perspectives for more detailed geological and geophysical investigations.

Keywords: dysmigration, gravimetric profile, anomaly residual, oil source rock potential, petroleum system, Mount Bangu

INTRODUCTION

The West Congolese Basin remains a region where sediment thickness is still insufficiently constrained, as highlighted by several authors [23]. This uncertainty fully justifies the present study, which aims to estimate sediment thickness through an applied geophysics approach, specifically gravimetry. The formations of the West Congolese sub-basin are known to contain stromatolithic sediments [2],[17], which may evolve into hydrocarbon source rocks under suitable geological conditions, including burial depth and temperature.

Geological and tectonic setting of the study area refers to all deformations that have affected geological formations after their formation (faults, folds, schistosity, etc.) as a result of opposing stresses [6],[8]. A perfect example of such deformation is Mount Bangu, which illustrates the structural modifications that affected the geological formations of the western Congolese zone (Figure 1). The outcrop displays deformed stromatolitic and fine-grained sedimentary formations affected by compressive tectonics. The structural configuration suggests a synclinal geometry consistent with sediment accumulation in a graben-like structure within the West Congolese Belt. This morphology supports the gravimetric interpretation of subsurface sediment thickening.

Figure 1*. General view of Mount Bangu illustrating its folded sedimentary structure* [24].

According to several authors [14], the West Congolian region is considered one of the seven sub-basins of the Central Cuvette. However, it exhibits distinctive characteristics compared to the Neoproterozoic outcrops found in other regions of the Central Cuvette, such as the Indien, the Katanguien, and even the West Congolian itself. This justifies considering the West Congolian as a basin in its own right.

The West Congolian Belt (Figure 2) is located along the Atlantic coast, bordering the Congo Craton to the west. It experienced intense tectonic events, notably a cratonization phase estimated at about 2,500 Ma, followed by an oceanization phase. This oceanization resulted in the separation of the Congo Craton and the São Francisco Craton in Brazil, which were once connected. The two continental margins evolved after 2,000 Ma, leading to subduction followed by the collision of the active Brazilian continental margin with the passive Congolese margin, thereby generating intracratonic volcanic activity. This collision is part of the Pan-African tectonic event, with geological structures indicating an eastward vergence.

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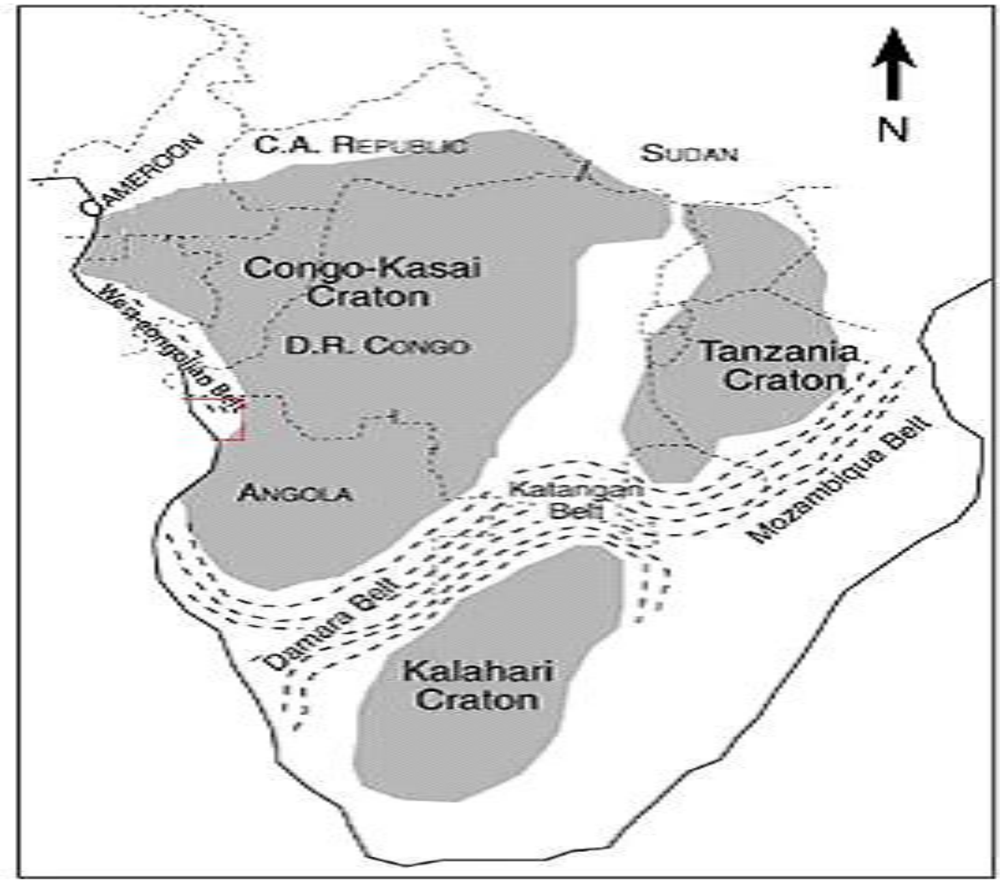

***Figure 2**. Structural framework of the West Congolese Belt bordering the Congo Craton* [27] *long dashed lines represent major tectonic fault, short dashed line indicated secondary fault, and dotes lines correspond to interpreted structural boundaries. The belt extends along the western margin of the Congo craton and record pan-African compressional tectonics.*

Around 1,000 Ma, the West Congolian Belt underwent a rifting event [16]. This phase was marked by regional uplift in the axial zone of the belt, leading to the formation of the Kongo Central aulacogen, where Upper Proterozoic deposits (West Congolian formations) accumulated.

The West Congolian Belt borders the Congo Craton to the west and extends over nearly 5,000 km in length and 150 km in width, from Namibia to Gabon, passing through Angola, the DRC, and Congo [5],[23]. It has been extensively studied by Cahen in the DRC, Staton in Angola, Dahet in Congo-Brazzaville, and Hudelay in Gabon. Recently, the General Secretariat for Hydrocarbons has focused on this basin, as previously described.

It has been mainly investigated by several authors, and a synthesis of existing data was presented by [25]. The belt results from the collision between an eastern passive Congolese margin and a western active Brazilian margin. This belt overlaps older orogenic events, for which geochronological and structural studies have helped identify key features. Rifting was later followed by subsidence, which led to the formation of grabens and horsts in the Congo Basin. These structures are currently masked by Phanerozoic deposits. These events marked the beginning of the Pan-African cycle [11].

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The geological formations found in Mount Bangu (Figure 3) are:

A – Stromatolitic limestone;

B – Shale unit;

C – Sandstone formation;

D – Crystalline basement.

Figure 3 illustrates fault-bounded sedimentary compartments and folded strata resulting from compressional stresses. The structural arrangement favors sediment preservation within synclinal depressions, consistent with the interpreted graben-like geometry derived from gravimetric analysis. When tectonic forces fold sedimentary layers to form a fold structure, porous layers are overlain by an impermeable layer, with the source rock situated below. Petroleum and/or gas accumulates in the porous layers of the fold. Between normal or reverse faults, hydrocarbon accumulation occurs in the uplifted part of the reservoir rock [15].

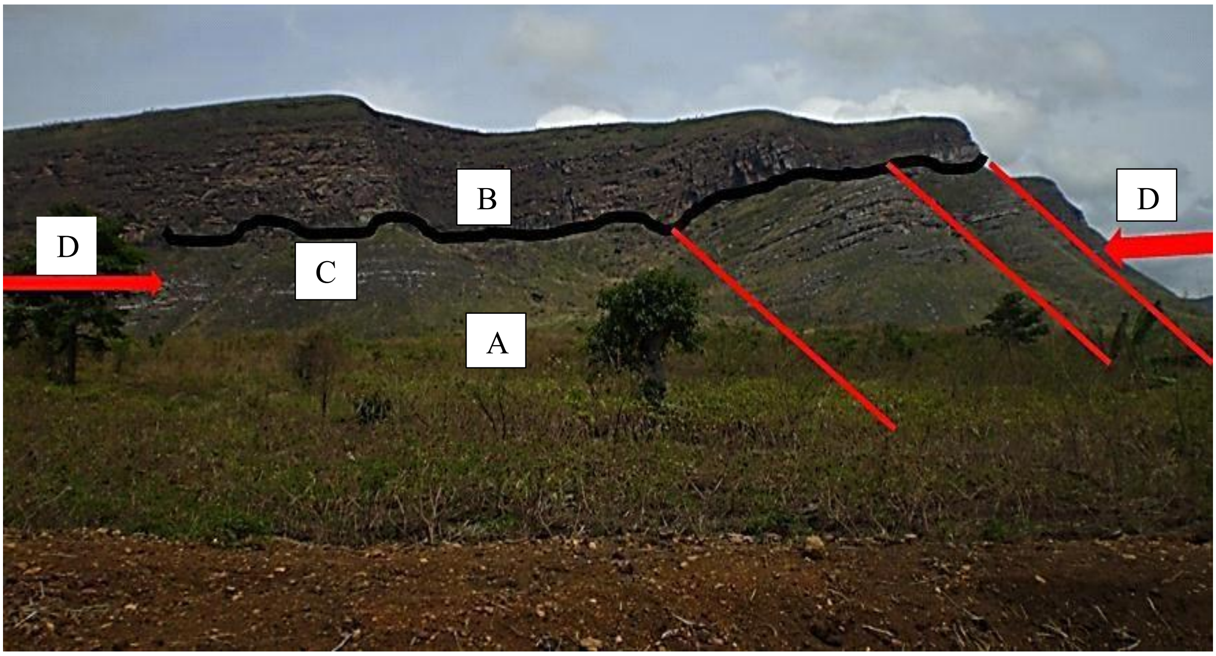

***Figure 3**. Compressive tectonic structure observed at Mount Bangu* [24].

The West Congolese Belt forms part of the Central African Pan-African orogenic system. It borders the Congo Craton to the west and extends from Namibia to Gabon. The belt experienced multiple tectonic phases, including cratonization (~2.5 Ga), rifting (~1.0 Ga), and Pan-African collision events, resulting in the formation of graben and horst structures. Mount Bangu represents a folded and faulted structure interpreted as a syncline associated with extensional tectonics, favoring sediment accumulation.

Several sites presenting solid, liquid, and gaseous surface hydrocarbon indicators have been reported in the West Congolian sub-basin. Notable examples (Figure 4) include hydrocarbon seepages observed around Kimpese, Kisantu, and Mbanza-Ngungu [2],[13].

Figure 4.1 Surface hydrocarbon indicators near Kisantu and Kimpese [22].

Applied geophysics offers effective tools to characterize not only the thickness but also the structure of sedimentary deposits. From gravimetric data, it is possible to estimate burial depth, which can then be correlated with the regional geothermal gradient to assess the thermal maturity of organic matter. In the case of the Central Cuvette, of which the West Congolese sub-basin is a part, the JNOC report [12] establishes the following correlations:

- 0°C to 80°C (≈ 3 km): Immaturity zone,
- 80°C to 110°C (≈ 4.2 km): Early maturity – onset of oil generation,
- 110°C to 130°C (≈ 5 km): Full maturity – generation of liquid hydrocarbons (oil),
- 130°C to 155°C (≈ 6 km): Over-maturity – gas generation.

Thus, precise knowledge of sedimentary thickness is a key parameter for assessing the petroleum potential of the region.

In this study, we use spatial gravimetric data to analyze geological structures of petroleum interest around Mount Bangu. The processing steps include:

- Calculation of the Bouguer anomaly,
- Separation of regional and residual anomalies,
- Derivatives along the *X*, *Y*, and *Z* axes,
- Superposition of gravimetric anomalies with the topography of Mount Bangu.

This work aims to provide an improved geodynamic interpretation of the area, to refine the estimate of sediment thickness, and to determine whether the conditions required for hydrocarbon generation are met within the West Congolese sub-basin.

MATERIALS AND METHODS

Located in the heart of Kongo Central Province in the Democratic Republic of Congo, the study area is part of the West Congolian Basin, between Mbanza-Ngungu and Songololo, passing through Kasangulu and Madimba [1]. The town of Kimpese lies between 5°12' and 5°24' south latitude and 14°13' and 14°18' east longitude at an elevation of 337 m, within the territory of Songololo in the Cataractes District. It is in this town of Kimpese that the famous Mount Bangu is found, which constitutes the primary focus of our study.

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Figure 5 provides regional geological context for the gravimetric investigation. The map shows the geographic position of Mount Bangu between Mbanza-Ngungu and Songololo, within the West Congolese sub-basin, which forms part of the larger Congo Basin. Administrative boundaries, main towns (Kimpese, Kisantu, Mbanza-Ngungu), and geographic coordinates (WGS84) are indicated.

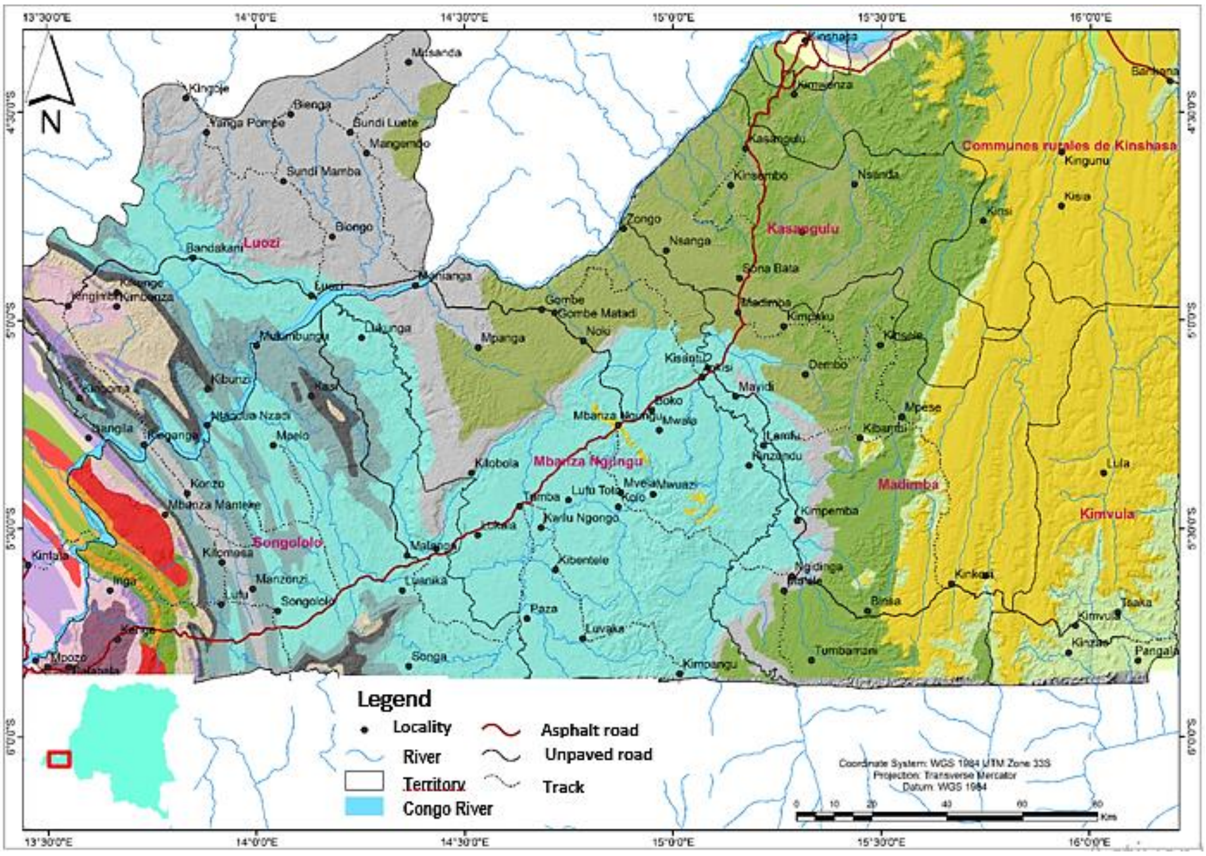

Figure 5. *Location of the study area within the West Congolese sub-basin (Congo Central Province, DRC) developed using Arc GIS software.*

Data Satellite gravimetric data related to Bouguer anomalies were obtained from the International Gravimetric Bureau (BGI). The dataset consists of 3,722 measurement stations characterized by longitude, latitude, and Bouguer anomaly values. Data processing and map generation were performed using Surfer 19 and Oasis Montaj software. ArcGIS 10.8 was used for cartographic representation and spatial overlays. Standard gravimetric processing steps were applied, including Bouguer anomaly calculation, separation of regional and residual anomalies, and computation of horizontal and vertical derivatives. A representative sample of these stations was selected, as shown in Table 1.

Table 1. *Presentation of spatial Bouguer anomaly data.*

Longitude (Degree)	*Latitude (Degree)*	*Bouguer Anomaly (mGal)*
12.63	-4.30	78.86
12.67	-4.30	82.06
12.70	-4.30	91.35

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Longitude (Degree)	*Latitude (Degree)*	*Bouguer Anomaly (mGal)*
12.73	-4.30	89.90
12.76	-4.30	86.69
12.80	-4.30	81.31
12.83	-4.30	79.43
12.86	-4.30	80.14
12.90	-4.30	77.57
12.93	-4.30	79.97
12.96	-4.30	78.19
13.00	-4.30	75.38
13.03	-4.30	82.46
13.06	-4.30	83.47
13.10	-4.30	77.76
13.13	-4.30	82.18
13.16	-4.30	77.91
13.20	-4.30	76.68
13.23	-4.30	77.14
13.26	-4.30	76.50
13.30	-4.30	74.81
13.33	-4.30	72.58
13.36	-4.30	71.06
13.40	-4.30	61.43
13.43	-4.30	43.83
13.46	-4.30	67.69

RESULTS

Separation of anomalies

The regional and residual anomaly maps were obtained from the Bouguer anomaly map (Figure 6). Although regional removal is conceptually similar to filtering operations, the solution is not as simple as applying a filter to remove low-frequency anomalies. In general, it is often more realistic to treat residual anomalies as noise and extract the regional anomaly [18],[19].

Thus, the choice of regional anomaly depends on prior geological knowledge of the region as well as the anomalies to be interpreted. The best definition of the regional anomaly is that it corresponds to the effects of masses that we do not intend to interpret. The residual anomaly then corresponds to the anomalies whose sources we want to identify [20].

The Bouguer anomaly represents the gravity response caused by subsurface density heterogeneities. Interpretation is therefore based on it. The corrections applied to the measured gravity compensate for all non-geological effects that are unavoidable during measurement. The theoretical field is a mathematical model resulting from a homogeneous spheroid whose external surface corresponds to the reference ellipsoid, which is a mathematical approximation of Earth's surface.

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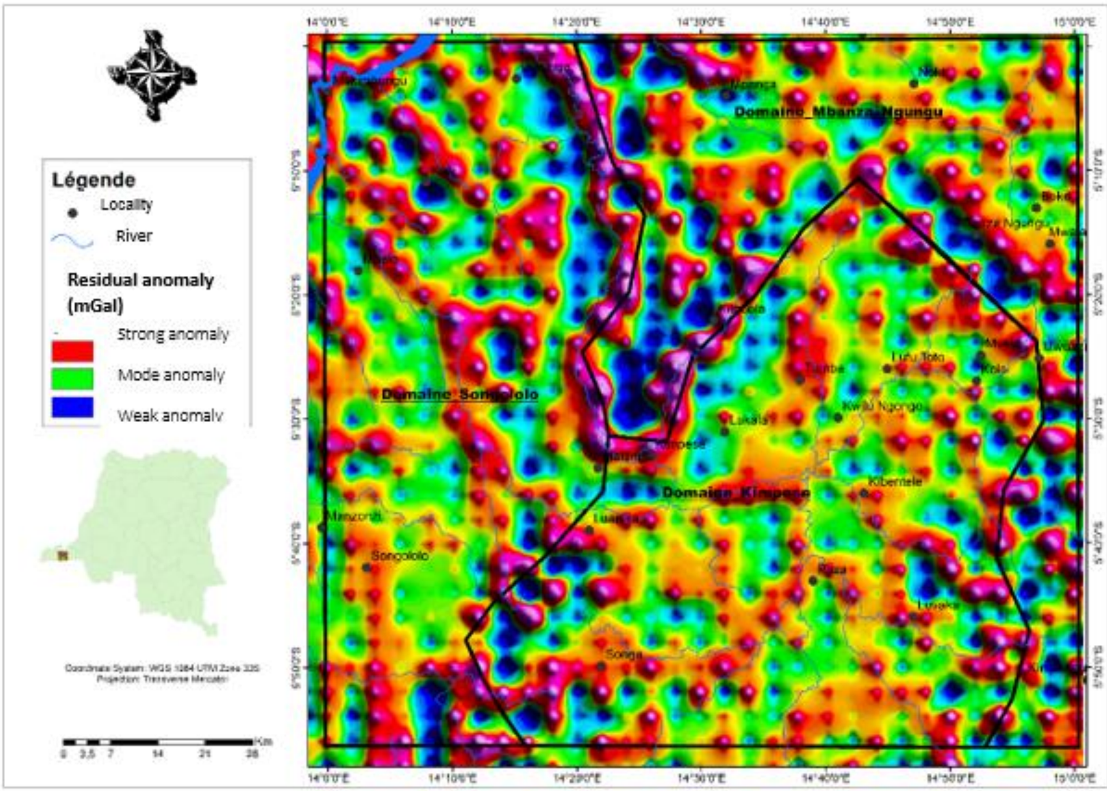

Figure 6. *Residual anomaly map.*

The regional anomaly was calculated from the Bouguer anomaly map. Since the Bouguer anomaly is known at the nodes of a regular interpolated grid, the regional anomalies were analytically estimated by calculating the first terms of an n-degree polynomial, whose coefficients were obtained by least squares. The regional anomalies therefore represent the effect of deep masses. The residual anomaly at each grid node was calculated by subtracting the regional anomaly from the Bouguer anomaly. The residual anomalies thus represent the effect of shallow perturbing masses [26].

The residual Bouguer anomaly map (Figure 6) shows peaks of high and low anomalies oriented in various directions across the different domains:

- Songololo: anomalies oriented NW–SE in the northern part; N–S in the southern part,
- Mbanza-Ngungu: in the west, anomalies oriented N–S; in the east, oriented NW–SE,
- Kimpese: anomalies oriented N–S.

Heavy anomalies occur next to lighter anomalies, shaping the area into a horst-and-graben system.

Derivative

The vertical derivative reveals several peaks in the Bouguer anomalies, especially in the Songololo and Mbanza-Ngungu areas, and toward the eastern part of Mbanza-Ngungu. In the Kimpese area, the anomaly peaks are also present, but their intensity is lower than those of Songololo and Mbanza-Ngungu. Vertical derivatives of gravity anomalies enhance the effects of shallow sources relative to deeper sources [7]. The vertical derivative enhances shallow density contrasts and structural discontinuities. High-amplitude gradients indicate near-surface faulting and tectonic lineaments, refining the structural interpretation of the sedimentary basin.

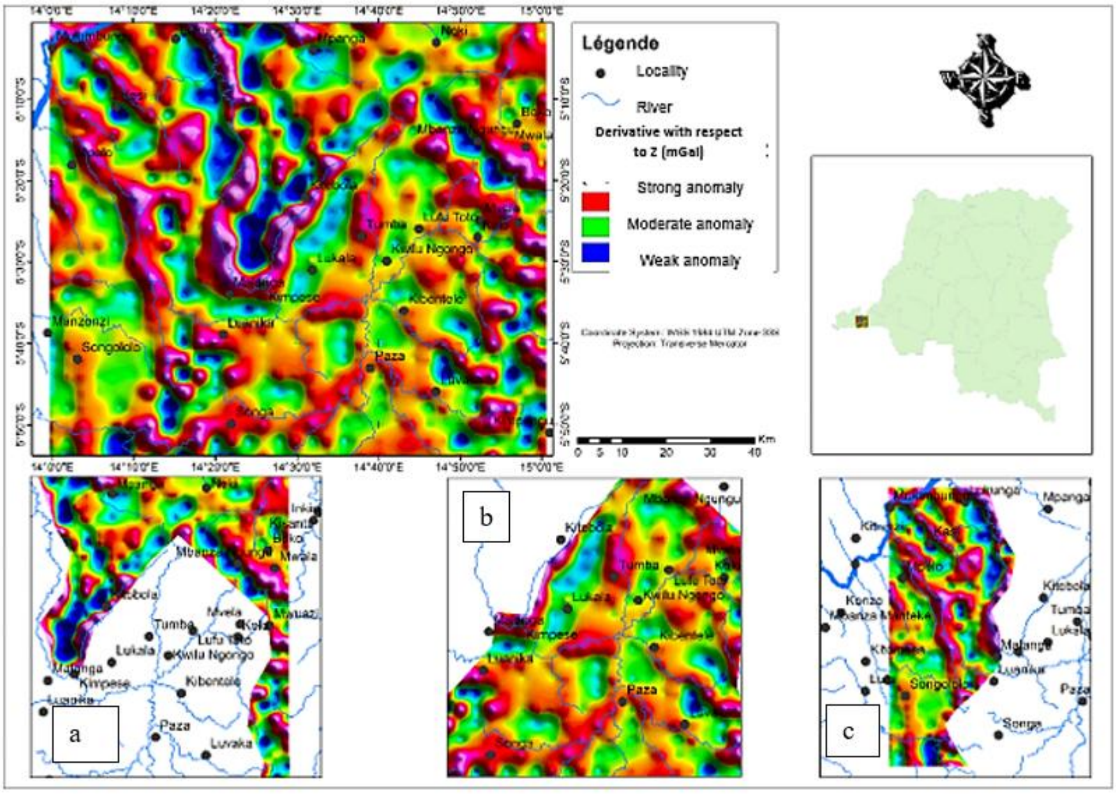

Figure 7*. Vertical derivative map of Bouguer anomalies highlighting structural discontinuities in the Mount Bangu area: (a) Western sector (Songololo) major structural lineaments; (b) Central sector (Mbanza-Ngungu) secondary fault systems; (c) Eastern sector (Kimpese) zone of significant density contrast revealed by gravity gradient.*

Bouguer Anomaly

Figure 8 highlights the zones where the anomalies are heavier or lighter, as well as the predominant directions of the anomalies. The Bouguer anomaly map of the study area reveals various intensities of gravimetric anomalies [3]. Toward the northwest and the eastern part extending toward the center, the anomalies are heavier, with intensities ranging from 67.9 to 80.5 mGal, according to the spatial data. The northern and southern parts also show heavy anomalies, but with slightly lower intensities, ranging from 50.4 to 67.9 mGal. Overall, the Bouguer anomalies in the study area vary between 50.4 and 80.5 mGal. Warmer colors represent higher-density zones, possibly related to basement uplift or compact formations, whereas cooler colors indicate thicker sedimentary accumulations. The spatial distribution of anomalies reveals structural compartmentalization consistent with extensional tectonics.

The Bouguer anomalies are thus heavier toward the northwest and a portion of the east, while the northern and southern parts display weaker Bouguer signatures. This observation suggests that Mount Bangu contains a significant thickness of sediments, which explains its low gravimetric signature.

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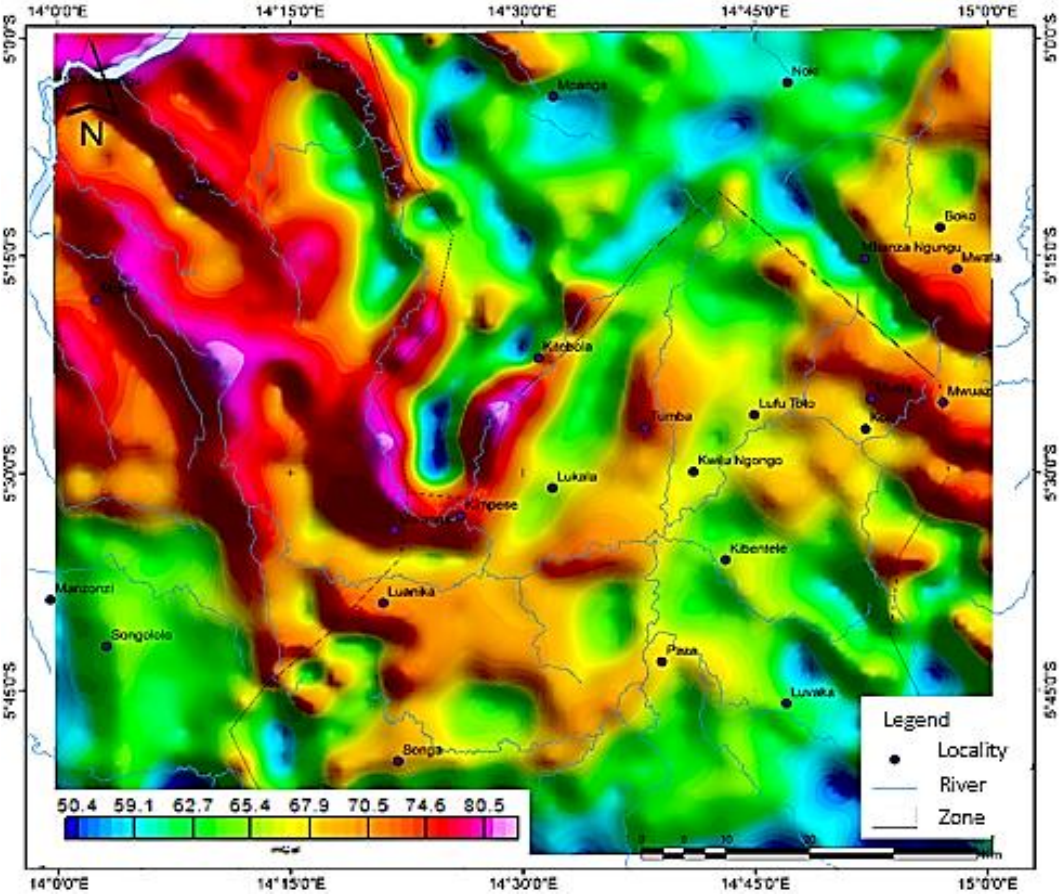

Figure 8. *Bouguer gravity anomaly map of the Mount Bangu study area showing gravity value ranging from approx. 50.4 to 80.5 mGal. Higher anomaly (red to pink colors) indicate zones of higher density; possibly related to basement uplift or compact geological formations, whereas lower anomalies (green to blue colors) correspond to areas of thicker sedimentary deposits. The spatial distribution of the anomalies suggests structural compartmentalization within the basin.*

DISCUSSIONS

Determination of sediment depth in Mount Bangu

The gravimetric anomalies over Mount Bangu are relatively weak, falling within the range of 54 to 56 mGal. Observations of the dip of the layers in this area show that Mount Bangu is a syncline, which explains the low gravimetric signatures.

Figure 9 presents 2D and 3D models of the Bouguer anomalies superimposed on the morphology or topographic shape of Mount Bangu [9],[3]. This superposition allows visualization and analysis of the correlation between gravimetric anomalies and the region's topography. The Bouguer anomaly map highlights density variations in the subsurface, while the topographic shape of Mount Bangu displays the geological configuration of the region.

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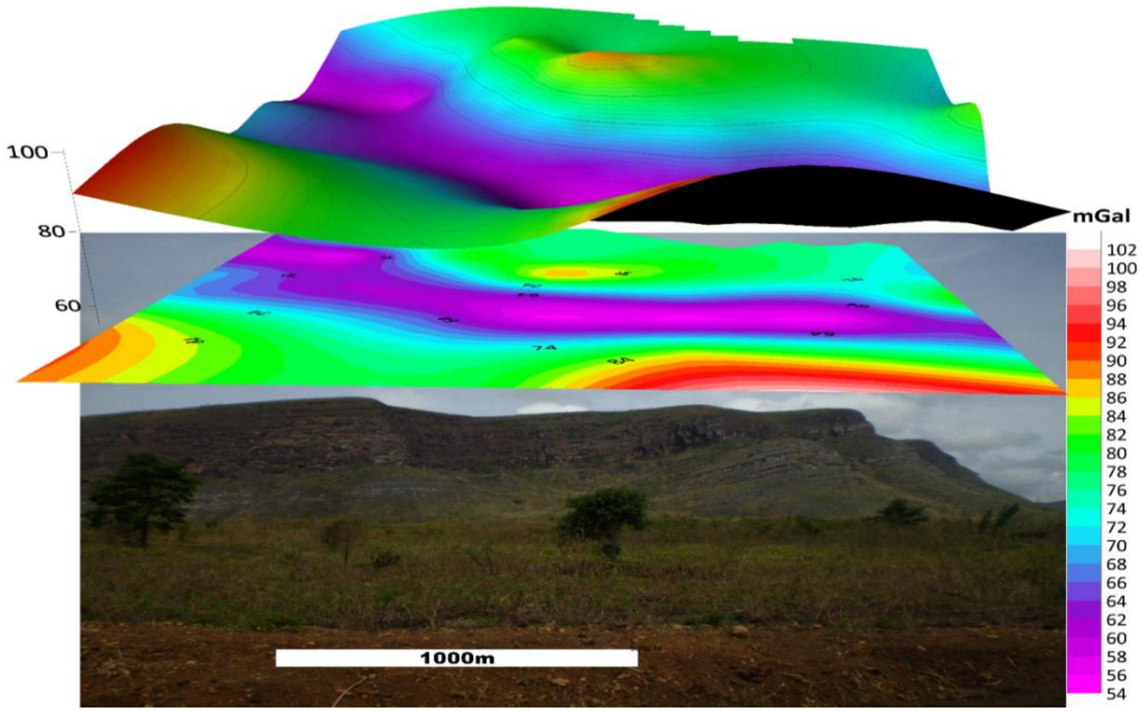

***Figure 9**. Superimposition of 3D and 2D Bouguer anomaly map with the photo of Mount Bangu.*

To achieve this, we used two approaches developed by J. Goguel (1963): a graphical method and a computational method [10].

Graphical Method

The extension (2*d*) can also be determined graphically (Figure 10) by the following method described in [10].

Let M and M′ be the two points where the anomaly reaches half of its maximum value. Consider the circle whose diameter is MM′. The horizontal band sought is found at the endpoints of this circle. Indeed, angle AMB is half the central angle AOB, according to a basic geometry theorem.

Now consider the points Q and Q′ where the anomaly reaches one quarter of the maximum, and let C be the point on the circle centered at O located above O. The circle centered at C passing through Q and Q′ also passes through points A and B. In fact, angle AQB is half of ACB, which itself is half of AQB; thus, the band AB is determined.

As verification, a third construction can be used: let T and T′ be the points where the anomaly is three-quarters of the maximum. Join CT and draw at T a perpendicular that intersects the axis of the figure at D. The circle centered at D passing through T will also pass through A and B.

Computational method

We seek the abscissas $x_{1/2}$ et $x_{1/4}$ for which the anomaly reaches respectively half and one quarter of its maximum value. Consider, at depth h, a thin layer of extension $2d$ with a superficial density.

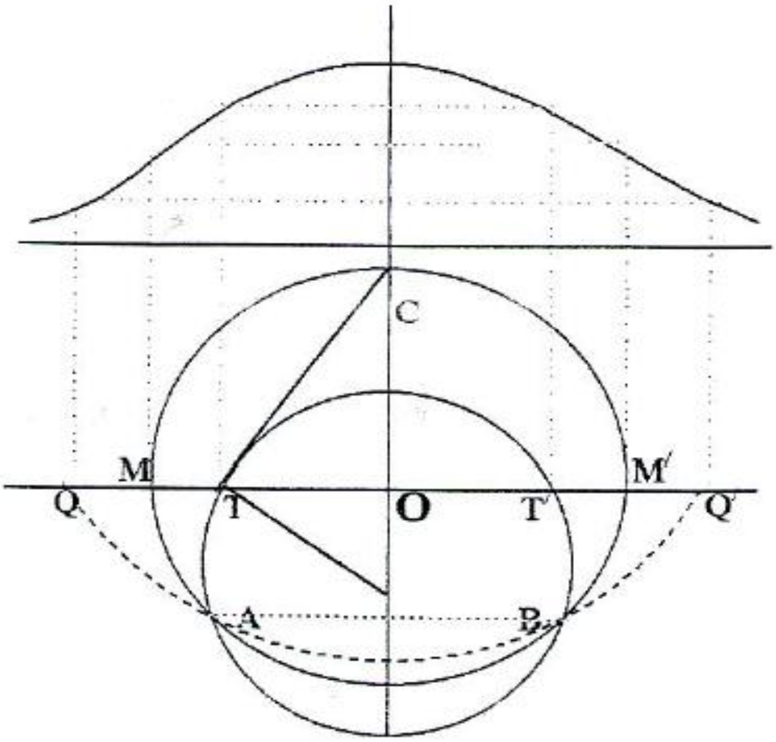

Figure 10. *Demonstrative diagram of graphics determination of extension* [10].

$$\mu = S.ds \tag{1}$$

The origin of coordinates is placed at the center of the layer, and q denotes the angle under which the layer is viewed from the observation point.

$$\Delta g(x,0) = 2G\mu[\tan^{-1}\left(\frac{x+d}{h}\right) - \tan^{-1}\left(\frac{x-d}{h}\right)] = 2G\mu\left(\varphi_1 - \varphi_2\right) = 2G\mu\theta \tag{2}$$

From the formula, the anomaly reaches its maximum at *x* = 0. Dg (x, 0). Let ∅ denote the angle under which the layer is viewed from the origin.

$$\Delta gmax = 2G\mu\emptyset = 4G\mu\tan^{-1}\left(\frac{d}{h}\right) \tag{3}$$

$$\emptyset = 2\tan^{-1}\left(\frac{d}{h}\right) \tag{4}$$

Where we are looking for $x_{1/4}$ and $x_{1/2}$ corresponding to $\Delta g_{max}/4$ and $\Delta g_{max}/2$

$$\tan^{-1}\left(\frac{x_{1/2}+d}{h}\right) - \tan^{-1}\left(\frac{x_{1/2}-d}{h}\right) = \tan^{-1}\left(\frac{d}{h}\right) \tag{1}$$

$$\tan^{-1}\left(\frac{x_{1/4}+d}{h}\right) - \tan^{-1}\left(\frac{x_{1/4}-d}{h}\right) = \tan^{-1}\left(\frac{d}{h}\right) \tag{6}$$

The solution of the systeme with two unknowns gives:

$$x_{1/2} = \left((h^2 + d^2)^{1/2}\right) \tag{7}$$

$$x^2_{1/4} = (h^2 + d^2) + 2h(h^2 + d^2)^{1/2} \tag{8}$$

And subsequently:

$$h = \frac{x^2_{1/4} - x^2_{1/2}}{2x_{1/2}} \tag{9}$$

$$2d = 2\sqrt{x^2_{1/2} - h^2} \tag{10}$$

$$\mu = \frac{\mathrm{G.\Delta gmax}}{4\tan^{-1}\left(\frac{\mathrm{d}}{\mathrm{h}}\right)} \tag{11}$$

Determination af thickness – Case of Mount Bangu (Bangu Graben)

Let us now apply the above computational methods to the Bangu Graben. At Mount Bangu, we obtain the following values:

- $x_{1/2}$: lowering at which the anomaly is half of the total residual anomaly,
- $x_{1/4}$: lowering at which the anomaly is one quarter of the total residual anomaly.

The gravimetric profile of Mount Bangu shows that, from the Bouguer anomaly (*y*-axis) and the distance (*x*-axis), we can determine ($x_{1/2}$) the lowering corresponding to half of the residual anomaly,($x_{1/4}$) the lowering corresponding to one quarter of the residual anomaly, which allowed us to obtain the respective values of $x_{1/2}$and de $x_{1/4}$ used to calculate the depth *h* and the extension 2*d*. From Figure 11 (gravimetric profile) we found: $x_{1/2} = 8000m$, and $x_{1/4} = 12000m$ or $x_{1/4} > x_{1/2}$

We have for *h* (the depth of the sediment) which is equal to:

$$h = \frac{x^2_{1/4} - x^2_{1/2}}{2x_{1/2}} \tag{12}$$

$$h = \frac{12000^2 - 8000^2}{2*8000} = \frac{144000000 - 64000000}{16000} = \frac{80000000}{160000} = 5000m$$

Therefore, the sediment depth *h* = 5 km. The calculated sediment thickness beneath Mount Bangu indicates a depth of approximately 5 km. At this depth, it is estimated that the organic matter has reached the hydrocarbon maturation stage.

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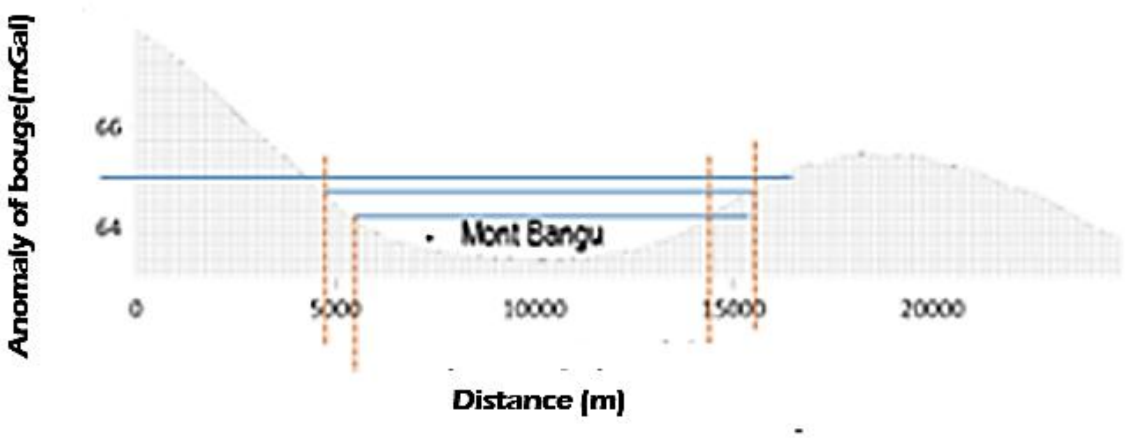

Figure 11. *Gravimetric profile across Mount Bangu.*

And the extension of this sediment is equal to:

$$2d = 2\sqrt{x^2{}_{1/2} - h^2} \quad (13)$$

or $x_{1/2} = 8000m$ and $x_{1/4} = 12000m$, or $x_{1/4} > x_{1/2}$ and $h = 5000m$,

$$2d = 2\sqrt{8000^2 - 5000^2} = 12489{,}996m \approx 12490m$$

The lateral extension of the sedimentary body is approximately 13 km. Thus, Mount Bangu not only contains fine stromatolithic sediments at an estimated depth of 5 km but also displays an extension exceeding 13 km.

Briefly, sedimentary thickness beneath Mount Bangu was estimated using the graphical and analytical methods developed by Goguel [10]. Gravimetric profiles indicate that the anomaly reaches half and one-quarter of its maximum at specific distances, allowing depth (h) and lateral extension ($2d$) to be calculated. The calculated sediment depth is approximately $h = 5$ km, while the lateral extension reaches about $2d = 13$ km.

Considering the regional geothermal gradient of the Central Cuvette, sediments buried at approximately 5 km depth are expected to reach temperatures between 110°C and 130°C, corresponding to the oil generation window. Surface hydrocarbon seepages reported near Kimpese and Kisantu further support the hypothesis of an active petroleum system.

CONCLUSIONS

The main objective of this study was to accurately determine the depth and lateral extent of the sediments present at Mount Bangu, a structure often perceived by observers as a massive rock body, but which in reality contains stromatolithic sediments. To achieve this, we applied geophysical methods specifically gravimetry in a context where the West Congolese sub-basin remains largely underexplored.

Mount Bangu, located in the West Congolese sub-basin in Kongo Central Province (DRC), is situated in an area known to be sedimentary. Our initial analyses, supported by the Bouguer anomaly map, confirmed this assumption. Interpretation of the various gravimetric maps revealed that although Mount Bangu appears at the surface as a prominent topographic feature, its subsurface configuration does not correspond to a compact mountain. On the contrary, the results suggest a morphology more consistent with a graben or a depression filled with sediments.

The gravimetric profile allowed us to estimate the depth of the stromatolithic sediments at approximately 5 km, with a lateral extension exceeding 12.5 km. Based on the geothermal gradient characteristic of the Central Cuvette, temperatures between 110°C and 130°C are expected at this depth conditions favorable for the transformation of organic matter contained in the stromatolites into hydrocarbons.

This interpretation is further supported by several surface manifestations of hydrocarbons dysmigration, seepages observed in the region, particularly near Kimpese and Kisantu, which lie along the same geological alignment as Bangu. These indicators suggest a potentially active petroleum system in the area.

In summary, the gravimetric study conducted at Mount Bangu provides new and significant insights into the sedimentary structure of this poorly understood region. It also opens promising avenues for future geological and petroleum investigations in the West Congolese sub-basin.

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