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CONTRIBUTION OF THE COMBINED INTERPRETATION OF GEOPETROLEUM DATA IN THE PETROLEUM EXPLORATION PROGRAM OF THE CONGO BASIN – CASE OF THE LOKORO SUB-BASIN

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ABSTRACT

The contribution of the combined interpretation of geo-petroleum data in the oil exploration program of the central Cuvette basin "case of the Lokoro sub-basin" carried out as part of our scientific research for Diplome d'Etudes Approfondies studies (DEA). The objective of this research is to update knowledge on oil exploration in the Lokoro sub-basin. We combined and analyzed geological, geochemical and geophysical data to obtain the following results:

- Static terrestrial gravity campaign in the western part in order to have information on the sedimentary cover of this zone and the geological structures;
- The Kiri structure is a salt dome superimposed by fragments of granitic rock which give a signature of heavy gravity anomaly;
- The highlighting of three prospective zones, Zone A, Zone B and Zone C, for which we have proposed seismic work adapted to geological realities;
- The L59 seismic line of the Dekesse well was not drilled in the right place, the interpretation of this profile shows the deformation by salt tectonics, which generated geological structures of oil interest, the location of which we had proposed drilling.

Keywords: geopetroleum data, petroleum exploration, Lokoro sub-basin

1. INTRODUCTION

The Congo Basin (Central Cuvette) is one of the largest intracontinental basins in Africa with 800,000 sqkm. The oldest geological and geophysical works related to the "Syndicate pour l'Etude géologique et minière de la Cuvette Congolese have indicated the presence of a vast sedimentary basin filled with Infracambrian to recent series. Logs from the wells (Samba TD at 2038 m, Dekese TD at 1856 m, Mbandaka-1 TD at 4350 m and Gilson-1 TD at 4665 m) reveal that its sedimentary filling reaches up to 5 km but would be greater than 9 km in some places as shown by seismic interpretation. [1] Exploration works started around the years (1952-1956) and (1973-1988), until now no discovery of economic value, however, the highlighting of drillable structures coupled with the presence of a certain petroleum system are already positive and very encouraging elements for further exploration in this Basin full of promises. [2] Three main sub-basins are recognized within the Congo Central Basin: The Northeastern Busira and Lomani sub-basins, the Northern Lindian sub-basin and the Central Lokoro sub-basin. These sub-basins are separated by three basement highs, Inongo, Kiri and Lonkoni. [3] The choice of the Lokoro sub-basin is justified by the fact that this sub-basin has geological, geochemical, geophysical and well data which are one of the main reasons for the oil companies to negotiate during the contracting of oil blocks, but also the discovery of oil on the Brazzaville side in the Ngoki block, obliges to move forward with the work. The continuation of work in this promising sub-basin will contribute to the discovery of oil in the central basin on the side of the D.R. Congo.

2. LOCATION, GEOLOGY, MATERIALS AND METHODS

2.1 Location

Our study area is located in the southwest of the D.R. Congo, entirely in the new province of Mai-Ndombe. It is limited (Figure 1): to the North by the province of Equateur and Tshuapa; to the South by the province of Kuilo and Kasaï and the city of Kinshasa is located to the South-East; to the East by the province of Sankuru; to the West by the Republic of Congo Brazzaville along the Congo River.

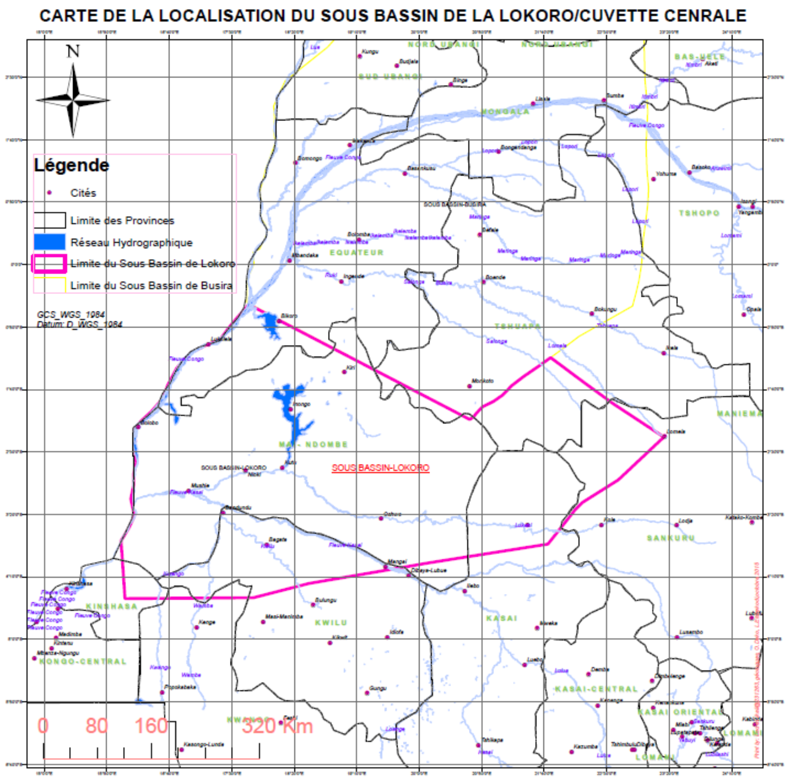

***Figure 1**. Map of the location of the Lokoro sub-basin (modified after [17])*

2.2. Geology

The land bordering Lake Mai-Ndombe to the northwest is formed of recent alluvium, as is the bottom of the valleys of some tributaries on the west bank; the entire eastern coast and a good part of the southwest belong to older layers of Pleistocene or Pliocene age [3]. Stratigraphic column of the Proterozoic to Cenozoic Central Cuvette of Congo, showing potential source rocks, seals as well as tectonic events and lithostratigraphy (Figure 2).

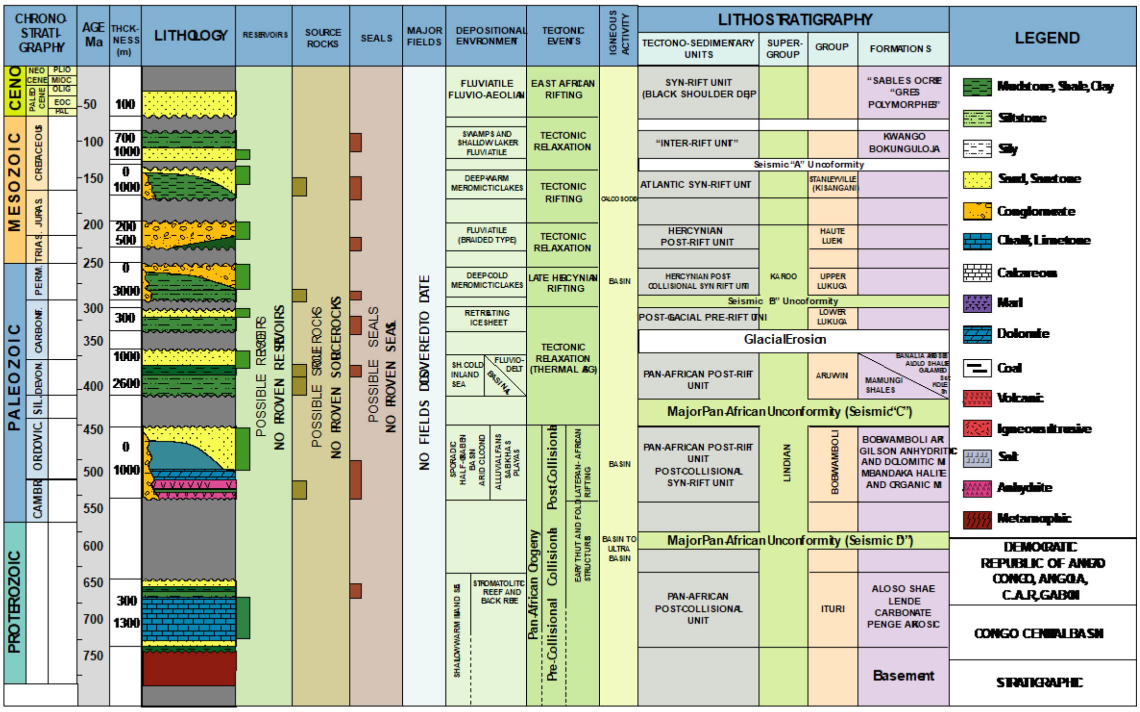

__Figure 2__. Stratigraphic column of the Central Cuvette of Congo [18]

The geological formations of the Lokoro sub-basin begin with the almost tabular Mezozoic, Triassic, Paleozoic "Cambrian and Ordovician" horizons, as well as the Vendian, which are subject to tectonic deformation (Figure 3).

The map of the structural elements below (Figure 4) is dominated by dip-silp faults oriented from the North-West to the South-East parallel to the layer pandages and Strike-dip oriented from the North-East to the South-West parallel to the layer directions.

2.3 Materials and Methods

The mapping software (Arc-Gis and QGis) allowed us to realize the different maps of the study area, combined with several aspects that concern the oil exploration and the SUFER for the realization of the gravimetric and magnetic map of the Lokoro sub-basin. Geosoft 8.4 was used for the visualization of the seismic data in Seg-Y format.

We proceeded to the bibliographical study (in the services of the State of the country) of the works relating to the exploration of the central basin and particularly the sub-basin of the Lokoro, and the realization of the present work is based on the analyses and the interpretations of the available data to our possession.

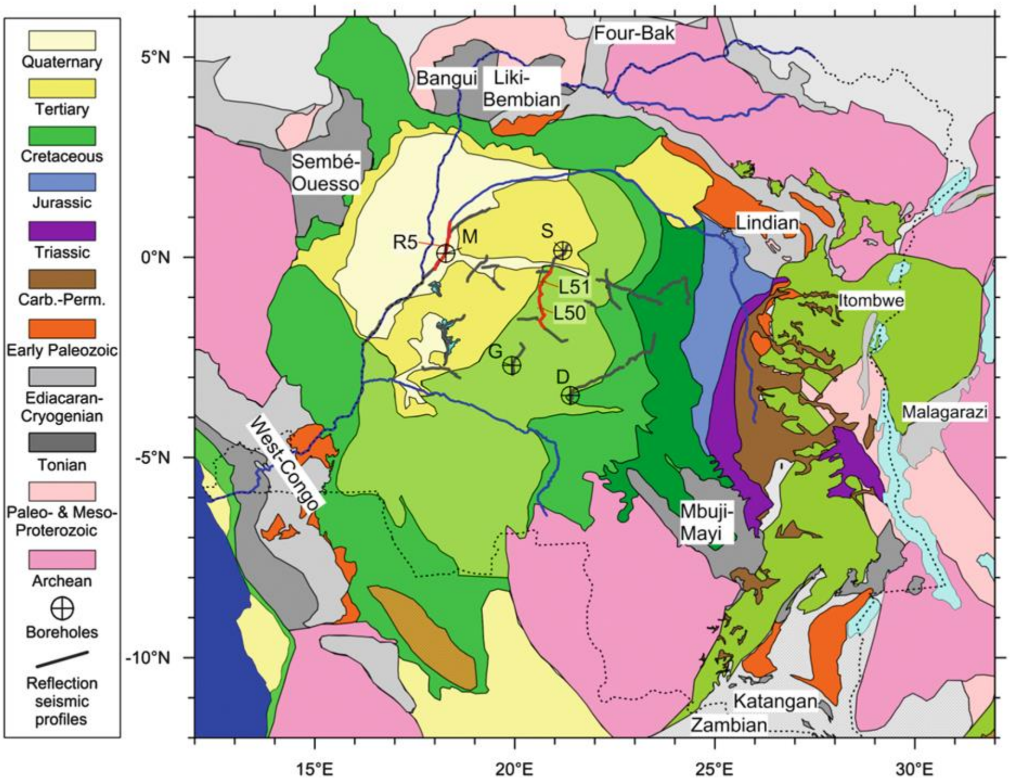

***Figure 3**. Geological map of the central basin [1]*

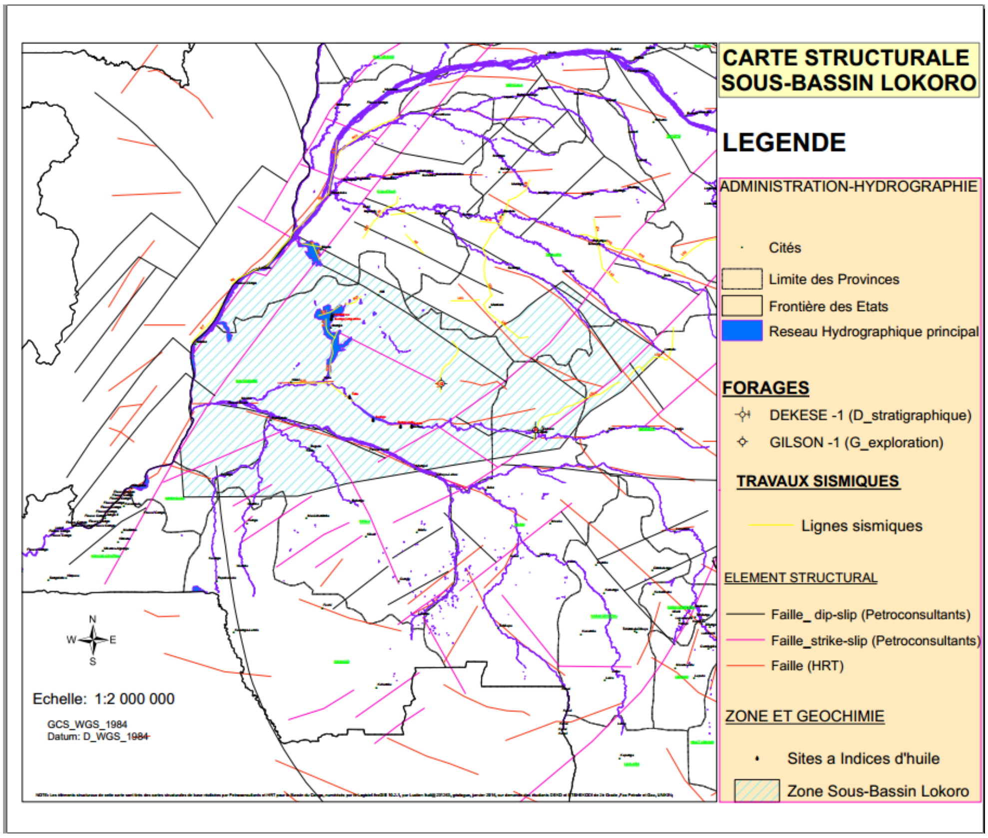

***Figure 4**. Structural map of the Lokoro basin (modified after [18])*

3. DATA ANALYSIS, INTERPRETATIONS AND RESULTS

We present the data that we have collected, geochemical, geophysical and well data from the Lokoro sub basin.

3.1 Geochemical data

High Resolution Geochemical Technology analyses of the two available seeps from the Cuvette Centrale (Central Cuvette of Congo) were done. The first sample was taken from a well named Ezoka at a site named Ilanga-Nkole, Lokoro sub-basin, on October 27, 2006, at a depth of 1 m. The second sample was taken from a well named Ngoy&Adrien, at a site named Tolo, also in the Lokoro sub-basin, on October 24, 2006 at a depth of 2 m. It should be mentioned that both samples were mixtures of oil and water collected from their respective wells. [4, 5, 6].

The use of specific biomarkers such as C_{36} "steranes", 3 and 4 "methyl steranes, dinosterane type steranes and C_{30} steranes" has allowed geochemists not only to distinguish the different origins related to specific organic facies for petroleum in a particular basin, but also to determine the approximate age of each organic facies. This is of extreme importance when determining which petroleum systems are active in each basin and of course, has a profound impact on exploration strategies very small quantities. The identification of deep sources implies that if the deep structures in the area can be identified seismically and if adequate reservoir porosity and permeability exist, and then these structures will certainly have been loaded by that deep source. And if the seals are tight, huge new discoveries can be made.

The application of this methodology was taken involving samples from two oil seeps in the Central Cuvette of Congo (Figure 5 and Figure 6).

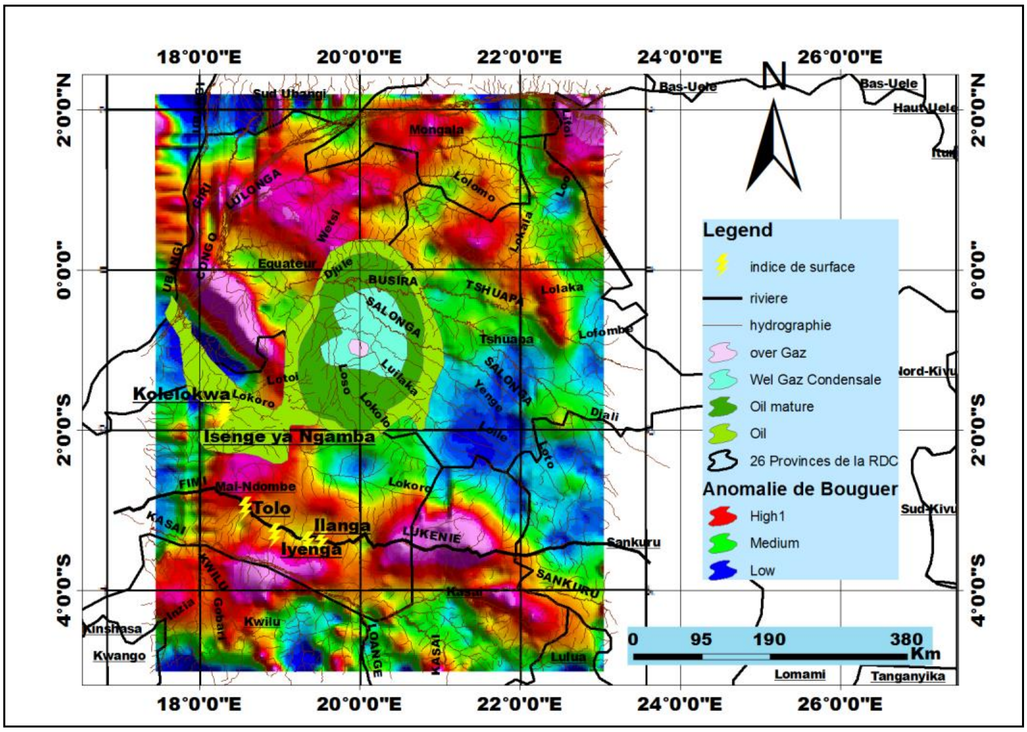

Figure 5. *Location map of two oil seeps (Ezoka and Ngoy & Adrien) in the Lokoro sub-basin in the Central Cuvette of Congo. [19]*

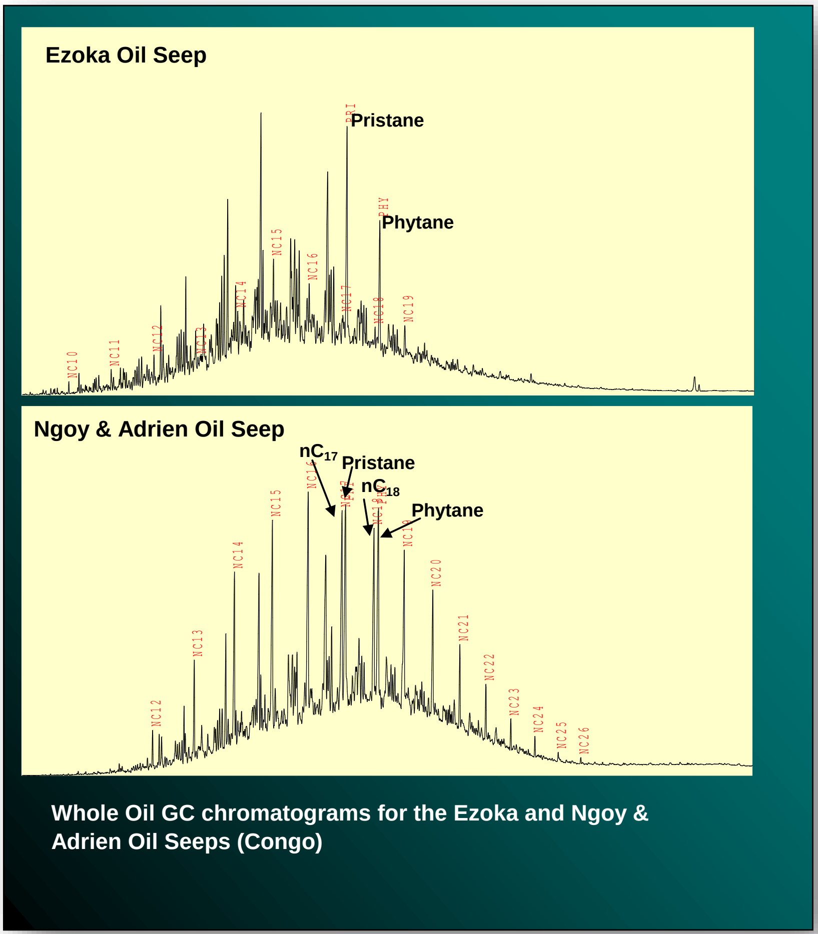

Figure 6*. Complete oil gas chromatograms from Puit Ezoka and Ngoy & Adrien oil seeps. [19]*

3.2. Geophysical data

The search for hydrocarbons takes into account several geophysical methods which are: Gravimetry, Magnetometry, Seismic; and Electromagnetic; with several objectives, but the purpose is to determine the geological structures that can play the role of hydrocarbon trap. The different methods of geophysical prospecting inform us about the distribution of the physical properties of the subsoil. Their main advantage lies in their non-invasive and non-destructive character; the environment is not permanently disturbed after their passage.

The choice of method is a function of the structure or area of study, and therefore the model that best accounts for the observed anomaly will depend on the method used.

3.2.1. Magnetometry

An airborne survey was carried out by CGG, ESSO TEXACO in collaboration with the Congolese state structures responsible for hydrocarbons during a period from 1973 to 1987 under central government funding. The aim of this campaign was to highlight the possibility of finding a petroleum system in the Central Cuvette, which is a vast subsidence zone and abounds in several seepages across its surface. It is from this campaign that the Lokoro sub-basin was entirely covered by magnetometric prospection. The flight plan is composed of North-South lines spaced 25 km apart and East-West crossings made every 18 km (Figure 7). But in the Oshwe territories this spacing was divided by two, thus, it went from 18 km to 9km; this is to highlight the seepage discovered in this area [7].

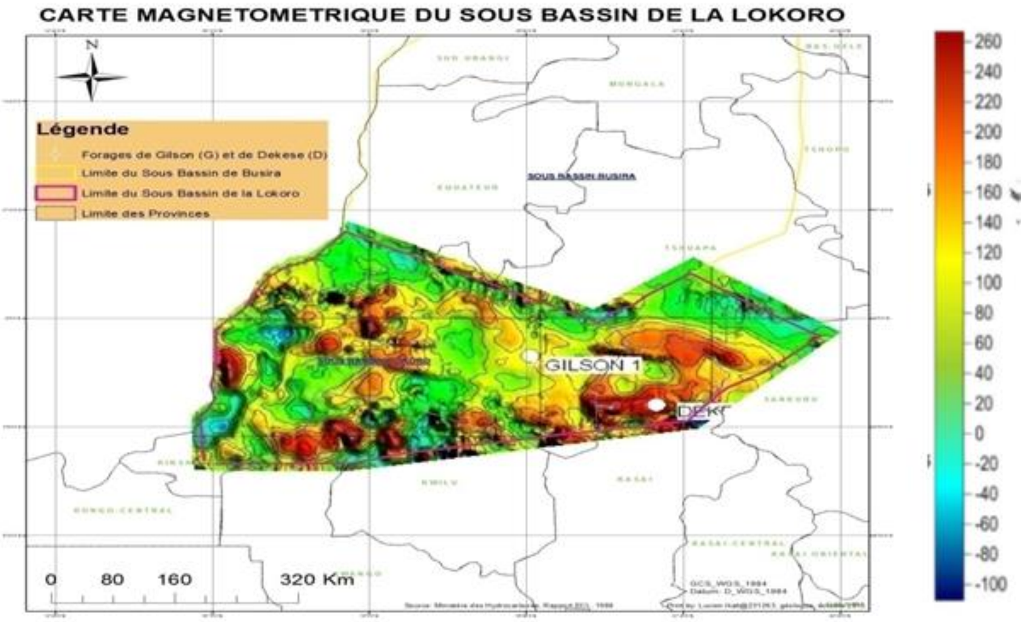

Figure 7. Magnetometric flats of the Lokoro sub-basin (modified after [19]).

We note a high concentration of large magnetic anomalies on the southeast and northwest sides. Therefore, knowing that sedimentary rocks have a lower magnetic susceptibility than magmatic and metamorphic rocks, we can say that the basement in the Lokoro sub-basin is elevated on the South-East side where the Dekese borehole is located and on the North-West side approximately on the side of the Mai-Ndombe Lake. Based on the analysis of this magnetic anomaly map, we note:

- A large sedimentary cover in the north of the sub-basin, or at the border with the Busira South sub-basin where the famous Kiri High Ground is located;
- In the center, we can see an equally important sedimentary cover.

3.2.2. Gravimetry method

Gravimetry is a geophysical method that seeks to determine from the perturbations of the field of gravity at different points on the surface of the ground, the probable distribution in the subsoil of various types of rocks characterized by their density. This method is a technique that measures variations in the Earth's gravitational potential field. The determination of density anomalies in the subsurface. Can be measured by gravimetric surveys, using extremely sensitive instruments (gravimeters). Gravimetry sees the shape of the content at depth and defines the content values in terms of geological layers.

To make the processing of the data; corrected the data; calculate the regional and local anomaly; filter the data: thus reduce the noise and strengthen the signal [8]

The different methods that allow these gravimetric interpretations are the direct, indirect or inverse methods. In the interpretation we use the Bouguer Anomaly which is the value of the anomaly after the application of some corrections:

$$\Delta g_{bouger} = \Delta g_{obs} + \pm C_A \pm C_P \pm C_R \pm C_D \pm C_F$$

- C_A: Correction de latitude;
- C_P: Correction de plateau;
- C_R: Correction de terrain;
- C^D: Correction de dérive de l'appareil;
- C_F: Correction de relief.

The Bouguer anomaly represents the variation of *g* with respect to a given vertical reference frame. The errors on each of the corrections are added together. The gravity map of the Bouguer anomalies of the study area observed below (Figure 8) has been cross-checked and georeferenced from the gravity map of the central basin that is currently available to the General Secretariat of Hydrocarbons.

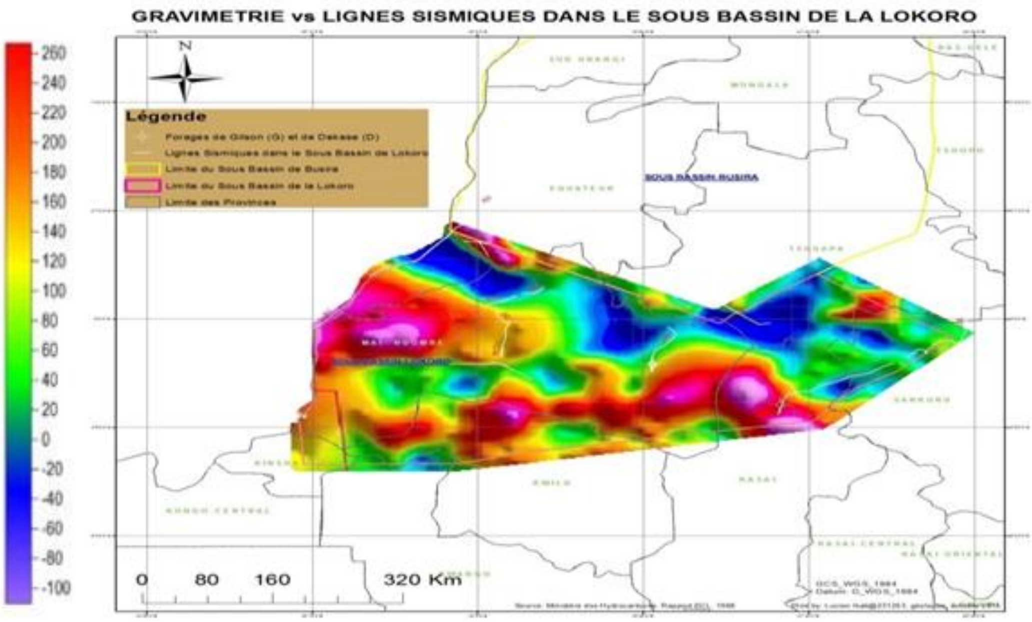

Figure 8. *Map of gravity anomalies and drilling in the Lokoro sub-basin (Gravity values legend, Blue=low values (center deposit), Red=high values (Soncle).*

For our information this gravimetric map is the result of terrestrial gravimetry performed by REMINA 1952, we had observed that the distribution of measurement points did not follow a regular grid and that this distribution of measurement points has a very low density on the southwest side (Figure 9).

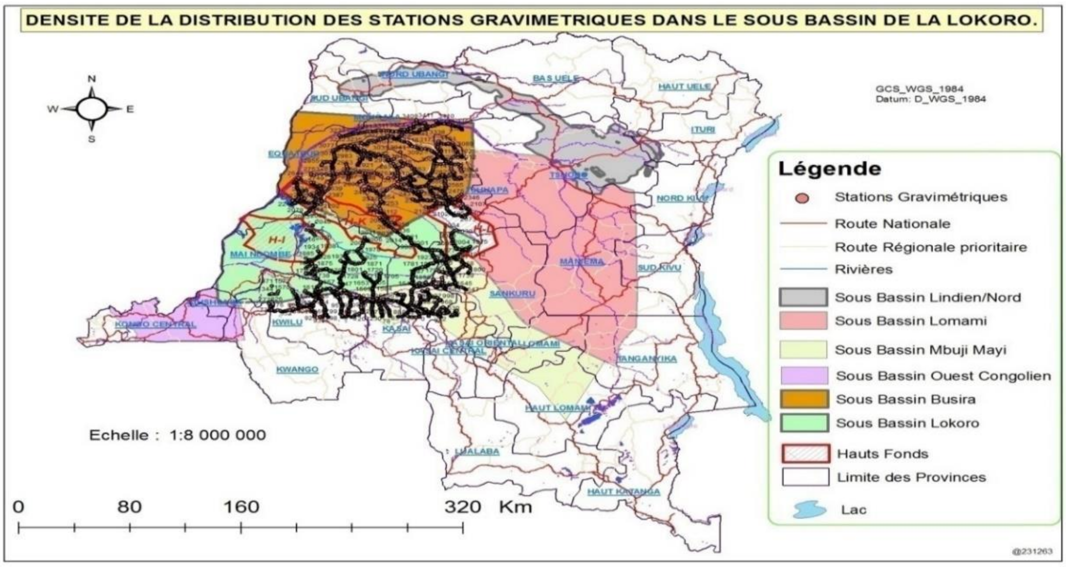

Figure 9*. Density map of the distribution of gravity stations in the Lokoro sub-basin*

We wanted to see if the new gravimetric campaign could be useful in the Lokoro sub-basin, for this we need to talk about the grid of this campaign, the Cuvette covers about 800,000km^2 or 62 square degrees; the density of the stations is ±106 stations per square degree; the average distance between stations is ±5km [9], given the spacing of the stations, the indications obtained have a geodetic character and could perhaps provide elements to clarify the geology of the Congolese Cuvette basement and specify the main structural lines.

These observations push us to the proposal of a local static terrestrial gravimetric campaign which will have for object to bring out the faults in the sediments, the sedimentary structures, the salt diapirs, because these geological parameters which are at the origin of the gravimetric anomalies [10].

3.2.3 Seismic Method

Seismic exploration methods consist in provoking tremors in the subsoil and observing on the surface the waves reflected on the geological layers or refracted along certain interfaces [11].

Seismic data, although sparse, as well as the presence of several widespread oil and gas seeps in the Lokoro sub-basin and correlation with the Middle East (Oman and Yemen) and North Africa (Libya, Algeria, and Tunisia) and Brazilian Paleozoic sedimentary basins such as the Amazonas, Parnaíba, and Paraná basins, suggest the presence of multiple petroleum systems in the central Congo basin [12].

The seismic coverage of the Lokoro sub-basin proves 14 seismic lines of which these lines were executed along the rivers and roads (Table 1).

These seismic lines executed in the roads and rivers did not take into account all the requirements of the geological structure of the Lokoro sub-basin.

Seismic line number	*Lengths (Km)*	*Acquisition environments*	*Purpose*
R1	*19,436542*	*River*	-
R2	*25,573198*	*River*	-
R3	*160,683657*	*River*	-
R6	*61,639457*	*River*	-
R7	*82,205471*	*River*	-
R21	*36,772274*	*River*	-
R22	*77,217619*	*River*	-
R23	*39,6208361*	*River*	-
R24	*29,258824*	*River*	
R25	*113,097636*	*River*	-
L58	*145,856495*	*Road*	-
L59N	*150*	*Road*	*Dekese (stratigraphic drilling)*
L60	*99,339553*	*Road*	*Gilson (Exploration drilling)*
L62	*120,178399*	*Road*	*Our interpretation*

4. TERRESTRIAL GRAVIMETRIC SURVEY

Gravity measurements performed on the surface of the Earth provide access to the Earth's gravity with a resolution directly related to the density of the measurement points. Since the density of measurement points is very low on the western side of the sub-basin, this motivates a projection of the local terrestrial gravity survey work. (Figure 10). Gravimetric planning of the western sector of the Lokoro sub-basin].

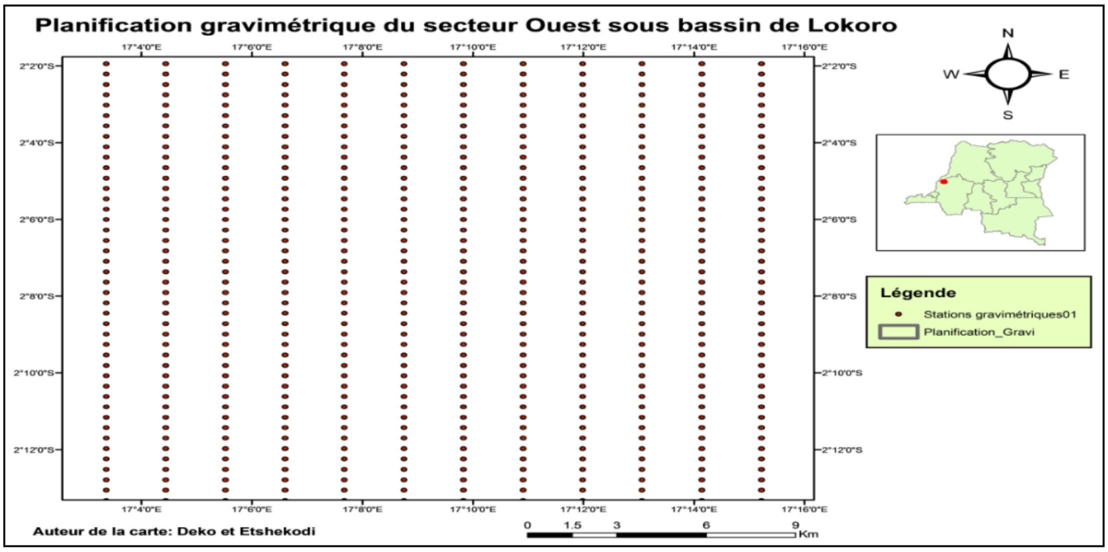

***Figure 10**. Gravimetric planning of the western sector of the Lokoro sub-basin.*

- ✓ 141,300 measuring stations;
- ✓ Equidistance of the lines: 2000 m;
- ✓ Equidistance of the stations: 500 m.

Why the static terrestrial gravity survey ?

Here are the reasons that lead us to the choice of the static terrestrial gravity survey:

- ✓ The detail obtained on the ground is much better than that obtained by airborne surveys;
- ✓ It is not expensive compared to airborne gravimetry ;
- ✓ The work will be performed by local labor.

The purpose of the gravimetry and the choice of the mesh is justified by the Figure 11, below.

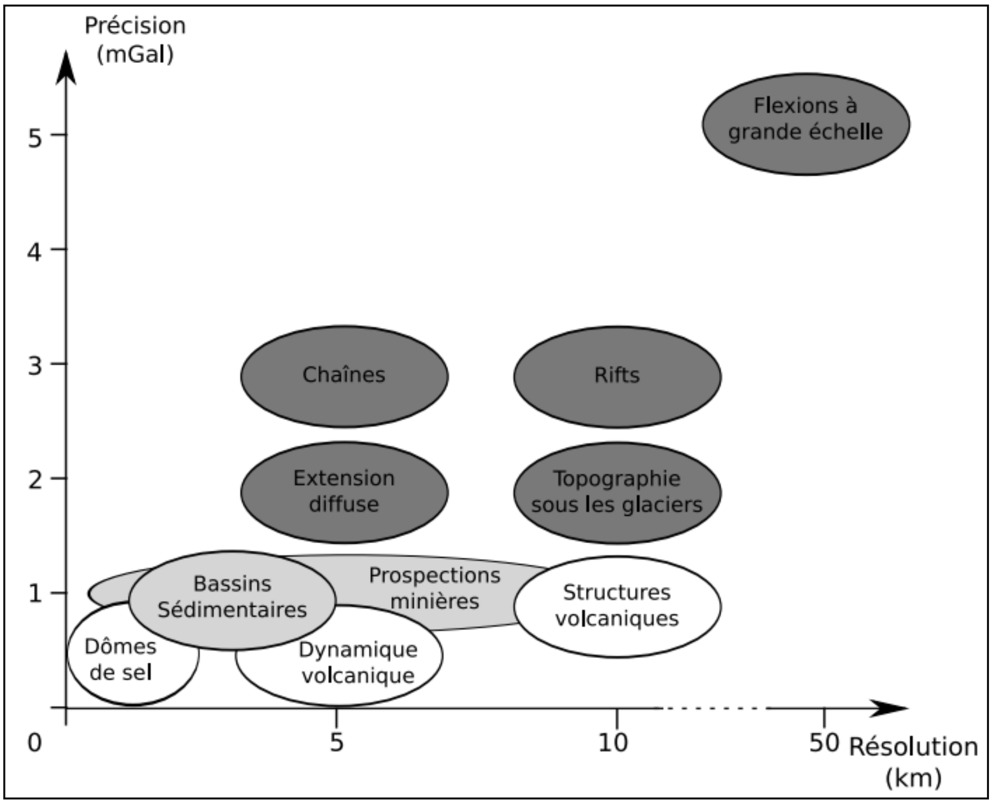

Figure 11. *Resolutions and accuracies in gravimetry required for different structural studies.*

The gravimetric map of the Lokoro sub-basin, allowed us to privilege three blocks for the seismic works that we had entitled to three blocks A, B and C (Figure 12).

These three blocks are:

- Block A - 6 seismic lines;
- Block B - 6 seismic lines;
- Block C - 6 seismic lines.

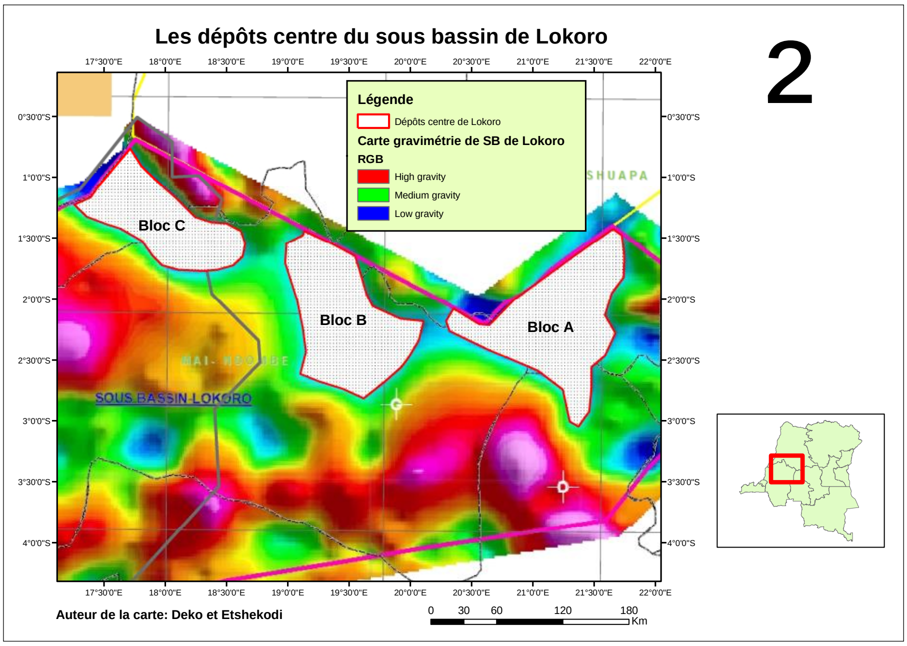

Figure 12. Mapping of three blocks for seismic work.

This classification is based on the order of importance. The reasons that led us to the determination of the lengths and numbers of the seismic lines (figure 13):

- The seismic lines must pass in places corresponding to magnetic anomalies and weak movement, that is, where there are large sedimentary deposits;
- The length of the seismic line (Ls) must be longer than the depth of the deepest target;

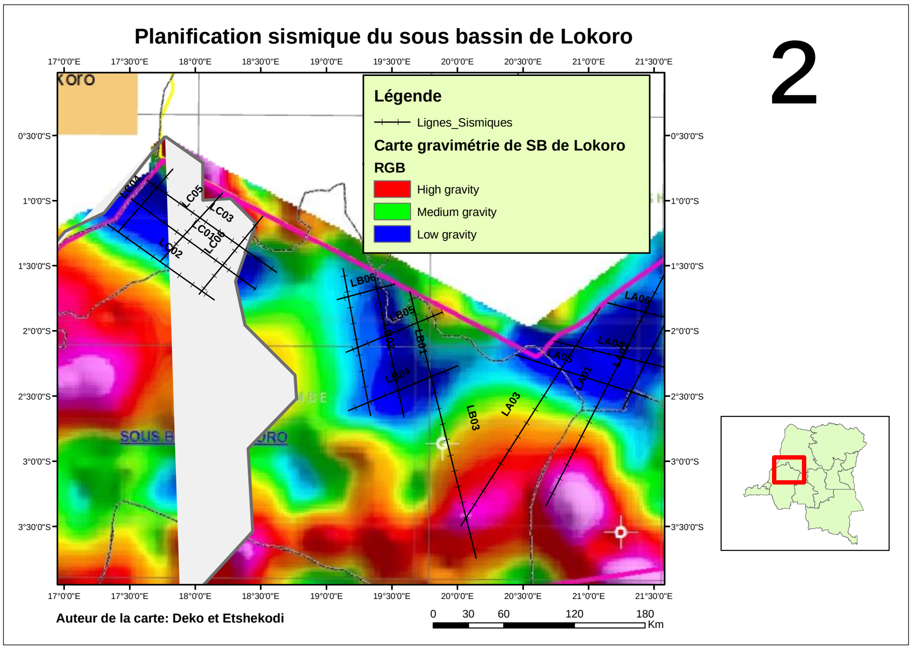

Figure 13. Orientation map of seismic lines

This program of work of seismic lines aims only the systematic, detailed and precise research of potential geological structures to give the maximum information so that the drillings are undertaken then with the maximum chance of success, in order to provide the first liter of oil in the sub-basin, it is essentially to accumulate seismic data rich in information, thanks to a kind of "echography" of the basement or "seismic reflection", seismic reflection of narrow grid 2D. To find the geological structures to be drilled, it is necessary to combine these seismic data with the GMT technique. This method is based on the study of bacteria feeding on hydrocarbons, in particular C_4 from butane. The method consists of identifying geomicrobial anomalies by combining the data of these anomalies with the seismic lines. It is by associating this method with the seismic that it finds a very capital importance because it will allow us to well circumscribe our prospect already identified with the help of the seismic and to propose the place to be drilled based on the geomicrobial anomalies. The table below gives details on the seismic lines of the blocks of the Lokoro sub-basin.

Table 2. *Seismic lines of blocks A, B, C.*

Block A	***Block B***	***Block C***
6 lines, three longitudinal lines and three transversal lines	6 lines, three longitudinal lines and three transversal lines	6 lines, three longitudinal lines and three transversal lines
Block area : 11581 sqkm	Block area: 10553 sqkm	Block area: 7558 sqkm
LA01 : 237.4 km	LB01 :120.5	LC01 :131.2
LA02 : 119.64 km	LB02 :127.6	LC02 :111.85
LA03 : 220.4 km	LB03 :233.89	LC03 :135.6
LA04 : 102.58 km	LB04 :101	LC04 :70.77
LA05 :118.8 km	LB05 :89.54	LC05 :79.4
LA06 :55 km	LB06 :51.4	LC06 :86.2

The oil works have often negative and irreversible impacts on the environment, for this reason that in the preparatory works of any project in this sector requires the realization of the Environmental and Social Impact Studies accompanied by its Environmental and Social Management Plan (ESMP). The terms of reference that we propose in these studies are:

- The Tumba Lake reserves;
- The Mangai hippopotamus reserves;
- North Salonga National Park;
- South Salonga National Park;
- The activities of the local population.

The sub-basin is a low natural risk area, and these reference themes are shown on the map of protected areas below (Figure 14).

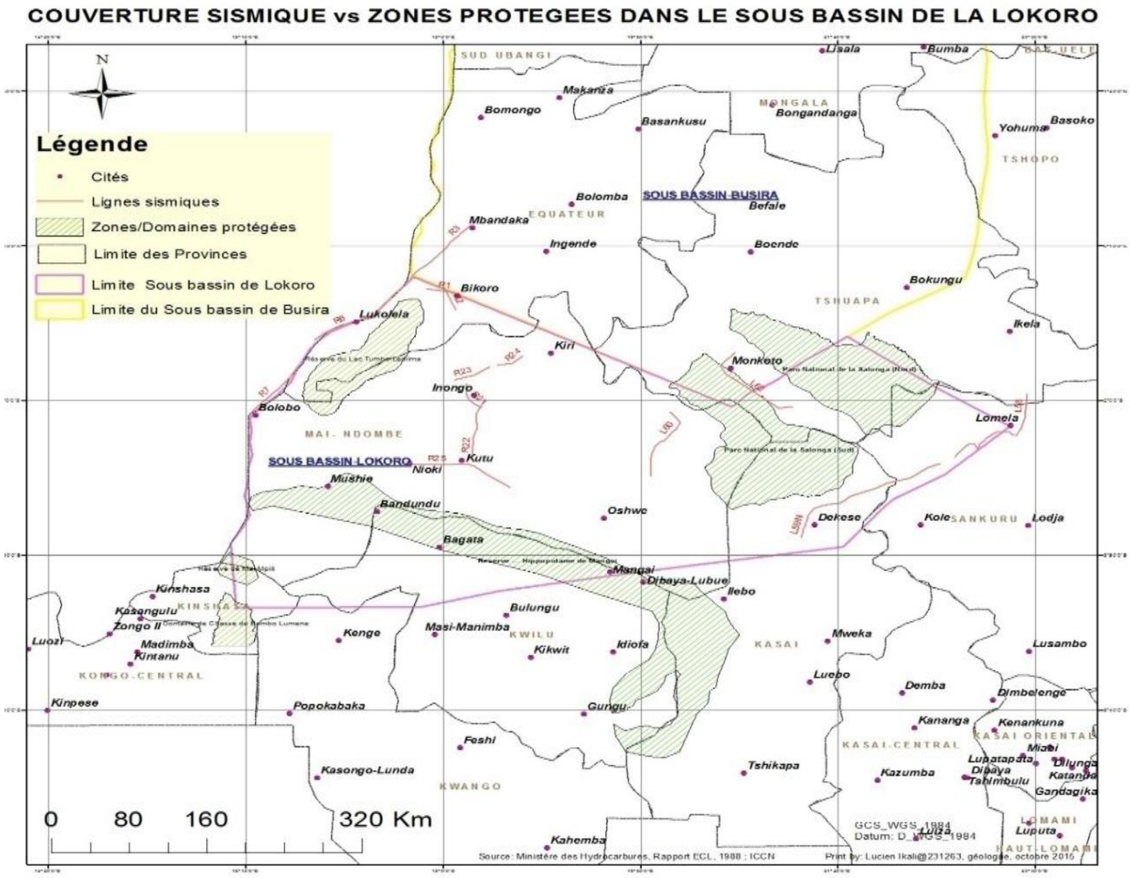

Figure 14*. Mapping of the protected areas and the seismic coverage.*

5. SEISMIC DATA ANALYSIS

Seismic data analysis will consist of visualizing the seismic profiles in order to interpret them to detect or determine potential hydrocarbon zones.

The seismic line data presented in Table 1 above were collected along rivers and roads. Seismic line names beginning with the letter R were therefore collected along rivers and the letter L along roads or trails. [13, 14, 15].

5.1. Processing and interpretation of seismic data

The processing of the seismic data consists in visualizing the distributions of attributes as a function of depth and distance along a line [16, 17]. These visualized attributes will allow us to perform structural and stratigraphic interpretations in order to highlight the petroleum potential.

5.1.2. Profile R6

Two important horizons made up of compact rocks which can be cover rocks and/or mother rocks. These are the H4 and H2 horizons. These horizons are located between 600 to 1000 m depth for the H4 horizon and from 1900 to 2500 m depth for the H2 horizon. The H3 horizon made up of coarse grains can constitute a potential reservoir; it is located between 1000 to 1900 m depth. (Figure 15).

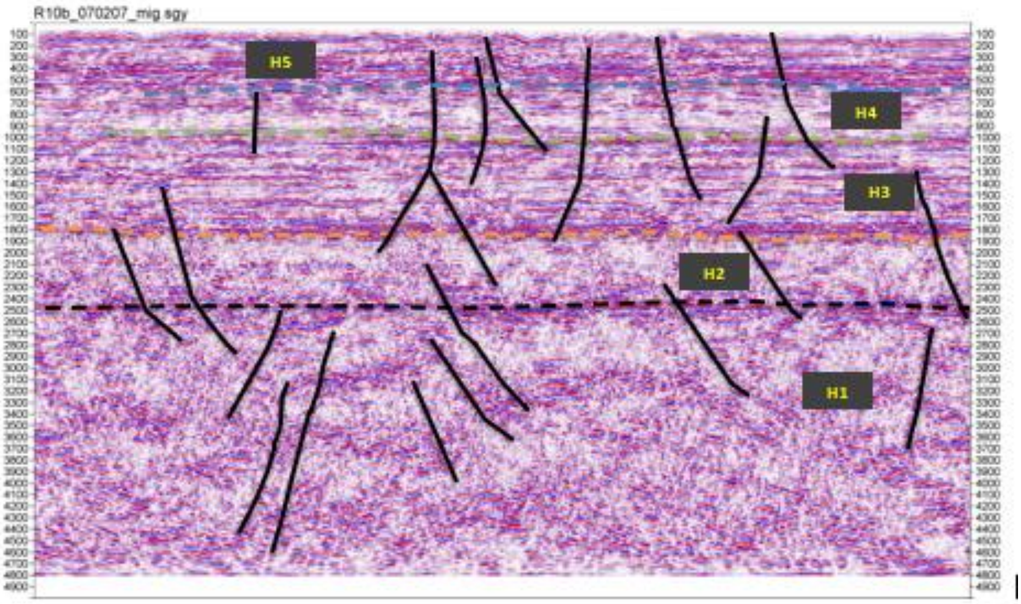

Figure 15*. Interpreted seismic profile R6 [19]*

5.1.3. Profile of the L59 seismic line

This profile is evidence of deformation and the presence of salt domes in the Central Basin of the RD Condo. Several structures show the action of halokinetic phenomena creating several structures of petroleum interest. Thus, it is about Bevels, anticlines, faults, etc. In this seismic profile, we observe 7 horizons affected by the faults. There are several structures in this case the anticlines, the faults caused by the dome of salt.

The illustration of the structural and stratigraphic interpretation of the seismic line L59 is presented on the figure below (Figure 16).

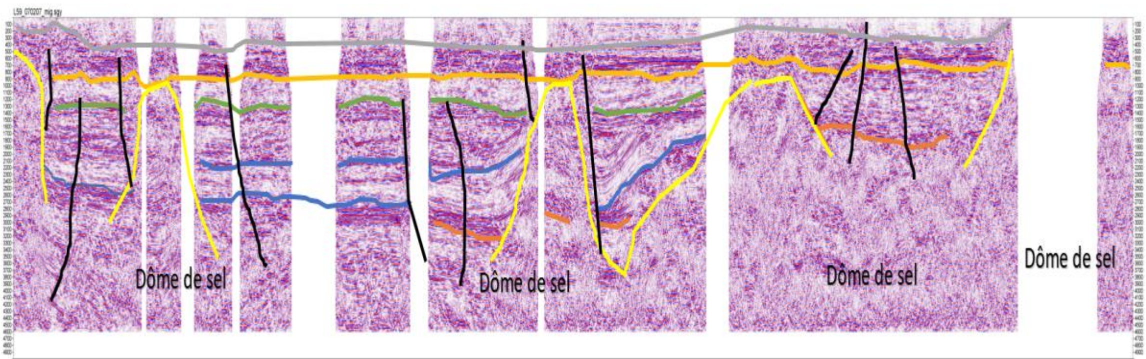

Figure 16*. Seismic profile interpreted L59 [19] (Legend of the interpreted horizons: Orange= salt tectonics; Blue= Post saliferous dolomite; Green= sand/sandstone).*

The map of structural elements below, combined with the prospects, highlighted by ECL 1988 and seismic lines in the Lokoro sub-basin, allowed us to make a critique on the location of the drillings (Gilson and Dekese) that were executed outside the prospects, which allowed us to make the proposal on the seismic section L59. The map of the structural elements of the Lokoro sub-basin presents the prospects which are surfaces in yellow colored, the seismic line in red, the gravity map presents the weak anomalies (center deposit) blue coloring and the strong anomalies red coloring (high background) Seismic section L59 shows us the location of the Dekese borehole. (Figure 17)

Our analysis is critical on the Dekese drilling, we demonstrate starting from the structural elements map, the prospects, the gravity map and the L59 seismic section that the drilling was badly positioned and this for all the two drillings in white coloring in the gravity map. Gilson and Dekese drilling was not in the center deposit but in the shoal, which is not interesting for exploration drilling

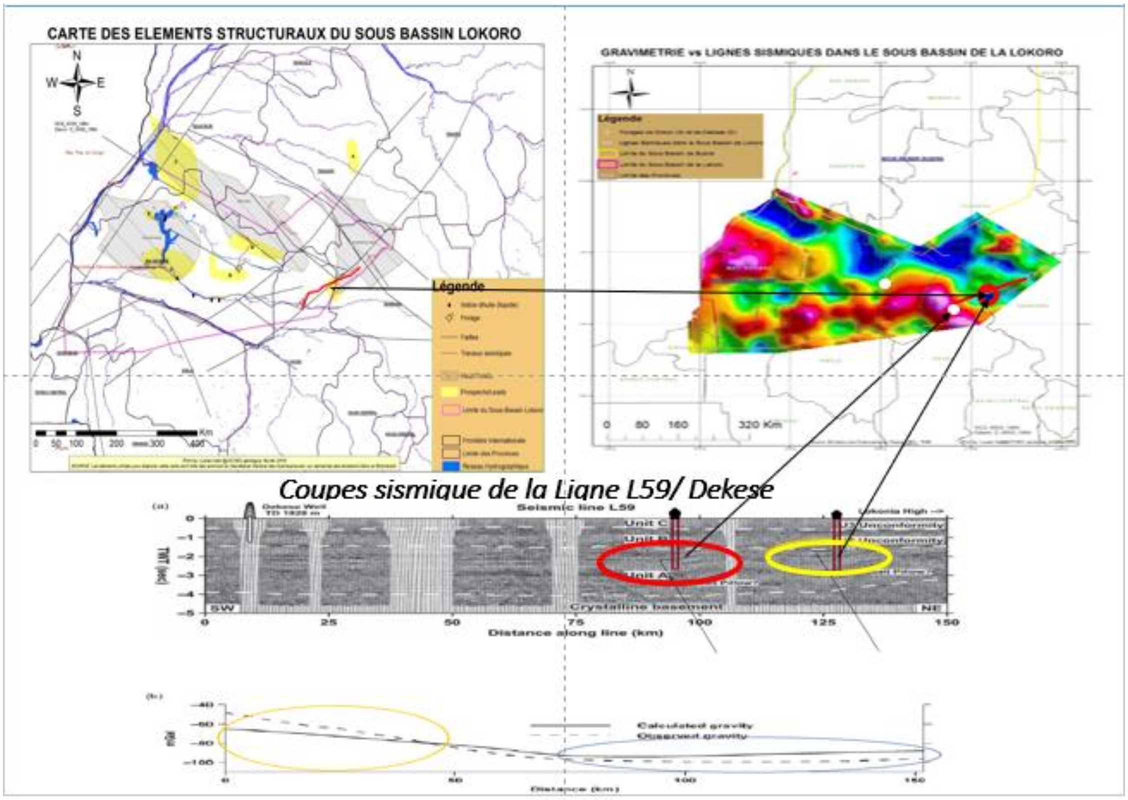

Figure 17*. Map of structural elements, seismic and gravity lines and boreholes in the Lokoro sub-basin (modified after [1]).*

We can highlight the following observations:

- The L59 seismic line was not drilled in the right place;
- the gravity map shows the central deposit and this location where the prospect is also found, next to the Salonga National Park;
- The 7 prospects/leads are generally found next to the bottom;
- Drilling at the sub-basin level has not been positioned on the prospects;
- The two shoals of Kiri and Lonkonia do not confirm the uplift of the basement but the existence of saliferous tectonics.

To put our opinion on the location of the drilling, we first wanted to talk about the notion of prospects.

While by definition a prospect is a buried geological object in which the presence of hydrocarbons (oil or gas) is possible, in sufficient quantity to allow an economically viable production project [17]

6. CONCLUSION

The future of the exploration of the central basin and the Lokoro sub-basin is particularly promising, starting from the evidence of the active petroleum system in this sub-basin and the certification of the surface showings of Lukenie and Mai-Ndombe are irrefutable evidence of the existence of oil. There is no reason to give up hope of discovery, but it is necessary to multiply exploration efforts, making projects that are adapted to geological realities.

After processing and analyzing gravimetric, magnetic and seismic data from our study area, the results found can be summarized as follows:

- Static land gravity campaign in the western part in order to have information on the sedimentary cover in this area and the geological structures;
- The structure of Kiri is a salt dome superimposed by fragments of granitic rock which give a signature of heavy gravity anomaly;
- The highlighting of three prospective zones which are zone A, zone B and zone C, which we have proposed seismic work adapted to geological realities;
- The L59 seismic line of the Dekesse Drilling was not drilled in the right place.

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