Romanian Journal of Petroleum & Gas Technology
Vol. VI (LXXVII) • No. 2/2025

CONTRIBUTION TO THE STRUCTURAL STUDY AND PETROLEUM INTEREST OF THE NORTHERN PART OF THE TANGANYIKA BASIN OF THE WESTERN BRANCH OF THE EAST AFRICAN RIFT OF D.R. CONGO

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DOI: 10.51865/JPGT.2025.02.01

ABSTRACT

Discoveries are succeeding each other as oil was perceived, a long time ago, as a rather rare resource in sub-Saharan Africa. Paradoxically, it is found everywhere, from Angola to Guinea-Bissau, then along the entire western coast, notably in Ghana, Ivory Coast, and other countries. In addition, for East Africa, interest is not only focused on offshore oil from the Indian Ocean (Mozambique, Tanzania), but also within the continent in the geological structures formed by the East African rifts. In our work, we consider the Tanganyika basin in the East African rifts. Indeed, in certain parts of the Tanganyika basin, oil seepages are visible, with a significant proportion on the side of the D.R.C. (Cap Kalamba), indicating the maturation of the source rock in this area. Thus, the Tanganyika basin has been the subject of hydrocarbon research by several companies, universities, and organizations. However, a problem arises; in 1987, former oil company AMOCO conducted a drilling campaign in the Ruzizi plain during which two wells were drilled, Buringa-1 and Ruzizi-1. Neither of these wells produced oil, and subsequently, AMOCO abandoned all its concessions in the rift region in 1989.

This work consists of contributing to the reinterpretation of seismic data conducted by Duke University in 1983-1984 as part of the project PROBE (Proto-Rifts and Oceanic Basin Evolution) in the northern part of the Tanganyika basin, with a view to clarifying its structural model and its oil potential. Indeed, with the advancement of technology, the reinterpretation of these old data can prove important in that we may be able to highlight certain previously unnoticed information due to the limitations of interpretation tools.

Keywords: oil interest, geological structures, Tanganyika basin, seismic data, reinterpretation

INTRODUCTION

The Tanganyika graben, a sub-basin of the West branch of the East African Rift, is shared by D.R.Congo, Zambia, Burundi and Tanzania [20], [23]. This sub-basin extends over the whole of Lake Tanganyika and has onshore fractions in the Ruzizi plain and the Lukuga depression. It lies between 2° 5' and 8° 5' south latitude and 28° 4' and 30° 8' east longitude (Figure 1) [13].

***Figure 1**. Location of the Tanganyika basin (Wikipedia)*

Lake Tanganyika, located in the East African Graben, forms a depositional zone within the graben. In terms of water volume and depth (1400 m), it is the 2nd largest freshwater lake and the 2nd deepest lake in the world. In terms of surface area (34,000 km^2, roughly the size of Belgium), Lake Tanganyika is the 7th largest freshwater lake in the world. Lake Tanganyika is 670 km long and 50 to 80 km wide, with its northern end separating D.R.C. and Tanzania from Burundi, and its southern end from Zambia. To the west (on the Congolese side) are the Mitumba Mountains. [6], [11], [17]. With a large number of endemic species, Lake Tanganyika is very famous; the species living around the lake are:

- Crocodiles: *Crocodylus niloticus* and *Crocodylus cataphractus hippos*;
- Various fishing birds: herons, eagles, anhingas, fishermen, etc. [16], [18]

Geologically, the rift is linked to major tectonic activity that has built up large volcanic apparatuses with fertile land on both sides, whose altitude gives the region a rather temperate climate despite its equatorial location [1]. The geomorphology of Lake Tanganyika is characterized by three main bathymetric basins. The Kigoma basin (northern basin) and the southern basin, separated by a shoal known as the "Kalemie-Mahali ridge", and a third minor basin located in the northern part of the lake, the Ruzizi sub-basin, which is separated from the Kigoma basin by the Ubwari relief [6], [22].

METHODS AND MATERIALS

We began by collecting data on the study area. This data collection enabled us to orientate our study. Apart from the existing literature, the basic data used to conduct this study were seismic data in electronic "SEG-Y" format from the Tanganyika basin, and petrophysical data in electronic "LAS" format from the Buringa-1 and Ruzizi-1 wells [2], [25]. Petrel software was used for seismic and petrophysical interpretation of the wells. The first task was to carry out a quality control study on these data after they had been uploaded to Petrel. Based on the quality control results, it was important to start with a miss-tie before starting with the interpretation [3], [4].

Given the absence of check-shot data, it was difficult to make the "well tie" that would also enable us to convert the isochronous map to depth. Nevertheless, we used the interpretation of an old line already interpreted by AMOCO oil company, to identify the interface for each sequence. Once identified, it was easy to find the same reflectors (interfaces) on other lines thanks to in-line and cross-line. Interpretation of each interface enabled us to draw up time maps for the roof of each sequence.

GEOLOGICAL FRAMEWORK

Seismic and radiocarbon methods suggest that the Tanganyika Basin began to form before 12 Ma in its central part, around 7-8 Ma in the northern part and around 2 Ma in the southern part [3], [13], [15]. However, although the Tanganyika Basin developed exclusively during the Neogene [12], its present position and orientation are inherited from major fault series movements associated with metamorphism and ancient tectonics [10]. These include structures within the craton and orogenic belts emplaced during the Late Precambrian and Early Precambrian [5], [12].

The Lake Tanganyika basin is formed within two belts to the west of the Tanzanian craton. The N 130°-140° Ubendan (Ruzizi) belt is formed of granite, gneiss and micaschists overprinted by the Paleo-Proterozoic Eburnian orogeny, while the N 30°-50° Kibara belt is linked to the Kibaran orogeny. The Tertiary Rift is dominated by half-grabens in the offshore part and are defined as major sedimentological domains [1], [12].

STRATIGRAPHY OF THE TANGANYIKA BASIN

The Tanganyika Basin suffers from a lack of a well-defined stratigraphic scale (Figure 2). Nevertheless, two stratigraphic phases are revealed in the Tanganyika Basin; pre-rift stratigraphy and syn-rift stratigraphy. Some authors suggest that the Nyanja Formation underlies the syn-rift unconformity overlying the pre-rift formations [14], [19].

- ✓ From the Miocene to the present rift fill, lacustrine clays and turbidite sands are reported. Fan-glomerates are localized along fault margins.

- ✓ Red layers of fluvio-continental sands and siltites are found in the Permo-Triassic.
- ✓ In the Permian, deltaic sediments, coal and lacustrine clays “predisposed to oil” are reported [15].

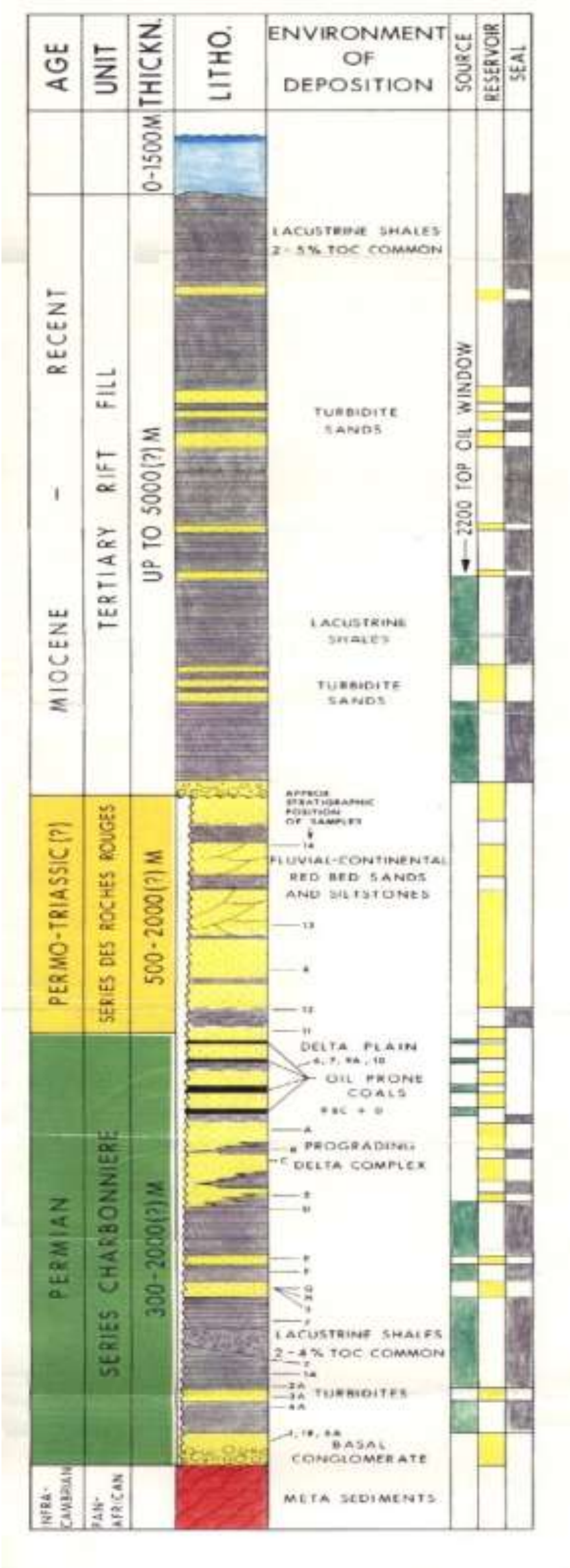

Figure 2. *The stratigraphic scale of the Tanganyika Basin* [23].

RESULTS AND DISCUSSIONS

A seismic campaign, like any geophysical prospecting campaign, generally comprises three stages: data acquisition, information processing and interpretation [2].

- Data acquisition is achieved by deploying appropriate emission, detection and recording systems in the field. It uses the most modern electronic techniques, enabling digital recording of information with considerable speed and precision.
- The aim of processing is to improve the signal-to-noise ratio and to format the information for easier interpretation. Modern computerized information processing methods have made it possible to develop increasingly efficient software systems.
- Interpretation, which is the stage at which our work is built, aims to determine and characterize the geological layers of the subsoil and define its structural model [3], [4].

Seismic is the most widely used method for determining subsurface structures during oil exploration. The most widespread application is multiple coverage seismic reflection. This technique provides a 2- or 3-dimensional echography of the subsurface [7]. The 2D seismic used in this work presents a processed image called a seismic section. The horizontal axis of the section represents the line traces along the acquisition profile, and the vertical axis represents the wave propagation times (in TWT).

Seismic events appearing on the section correspond to wave arrivals reflected at normal incidence on seismic markers. Seismic markers correspond to discontinuities caused by variations in acoustic impedance depending on the lithology or formations crossed by the waves, providing us with a structural image of the subsurface. Analysis of the attributes and character of seismic events paves the way for stratigraphic and lithological interpretations of seismic reflection [3].

The structural study of a sedimentary basin can lead us to assess its petroleum potential. In our work, we take as our starting point the reinterpretation of seismic data carried out by Duke University as part of the Probe project in the Tanganyika Basin, to highlight its structural model, which will help us to define the zones of interest, or first and foremost the leads [5], [11].

PRESENTATION OF SEISMIC LINES AND QUALITY CONTROL

The seismic lines acquired during the Probe Project show a good distribution of lines in the northern part of Tanganyika, where cross lines and in lines are well represented, whereas in the southern part of the block there is a poor distribution of cross lines (Figure 3). This would affect the reliability of the results, so we opted for the northern basin (Kigoma and Ruzizi), where the seismic lines are well distributed.

A study on the quality control of seismic lines from this campaign, which helped us carry out our study, reveals that [24]:

- ✓ There is a considerable offset between lines acquired in 1983 and those acquired in 1984. This offset is easily observed when we have a cross line from 1983 and an in line from 1984, or vice versa. To overcome this problem, it is important to make the mis-tie to bring these lines back to the same level.

- ✓ Analysis of the various reflectors, traces and amplitudes tells us that these lines cannot be used in calculations of several seismic attributes that could enable us to carry out other studies, such as: calculations of seismic inversions, reservoir characterization, seismic stratigraphy, etc. This is why it is necessary first of all to determine the level of the lines. Hence the need to use more advanced technology to improve the quality of these lines. Nevertheless, these lines can help in structural studies, which is the subject of the present work. The poor quality of seismic lines is probably due to their poor preservation.

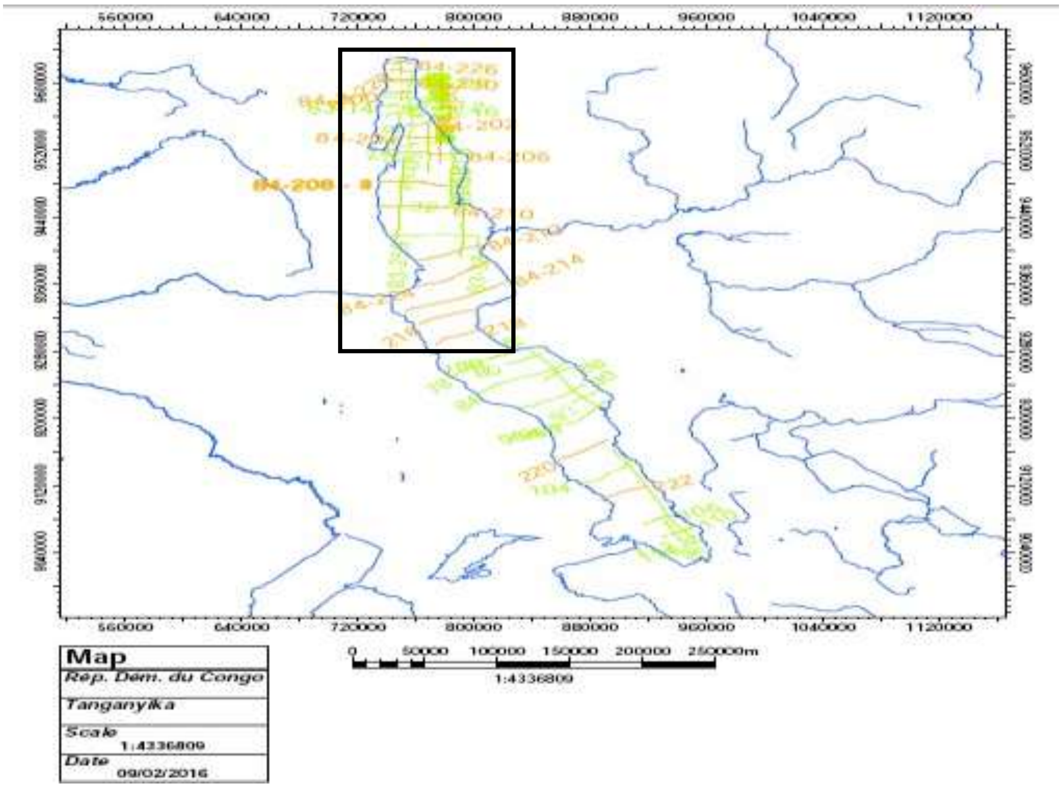

***Figure 3**. Map of seismic line acquisition in Tanganyika (Petrel)*

INTERPRETATION OF SEISMIC LINES AND PRESENTATION OF RESULTS

We interpreted 24 seismic lines in the northern part (Ruzizi and Kigoma) as well as in the Kalemie sub-basin. In this article, we will present some particularly interesting seismic lines (the lines being analyzed in depth), which enabled us to carry out an in-depth structural study. This analysis led us to draw certain conclusions about the geometry and organization of the structure of the study area, as well as to identify several avenues of investigation for future work.

Lines 84-214 and 84-224 intersect the Kigoma sub-basin to the east and the Kalemie sub-basin (southern basin) to the west, as can be seen in Figure 4 and 5. It is important to note that, at the level of these lines, the Kalemie sub-basin is younger than the Kigoma sub-basin, as already mentioned in the first chapter, and these two basins are separated by a Horst structure that constitutes the accommodation zone delimited by two main fault systems. This horst is generated by faults that we consider to be NW-SE-trending transfer faults [13], [23].

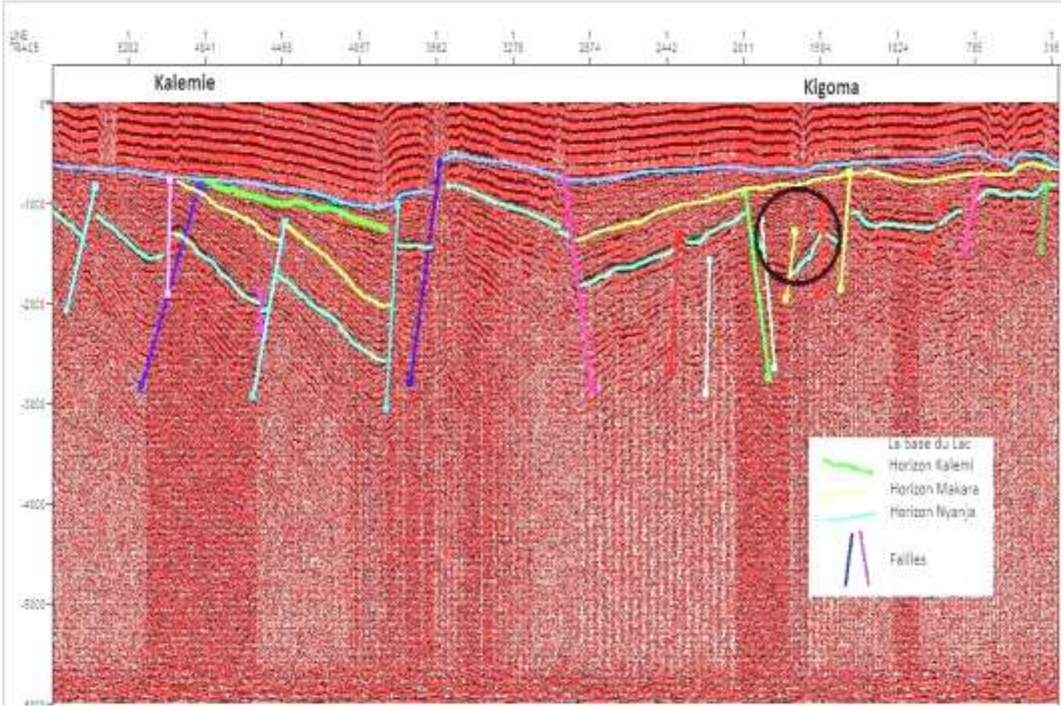

Figure 4. *Seismic profile 84-214 (WSW-ENE orientation) (Petrel)*

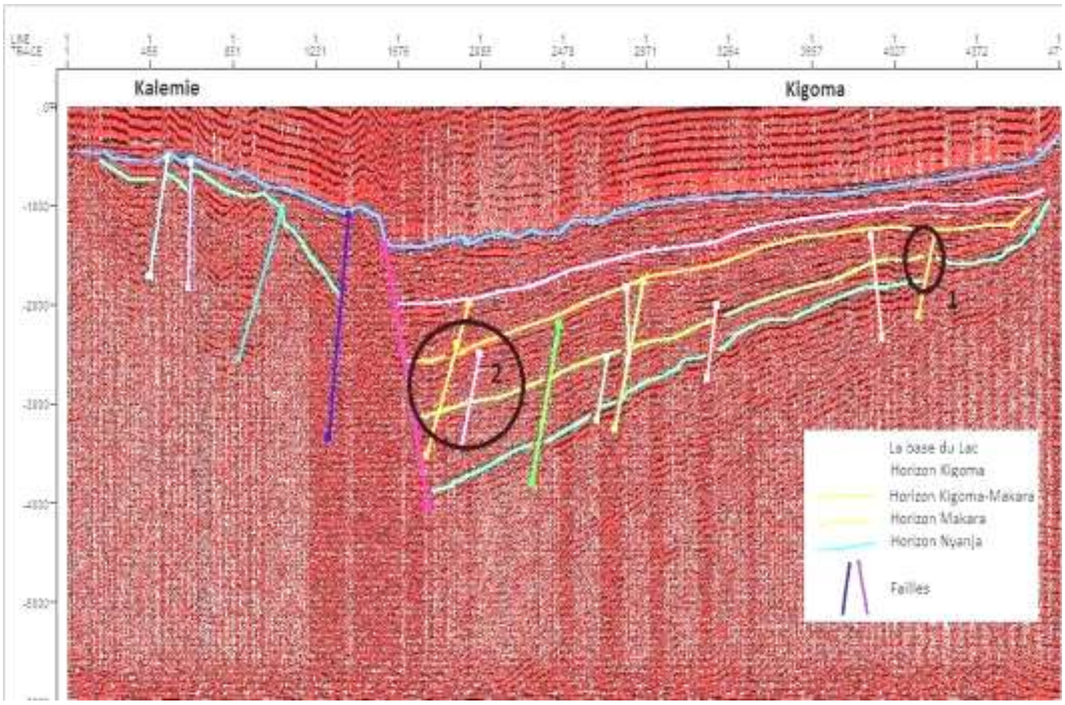

Figure 5*. Seismic profile 84-224 (WSW-ENE orientation), (Petrel)*

To the west, i.e. in the Kalemie sub-basin area, which in relation to the accommodation zone appears as a half graben, stratigraphic evidence points to the presence of the Kalemie sequence on line 84-214, which was deposited just after the Makara sequence, whereas to the east of this line in the Kigoma sub-basin, the absence of the Kigoma-Makara and Kigoma sequences, which in principle should be deposited successively above the

Makara sequence, is noted. This phenomenon is thought to be due to crustal uplift [8], [14]. Unlike line 84-214, line 84-224 shows uplift in the Kalemie section, which means that some sequences are missing, whereas all sequences are represented in the Kigoma section (Figures 4 and 5).

The faults are generally oriented North-South in both sub-basins, except that in the Kigoma section on line 84-214, two fault families with opposite dip directions are noted. The first family dips to the east, while the second dips to the west. On the oil side, there are a few faults that can be considered as potential traps [20], [21].

We were able to identify two leads based solely on fault studies. Lead 1, identified on line 84-224, would constitute a good closure compared with lead 2, where the transfer fault goes all the way to the bottom of the lake, which would constitute a major problem on the tightness of the said fault. Certainly, further studies are needed to estimate the tightness of this fault and to move from leads to prospect [10].

Line 84-216 (Figure 6) also intersects the Kalemie sub-basin and a small part of the Kigoma sub-basin. The two sub-basins are separated by a zone of accommodation (horst). We have identified two leads, one in the Kigoma area, which is more optimistic than the second in the Kalemie sub-basin. On line 84-216, and also on line 84-218, two structures (F1) and (F2) were noted, which could probably be reverse faults due to the "sliding" movement of the Kigoma sub-basin and the southern sub-basin [16]. Only one lead was observed on seismic line 84-218. (Figure 7).

Line 83-03 is a “cross-line” running from north to south of Ruzizi, intersecting the southern part of the accommodation zone (horst), considered to be a strike-slip zone. Lead 1 would probably be associated with a mixed trap, whereas lead 2 would be unpromising due to the strike-slip fault at the base of the lake (Figure 8) [10], [24].

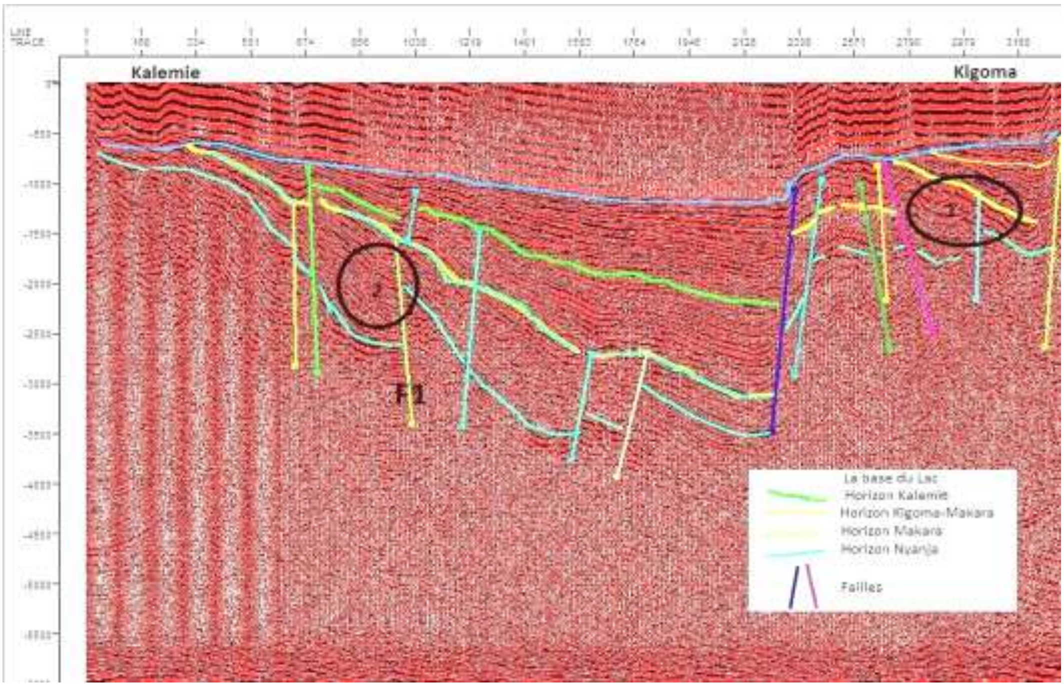

Figure 6. *Seismic profile 84-216 (Petrel) (WSW-ENE orientation)*

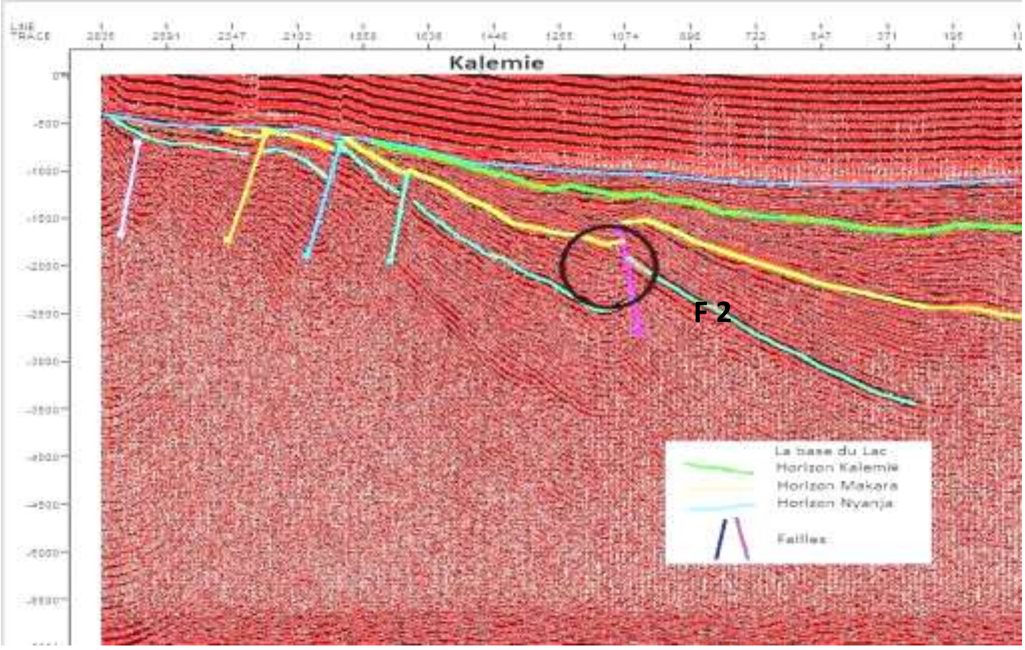

***Figure 7**. Seismic profile 84-218 (WSW-ENE orientation) (Petrel)*

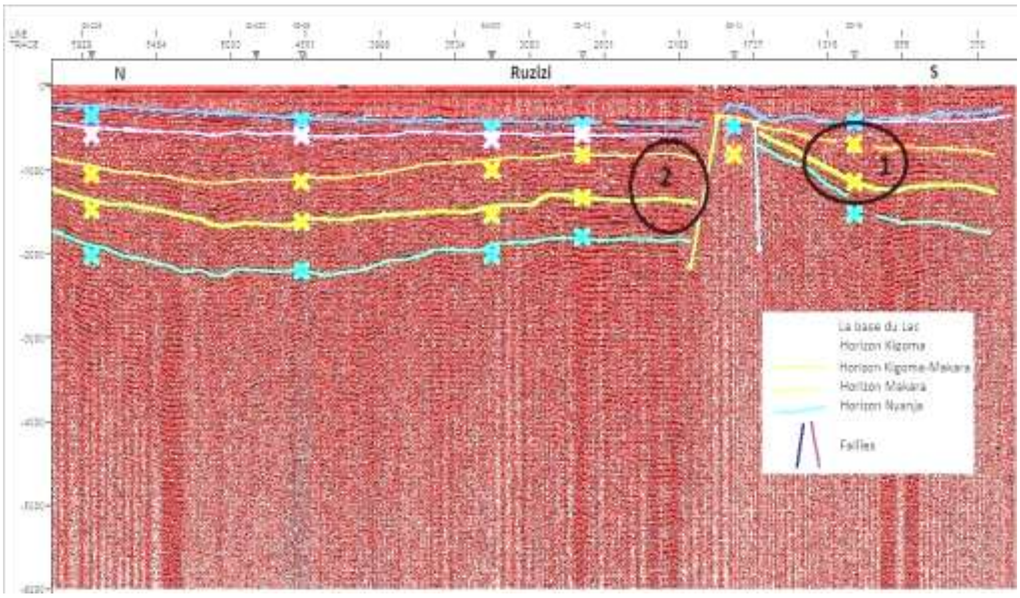

***Figure 8**. Seismic profile 83-03 (Petrel)*

Line 83-16 crosses the Ruzizi sub-basin to the west and the Kigoma sub-basin to the east. An accommodation zone (horst) separates the two sub-basins. These faults are considered to be NE-SW strike-slip faults. One sequence, the Kigoma sequence, is conspicuously absent. A few major faults have been identified as interesting structures. This has enabled us to identify three leads (Figure 9). Lead 1 is located between two interesting faults, especially if the overlying formation acts as a cover [8]. However, the drop fault (in green) could be an obstacle for this lead if it were not watertight, due to its contact with the lake bottom. The problem of fault tightness would also arise for leads 2 and 3, because of the faults that cut all the sequences until they reach the lake bottom. From a sedimentological point of view, we note the absence of the Kigoma sequence [5], [17]. This phenomenon is thought to be due to crustal uplift.

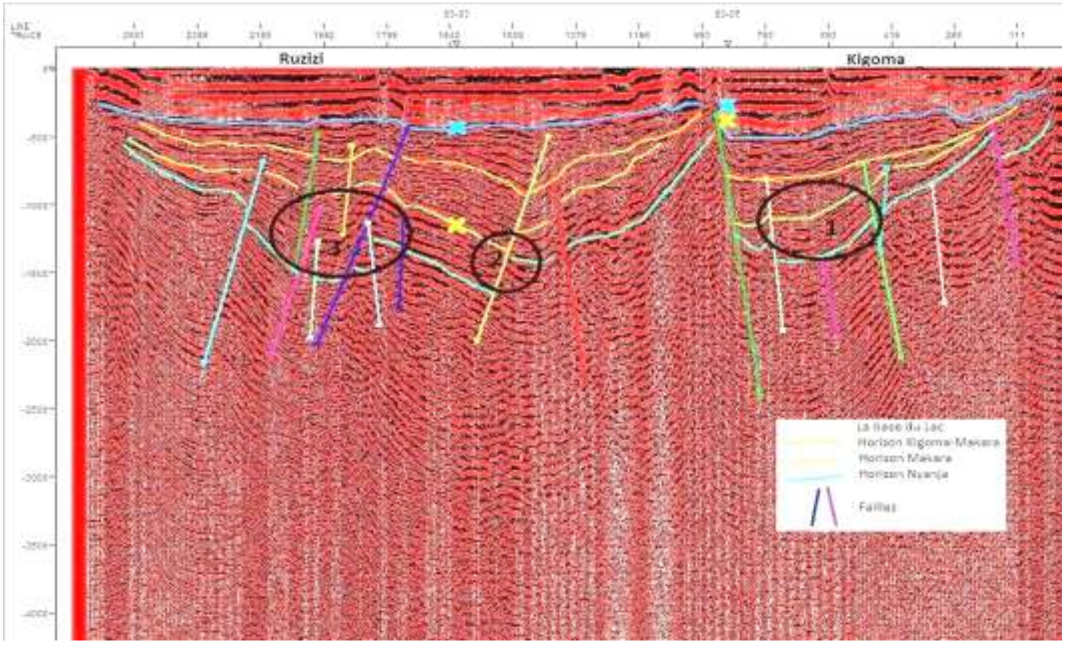

Figure 9*. Seismic profile 83-16 (N-S orientation) (Petrel)*

GAMMA-RAY AND SONIC VIEW OF RUZIZI-1 AND BURINGA-1 WELLS

Gamma ray interpretation of the Ruzizi-1 and Buringa-1 wells using PETREL software (Figure 10), shows an absence of argillaceous rocks that could play the role of caprock or source rock [14]. Integration of this analysis with the neural net (Petrel) shows small sections of clay that cannot play the role of caprock, let alone source rock. In the Buringa-1 well in particular, an increase in radioactivity of up to 150 g API was observed between 3,000 and 3,600 feet, i.e. from 914.4 to 1097.28 m [11], [12]. The lithological data indicate that between 3,000 and 3,600 feet, we find the crystalline basement that we consider here to be rich in potassic feldspar, given its high gamma ray. Interpretation of SPHI sonic porosity indicates high primary porosity in both wells [2], [9].

CONCLUSIONS

The present work has set itself the objective of contributing to the structural study and petroleum interest of the northern part of the Lake Tanganyika basin. At the end of our work, we would like to highlight the following points: Tanganyika Basin is an asymmetrically-extending system, with the greatest deposit thicknesses in the Congolese part; the exclusively normal faults observed bear witness to distension in this zone.

We note that the presence of hydrocarbon seepage in this zone (Cap Kalamba) bears witness to the maturation of the source rock and the expulsion of hydrocarbons, dysmigrating through imperfectly sealed faults. Thus, the leads we have highlighted in this work would be structures conducive to the trapping of these hydrocarbons expelled from the bedrock. Nevertheless, further study will enable us to move from the lead to the prospect. The boreholes drilled by Amoco, Ruzizi-1 in particular, were located on shallow sedimentary cover, which meant that a complete stratigraphic log of the basin could not be obtained.

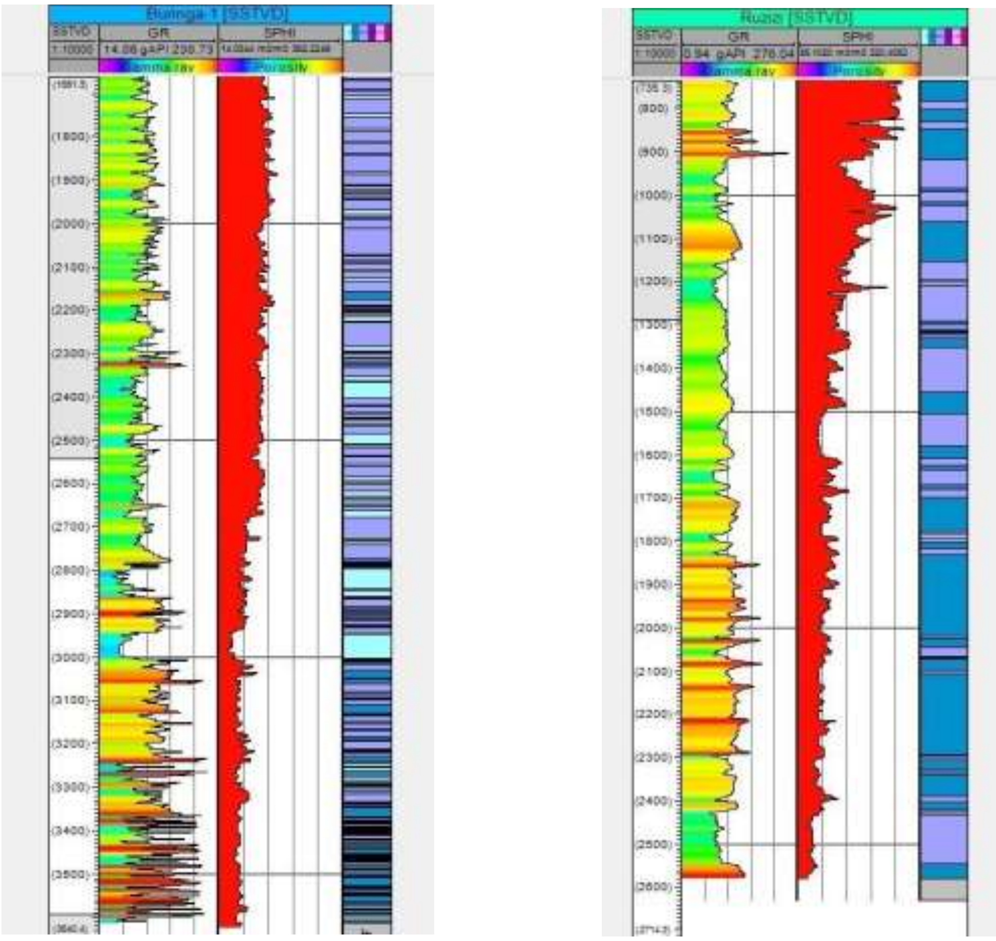

Figure 10. *Gamma Ray and Sonic logs of the Buringa-1 well on the left and Ruzizi-1 well on the right (Petrel)*

To date, the Tanganyika basin's stratigraphy remains imprecise. Stratigraphic drilling is essential if we are to know the stratigraphy of this basin. Given that the Congolese part of the basin is richer in deposit-centers than the rest of the basin, it would be conceivable that this drilling could be carried out in this part of the basin in order to obtain maximum information. What's more, analysis of the hydrocarbons seeping from Cape Kalamba gave a pre-Tertiary age, which implies the presence of pre-Tertiary sediments, like the Karoo formations found in the Luama Gap, buried beneath syn-rift sediments of Tertiary age. At this level, these Karoo source rocks would have fulfilled the conditions for maturation and the expulsion of their hydrocarbons. Since seismic quality is unable to distinguish (by its attributes) pre-rift from syn-rift sediments, repeat seismic or stratigraphic drilling would be the only way to overcome this Karoo burial problem.

Seismic interpretation identified structural traps, generally represented by counter-fault traps, and a few mixed traps were identified. It should be noted that, given the sedimentation dependent on the structural geology of the area, stratigraphic traps would be frequent in this basin.

All these elements attest to the fact that the Lake Tanganyika Basin offers improved prospects for oil exploration.

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Received: June 2025; Revised: July 2025; Accepted: August 2025; Published: August 2025