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RESERVOIR CHARACTERIZATION OF THE CHELA FORMATION OF THE NSIAMFUMU AND LIAWENDA FIELDS IN THE ONSHORE COASTAL BASIN, D.R. CONGO

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ABSTRACT

Petrographic and petrophysical characterizations of the pre-salt Chela formation of the Nsiamfumu and Liawenda fields in the onshore Coastal Basin of the D.R. Congo it was performed. These characterizations, as part of the static modelling of the reservoirs, involved reading log measurements, thin-slice observations of rock samples taken from this formation, calculations and interpretation of logs, CPI (Computer Processed Interpretation) and DST (Drill Stem Testing) from well tests.

The following observations were obtained:

- Wells Lw-1: the formation is characterized by dolomitic limestone and micaceous black shale with a thickness of 34 m having heavy oil indices and an average porosity of 17% and a salinity greater than 300 gr/L;
- Well Lw-2: the formation is characterized by islands of sand, coarse sandstone and a few quartz pebbles with a thickness of 10m showing evidence of light oil, gas and an average porosity of 24%;
- Shaft Lw-3: the formation is dominated by micaceous shale and dolomite interbeds with a thickness of 14m showing little evidence of hydrocarbons, only salt water and residual oils;
- Puits Ns-1: the formation is characterized by beige to grey dolomite, grey shale and white sand with a thickness of 6m showing evidence of light oil and an average porosity of 20%.

Keywords: reservoir characterization**,** petrophysical parameters, logs, Cretaceous deposits, oil field, oil potential

INTRODUCTION

It should be noted that the country's oil production is still very low in relation to its resources. According to the statistics compiled by Congo's central bank, the country produces around 23,000 BOPD (8 million BOPD), placing it 70th in the world, far behind its neighbours Angola, Congo Brazzaville and South Sudan. The D.R. Congo is therefore far from playing in the big league, even though its oil potential is estimated at 22 billion barrels of oil, i.e. 37% of Africa's oil potential, or 6% of the world's oil potential, [1], [2].

Because of this low production, even though Perenco-rep and associates drill nearly 20 new development and injection wells every year, oil production remains a subject of much controversy, given that the oil exploration and production chain is capital-intensive, which is why oil exploitation must be optimal. The search for new deposits, taking into account different reservoir types, is therefore necessary to offset the costs incurred during both exploration and production.

Indeed, the petrographic description of petroleum reservoirs requires the characterization of each element (notably permeability, porosity, etc.) and each process (drilling, logging, etc.) that make them up, and this from a different point of view to conventional descriptions on a macroscopic and microscopic scale. These reservoirs rocks may be siliciclastic or carbonate, and porosity in both types of reservoir is calculated as the ratio of pore volume to total rock volume, [3], [4].

This study consists of the comprehensive reservoir characterization of the Chela reservoir of the Nsiamfumu and Liawenda fields in the onshore Coastal Basin of D.R. Congo. Reservoir characterization represents an important part of the static geological modeling of oil reservoirs, [5], [6], [7]. The geologo-geophysical analyses and interpretations reveal an excellent potential for hydrocarbon reservoir of the Chela Formation. Considering petrographic character and good petrophysical parameters, the Chela reservoir it stands out as a profitable oil production area, both in the studied area (Nsiamfumu and Liawenda fields), as well as in all onshore fields in the Coastal Basin of D.R. Congo.

GEOLOGY OF NSIAMFUMU AND LIAWENDA FIELDS

Nsiamfumu field

The Nsiamfumu field is a faulted anticline of Cenomanian age located beneath the coast of D.R. Congo and belonging to the onshore Liawenda-Kinkasi permit. The dome-shaped structure was discovered in 1977 by Fina with the NS-01 well and brought on production by the same well for the first time in 2006 by Perenco.

The field lies offshore in less than 5 m of water, while onshore drilling is constrained by the presence of the village of Nsiamfumu, a limitation to field development.

The Nsiamfumu field is located on the edge of the Atlantic Ocean, at the north-western end of the Nsiamfumu agglomeration whose geographical coordinates are: 198.222 UTM and 9.351.143 UTM; it is close to SP 266 of the SC2N line in terms of seismic position (see Figure 1 below). [8], [9], [10]

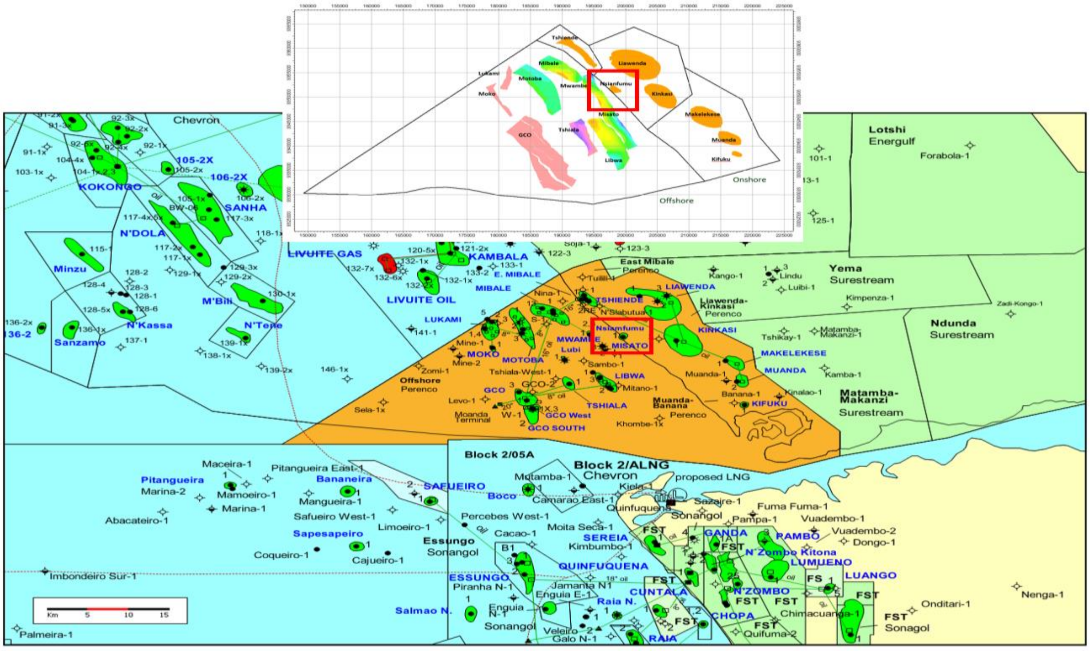

Figure 1. *Location of the Nsiamfumu field* [8]

The field is located at [9]: 12 km from the town of Muanda; 20 km from the SOCIR refinery; 7 km from the west side of the Kinkasi field; 8 km southwest of the Liawenda field structure and, 3 km from the MISATO-1-X offshore well. Most of the Nsiamfumu field lies offshore in less than 5 m of water, and its eastern part straddles the coast where the village of Nsiamfumu is located (see figure 1). For these reasons, the economic development of Nsiamfumu is only possible from onshore wells going offshore. However, it is possible that a vertical well will be located to the north-west of the Nsiamfumu village, [8], [9], [10]

The Nsiamfumu field produced from a single well, NS-01, at 30 BOPD from 2006 to 2013, the following year, following two fracturing operations carried out on the NS-1 well, the field upped its production potential to 200bopd. After an acidizing compression with significant gas, the NS-2 well produced 30 BOPD in the H, I and A intervals. In 2018, Perenco-rep drilled the third and fourth wells in the northern part of the Nsiamfumu anticline targeting the Cenomanian; these were drilled to follow up on the good STOOIP result obtained by the first well after frac operations.

Geology and stratigraphy

The lithology of the Nsiamfumu field is generally similar to that of the neighbouring fields, and the lithological descriptions from surface to depth are as follows: Serie des Cirques from the surface to 47 m (Pleistocene); Malembo from 47 to 518 m (Miocene); Iabe Tertiary from 518 to 708 m MD (Paleocene); Iabe Cretaceous (Supra-Liawenda) from 708 to 1129 m MD (Senonian); Horizon Liawenda from 1129 to 1161 m (Turonian); Kinkasi from 1234 to 1485 m (Cenomanian); Pinda from 1485 to 1815 m (Albian). In this monotonous series, however, we noted: Vermelha from 1650 to 1740 m (Albian).

Figure 2 shows the ante- and post-salt formations usually found in the Coastal Basin and recognized in the Nsiamfumu field. [9], [10].

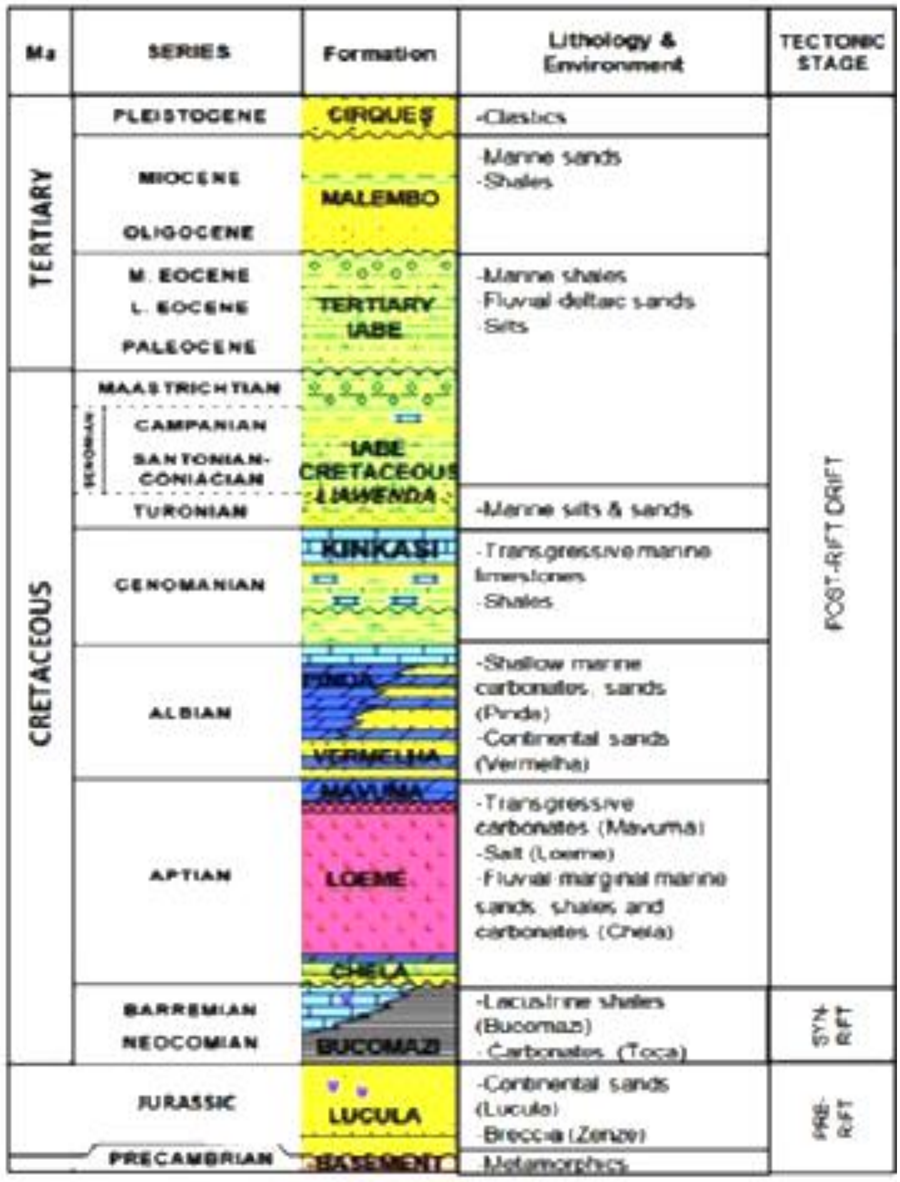

***Figure 2**. Litho-stratigraphic description of the Nsiamfumu field* [10]

Geological structure

The structure of the Nsiamfumu field is an anticlinal structure bounded by a SW-trending normal fault growth from which the Lower Cenomanian formation is absent in NS-2 where there has been erosion or non-deposition. Indeed, to the northwest the field is bounded by a Pinch closure of the Kinkasi formation on the Pinda formation, [8], [9], [10]. It can be seen that all dips have a direction in the northeast quadrant, which is in good agreement with the image of the seismic section and stratigraphy of the Nsiamfumu field in figure 3 below. Thus, the Cenomanian structure is controlled by a series of northeast-southwest-trending normal faults that were partially active during deposition of the Kinkasi Formation.

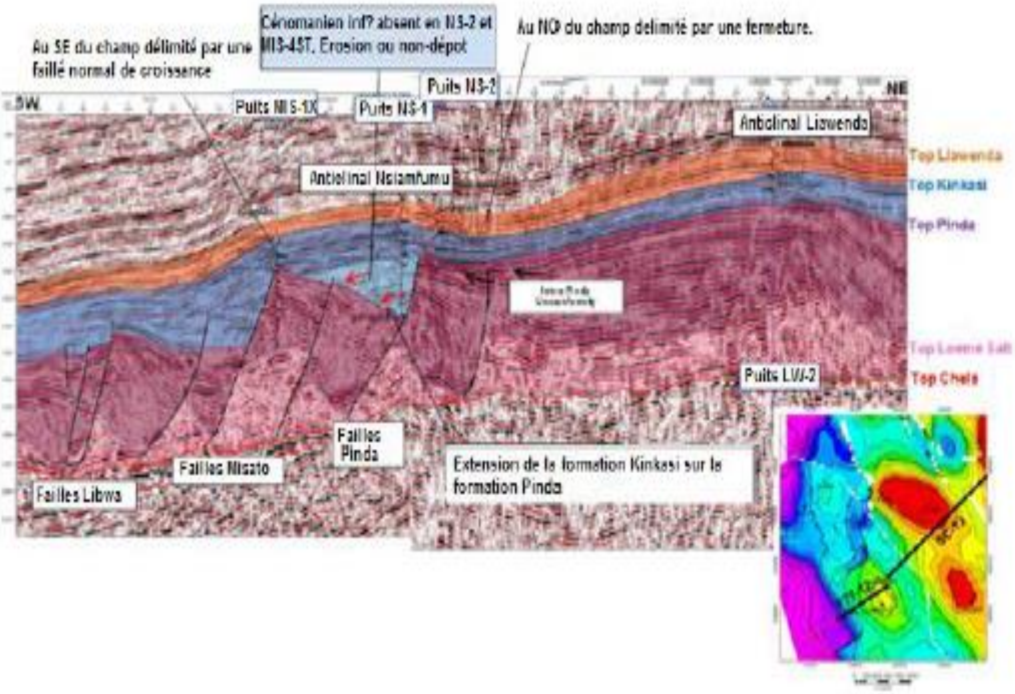

Figure 3*. Seismic section of the Nsiamfumu structure* [10]

Liawenda field

The Liawenda field is part of the onshore Coastal Basin of the Democratic Republic of Congo in the Perenco-rep concession. [11] The field has a crude oil production and pretreatment center (stockyard) and is a large field in the Perenco concession, [1], [2], [3], [11]. Located in the Province of Central Congo, the Liawenda field is limited to (Figure 4): 15 km east of the city of Muanda; 4.5 km from the Tshiende field; 4 km from the Kinkasi field; 25 km from the Muanda field.

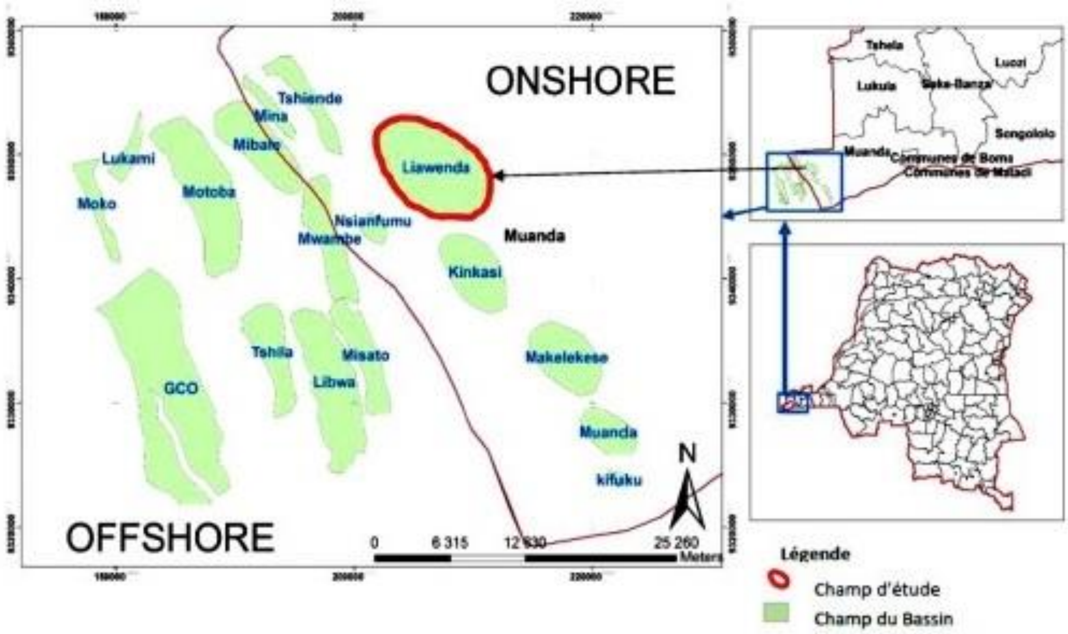

Figure 4*. Location of the Liawenda field* [11]

Discovered in 1972, the first exploration well, LW-01X, intercepted horizons teeming with oil in the onshore Coastal Basin. Following the drilling of this well, a field delineation campaign identified two producing reservoirs: Turonian (Liawenda silt) and Cenomanian (Kinkasi limestone), both Cretaceous in the Mesozoic Era. Currently, the majority of production, estimated at 4,950 BOPD, comes from the Turonian, compared with 800 BOPD extracted from the Cenomanian. [12]

MATERIALS AND METHODS

By reading the logs using a combination of sonic, neutron and density tools, we were able to establish the lithology of the pre-salt Chela formation in the onshore coastal basin of D.R. Congo, locate the formation, determine its facies and matrix and define its nature. [13], [14]. Microscopic analysis of samples from the pre-salt Chela formation in the onshore coastal basin of the D.R. Congo was used for this research, along with mapping software to produce the maps.

***Figure 5**. Microscopic analysis equipment*

RESULTS AND DISCUSSIONS

Geological analysis of the Chela onshore coastal basin of D.R. Congo, from the altered subsoil upwards, shows that the formation consists of a dark grey to dark green biotite mica, with feldspar and quartz channels; its texture is gneiss and open fractures are observed in its upper part (Figure 6).

Four wells (Nsiamfumu-1, East Mibale-1, Liawenda-1 and Liawenda-2) were tested in the Chela and nine wells penetrated the subsurface formation with 5 wells tested (Liawenda-1, Liawenda-2, Nsiamfumu-1, Nsiamfumu-2 and Kinlao-1). (Figure 7)

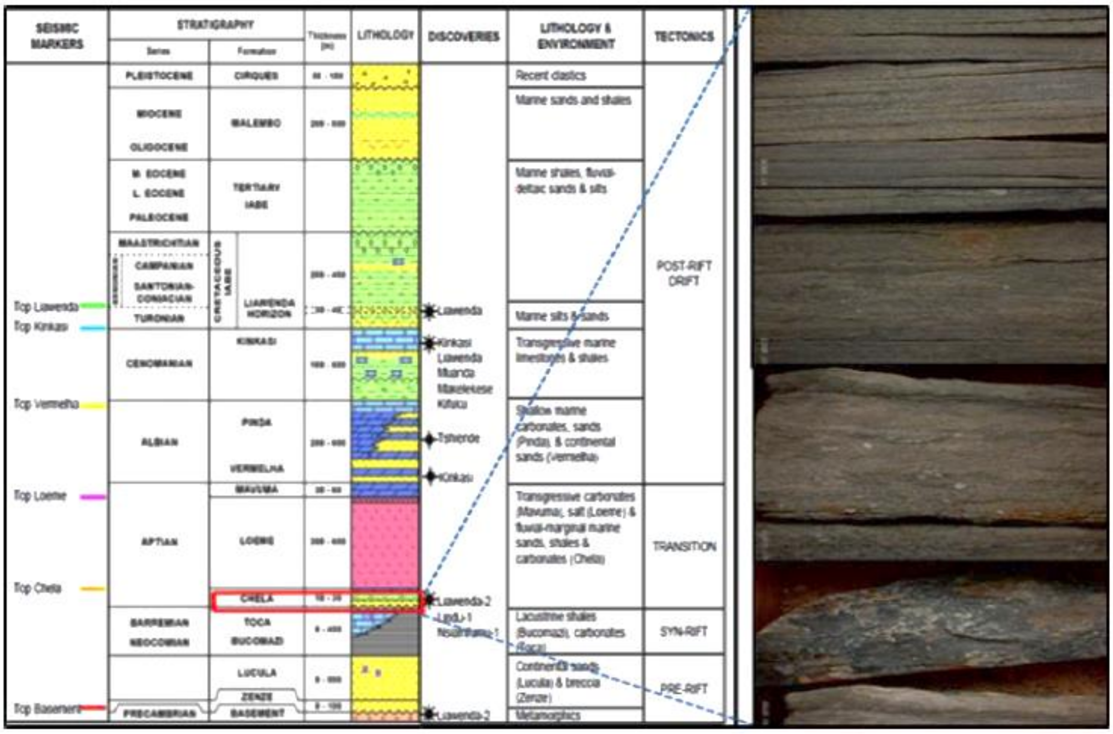

Figure 6. *Stratigraphic column of the D.R. Congo* [8]

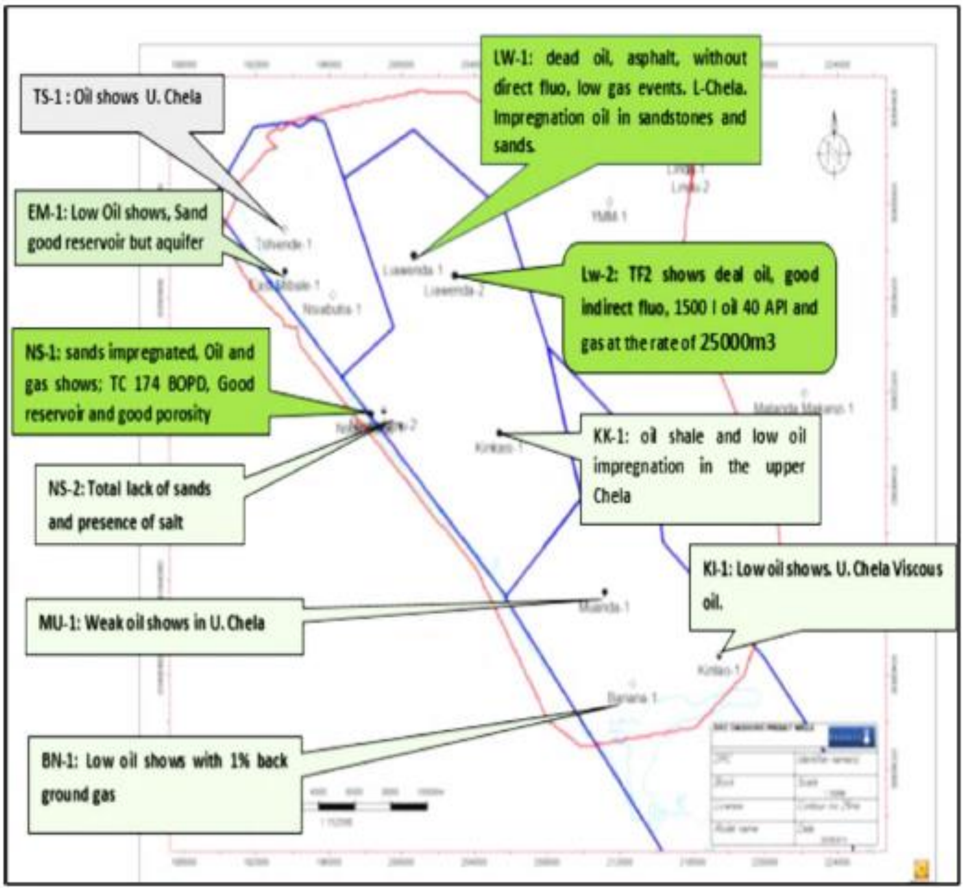

Figure 7. *Shaft through the Chela formation, on the surface.* [2]

Petrographic analysis

Our reservoir is characterized by vertical and lateral facies changes. Lateral changes are caused by a predominance of halite and anhydrite shale deposited on the marine lagoon, evolving towards carbonate shale sediments on the fluvio-deltaic slope and sandstone in the fluvio-deltaic environment. [8], [9], [10], [15]

These traps have a combination of structural and stratigraphic trapping with the eastern seal of the reservoir provided by anhydritic shale laterally transforming to halite.

The Chela sandstone in the onshore D.R. Congo Coastal Basin serves as the main support bed system for hydrocarbons generated in the underlying organic-rich lacustrine layer (Figure 8).

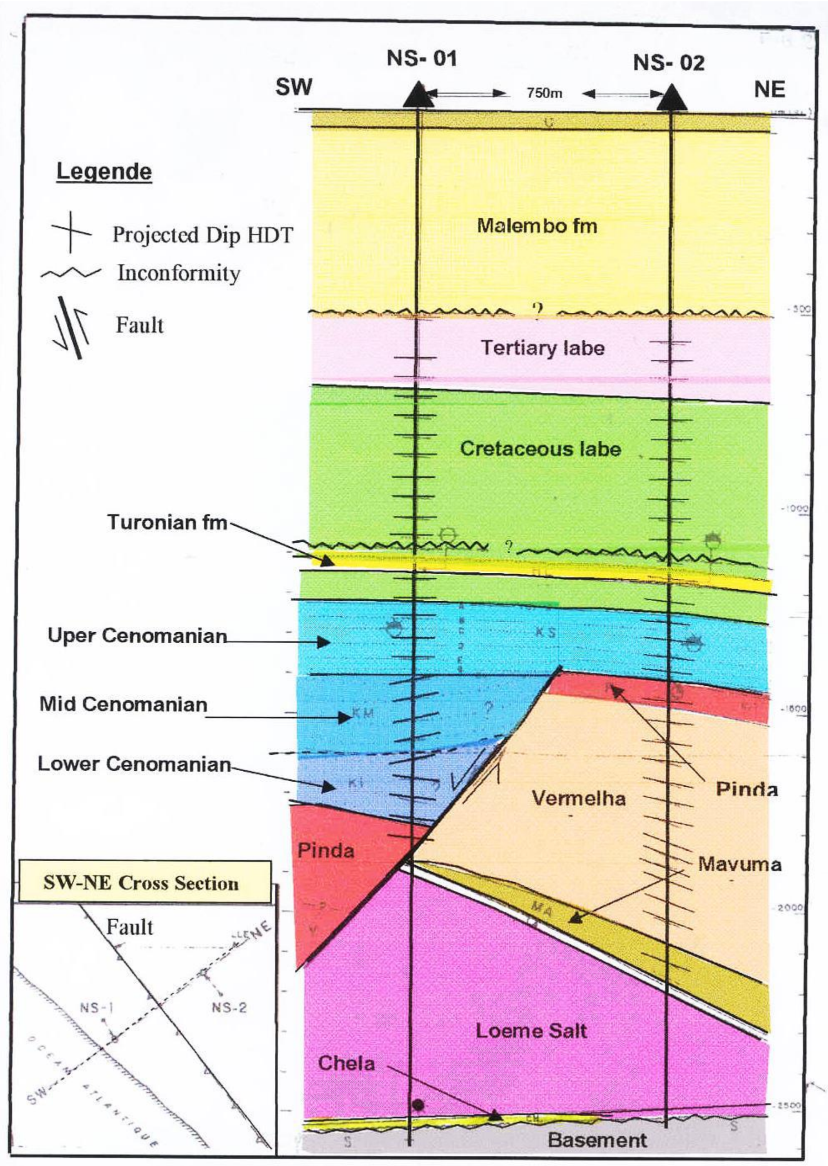

***Figure 8**. Ns field wells crossing the Chela formation, at depth* [8]

Chela sandstone

The Chela sandstone in the onshore D.R. Congo coastal basin is medium-grained, very feldspathic to arkosic (less than 25% feldspars) and abundantly micaceous (mainly biotite), with conglomeratic levels. Garnets are also abundant (in appreciable percentages). The morphoscopy of these sandstones is mostly subangular to subrounded, with a few levels dominated by rounded grains.

In the non-conglomeratic levels, sand classification is quite good. [16], [17]. Carbonate cement is rare and hardly exceeds 6%, while clay cement is present. We were able to demonstrate this with certainty by disaggregating with water and filtering the detrital material obtained.

In the conglomeratic zones, the subangular to subrounded elements are composed of fragments of biotite gneiss, garnet gneiss and fragments of pegmatite.

Petrophysical description

The petrophysical parameters (net-to-gross ratio, porosity and oil saturation) are taken directly from CPI. [8] The high GOR value is based on the production test in the NS-I well, which produced 174 BOPD and 1.6 MMSCFGPD (Figure 9). CPI showed an average porosity of 20%; hydrocarbon content ranged from 3 to 10%; thin sheet porosity ranged from 12 to 19% and permeability was not measured.

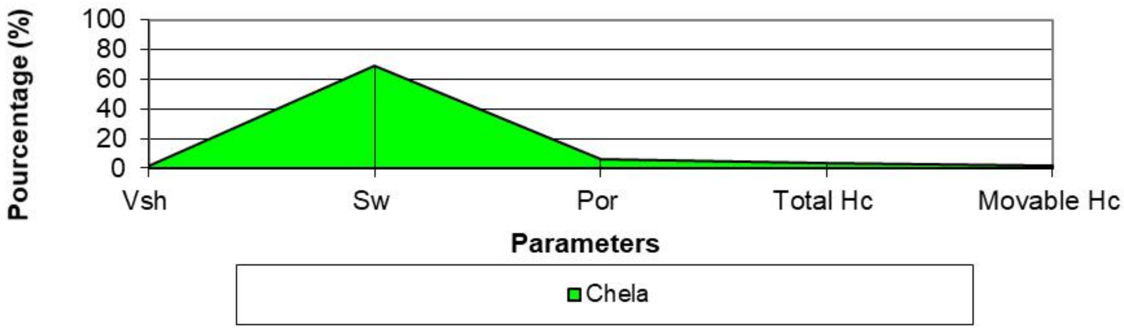

Figure 9. *Chela petrophysical parameters in Ns-1*

The Chela sandstone levels in the onshore between 2550.15 m and 2553.25 m show a porosity that oscillates between 12 and 30%.

True porosity may be slightly overestimated, given the very long passage of the sample (over a month) through the Soxhlets, where the finest fraction may have been partially entrained. These porosities seem satisfactory for a reservoir. No permeability measurements could be made, as the friable nature of these sandstones makes it impossible to sample cylindrical plugs. [18].

In any case, the highly micaceous nature of the sandstone (biotite stacking and bedding in places) is not conducive to good vertical permeability. [18]. The indurated dolomite has fragmented, while the more plastic argillites have deformed. These breccias are composed of clayey varved dolomite cemented by salt (Figure 10).

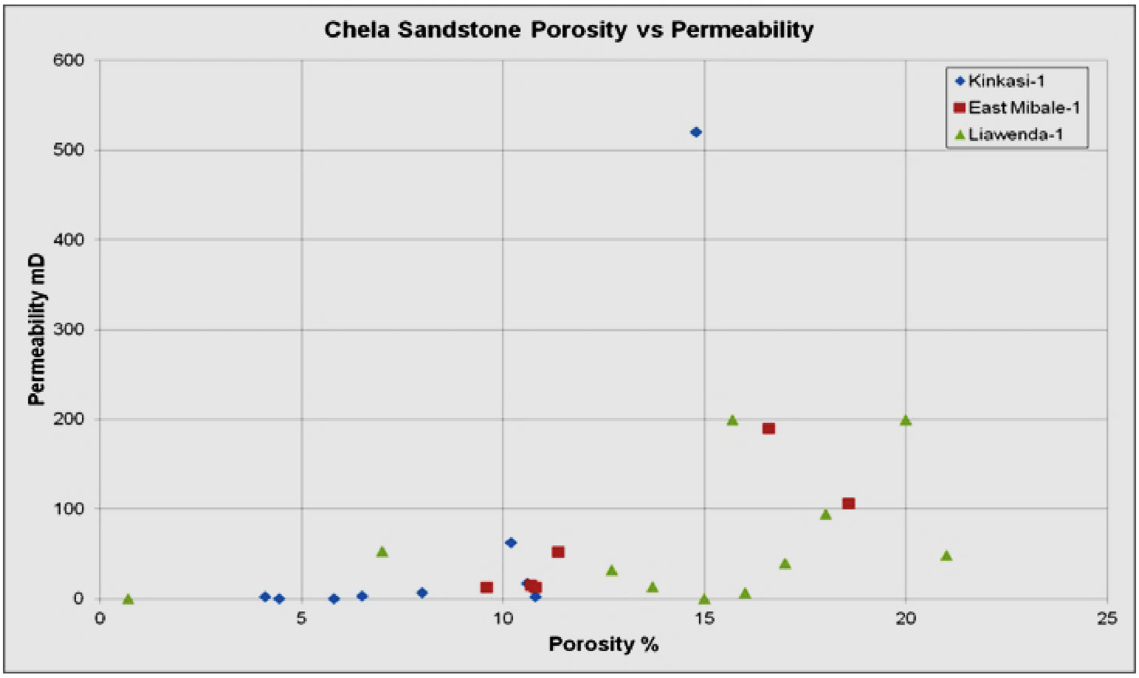

***Figure 10**. Chela sandstone, porosity and permeability*

Hydrocarbon tests and indexes

The Ns-1 well encountered hydrocarbon-impregnated gas in the Chela and traces of oil (Table 1).

***Table 1.** Hydrocarbon indices in Chela reservoir tests*

Reservoir	***Hydrocarbon indices***	***DST***	***Production Test***
Chela	Oil and gas in Chela	TF3: oil and gas in Chela	TP1 (max flow) =174 BOPD + 1.6 MMSCF GPD
	GOC 2537m		

The various tests carried out between intervals (Table 2 below) concluded that the Chela in well Ns-1 (2540-2,560 m MD - TF3) has green carrier oil.

***Table 2.** Ns-1 well test results*

Well	***Test***	***Lithology***				***Thickness (m)***
NS-1			Oil	9400 SCF/BBL	Gas	
	TF3	Sand	174bopd		C1=87,7%	
					C1=6,2%	
					C3=4,4%	2533-2540
					C4=1,63%	
					C5=0,45%	
	T Casing		Good	Good		

Interpretation of the logs and CPI showed interesting zones of impregnation during various tests in this reservoir. The CPI showed an average porosity of 20%, hydrocarbon contents of 3 to 10%, porosity between 12 and 19%; permeability was not measured.

A succession of cased tests was then carried out over the interval (2540 to 2560 m) for more than 70 hours, with decreasing drawdowns and smaller chokes (TP1, TP2 and TP3). This resulted in the highest rate of 180 BOPD with a high GOR up to 9,400 scf.stb-1, decreasing to 45 BOPD with 800 scf.stb-1, with oil densities reported at 36°API, the difficulty of stabilizing rates often being reported.

Given the decrease in GOR, the reported oil density and an estimated condensate gas ratio test above 100 stb MMscf-1 (rather high), in the Nsiamfumu field, Chela is unlikely to be a gas reservoir, but rather an oil discovery with a primary gas deposit neighbouring the conical plug downwards depending on the pressure applied. This was later confirmed while producing, with similar rates of 150 BOPD and highly variable gas flow rates (GOR equivalent from 2107 to 10373 scf.stb-1). The Chela DST (2548 to 2560.5 m) yielded 170 BOPD of gaseous green oil (d=0.845 at 27°C). [9], [10].

However, the petrophysical data from well NS-01 seem more consistent with the distribution of oil shows observed in the Chela than in the Cenomanian. The TE9 open-hole test (2671.45-2692 m) collected 13 m3 saturated with salt water (33 g/L) and traces of oil and gas after 60 min of operation. TF9 unambiguously demonstrates that the Chela sands in the onshore D.R. Congo Coastal Basin are a good reservoir [1].

Log calculations indicate porosities ranging from 13 to 20.5% (Sonic) - corresponding to water saturation (SW) ranging from 59 to 64% (Figure 11).

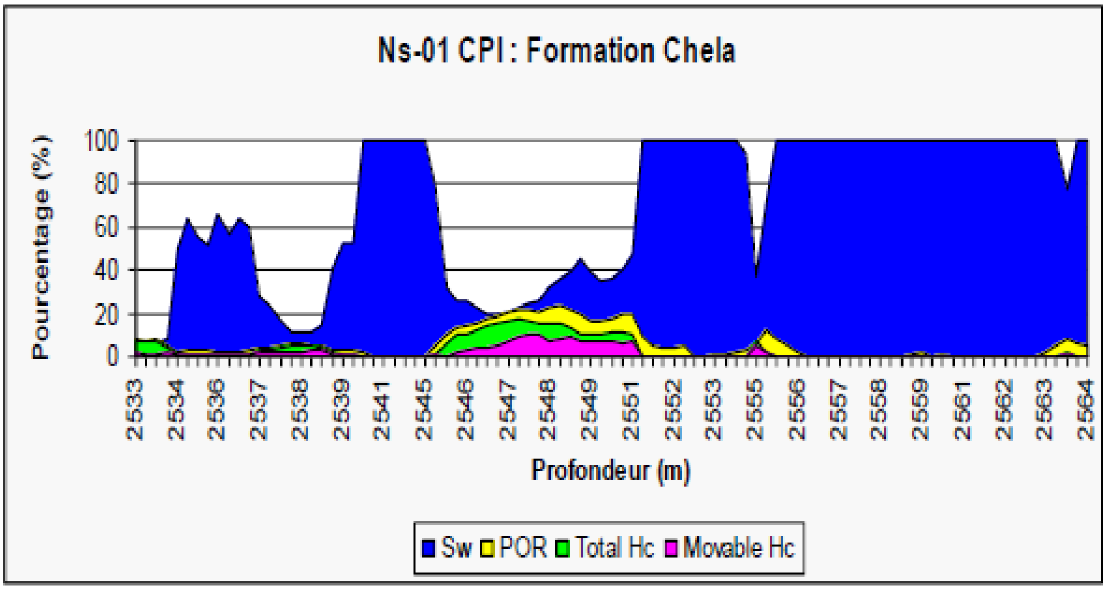

***Figure 11**. Ns-1 CPI in Chela reservoir*

Liawenda field, the drilled wells are the mainstays of the seismic interpretation of the Chela structure in the Liawenda area, with the associated volume estimated at 3 MMSTB, assuming a WOC at the spill point of 2288 m/s2 (see figure 12 and table 3 below), [2], [8], [9].

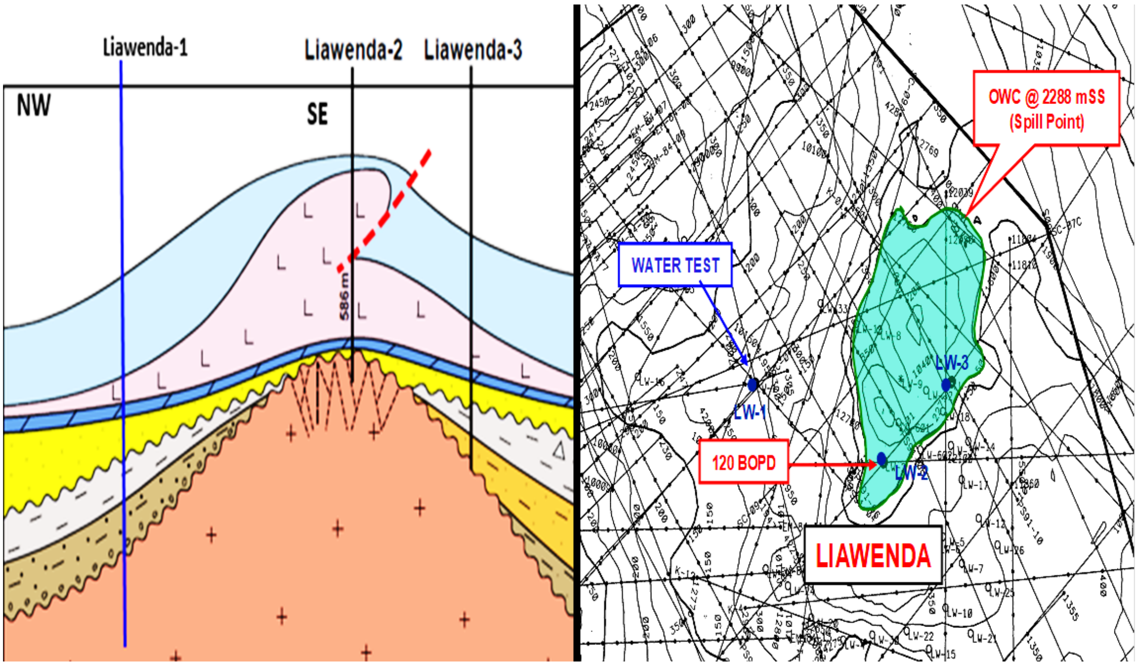

Figure 12*. Chela depth map in the Liawenda field* [2]

Table 3*. Petrophysical characteristics of the Chela in the Liawenda field*

Well	Top (m MD)	Base (m MD)	Thickness (m)	Oil index	Porosity	Gas Index	Test
LW1	2418	2448,5	30,5	✓	17	✓	✓
LW2	2328	2337,5	10	✓	24	✓	✓
LW3	2393	2407	14	✓	22		

However, only the Liawenda-2 well encountered a mixed Chela reservoir in the onshore of the Lower D.R. Congo Coastal Basin, which is of good quality and tested at 120 BOPD. The Liawenda-1 well was found to be water bearing and the Liawenda-3 well-showed weak hydrocarbon shows and asphalt in the Chela onshore of the D.R. Congo Coastal Basin.

The Chela lithology in well Lw-1 is composed of:

- Dolomitic limestone, light beige, white to brown, clayey;
- Micaceous black shale, often formed almost exclusively by the stacking of coarse, little-altered biotite chips, down to bituminous zones and beds of fine crystalline sandstone with anhydrite cementing traces of oil.

The sandstone and anhydrite or dolomite cement is subangular-grained, poorly graded, little altered, rich in biotite, in thin layers or intersecting oblique stratifications from the lower part to the sandy schist medium, subangular-grained, highly micaceous (Figure 13).

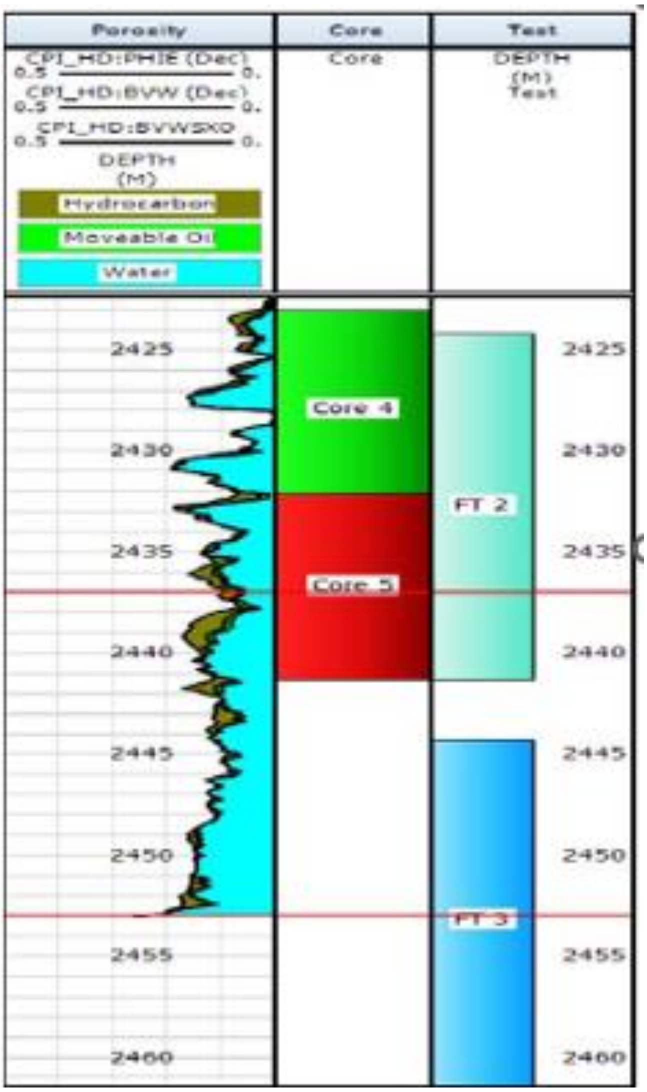

Figure 13*. Chela geophysical log in Lw-1 well* [1].

The cores have porosities ranging from 14 to 21%, with Hager values in the upper sandstones (19% up to 2435 m) than in the lower sands (average 14%).

The Lw-2 well, drilled in November 1972, was designed to survey the entire stratigraphic series at the base at around 2850 m, with the following oil targets in order of interest: infra salt in the series:

- Lucula sand and sandstone, Bucomazi series;
- Chela sands and sandstones in the onshore D.R. Congo Coastal Basin, which provided good hydrocarbon showings at the Lw-2 well.

Liawenda-2 has impregnated subsoil layers. At present, Lw-2 is a Turonian oil-producing well (Figure 14).

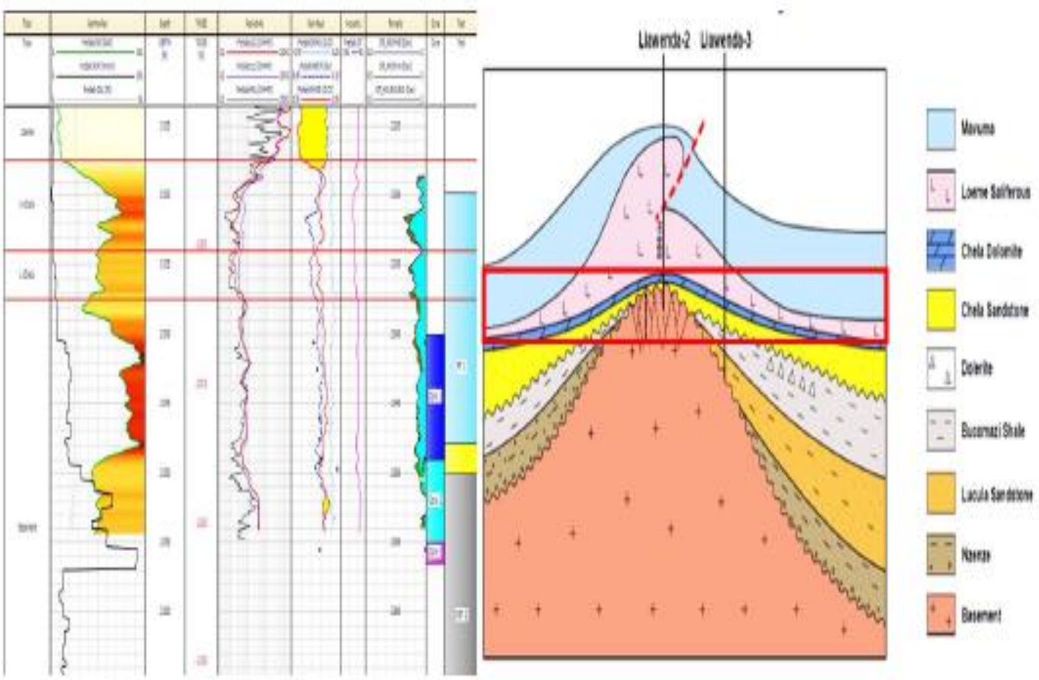

***Figure 14**. Chela cross-section in Lw-2* [2, 3].

The well-sampled Chela thickness (10 m) in well Lw-2 consists of islets of sand and a medium-coarse, micaceous sandstone with some quartz pebbles at the base, overlain by micaceous argillite, silt and argillaceous limestone, [8], [9]. The Liawenda-3 well consists of 7 m of micaceous shale with dolomite interbeds in the upper Chela onshore of the D.R. Congo Coastal Basin, with alternating thicknesses of micaceous sandstone, micaceous shale and siltstone in the lower sandstone (Figure 15).

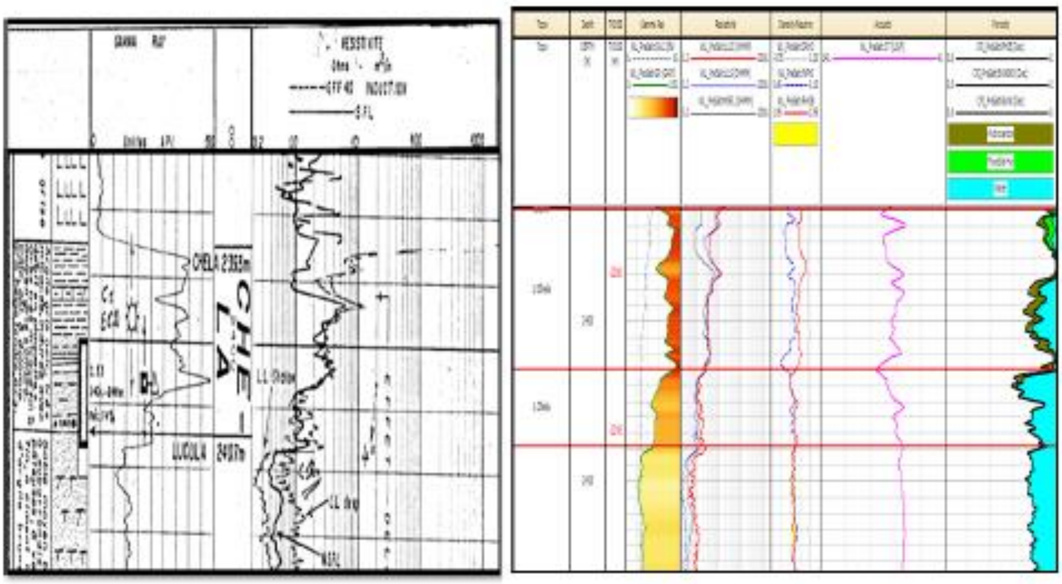

***Figure 15**. Well logging Lw-3* [3].

The stakes for Chela production in the D.R. Congo Coastal Basin onshore are enormous. Hydrocarbons are certainly present and easily exploitable due to its API degree, petrophysical properties and pressure, but a high-performance rig would still be needed whose power could reach until 2600 m depth or beyond to drill the intervals we suggest (Table 4, Figure 16) in order to confirm with certainty the presence of hydrocarbons and their quantity in place. [19], [20]

***Table 4**. Intervals to be perforated*

Well	**Formation**	**Intervals (m)**	**Thickness (m)**
LW-1	Upper Chela	2418 to 2427	9
LW-2	Lower Chela	2329 to 2355	26
LW-3	Upper Chela	2350 to 2375	25
NS-1	Lower Chela	2545 to 2560	15

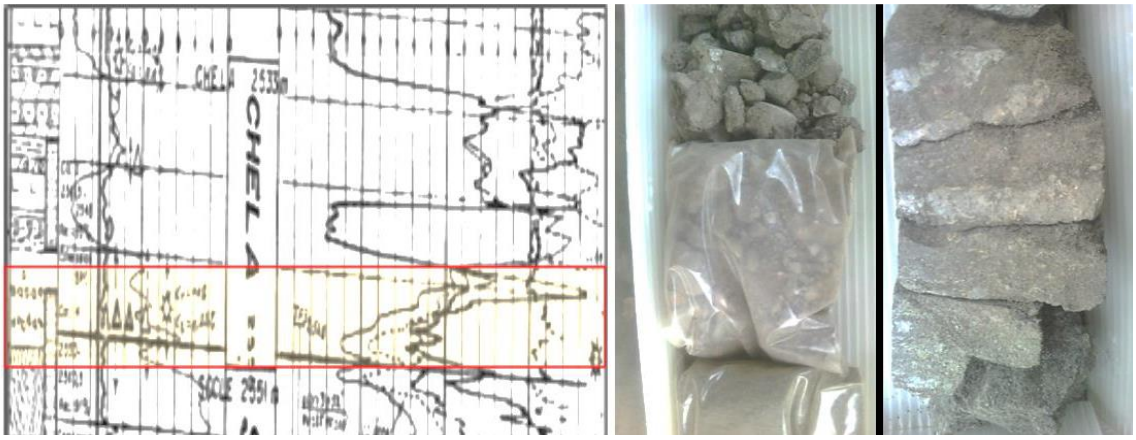

***Figure 16**. Interval to be perforated in the Nsiamfumu field* [3]

The original oil in place of Chela in the onshore Coastal Basin of DR Congo in the Liawenda was estimated at 1.4 MMSTB. The total production of Chela is 3410 barrels of oil, which represents a recovery, factor of 0.2% of the estimated STOIIP, [8], [11], [12].

The summit of Chela in the onshore Coastal Basin of DR Congo is at 2393 m; sandstones and sands of the latter starting at 2400 m should normally assume continuity between Lw-2 and Lw-3 with oil impregnation; unfortunately which is not the case and to explain this lack of oil in Lw-3, it would be desirable to introduce a discontinuity between wells Lw-2 and Lw-3.

In this case, we think that this discontinuity is due to defects in the interpretative sections, the Chela in the onshore of the Coastal basin of the D.R. Congo is always represented as a continuous structural horizon free of defects, while major dislocations affect the encompassing series. Well Chela Lw-2 can assume that in fact weak bases of fault rejection in a series of fragment it panels isolated from each other.

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The challenges for Chela production in the Onshore Coastal Basin of DR Congo are enormous; certainly the hydrocarbons are found there and are easily exploitable because of its API degree, its petrophysical properties and its pressure but it would still require a high-performance rig whose power could reach at a depth of 2600 m or beyond to be able to drill the intervals that we suggest (Figure 17).

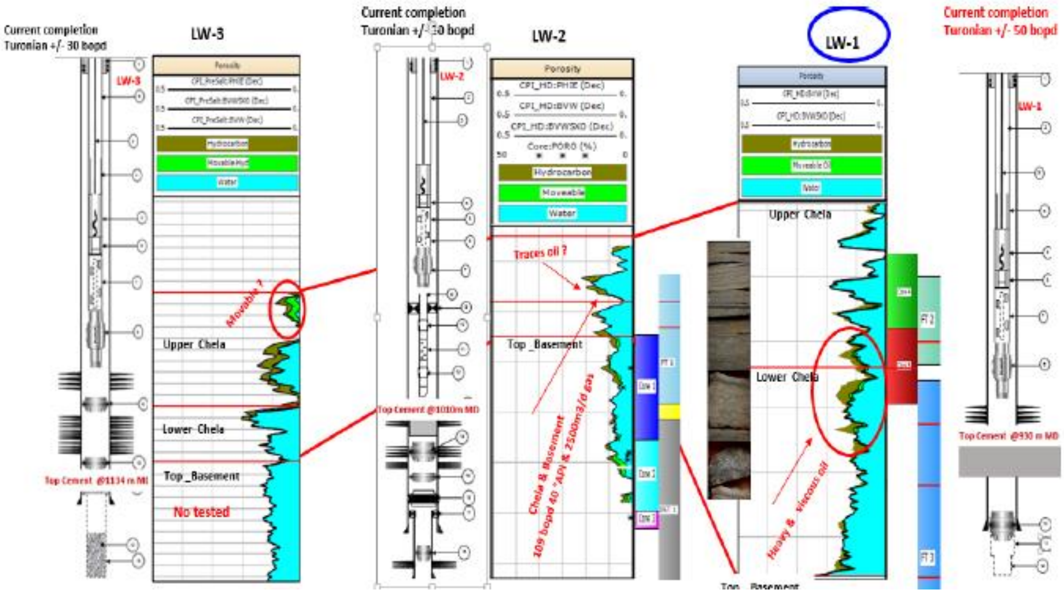

Figure 17. *The intervals to be perforated taking into account the logging logs*

CONCLUSIONS

The aim of this research is the reservoir characterization both petrographic and petrophysic of the pre-salt Chela formation of the Nsiamfumu and Liawenda fields in the onshore Coastal Basin of D.R. Congo. Reservoir characterization represents an important part of the static geological modeling of oil reservoirs. After analysis and interpretation of the geologo-geophysical information correlated with CPI and DST test results, the main results obtained are as follows:

- Well Lw-1: the formation is characterized by dolomitic limestone and micaceous black shale with a thickness of 34 m, showing heavy oil, an average porosity of 17% and a salinity greater than 300 gr/L;
- Well Lw-2: the formation is characterized by islands of sand, coarse sandstone and a few quartz pebbles with a thickness of 10m showing indications of light oil, gas and an average porosity of 24% ;
- Well Lw-3: the formation is dominated by micaceous shale and dolomite interbeds with a thickness of 14m showing little evidence of hydrocarbons, only salt water and residual oils;
- Well Ns-1: the formation is characterized by beige to grey dolomite, grey shale and white sand with a thickness of 6m showing evidence of light oil and an average porosity of 20%.

We can conclude as follows:

- The pre-salt Chela formation of the Nsiamfumu and Liawenda fields in the onshore Coastal Basin of D.R. Congo is a good hydrocarbon reservoir containing light oils tested at 36° API 174bopd (Ns) and 40° API 120bopd (Lw).
- Given its good petrographic character and petrophysical parameters, the Chela reservoir could be a profitable oil production area, but structural studies of this reservoir first need to be deepened in the Nsiamfumu and Liawenda fields, as well as in all onshore fields in the Coastal Basin of D.R. Congo.

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