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PETROPHYSICAL CHARACTERIZATION BY 3D MODEL OF ZONES 4 AND 3 OF THE TURONIAN RESERVOIR OF THE KINKASI FIELD IN THE D.R. CONGO COASTAL BASIN

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ABSTRACT

Kinkasi is one of the oil fields of the DR Congo Coastal Basin. It is essentially formed of two main geological units (A and B) in the Turonian, each composed of a succession of different horizons (Zones) according to the type of siltstone. These two main units contain 6 Zones. Unit A consists of Z6 and Z5 of Coniacian age, while the rest of the reservoir (Z4, Z3, Z2 and Z1) is of Turonian age which is characteristic of Unit B. Indeed, the present study is devoted to the petrophysical characterization of the two zones Z4 and Z3 of the unit B in order to locate the interesting zones to develop this oil field. For this fire, we used the data of 11 wells having the geographical coordinates, the porosity, the permeability as well as the water saturation. The processing and interpretation of these data using the Kriging method allowed us to deduce from the scale of appreciation the areas that contain high values of porosity, permeability and water saturation. Porosity in zones 4 and 3 varies from good to very good, saturation 3 to 59% for zone 4 and 32 to 53% for zone 3 as well as permeability from poor to low for both zones. The combined interpretation of these three properties allowed us to find an interesting zone located towards the east of zones 4 and 3 with high porosity and permeability values and low water saturation values.

Keywords: Turonian; petrophysical properties; Kriging; Kinkasi oilfield

INTRODUCTION

A petroleum reservoir is a porous, permeable underground formation containing a natural, individual and separate accumulation of hydrocarbons (oil and/or gas), bounded by a layer of impermeable rock and often by an aquifer, and characterized by a unique natural pressure system. [1]. Reservoir rock is porous and permeable. These characteristics enable it to contain fluids (water, oil, gas, etc.). With their fluid content, these rocks become economically interesting, especially when they are covered by impermeable rock that doesn't allow the fluid to escape. These rocks have a reservoir rocks can be of greater interest if their pore volume is considerable and if the capacity of fluids to circulate is high. Reservoir rock is also known as store rock. [2]. During exploration and development drilling, it is advisable to study the behavior of the reservoir by knowing these different petrophysical and fluid properties through the methods used to evaluate them. The petrophysical and fluid properties of the reservoir enable engineers to quantify the hydrocarbons and carry out a modeling study to target the zones (locations) containing these good properties for the development of this field.

The main objective of this work is to characterize the petrophysical properties of two zones of the Kinkasi field's Turonian reservoir in order to locate areas with good values of these properties. The information and data used in this study come from 9 wells drilled in zones 4 and 3 of the Kinkasi field's Turonian reservoir. The data consist mainly of petrophysical properties such as porosity, permeability, water saturation and roof and wall depths. Processing of the petrophysical data involved the production of various isovalue maps in the 3D model using Sig (Geostatic analyst extension of ArcMap, Arcsène) and Surfer 23 software. Interpretations were based on the scale of appreciation of these properties. The aim is to locate areas of major interest with good permeability and porosity and low water saturation.

1. KINKASI FIELD

1.1. Geographic location

Located on the edge of the Democratic Republic of Congo in the Muanda region (Figure 1), the Kinkasi field was discovered by Fina in April 1972 with the drilling of KK01 near the top of the structure, but production only started in March 1980. Three reservoirs have been produced: the Turonian at an average depth of 1000 m, provides gas to some gas elevator wells while the Cenomanian at 1100 m and the Vermelha at 1600 m produce oil. Recently, about 1,800 b/d of average oil at light are produced from both the Cenomanian and Vermelha by 49 wells. The Vermelha, intermingled with the Cenomanian by a single well (KK44), represents less than 3% of the total Kinkasi production. [3]. It is located in the onshore part of the basin exploited by PERENCO-REP which operates in a concession covering an area of 462 sqkm with geographical coordinates 12°20'0" to 12°25'0" East longitude and 5°55'0" to 6°0'00" South latitude.

1.2. History of the field

Initially, the field development was focused on the upper Cenomanian layers (G to K). Only a few of the disposal wells produced in the lower C, D, E layers via the KK-01, -04, -05, -07, -10, -11 and -17 wells. In 2006, additional perforations in the E layer of wells KK-44 and KK-45 gave good results of production and its potential is proven for the lower layers (A, B, C and D). Following these encouraging results, 9 additional wells targeting the lower layers were drilled in 2007. As of March 2009, 17.80 million barrels have been produced from the Cenomanian reservoir, mainly in the upper layers, with an estimated STOIIP of 245 million barrels which gives a current recovery factor of 7.2%. The 2P developed for the field is estimated at 5.9 million barrels and leads to an estimated final recovery rate of around 9.7% with existing wells only.

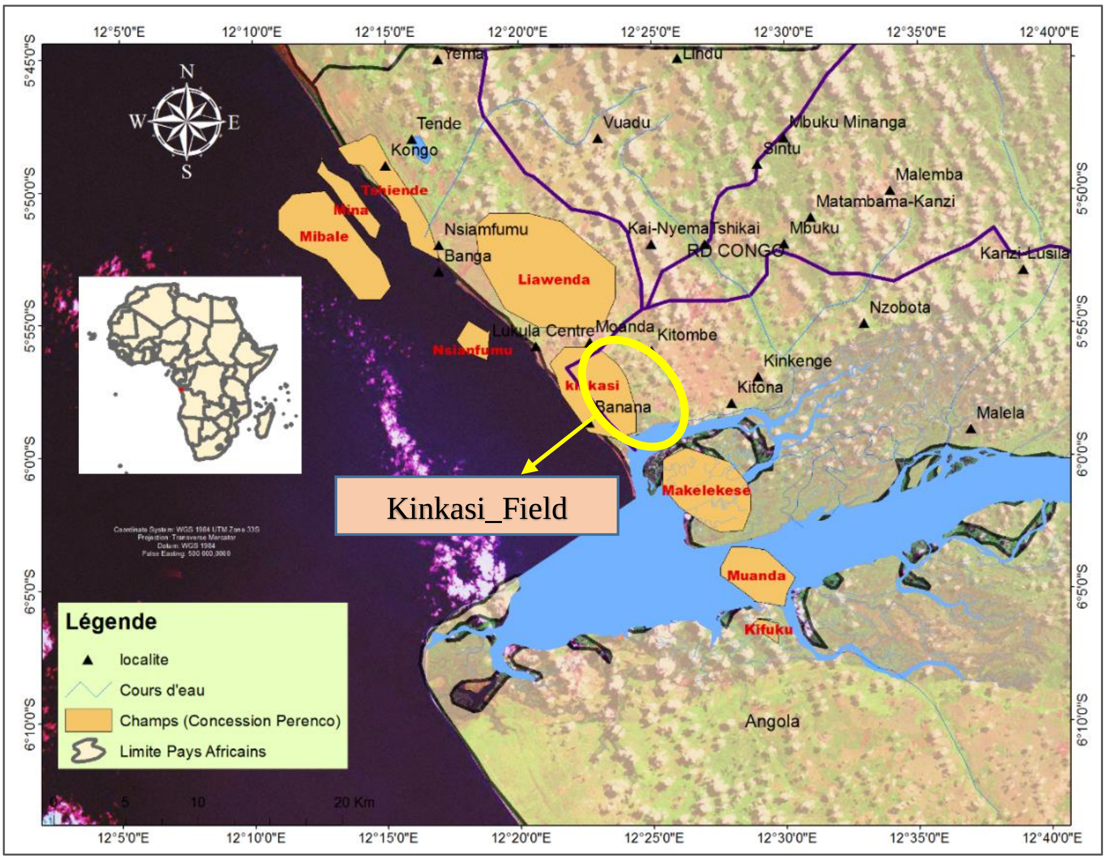

Figure 1. *Location of the fields of the Coastal Basin*

1.3. Lithofacies of the Turonian-Coniacian

The Turonian-Coniacian reservoir has a relatively simple petrographic profile. It is essentially formed of two main geological units (A and B) each composed of a succession of different horizons according to the type of siltstone observed:

- Unit A, composed of massive limestones and coarse-grained, well-graded, angular to well-rounded siltstones, with rare intercalations of silty skeletons, is subdivided into 3 lithofacies (AI, AII and AIII) distributed according to the petrographic and sedimentological logging pattern of well KK-01;
- Unit B consists of coarser grained skeletons and massive siltstones than in Unit A. It locally contains silty limestone horizons intercalated with debris limestone, mudstone and lime; it includes 5 lithofacies (B, BI, BII, BIII and BIV) identified by petrographic and sedimentological logging of well KK-01 (Figure 2).

1.4. Turonian-Coniacian lithofacies

The zonation of the Turonian-Coniacian reservoir is presented according to the criteria:

- The boundaries of the GR and SP logs coincide with an actual geological event;
- Zones are associated with pre-identified sedimentological sequences and rock types or sequences;
- Zone boundaries take into account fluid distribution and content.

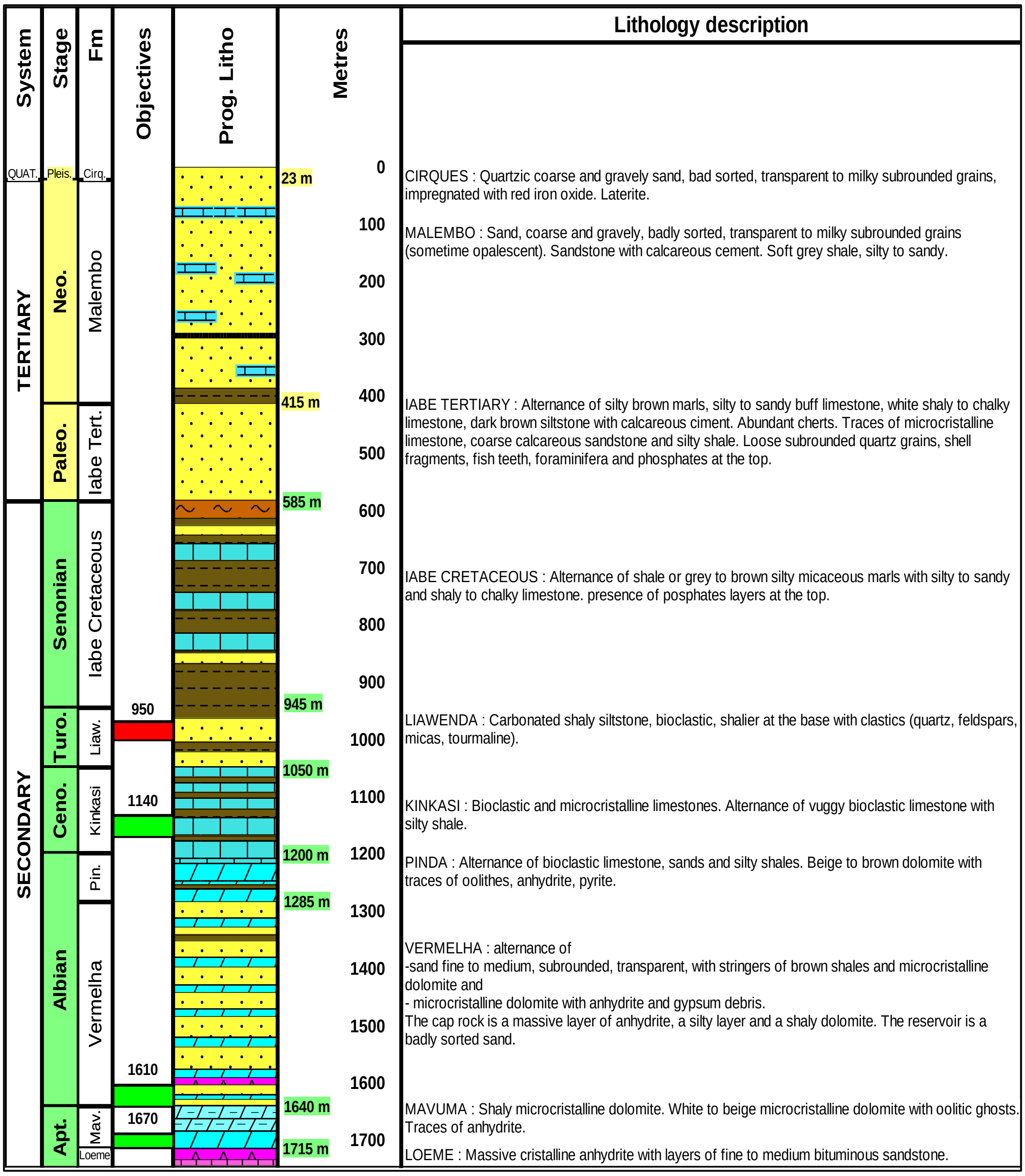

***Figure 2**. Lithofacies of the KK01 well in the Kinkasi field.* [4]

The results for all of these parameters are reported in Table 1. Thus, the Z6 and Z5 zones are Coniacian in age, characterized by rock unit A, while the rest of the reservoir (Z4, Z3, Z2 and Z1) is Turonian in age, which is characteristic of unit B.

Peak-to-peak gamma-ray layer correlations allowed the construction of isobath maps. For a contour distance of 20m, the theoretical closure of the reservoir would be 6m; the gas-oil contact would be located at the extreme south-east of the Kinkasi field. Observations show that the Z6 and Z1 zones are rather weakly saturated with oil and have very low porosities. Furthermore, the analysis of the cuttings from these two zones shows no trace of oil. They are rather very saturated in water although they are composed of siltstones considered to be of better quality. These siltstones are found at the base of the Z1 zone and at the top of the Z6 zone, thus preventing direct oil-water contact with the other zones of the reservoir. The water known to be in the Z6 and Z1 zones would be isolated by a seal due to the very poor porosity-permeability properties that decrease the capillary pressure in these two zones very rapidly. [5]

Table 1. Fluid zonation. [4]

		Kinkasi	
		OWC	GOC
TURONIAN	Z6	Gas	-976
	Z5	Gas	-976
	Z4	-988	-982
	Z3	-988	-982
	Z2	-988	-982
	Z1	-988	-982

2. PETROPHYSICAL CHARACTERIZATION OF THE TURONIAN-CONIACIAN RESERVOIR

The petrophysical characterization of this Turonian-Coniacian reservoir is done by making a study of spatial distribution of porosity, saturation and permeability. The method used to achieve this distribution is Kriging.

Kriging is an exact, unbiased linear estimator based on the variogram. It takes into account the distance between the data and the target points (grid), possible anisotropies and allows the use of auxiliary variables correlated with the studied phenomenon. This technique minimizes the estimation variance and ensures the best global estimation of a variable. Kriging is used to estimate a local average quantity of a property in an environment. [6]

The main objective of geostatistics is spatial prediction, also known as kriging, which consists of predicting a regionalized variable of interest over a study area, based on data observed at certain locations. Kriging is basically based on the modeling and estimation of the spatial dependence structure. The description of the latter is commonly done using statistical tools such as variance, covariance, variogram, calculated over the entire domain of interest and under a stationarity assumption. [7]

The figure 3 below shows variograms of the various petrophysical properties studied (porosity, water saturation and permeability).

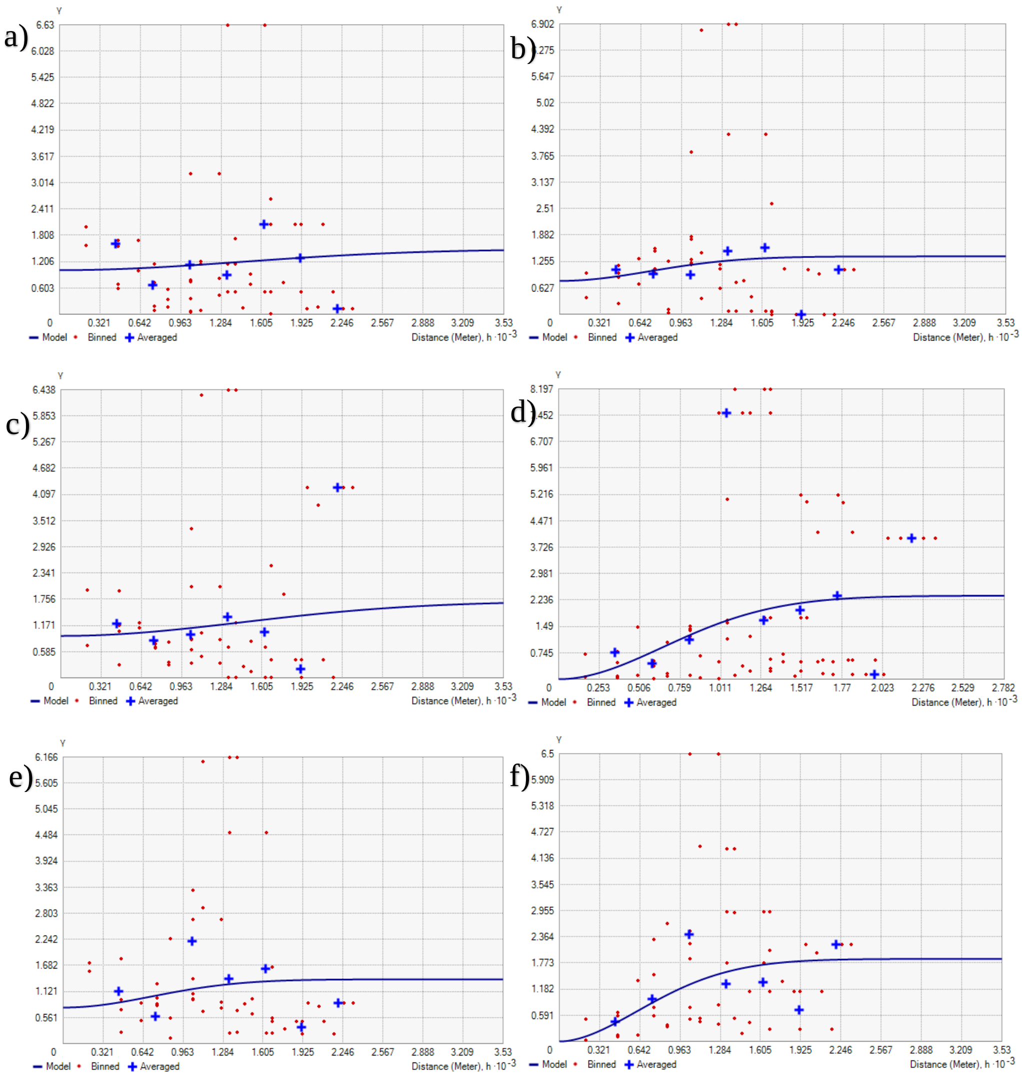

Figure 3. *Variograms (a: porosity of zone 4, b: porosity of zone 3, c: water saturation of zone 4, d: water saturation of zone 3, e: permeability of zone 4, f: permeability of zone 3)*

2.1. Map of isobaths

Zone 4: The 3D isobath model map of Zone 4 of the Kinkasi Field Turonian reservoir reveals that the structure of the Turonian reservoir in the northeastern part of the Kinkasi Field is monoclinal from the northeast to the southwest of the study area. Looking at the depth, we see that the depth of the roof of the isobaths in Area 4 varies between 931 and 996 m taken at sea level. And as for the variation of the depth of the Wall Isobaths of the Zone it varies between 933 to 1000 m, which allows to understand the variation of thickness of Zone 4 goes from 2 to 4m.

Zone 3: The isobath map of Zone 3, starting from 11 wells as a sample located to the east of the Kinkasi Field, shows a monoclinal structure going from the northeast to the southwest. This allows us to understand that our study area is located on the northeast flank of the Kinkasi Field Anticline (Figure 4).

The variation of the depths of the roof and the Wall taking into account the isobath map of the northeast part varies from 934 to 1000 m for the Roof and from 943 to 1009 m for the Wall. The analysis of the isobath map of these two areas allows us to understand the displacement of the flow by the effect of the pressure difference, that is to say, from a place of high pressure corresponding to the important depths to the areas of low pressure (low depth). This flow displacement is especially important from the North-East to the South-West in the two zones 4 and 3 of the Turonian reservoir of the Kinkasi Field.

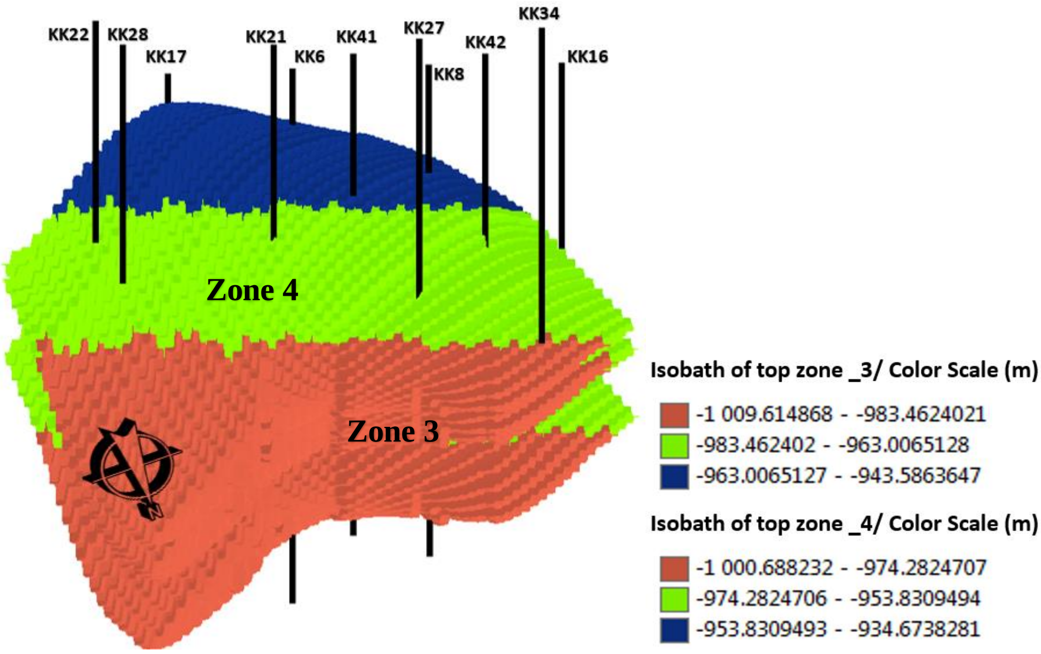

Figure 4. *Overlay of Zone 4 and Zone 3 isobath map of the Kinkasi Field Turonian reservoir*

2.2. The porosity

A sedimentary rock is made up of agglomerated or cemented solid particles between which exist spaces, called "pores" or sometimes "voids", constituting microscopic channels (diameter of the order of a few tenths of a micron for example). Let us consider a rock sample of total volume VT including a solid volume VS; (VT - VS) represents the volume occupied by the fluids, i.e. the pore volume Vp. Its porosity is expressed by the ratio:

$$\emptyset = Vp/Vt = (Vt - Vs)/Vt$$

We are particularly interested in the useful porosity, i.e. the one that takes into account only the pores that communicate with each other and with the outside. Reservoir rocks have very variable porosities, generally between 10 and 30%. Porosity values are obtained by core measurements and logging. [8].

The scale of porosity assessment is as follows:

- Negligible: if $\Phi < 5\%$;
- Poor: if $5 < \Phi < 10\%$;
- Good: if $10 < \Phi < 20\%$;
- Very good: if $\Phi > 20\%$.

Zone 4: The iso-porosity map for Zone 4 shows that porosity in the northeastern part of the Kinkasi Field Turonian reservoir is very good, ranging from 20.9 to 21.74.

Zone 3: The iso-porosity map of the northeastern part of zone 3 of the Kinkasi field shows that porosity in this zone is very good, with values above 20%. Porosity is highest in the eastern part where the blue color is present.

By superimposing the porosity maps of zones 4 and 3, the areas of interest to us are those towards the east, where we find very good porosity with high values. By superimposing the porosity maps of zones 4 and 3, the areas of interest are those facing east, as this is where the very good porosities with high values are found. Figure 5 below shows the 2D and 3D iso-porosity overlay maps for zones 4 and 3 in the northeastern part of the Turonian Field reservoir.

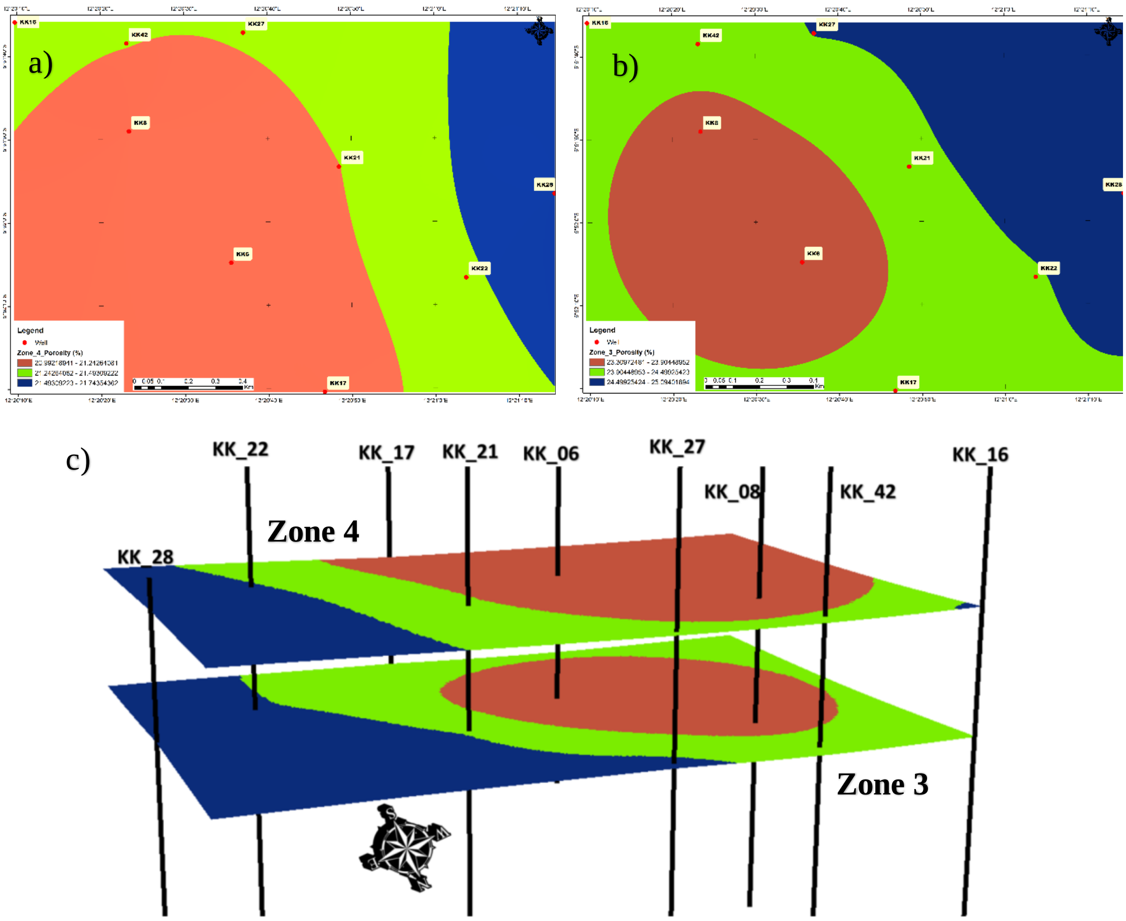

Figure 5*. Iso-porosity map: a) 2D model of iso-porosity in zone 4, b) 2D model of iso-porosity in zone 3 and, c) 3D model overlay of porosity in zones 4 and 3 of the Turonian reservoir in the Kinkasi field.*

2.3. The water saturation

The saturation of a rock sample with a fluid is the ratio of the volume of the fluid in the sample to the pore volume (Vp) of the sample. [9]. It is defined as follows:

- The water saturation Sw = Vw / Vp (Also called Sw, w for water)
- The oil saturation So = Vo / Vp (Also called So, o for oil)
- Gas saturation Sg = Vg / Vp (Also called Sg, g for gas)

The water saturation allows us to have an idea on the oil and gas saturation. Knowing the water saturation, we can get to know the oil saturation by the following formula:

$$Sw + Sg + So = 1$$

As we do not have the values of gas saturation, let us consider that there is no gas cap and therefore no gas-oil contact, so the gas saturation is zero, the formula becomes

$$Sw + So = 1$$

Zone 4: Looking at the water saturation map (figure 5) for zone 4, we can see that water saturation ranges from 30.6 to 59.1%. It is much higher in the blue zone. The zones of interest to oil companies are those containing high hydrocarbon saturations. However, hydrocarbon saturation is high when water saturation is low. Therefore, in this study, it's important for us to look for zones where water saturation is lower. In fact, the red color contains low water saturations ranging from 30.6 to 43.8%, giving us an idea of oil saturations ranging from 56.2 to 69.4%. Only well KK28 is located in this zone.

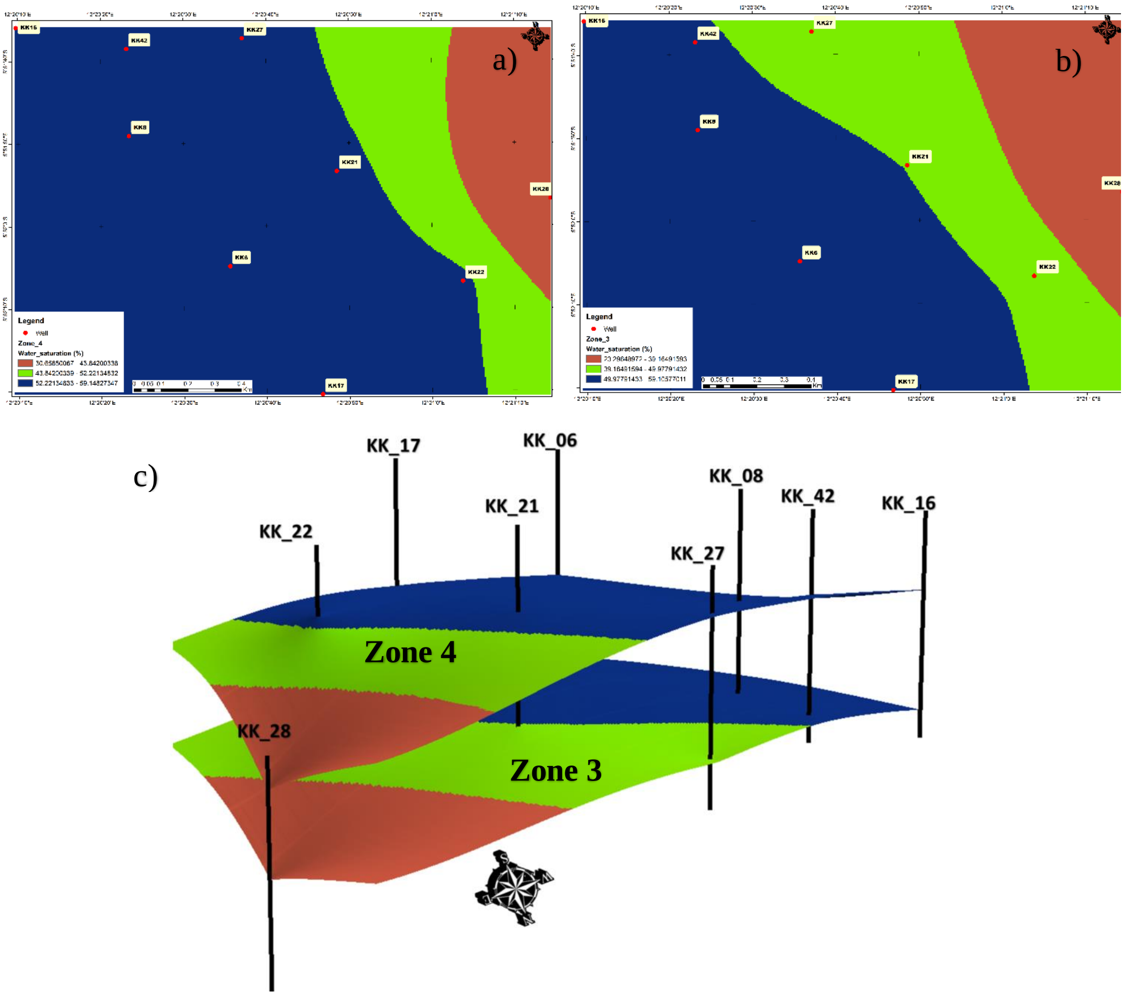

***Figure 5**. Water saturation map: a) 2D model of water saturation in zone 4; b) 2D model of water saturation in zone 3; c) 3D model overlay of water saturation in zones 4 and 3 of the Turonian reservoir in the Kinkasi field.*

Zone 3: According to the iso-saturation map of zone 3 of the Turonian reservoir in the northeastern part of the Kinkasi field, water saturation varies between 23.2 and 59.1%. The zone with the lowest water saturation and highest oil saturation is located in the red zone, with a variation from 23.29 to 39.1% and oil saturation from 60.9 to 76.71%. Only one well, KK28, is located in this zone of lowest water saturation.

To better understand the evolution of these two maps at depth, an overlay map of the 3D model has been drawn up, showing that there is a correlation between these two zones. It can be seen that water saturation is lower towards the east (figure 5).

2.4. The permeability

It represents the ease with which a fluid can move through the interconnected pores of a reservoir rock, or the ease with which a fluid moves between interconnected pores in a reservoir. It should be noted that permeability varies from point to point and improves with grain classification.

Generally, the effectiveness of water injection is achieved in reservoirs where the permeability varies from 1 to several Darcy. Consider a fluid flowing in the pore network of a right prism of rock reservoir of section S and height L. A pressure P1 prevails at the inlet side S1 and a pressure P2 at the outlet side S2 such that P2<P1.

Under the effect of this pressure gradient, the fluid of viscosity µ circulates with a flow rate given by the relation. [1].

Thus in practice, the permeability thresholds are as follows:

- K > 500 mD: excellent;
- 200 mD < K < 500 mD: good;
- 50 mD < K < 200 mD : average ;
- 10 mD < K < 50 mD: poor;
- 1 mD < K < 10 mD: poor.
- 1 Darcy =10^{-12} m^2; 1 milliDarcy = 10^{-3} Darcy.

Zones 4 and 3: Looking at the iso-permeability maps for Zone 4 shown in the figure 6 below, we can see that permeability varies from very poor to low. In fact, although the permeability of this zone is poor to low, the zone of interest is the part located east of well KK28. This is where the permeability contains high values of over 50 mD, close to the average permeability threshold.

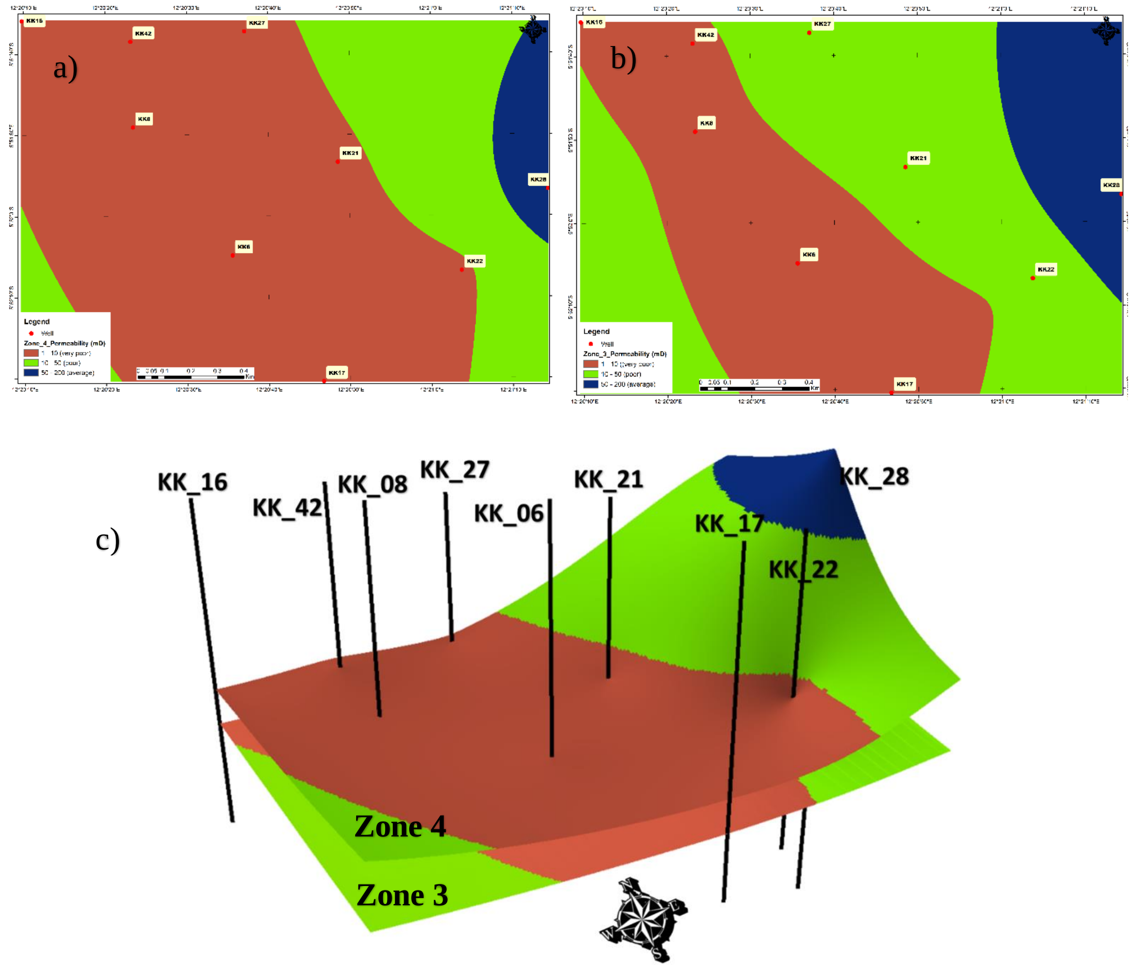

Figure 6*. Permeability map: a) 2D model of permeability in zone 4, b) 2D model of permeability in zone 3, c) 3D model overlay of water saturation in zones 4 and 3 of the Turonian reservoir in the Kinkasi field.*

3. Combined interpretation of petrophysical properties

After the analyses made through the maps illustrated above, we correlated these different petrophysical properties and highlighted the interesting zones. These are constituted by good porosity and permeability as well as a low water saturation.

Zone 4: Looking at the symbiotic results of the petrophysical properties of the northeastern part of Zone 4 shown in Figure 7, we note an interesting zone where the petrophysical properties studied above are of interest. This zone is located towards the eastern part of the study area. Petrophysical properties make a major contribution to well production and productivity. They are therefore important to know in order to characterize a petroleum reservoir and get an idea of its evolution, as production depends on them.

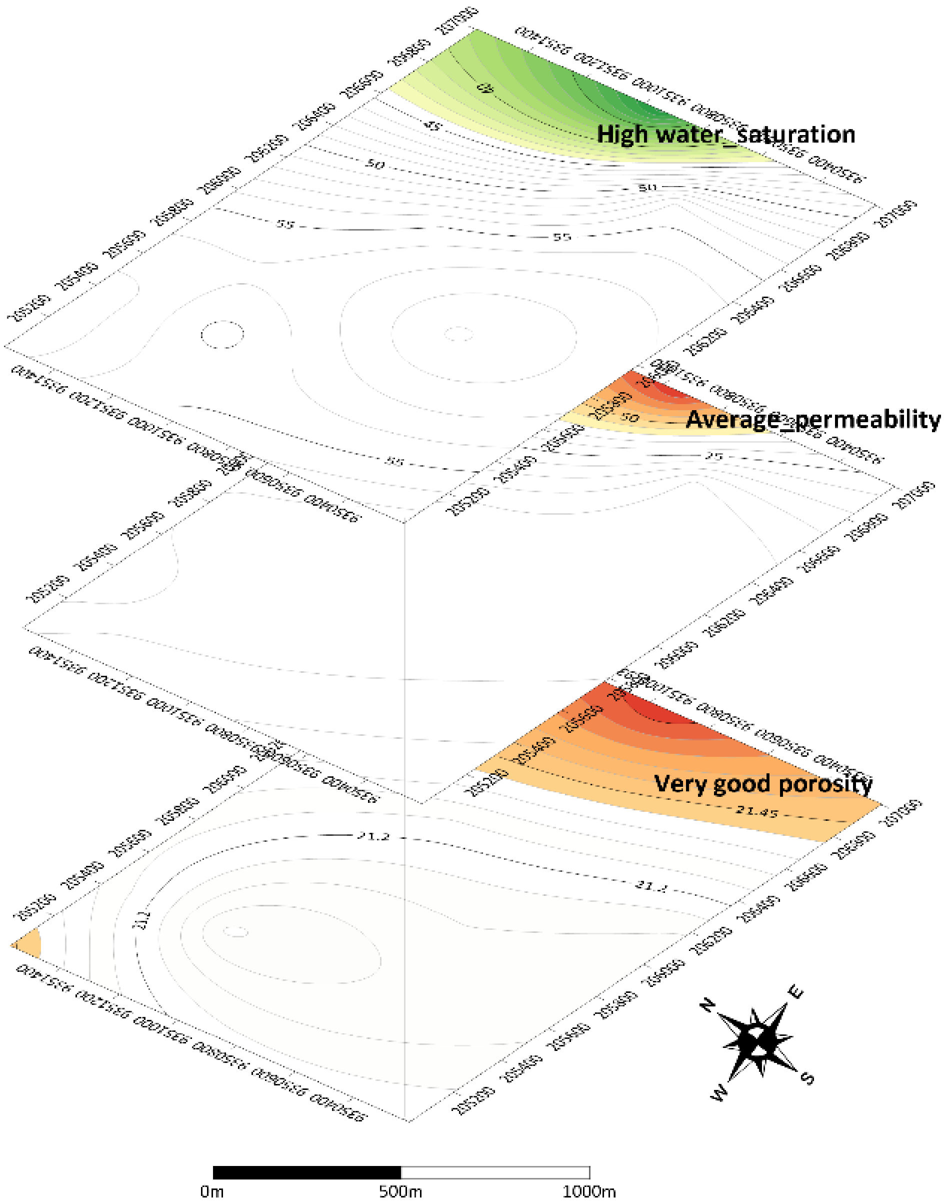

Figure 7*. Location of the Zone of Interest in Zone 4 of the Kinkasi Field Turonian reservoir*

Zone 3: Based on the results obtained on the map of the various petrophysical properties of zone 3 of the Turonian reservoir of the Kinkasi field illustrated in the figure 8 below, we understand that the 9 wells drilled from the study area in the northeastern part of the Kinkasi field in the present zone were not drilled in the zones targeted as being interesting, i.e. where all the petrophysical properties are interesting. There is an interesting zone located to the east where the KK28 well is located.

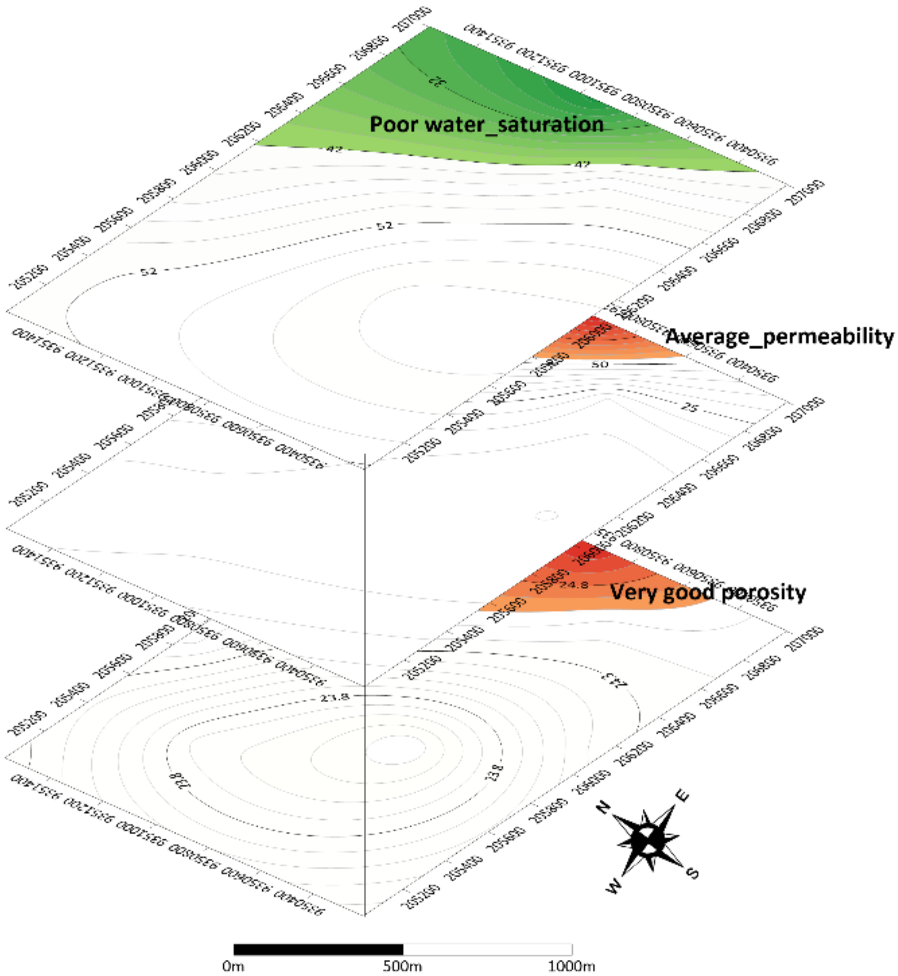

Figure 8*. Location of the zone of interest in Zone 3 of the Kinkasi field Turonian reservoir*

4. CONCLUSIONS

Our present paper is devoted to the study of the 3D model of petrophysical properties in the northeastern part of the Kinkasi field. This study enabled us to characterize and search for interesting zones with good petrophysical properties in the two zones (Zone 3 and Zone 4) of the Turonian reservoir. The main objective of this paper was to characterize and highlight interesting zones based on petrophysical data, using maps of their isovalues in the two zones of the Turonian reservoir. To do this, we collected petrophysical data (porosity, saturation and permeability) from 9 wells in Excel format. These data in Excel format enabled us to draw up iso-porosity, iso-permeability and iso-saturation maps using Arcgis software from the Arc-scene extension and Surfer 23, and to bring out the following interpretations:

- For zones 4 and 3, good porosity occupies the red and green areas, with porosity percentages ranging from 20.9 to 21.74% for zone 4 and from 23 to 25% for zone 3. According to the rating scale, porosity in zones 4 and 3 is very good porosity. The water isosaturation map of Zone 4 varies from 3 to 59%, which gives us an idea of oil saturation ranging from 41 to 97%. The wells in this zone are KK34 and KK41.

- The water saturation map shows values ranging from 30 to 59% for zone 4 and 23 to 59% for zone 3. The zone with the lowest water saturation and the highest hydrocarbon saturation is located to the east, with a variation of 30 to 43% for zone 4 and a hydrocarbon saturation of 57 to 70%.
- Permeability in Zone 4 and 3 varies from very poor to low. In fact, although the permeability of this zone is low, the zone of interest is the part to the east where well KK28 is located.

Examination of the combined interpretation of the petrophysical property maps of the northeastern part of Zone 4 and Zone 3 shows that there are interesting petrophysical properties located towards the eastern part of the study area, i.e. where we can find good, high hydrocarbon saturation with high permeability values.

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