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CHARACTERIZATION OF ISOBATHS IN THE CENOMANIAN RESERVOIR OF THE MUANDA FIELD – IMPLICATIONS FOR OPTIMAL OIL RESOURCE MANAGEMENT

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ABSTRACT

The study of isobaths characterization in the Cenomanian reservoir of the Muanda field focuses on optimizing petroleum resource management. Using geostatistical techniques and numerical analysis methods, the isobaths of the K, J, I and H layers were mapped. The K layer, the most superficial, is 44 meters thick, while the J and I layers reach 48 meters respectively.

This research highlights the spatial variability of isobaths, a key factor in understanding the rapid depletion of the reservoir, which is mainly attributed to the presence of argillites. The lithological heterogeneity, characterized by high clay content, influences reservoir permeability, complicating fluid flow and, consequently, well productivity. The study also subdivided the reservoir into distinct zones according to clay content, revealing that the southwestern zone has a clay content of over 57.42%, while the southeastern zone is less clayey, with a content of less than 41.87%.

The results underline the importance of a geostatistical approach to resource management, identifying target areas for potential interventions such as hydraulic fracturing. This study thus contributes to a better understanding of reservoir dynamics and to the formulation of appropriate strategies for the sustainable exploitation of petroleum resources in the Muanda region.

Keywords: reservoir, geostatistics, hydrocarbons, mapping, resource management

INTRODUCTION

The oil industry is facing major challenges, notably the depletion of reserves and the geological complexity of deposits. To overcome these obstacles, the integration of advanced numerical tools is becoming essential, and geostatistics is emerging as a key tool for optimizing hydrocarbon exploration and exploitation. It enables us to characterize the spatial heterogeneities of reservoirs and simulate their dynamic behavior, which is crucial for strategic decision-making [1],[2].

The aim of this work is to explore the practical implications of geostatistics in the oil industry, focusing on the isobaths mapping model of layers K, J, I and H of the Cenomanian reservoir in the Muanda field. These layers, located in an anticlinal structure, exhibit variations in thickness and depth, the understanding of which is essential for effective resource management.

The study covers a gap in the literature by providing a detailed analysis of the geological characteristics and spatial variations of the layers, an aspect often neglected in previous research. In addition, this research stands out for its innovative approach, integrating advanced geostatistical techniques to model underground formations, offering practical solutions in the face of growing industry challenges. The importance of this research lies not only in its theoretical contribution to geostatistics, but also in its practical implications for the oil industry, offering innovative solutions in the face of growing challenges [5].

MATERIALS AND METHODS

This work was made possible thanks to a number of reports on the various operations carried out in the Muanda field, as well as sustained documentation based particularly on geostatistical interpolation methods (Figure 1). A number of mapping, calculation and conversion tools were also used. These include:

- UTM CONVERT: used to convert well coordinates from the Clarke 1880 system to UTM Zone 33 South coordinates, which is an international projection system corresponding to the location of part of the western zone of the DRC;
- Excel 2016 : to create the Champ Muanda well information table;
- Surfer 19: For Kriging interpolation maps.

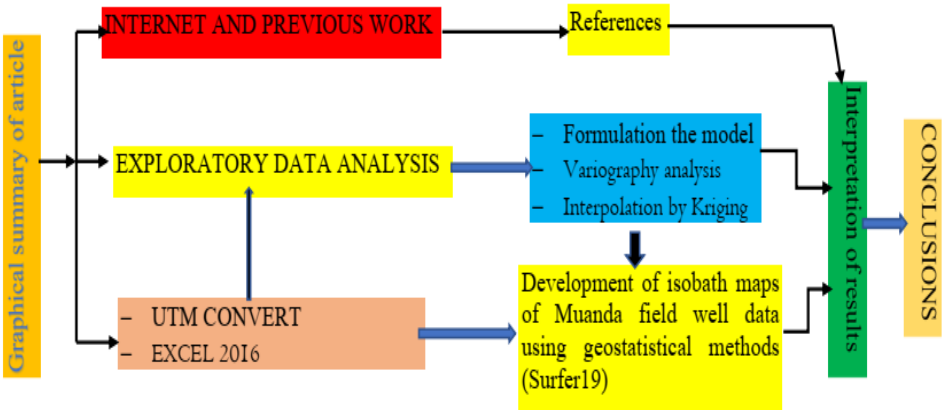

Figure 1. *Diagram describing the methodology used to produce the article*

GEOSTATISTICAL MODELING AND PETROPHYSICAL STUDIES

In the oil industry, the application of geostatistics has evolved considerably beyond its initial uses in exploration and reserves evaluation. It now plays a crucial role in the accurate quantification of reserves and the optimization of production processes, helping to increase the efficiency and profitability of petroleum operations. Geostatistics has also become an essential tool for managing the uncertainty inherent in estimating oil and gas reserves [26].

Geostatistical modeling

Reservoir modeling involves creating a digital representation of the reservoir from a geological point of view. The aim is to analyze various reservoir characteristics, such as hydrocarbon saturation (the proportion of empty space occupied by oil), porosity (the free volume in the rock that can contain a fluid), permeability (the ability of a rock to allow the passage of a fluid), and clay volume. These properties are essential for estimating the volume of hydrocarbons available and recoverable [21],[23].

The reservoir is subdivided into meshes (which can have shapes such as cubes, tetrahedrons or octahedrons), and for each mesh it is necessary to determine the petrophysical property value.

Objectives of reservoir modeling

- Define reservoir structure and properties for optimal characterization;
- Optimize oil exploitation and recovery to maximize operational efficiency;
- Gather relevant information to deepen understanding of reservoir behavior and capitalize on recorded data.

To accurately represent the geology of a region, we're going to build a model. This model will facilitate the creation of mental images of a three-dimensional environment. [21].

The oilfield services company Schlumberger has developed a high-performance software package called Petrel, which runs under Windows. The software is designed for 3D visualization, 2D and 3D mapping, and three-dimensional reservoir modeling and simulation.

In the oil industry, particular attention is paid to the development of both the geological model and the reservoir model. The latter forms the main basis of information, as it then serves as input data for advanced simulators, enabling reservoir behavior to be simulated and predicted during operation [25].

Method used in geological modeling

Geostatistics is a discipline at the crossroads of mathematics and earth sciences. It plays an essential role in reservoir modeling. Its aim is to statically evaluate reservoirs by processing a set of data spatially distributed over a given area. To do this, it estimates values in the vicinity of a point, based on a set of samples taken at different locations, considered as references.

Based on geostatistics, two approaches to reservoir modeling can be distinguished. The first is the Boolean method, also known as object-based methods. In this approach, objects are created and used to estimate property values, while continuous simulation calculates properties at each node (or pixel). Which method to use depends on the nature of the data available [23].

– ***Pixel-based method***

This method is based on kriging, an estimation technique derived from geostatistics. It therefore requires the definition of a variogram, which is a mathematical function illustrating the variability of sample measurements as a function of the distance between each pair of samples. [3]. The value to be estimated for a given node is independently correlated with each neighboring value. These values include:

– ***SIS (Simulation Indicatrice Séquentielle)***

This algorithm is used to model geological facies. It calculates grids corresponding to lithology and facies.

– ***SGS (Sequential Gaussian Simulation)***

An interpolation method using data that generates a distribution model based on the variogram.

– ***Object-based method***

This is the appropriate method for channel simulation. It models discrete data that are generated and distributed stochastically. All values are recorded, including geometric characteristics such as length, thickness and curvature. Reservoirs can be modeled in either of these ways:

- The geological (static) model integrates reservoir geometry and petrophysical properties. It takes into account the dynamic data needed to model the essential heterogeneities. It is crucial to include these dynamic data, notably by identifying the major faults that influence fluid flow and strategic barriers. To ensure the consistency of the final model, strong collaboration between specialists from different geodisciplines is essential.
- The reservoir (dynamic) model, on the other hand, consists of a grid of cells to manage and represent key heterogeneities, i.e. the main flow units, and to ensure consistency in the distribution of lithofacies and petrophysical properties.

Their aim is not to predict what the reservoir contains, but to anticipate its dynamic behavior and simulate the evolution of a field over time. [4].

PETROPHYSICAL STUDY OF THE RESERVOIR

A reservoir rock is a rock with both porosity and permeability characteristics, enabling the accumulation of hydrocarbons. [9],[11]. Under pressure, hydrocarbons migrate from their source rock, called bedrock, to the surface through different rock layers. They can become trapped when they encounter an impermeable layer, such as a clay layer, or a salt dome. [8],[12]. This type of reservoir, which consists of an impermeable layer above a porous, permeable layer saturated with hydrocarbons, is known as a conventional reservoir, as illustrated in (Figure 2). [22].

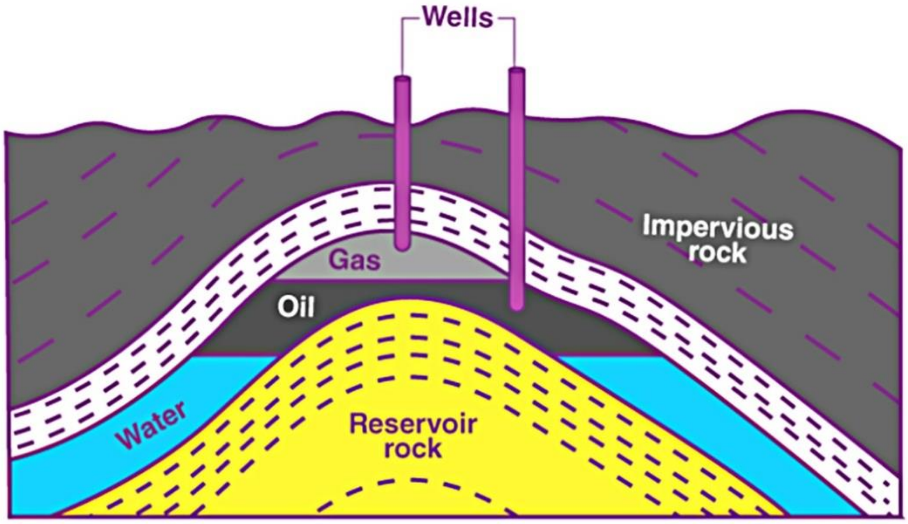

***Figure 2**. Diagram of a conventional hydrocarbon deposit.* [20],[21],[23]

PETROPHYSICAL ASPECTS

Understanding the petrophysical characteristics of rocks is essential for reservoir analysis. These parameters enable us to characterize the reservoir in terms of properties and quality. [10]. This helps to assess its potential and develop the various programs needed to exploit its reserves to the full. The characterization and distribution of the various reservoir parameters are mainly carried out using descriptive statistical and geostatistical methods. [14]. To strengthen the study of the distribution of petrophysical parameters, we felt it was appropriate to complement the traditional analysis with a geostatistical approach. [9],[12].

The appropriate methodology to begin this study is based on the geostatistical approach to porosity and permeability, supported by cartographic support. In general, the most significant petrophysical property is permeability, whose spatial distribution influences flow paths and the main obstacles encountered. A great deal of research is focusing on heterogeneities in reservoir models to understand the impact of complex architectures on fluid flows. [10],[13],[14],[15].

THE CENOMANIAN RESERVOIR OF MUANDA FIELD

This reservoir is characterized by a fractured anticline, unlike the fields further north. In this case, rapid facies variations can be observed. [17],[19]. It is composed of carbonates, silts and clays. [16]. with 16% porosity and 60% saturation [18]. The oil reservoir is 100 m thick, with a gas dome limit of 25 m. The Cenomanian reservoir is subdivided into 11 distinct sequences (K, J, I, H, G, F, E, D, C, B, A).[6],[7]. Impregnations range from K to G. The Muanda structure was discovered by Fina-Rep in June 1972 with the drilling of the Muanda-1 well. The second well drilled in this structure was the MU-2 well in August 1984. The Cenomanian reservoir was encountered at a depth of -1050 m below sea level, showing good traces of oil. [24]. The development of the field can be summarized as follows (Table 1):

Table 1. *Summary of field development information*

Year	Development of the field
1983	Fina drills 19 wells with a 600-metre grid. Production began in September 1983
2007	Drilling of 4 appraisal wells (MU-08/09/10 and MS-09);
2008	Drilling of 11 development wells with a mesh reduced to 350m
2010	Drilling of 18 development wells, plus pilot fracturing campaign
2011	Drilling of 25 development wells, continuous fracturing
2012	Drilling campaign of 25 wells (21 development wells + 4 appraisal wells) underway

DATA PRESENTATION

The data we have used in this article are roof (m) and wall (m) values for some layers of the Cenomanian reservoir, obtained from measurements made on several Muanda field wells. The tables below show some examples of the data found.

Table 2. *K-layer data*

WELL	*ROOF (m)*	*WALL(m)*
MU-002	976	988
MU-003	983	997
MU-004	977	988
MU-005	993	1009
MU-006	996	1011
MU-022	987	1003
MU-023	1015	1031
MU-024	1003	1019
MU-025	973	984
MU-026	989	1002
MU-027	977	993
MU-028	1001	1017
MU-029	977	989
MU-030	985	998
MU-031	999	1015

Table 3. *J-layer data*

WELL	***ROOF (m)***	***WALL(m)***
MU-002	988	998
MU-003	997	1008
MU-004	988	998
MU-005	1009	1020
MU-006	1011	1023
MU-022	1003	1013
MU-023	1031	1042
MU-024	1019	1031
MU-025	984	995
MU-026	1002	1013
MU-027	993	1003
MU-028	1017	1029
MU-029	989	998
MU-030	998	1008
MU-031	1015	1027

Table 4. *I-layer data*

WELL	***ROOF (m)***	***WALL(m)***
MU-002	998	1018
MU-003	1008	1030
MU-004	998	1015
MU-005	1020	1045
MU-006	1023	1049
MU-022	1013	1036
MU-023	1042	1068
MU-024	1031	1056
MU-025	995	1020
MU-026	1031	1034

MU-027	1003	1026
MU-028	1029	1054
MU-029	998	1018
MU-030	1008	1028
MU-031	1027	1051

Table 5. *H-layer data*

WELL	*ROOF (m)*	*WALL(m)*
MU-002	1018	1030
MU-003	1030	1043
MU-004	1015	1027
MU-005	1045	1067
MU-006	1049	1064
MU-022	1036	1050
MU-023	1068	1085
MU-024	1056	1073
MU-025	1020	1033
MU-026	1034	1048
MU-027	1026	1037
MU-028	1054	1068
MU-029	1018	1028
MU-030	1028	1040
MU-031	1051	1065

MODEL ISOBATHS MAPS OF THE K, J, I AND H LAYERS OF THE CENOMANIAN RESERVOIR

By integrating the data from the table (see Table 2, 3, 4, and 5), we drew up isobaths maps (see Figure 3) and thickness maps (see Figure 4) to interpret the results.

– ***K layer***:
    - This is the top layer of our isobaths map model, with a thickness of 44 m and a north-west to south-east axis;

- This is an anticlinal formation, as shown in (Figure 3) on the map at coordinate 9343600;
- Its greatest depth is divided into two zones: the North-East zone and the North-West zone;
- Its shallowest part is 16m (between 988m and 972m), the middle of the layer is located between 1000 and 988 meters (i.e. 12m) and the deepest is 16m (between 1016 and 1000m).

Regarding the evolution of its thickness: from north to south in the western part, we observe no variation, similarly we observe a homogeneous evolution of the layer in its eastern part.

– ***J layer***:

- Its thickness is 48 m; its axis is oriented from northwest to southeast;
- It is an anticline formation, as shown on map coordinate 9343600;
- Its greatest depth is observed in the northeast zone of the field;
- Its shallowest part is 16m (between 984m and 1000m), the middle of the layer is located between 1000 and 1016 meters (i.e. 16m) and the deepest part is 16m (between 1016 and 1032m).

With regard to changes in thickness, the layer is homogeneous in the north-western and south-western parts, at coordinates 213400. However, Figure 4 reveals a significant variation in thickness, which has a direct influence on the lower layer I.

– ***I layer***:

- Its thickness is 48 m; its axis is oriented from northwest to southeast;
- It is an anticline formation, as shown on map coordinate 9343600;
- Its greatest depth is observed in the northeast and southeast zones, as well as in the western part of the field;
- Its shallowest part is 12m (between 994m and 1006m), the middle of the layer is located between 1006 and 1026 meters (20m) and the deepest is 16m (between 1026 and 1042m).

Concerning the evolution of its thickness: several variations can be observed:

- From northwest to southwest, the layer widens;
- From west to east, the layer narrows at coordinate 213400, forming a synclinal pattern.

– ***H layer***:

According to the modeling process, the H layer gives similar thicknesses as J layer, and as a result, we no longer considered it necessary to investigate in this direction.

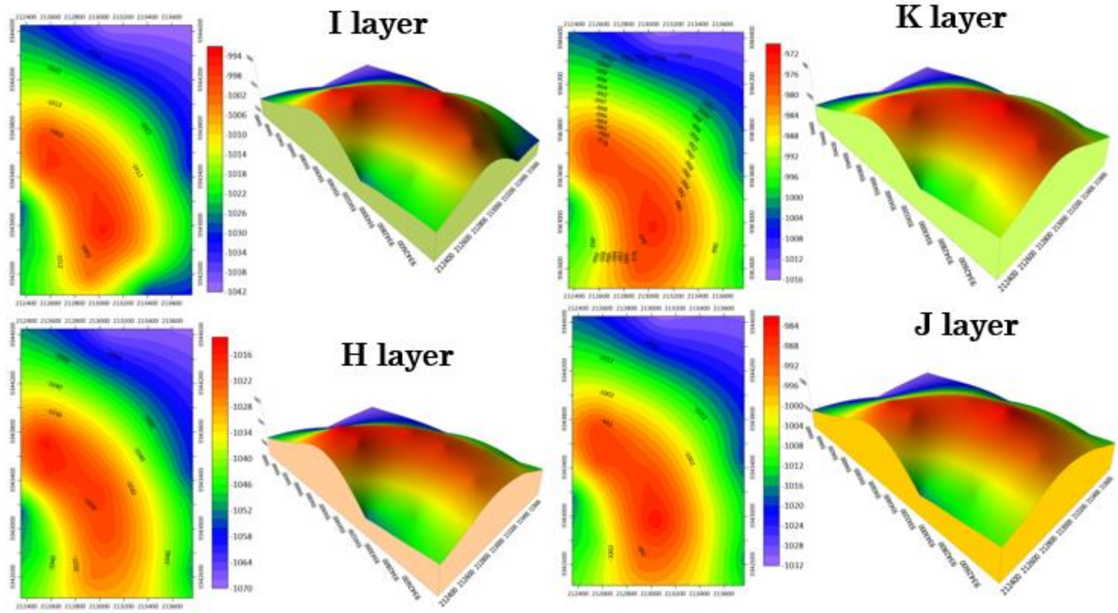

Figure 3. *Isobaths maps of the layers under study*

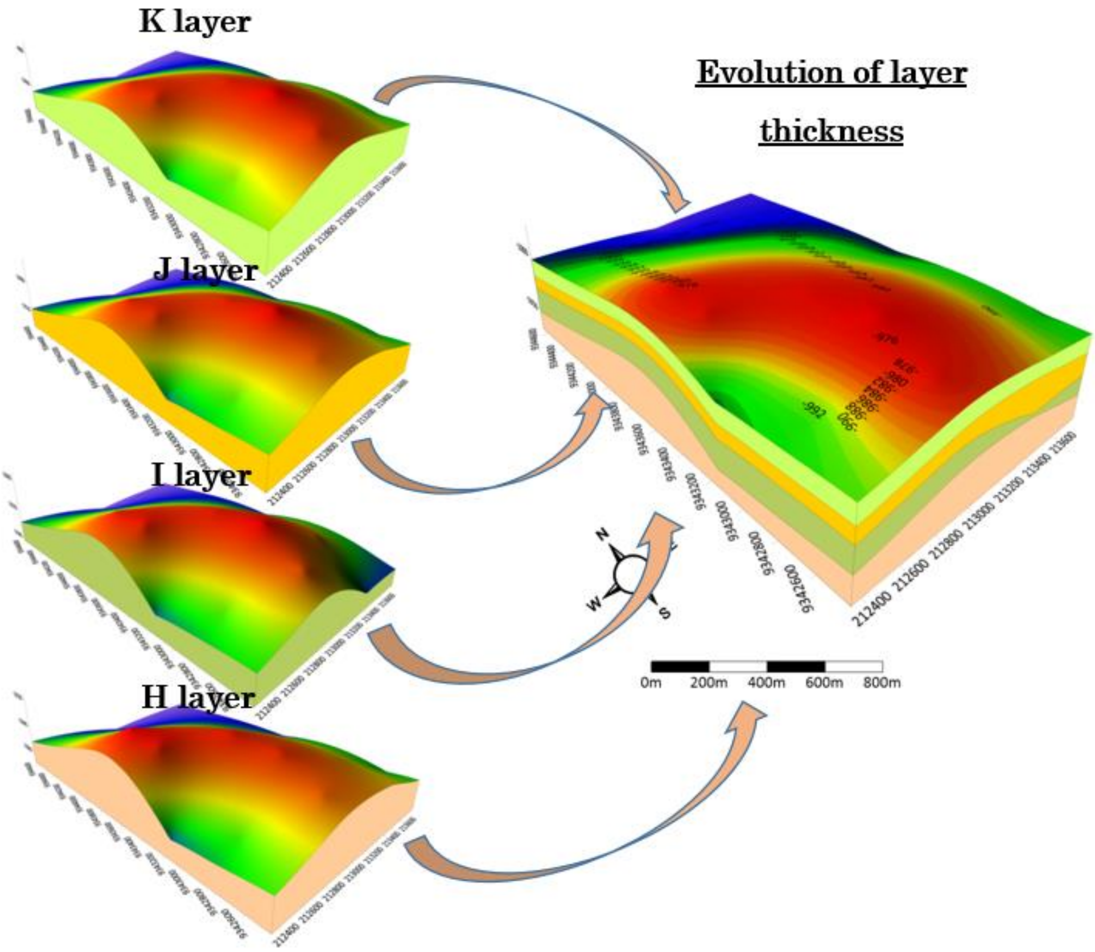

Figure 4. *3D model of the thickness of the K, J, I and H layers in the Cenomanian reservoir*

CONCLUSIONS

The study of the Cenomanian reservoir in the Muanda field, using a geostatistical approach, highlights the importance of characterizing petrophysical heterogeneities to optimize hydrocarbon exploitation. Understanding the isobaths of the K, J, I and H layers is essential for oil and gas exploration. These data help optimize drilling and evaluate potential reserves. By integrating advanced geostatistical models, this research paves the way for better resource management, taking into account local variations and interactions between different layers. Future research should further develop these models to maximize the efficiency of extraction operations.

This study represents a significant advance in our understanding of complex carbonate reservoirs. By shedding light on their petrophysical characteristics, it contributes to a more sustainable exploitation of petroleum resources. Effective management relies on accurate data and appropriate modeling, enabling the challenges of reservoir depletion to be anticipated. By integrating these elements, the oil industry can not only improve the profitability of its operations, but also minimize its environmental impact.

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