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Geological Modeling of Sandstone Formations and Petrophysical Characterization of Hydrocarbon Reservoirs in the Termit Basin, Eastern Niger: Case of the Goumeri Prospect

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Abstract

This study focuses on the geological model of sandstone formations and the petrophysical characterization of hydrocarbon reservoirs in the Termit Basin. The specific objectives are: (1) to establish a geological model visualizing the geometry of reservoir rocks and (2) to visualize the spatial and vertical distribution of the petrophysical parameters (porosity, permeability). The methodological approach integrated the interpretation of lithology data and petrographic parameters from the logs by using Petrel software 17.4 versions. The interpretation of the obtained results shows that: the reservoir formations present in the shape of sand lenses whose thickness varies according to another prospect. The petrophysical parameter models including the porosity and permeability model were used to understand the vertical and

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spatial distribution of the different reservoir units.

Keywords: Geological modeling, porosity, permeability, Termit basin

I. Introduction

The Termit Basin is a fractured and elongated intraplate basin of NW-SE direction (Genik, 1993 ; Liu et *al.,* 2015) (Figure 1), and belongs to the West African Rift Subsystem (WAS) which itself belongs to the West and Central Africa Great Rift System (WCARS) (Genik, 1992). It's formed in the meso-Cenozoic period rift basin that sedimentary filling is a Cretaceous lower to the Holocene-Pleistocene age (Michel, 1988). The Termit Basin is an intercontinental basin between Niger, Nigeria, and Chad. It's one of the largest basins in Eastern Niger, which straddles the Bornou Basin in Nigeria and the Doba-Bangor basin in Chad. This basin was developed during the opening of the Atlantic Ocean (Genik, 1993; Brownfield, 2016). The sediments filling the Termit Basin are cretaceous and quaternary age (Genik, 1992; Liu *et al.*, 2015). The thickness of terrigenous clastic sediments was from 300 m to 2500 m in the Lower Cretaceous, from 800 to 4200 m of marine clay, sandstone, and silts intercalated with calcareous banks in the Upper Cretaceous, from 350 m to 2500 m of sand in the Cenozoic (Figure 2) (Genik, 1992; Wan et *al.*, 2014). Oil exploration began in the Termit Basin around the years 1970 by Conoco, whose first oil showings were discovered in the Chad Basin, specifically in the Termit Basin near Lake Chad around 1974 (Genik, 1992; Harouna & Philp, 2012; Sarki, 2021). The target reservoir formations are the Eocene and Late Cretaceous sandstone (Genik, 1993; Harouna & Philp, 2012). Structurally, the Termit Basin has mainly faulted families of NW-SE and NNW-SSE directions (Liu *et al.*, 2012 ; Zhou et *al.*, 2017). A first family of faults is said to be early formed in the early Cretaceous (NW-SE faults) (Ahmed *et al.*, 2020 ; Konaté et *al.*, 2019), and a second family of faults is said to be late Paleogene formed (NNW-SSE faults) (Liu *et al.*, 2012 ; Zhou et *al.*, 2017). The Termit Basin is subdivided into ten (10) structural units (Figure 1): Iaguil Platform, Western Platform, Eastern Platform, Dinga Fault Zone, Dinga Depression, Western Yogou Slope, Fana Uplift, Moul Depression, Araga Graben and Eastern Trakes Slope (Lai et al., 2020 ; Liu et *al.,* 2019). The general objective of this study is to build a geological model of the petrophysical and sedimentological parameters of the study prospect. The specific objectives are to establish a geological model visualizing the geometry of reservoir rocks (**1**) and to visualize the spatial and vertical distribution of its petrophysical parameters (porosity, permeability).

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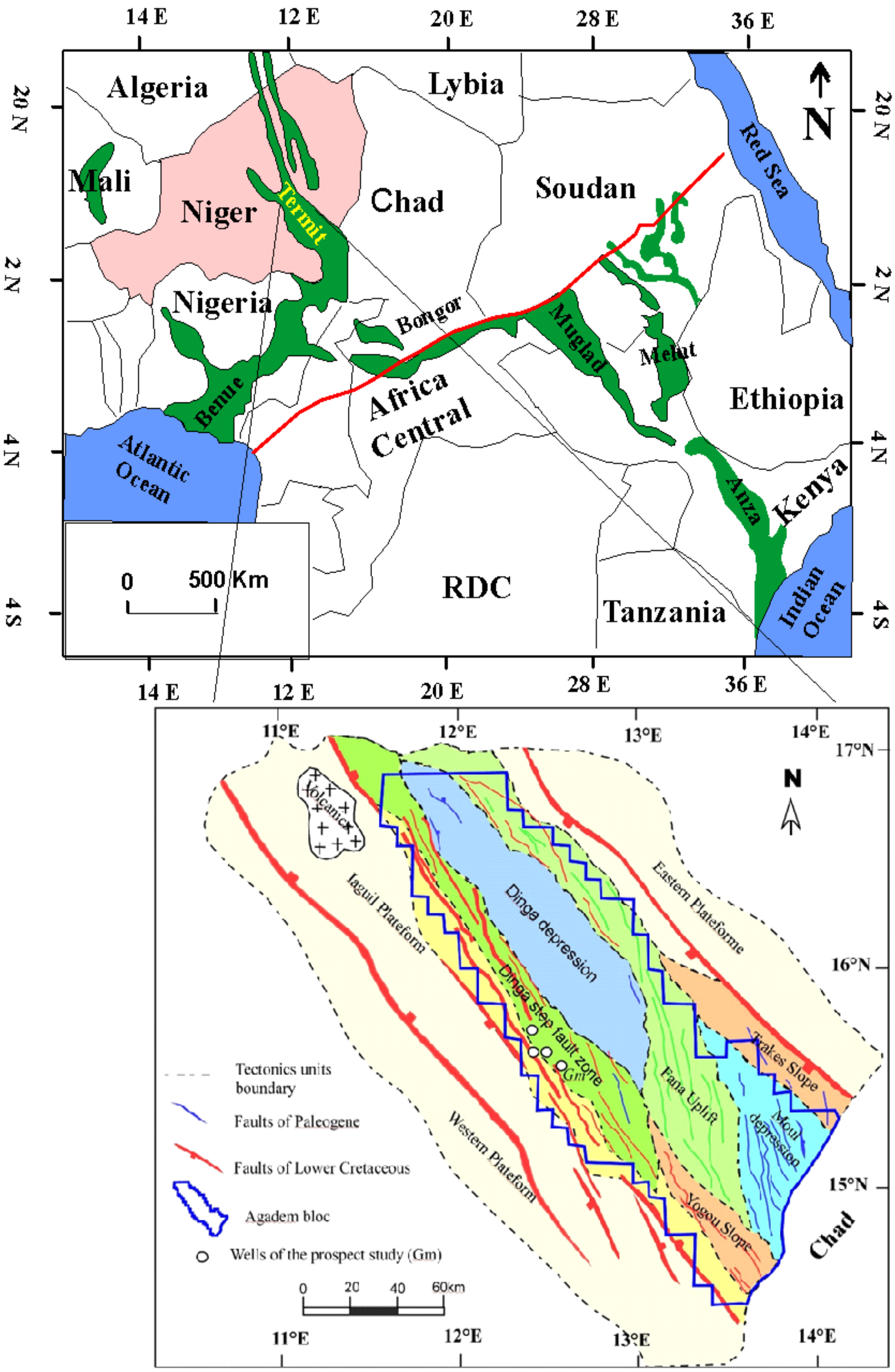

Figure 1. Location of the study area and structural units of the Termit Basin (Genik, 1993; Liu et *al.*, 2015; Liu et *al.* 2019)

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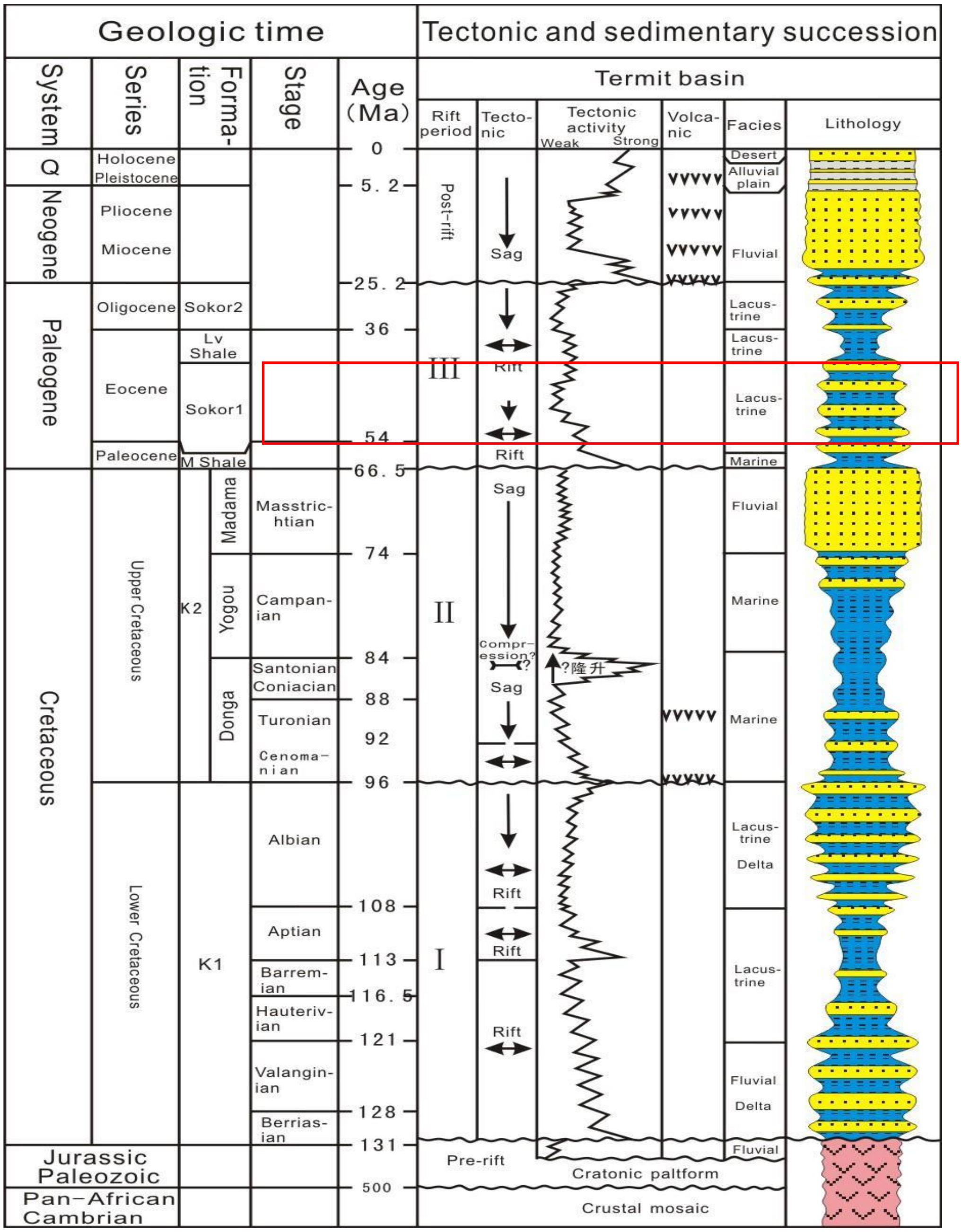

Figure 2. Litho-stratigraphic column of the Termit basin (Liu *et al.*, 2015).

II. Methodological approach

The methodological approach implemented in this work consists of importing the stratigraphic, lithologic, and petrophysical parameters data into the petrel geomodeling software 17.4 versions. This software allows the construction of the 3D geological model as well as the models of the

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petrophysical parameters (porosity permeability) allowing us to visualize their spatial distribution on the whole study prospect. The petrophysical and sedimentology data used in this research come from the wells of Goumeri prospects. The porosity, permeability, and sedimentology values were determined from core measurements (direct measurements) and log measurements (indirect measurements) (Table 1). For modeling the heterogeneity of the reservoir formations facies, the following approaches using Petrel 17.4 versions stochastic methods were applied in this study. These approaches allow the construction of the different geological layers as well as their extension from north to south of Goumeri prospects.

Table 1. Table showing the porosity and permeability values of the Goumeri prospect wells.

Name of the Wells	Mean of the porosity (%)	Mean of the Permeability (mD)
Goumeri-1	10,25	378,7
Goumeri -2	11,32	228,01
Goumeri -3	8,22	435,4
Goumeri -4	35,11	525,44
Goumeri -5	15,04	275,22
Goumeri -6	12 67	287,45
Goumeri -7	26,17	376,8
Goumeri -8	31,5	615,6
Goumeri -9	19,54	345,4
Goumeri -10	17,39	100,27
Goumeri -11	25,09	396,29
Goumeri -12	20,10	375,31
Goumeri -13	14,10	207,40
Goumeri -14	29,83	201,45
Goumeri -15	10,20	317,98
Goumeri -16	18,00	215,57
Goumeri -17	11, 33	201,80

III. Results and Discussion

1. Facies model

The model (Figure 3) of facies shows the variation in thickness of the sandstone layers in the reservoir formation of the unit E1 of the Goumeri prospect wells that constitutes the lithofacies (Chang & Zung, 2017). These facies corresponds to deposits from the channel bottom and infill of the river channel in the lower part (Fea *et al.*, 2022). According to the facies model, the clay facies in the Goumeri prospect is more dominant than the sandy facies (Caumon *et al.*, 2009; Makhloufi *et al.*, 2013).

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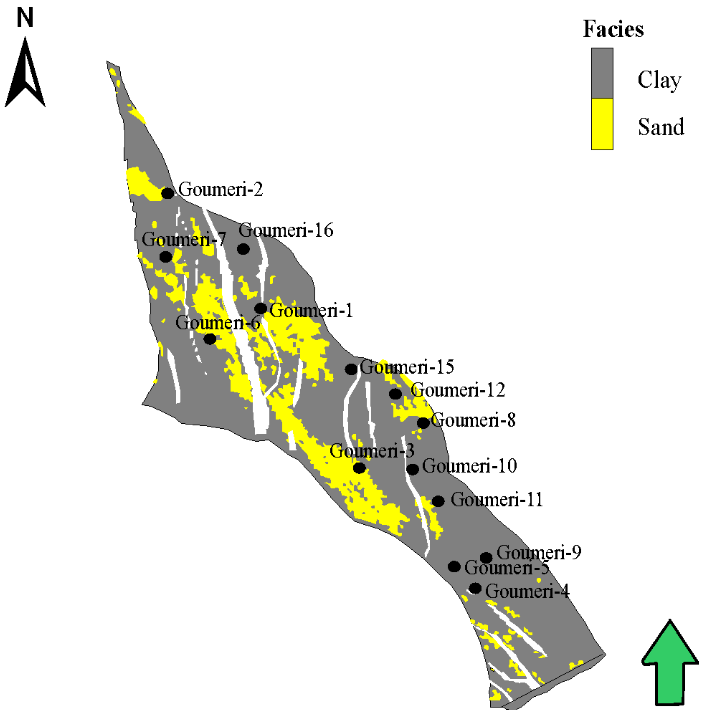

Figure 3. Facies model shows the spatial distribution of the sediments (yellow: sand and black: clay).

2. Porosity model

The porosity model indicates the spatial-lateral variation of porosity of the E1 reservoir unit of the Goumeri prospect wells. Within a well, the porosity of the E1 unit varies according to the lithology and the percentages of the different elements constituting the formation (Thomas, 2020; Fea *et al.*, 2022). According to this model (Figure 4), the good porosity (>15,10%) is concentrated in the northeast zone of the prospect (*Goumeri-2*, *6*, 8 and 12); the low porosity (<10,2%) is concentrated in the eastern zone of the prospect (*Goumeri*-1,10,11). This low porosity is explained by the fact that the intergranular spaces of the quartz grains are filled by the different types of cement (siliceous, clayey, ferruginous, and carbonate) (Makhloufi *et al.*, 2013).

The model of the geological section (Figure 5), shows a litho-stratigraphic section of the Goumeri prospect. According to this model, all the wells intersect NW-SE faults. Thus, the *Goumeri-6* crosses well an NW-SE Normal fault.

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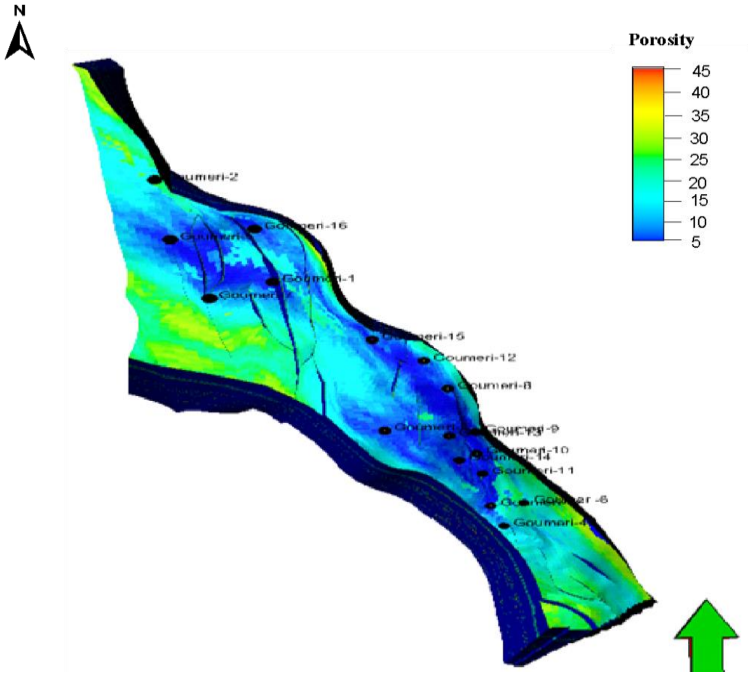
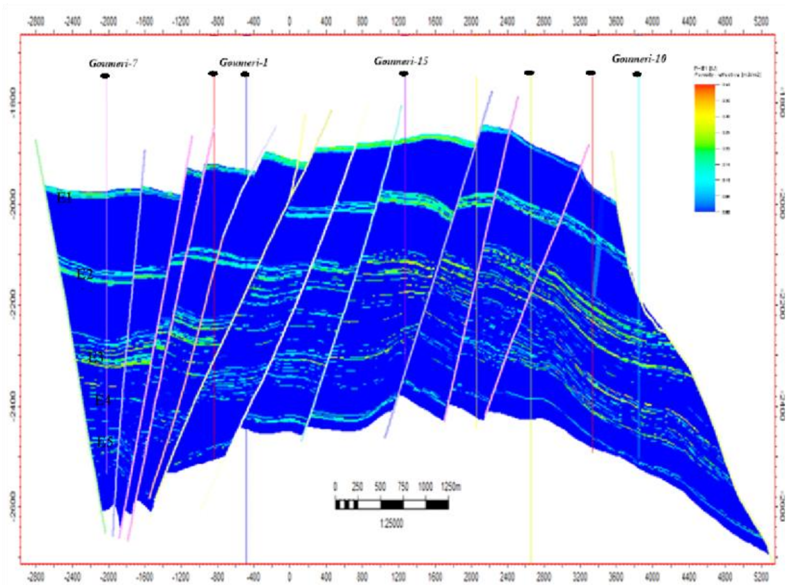


Figure 4. Porosity map showing the spatial distributions of porosity within the wells of the Goumeri prospect



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3. Permeability model

The model of permeability (Figure 6), shows the special permeability distribution of the wells in the Goumeri prospect. This model illustrates the permeability concentrations within the reservoir units of the Sokor-1 formation (Figure 7). According to this model, the good permeability (> 479,3 mD) is concentrated in the northeast zone of the prospect (Goumeri-2, 6, 8, and 12); the low permeability (<100 mD) was concentrated in the eastern zone of the prospect (Goumeri-1, 10, 11). The permeability varies from 100 mD to 615,62 mD (Table 1, Figures 6–7) in all the wells and the different reservoir levels of the Goumeri prospect depending on the mineralogical composition of the rocks. The sandstone reservoir levels have a predominance of quartz, which confirms a good permeability. This was demonstrated by Mao et *al*. (2019) in the Upper Cretaceous sandstone reservoirs of the Yogou and Donga formations in the Termit Basin and by Fea et *al*. (2022) in the Abian-Cenomanian reservoirs of the Ivorian basin.

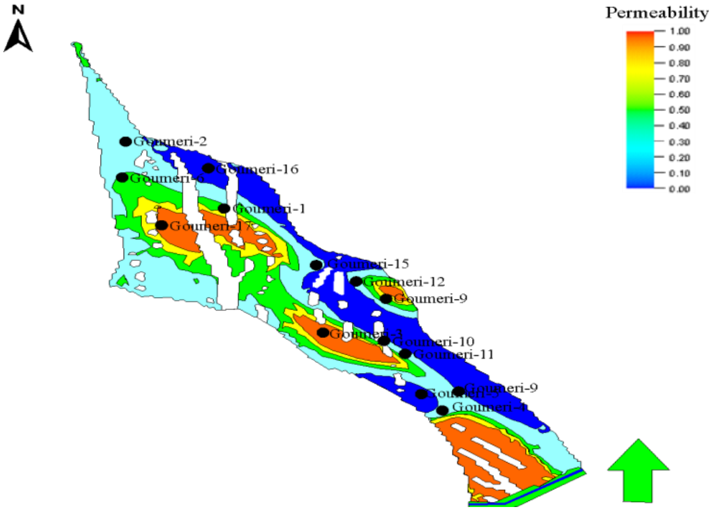

Figure 6. Permeability model showing spatial distributions of permeability within the wells of the Goumeri prospect

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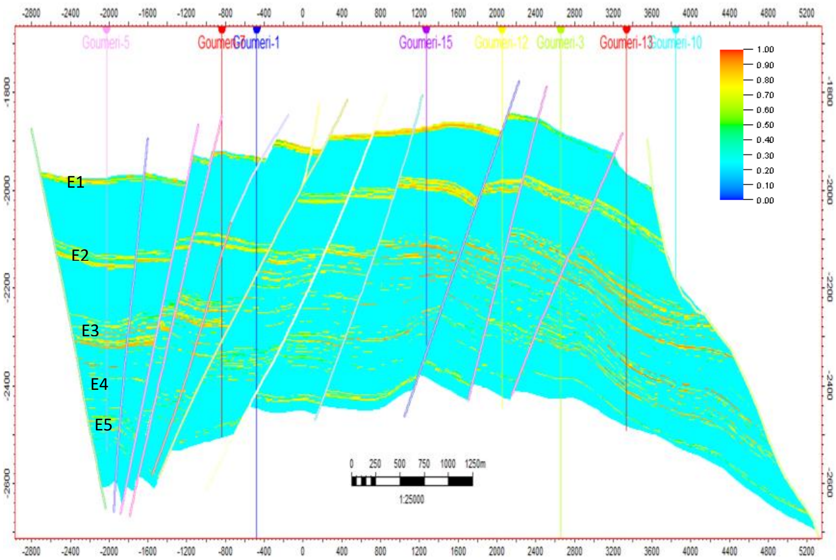

Figure 7. Geological section of the Goumeri prospect, showing the porosity of the reservoir units and normal NW-SE direction faults.

Conclusion

The main results of this research work, based on the geological modeling of sandstone formations and their petrophysical characteristics at the Goumeri prospect of the Termit Basin, have made it possible to understand that:

- Sandstone tank units are compartmentalized in tank units or levels interspersed with clay banks;
- Formation (Sokor-1) corresponds to a period of transgression/regression marked by a contribution of detrital sediments;
- The petrophysical parameters (porosity and permeability) of the reservoir units show good to excellent values (respectively >15,10% and > 479,3 mD) and low water saturation in the northeastern part of the basin.
- Geological models show the geometry and extension of theSokor-1 reservoir formation, according to this model, the sandy facies are more concentrated in the center of the basin.

Through this study, the extension and geometry of the sand and clay facies were determined, as well as the vertical distribution of the different reservoir levels.

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