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Modeling of Geological and Geophysical Data, Onshore Field of Potiguar basin, northeastern Brazil

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***Keywords*—Açu Formation, Leapfrog, Modeling, Potiguar Basin, Reservoirs.**

***Abstract*—This work presents the results of 3D Geological Modeling with a focus on the onshore field, in the context of the Potiguar Basin. Therefore, the object of study is the silisiclastic reservoirs of the Açu Formation, unit 3, which correspond to the Albian/Cenomanian fluvial sandstones, in which hydrocarbon accumulations are housed. In this way, a better understanding of the reservoirs of a part of the field was sought through the integration of geological and geophysical information in the Leapfrog software. Where the gamma rays (GR), density (ROHB) and neutron porosity (NPHI) profiles were used to identify regions of reservoir rocks and sealants or non-reservoir. And the microresistivity profiles (MSFL), to determine the water saturation in the formation, and from that the oil saturation in the respective intervals. Through modeling, it was found that the highest relative oil saturation is accumulated in the upper portion of the sequence, in reservoir R1, where the average is 45%. In reservoir R2, intermediate, the average is 30% and in reservoir R3, in the lower part, 38%. And a total volume of hydrocarbons of the order of 1.17 MM3 was estimated for the three reservoirs. From this integration, despite the stage of production categorizing the field as mature, it appears that there are still significant volumes to be exploited.*

I. INTRODUCTION

Several studies show the application of software for three-dimensional 3D modeling, treatment and interpretation of geophysical geological data from wells. Among the various ways of representing data such as maps and profiles, geological models in three dimensions have become increasingly present and important in decision-making, such as in the mining sector, exploitation of hydrocarbons, among others. In this work, the Leapfrog software was applied in the analysis and modeling of data from geophysical profiles of hydrocarbon producing wells in an earth field in the Potiguar basin (Figure 01).

Like other basins on the equatorial and eastern margins of Brazil, the Potiguar basin had its origin related to the breakup of the supercontinent Gondwana. In this basin, the source rocks and reservoirs are related to the tectonics of the rift and drift phases, which were responsible for its evolution [1] (Matos, R.M.D. 1992).

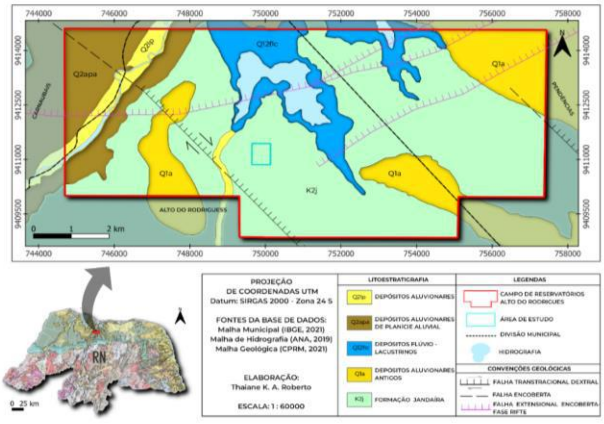


Fig. 1: Geological map and location of the study area.

Oil fields are located along the Carnaubais trend, controlled by the effects of the evolution of this geotectonic segment, which culminated in the implementation of the Potiguar basin (Figure 01). The structure of the field analyzed in this work, which controls the accumulation, configures an asymmetric anticline, defined by the interaction between the layers that dip to the north and the Carnaubais Fault to the south. This structure partly developed from features inherited from the basement [2] (Siqueira, J.B. 2005), which project into the sedimentary filling represented by the Pendência, Alagamar, Açu, Jandaira and Barreiras Formations.

The reservoir rock sequence is composed of sandstones of fluvial origin, and sealing shales of Albian/Cenomanian age. Which belong to Unit 3 of the Açu Formation [3] Conceição et al. (1984) [4] Nolla, F.R. (1992). The source rocks are related to the Alagamar Formation, and the hydrocarbon accumulations are housed in the siliciclastic reservoirs of the Açu Formation.

II. MATERIAL AND METHODS

Currently the representation of data made in a simple and direct way is extremely important in all area of geology, where the 3D models obtained stand out. Successors of block diagrams, and can be classified into two types: explicit and implicit modeling [5] Garcia, L.M. & Gonçalves, I.G. (2021).

Explicit modeling is essentially similar to an engineering drawing process. The modeler defines geological structures such as veins and faults by explicitly drawing them in regularly spaced sections and joining them together. However, geology does not come in boxes, triangles, straight lines or even fancy curves, they are just ways of representing geology on a computer. Implicit modeling is algorithmically generated directly from a combination of measured data and user interpretation. This modeling requires the vision of a geologist, but it is done in the form of trends, stratigraphic sequences and other geologically significant terms [6] Lane, R. (2015). This approach is faster, more flexible and fundamentally better suited for geological modeling.

In figure 2 the two sections look similar, however, the upper explicit section is created by manually joining the contact points, while the lower implicit section is created directly from the geological data. Then, geostatistical methods are used to interpolate the drilling data and thus seek the geological behavior of the solid to be modeled, optimizing the process.

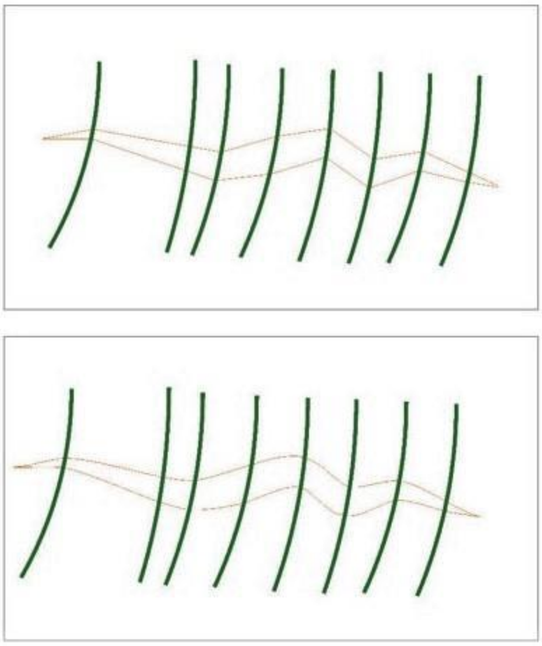


Fig. 02: Upper section generated by manually joining the points. Bottom section generated directly from the data. Source: [6] Lane, R. (2015).

Applying this foundation of implicit modeling, and with the support of the Leapfrog Geo software with Edge extension, this work sought to analyze and associate the physical properties of the lithological types using as input data the information from the geophysical profiles of wells, obtained from the readings every 20.0 cm in the profiling operation.

The modeling was carried out based on four main steps: creation of the topography of the land surface of the study area, import of drilling data (database containing geological and geophysical information of the wells in the study area), creation of intervals (selecting the subdivision of the lithotypes), creating the contact surfaces and generating volumes (Figure 03).

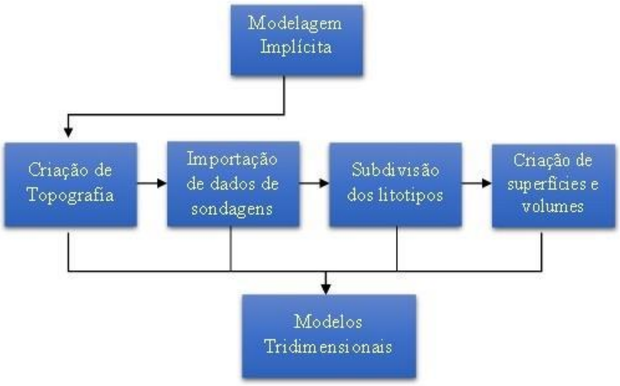


Fig. 03: Flowchart of the modeling steps in Leapfrog.

III. RESULTS

With the information generated in the previous steps that supported the 3D three-dimensional geological model, the numerical modeling step was carried out, which involved a statistical and geostatistical approach as described and illustrated below.

Both reservoir and non-reservoir rocks, whether in the category of seals or intercalations, and other parameters that are duly identified through the profiles, are specialized and analyzed. This understanding is essential, as it provides proper support along with fluid saturation in the numerical modeling stage and obtaining volume estimates. In the case of the subject under analysis, which is hydrocarbons, categorized here as oil. From the steps developed according to the implicit modeling flow of Leapfrog, the 3D geological model of the study area was obtained as a result (Figure 04).

In this model, the profile data obtained in the geophysics of the well, corresponding to the electrofacies (EFAC), which in the input table are represented by the numbers 1, 2, 3 and 4, were regrouped with the label FLAG (0, 1), to separate the intervals of non-reservoir rocks, of the intervals of permoporous reservoir rocks, respectively. Therefore, the data in the table now called FLAG, with their respective attributes, which originated from the electrofacies, are finally used to support numerical modeling in obtaining an estimate of fluid volumes. The final product of the 3D geological modeling is represented by three important reservoir zones (Figure 04).

Here these reservoirs, which are permoporous siliciclastic rocks, from member 3 of the Açu Formation [7] Vasconcelos, E.P. & Lima Neto, F. & Roos, S. (1990), are called reservoirs R1, R2 and R3, from top to bottom. Which are the permoporous rocks, in which hydrocarbon accumulations are lodged. And separated by important seals, called S1, S2 and S3. Which are very low to zero permeability rocks, which are responsible for retaining and maintaining the accumulation of hydrocarbons in the field (Figure 04).

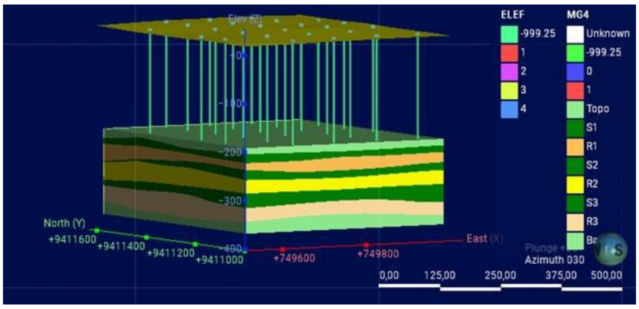
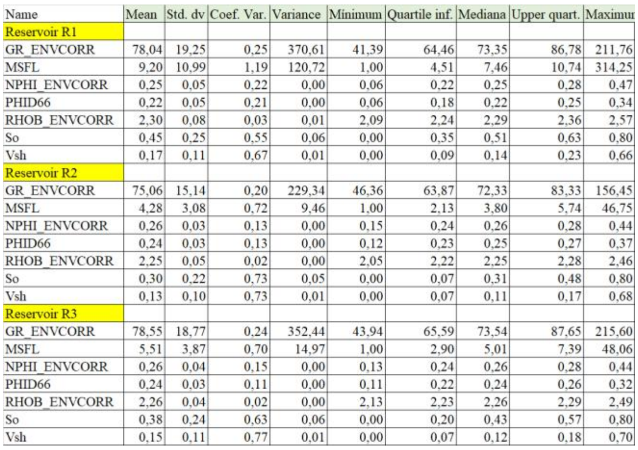


Fig. 04: Geological model (Topography, Electrofacies, Flag, Reservoirs and Seals).

Data statistics and geostatistics

From the 3D geological model, a statistical analysis of the information from the geophysics of the well was carried out, to see the distribution of values in reservoirs R1, R2, R3 and respective oil saturation (So). In this step, with the purpose of relating the information contained in the geophysics profiles of the well with the geology and other properties, the Merged table was combined. According to the statistical analysis, the R1 reservoirs have an average oil saturation (So) of 45%, R2 30% and R3 38%. In addition, in the statistical analysis, the Box plot alternative was explored to verify the relationships between fluid saturations and lithologies that make up reservoirs R1, R2 and R3. Where it appears that the highest relative oil saturation (So) is in the reservoir R1 upper portion, and R3 in the lower portion. And an overlapping of values in the intermediate reservoir R2 (Table 01 and Figure 05).

Table 01: Statistics by reservoir.



Name	Mean	Std. dv	Coef. Var.	Variance	Minimum	Quartile inf.	Mediana	Upper quart.	Maximur
Reservoir R1									
GR_ENVCORR	78,04	19,25	0,25	370,61	41,39	64,46	73,35	86,78	211,76
MSFL	9,20	10,99	1,19	120,72	1,00	4,51	7,46	10,74	314,25
NPHI_ENVCORR	0,25	0,05	0,22	0,00	0,06	0,22	0,25	0,28	0,47
PHID66	0,22	0,05	0,21	0,00	0,06	0,18	0,22	0,25	0,34
RHOB_ENVCORR	2,30	0,08	0,03	0,01	2,09	2,24	2,29	2,36	2,57
So	0,45	0,25	0,55	0,06	0,00	0,35	0,51	0,63	0,80
Vsh	0,17	0,11	0,67	0,01	0,00	0,09	0,14	0,23	0,66
Reservoir R2									
GR_ENVCORR	75,06	15,14	0,20	229,34	46,36	63,87	72,33	83,33	156,45
MSFL	4,28	3,08	0,72	9,46	1,00	2,13	3,80	5,74	46,75
NPHI_ENVCORR	0,26	0,03	0,13	0,00	0,15	0,24	0,26	0,28	0,44
PHID66	0,24	0,03	0,13	0,00	0,12	0,23	0,25	0,27	0,37
RHOB_ENVCORR	2,25	0,05	0,02	0,00	2,05	2,22	2,25	2,28	2,46
So	0,30	0,22	0,73	0,05	0,00	0,07	0,31	0,48	0,80
Vsh	0,13	0,10	0,73	0,01	0,00	0,07	0,11	0,17	0,68
Reservoir R3									
GR_ENVCORR	78,55	18,77	0,24	352,44	43,94	65,59	73,54	87,65	215,60
MSFL	5,51	3,87	0,70	14,97	1,00	2,90	5,01	7,39	48,06
NPHI_ENVCORR	0,26	0,04	0,15	0,00	0,13	0,24	0,26	0,28	0,44
PHID66	0,24	0,03	0,11	0,00	0,11	0,22	0,24	0,26	0,32
RHOB_ENVCORR	2,26	0,04	0,02	0,00	2,13	2,23	2,26	2,29	2,49
So	0,38	0,24	0,63	0,06	0,00	0,20	0,43	0,57	0,80
Vsh	0,15	0,11	0,77	0,01	0,00	0,07	0,12	0,18	0,70

From this verification of the consistency of the data, a careful analysis of the geostatistical parameters was carried out, starting with the search for the appropriate variogram for numerical modeling of the data on the X, Y and Z axes of the search ellipsoid in the estimation of hydrocarbon saturation, here called oil saturation. This procedure was initiated for the reservoirs in the upper zone R1 of the model defined in the geological modeling stage, and a similar routine was applied to the other R2 and R3, from top to bottom, in their specific zones.

Variography of the reservoir R1

It is gathered in the upper region of the field under the denomination R1 reservoir, the sequence of permoporous rocks and respective saturations of hydrocarbons. In this region, we tried to establish the adjustment parameters of the variogram that supported the search ellipsoid in estimating oil saturation in reservoir R1 (Figure 06).

Variography of the reservoir R2

In the middle region of the field, the sequence of permoporous rocks and their hydrocarbon saturation are grouped under the name R2 reservoir. In this region, as in the previous one, an attempt was made to establish the adjustment parameters of the variogram that supported the search ellipsoid in estimating oil saturation in reservoir R2 (Figure 07).

Variography of the reservoir R3

It is gathered in the lower region of the field under the denomination R3 reservoir, the sequence of permoporous rocks and respective hydrocarbon saturations. Figure 08 shows the adjustment parameters of the variogram that supported the search ellipsoid in estimating oil saturation in reservoir R3.

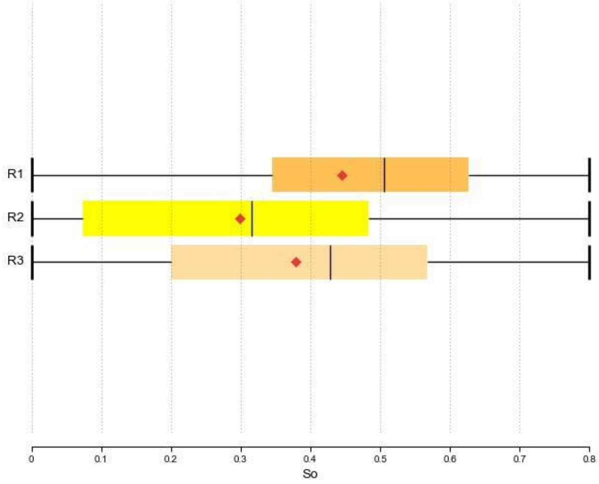


Fig. 05: Distribution of percentage oil saturation (So) in reservoirs R1, R2 and R3.

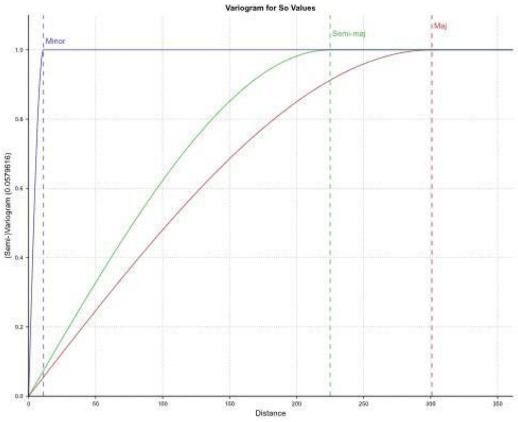
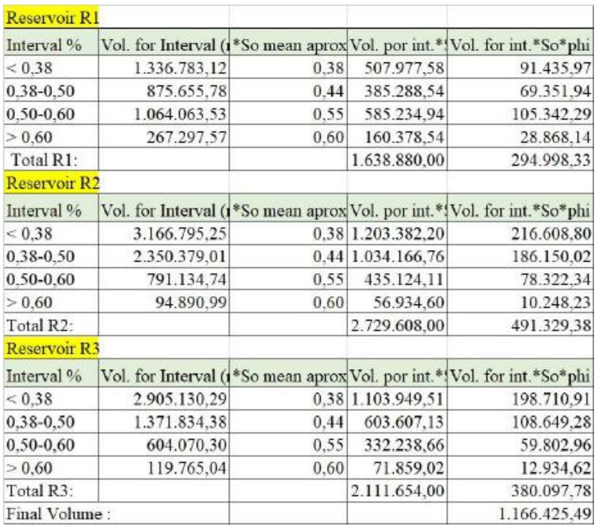


Fig. 06: Parameters and characteristics of the variogram applied to reservoir R1.

Table 02: Estimated volume of the study area by type of reservoir.



Reservoir R1				
Interval %	Vol. for Interval (	*So mean aprox	Vol. por int.*	Vol. for int.*So*phi
< 0,38	1.336.783,12	0,38	507.977,58	91.435,97
0,38-0,50	875.655,78	0,44	385.288,54	69.351,94
0,50-0,60	1.064.063,53	0,55	585.234,94	105.342,29
> 0,60	267.297,57	0,60	160.378,54	28.868,14
Total R1:			1.638.880,00	294.998,33
Reservoir R2				
Interval %	Vol. for Interval (	*So mean aprox	Vol. por int.*	Vol. for int.*So*phi
< 0,38	3.166.795,25	0,38	1.203.382,20	216.608,80
0,38-0,50	2.350.379,01	0,44	1.034.166,76	186.150,02
0,50-0,60	791.134,74	0,55	435.124,11	78.322,34
> 0,60	94.890,99	0,60	56.934,60	10.248,23
Total R2:			2.729.608,00	491.329,38
Reservoir R3				
Interval %	Vol. for Interval (	*So mean aprox	Vol. por int.*	Vol. for int.*So*phi
< 0,38	2.905.130,29	0,38	1.103.949,51	198.710,91
0,38-0,50	1.371.834,38	0,44	603.607,13	108.649,28
0,50-0,60	604.070,30	0,55	332.238,66	59.802,96
> 0,60	119.765,04	0,60	71.859,02	12.934,62
Total R3:			2.111.654,00	380.097,78
Final Volume :				1.166.425,49

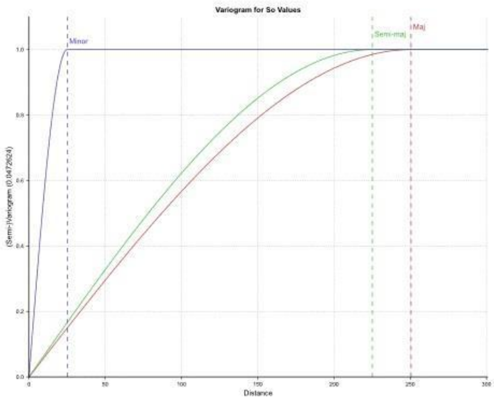


Fig. 07: Parameters and characteristics of the variogram applied to reservoir R2.

Volume estimation

After completing these steps of 3D and numerical geological modeling, considering the fluid saturation at the time the profiles were acquired, hydrocarbon volumes of the order of 0, 29MM3, and respective percentages of saturations per interval.

For reservoir R2 of the intermediate sequence 0.49MM^3, and R3 of the lower sequence 0.38MM^3. And a total volume of hydrocarbons of the order of 1.17MM^3 for the three reservoirs (Table 02).

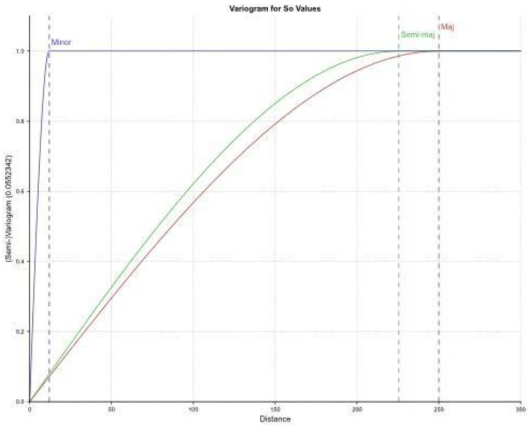


Fig. 08: Parameters and characteristics of the variogram applied to reservoir R3.

IV. CONCLUSION

Based on the observations made, it can be seen that the reservoirs in which the main accumulations of hydrocarbons in the study area are housed are made up of siliciclastic from the Açu Formation, member 3, composed of fluvial sandstones.

The highest relative oil saturations, are accumulated in the upper portion of the sequence, in reservoir R1. Where the average saturation is around 45%. In reservoir R2, intermediate sequence, the average saturation is 30% and in reservoir R3 in the lower part 38%. Through modeling, volumes of hydrocarbons of around 0.29 MM^3 were estimated for reservoir R1, for reservoir R2 0.49 MM^3 and for reservoir R3 0.38 MM^3. And a total hydrocarbon volume of around 1.17MM^3 for the three reservoirs.

Due to the current stage of exploitation, this area is part of a field classified as mature. Therefore, a way to optimize the use of these resources is through a better understanding of the reservoirs, as shown in this research, to verify the regions to be drained, and with that optimize the exploitation of the hydrocarbons that still exist.

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REFERENCES

[1] Matos, R.M.D. (1992). The Northeast Brazilian System. Tectonics, 2(4), 766-791.

[2] Siqueira, J. B. (2005). A falha de carnaubais e o controle do Campo de Alto do Rodrigues In: X SNET IV ISIT, Curitiba. Anais…, São Paulo: SBG. V1, 87-89.

[3] Conceição, L.A.Z., Barrocas, S.L., Silva, E.J.B., Gusso, G.L.N., Santos, M.A.A., Souza, M.S., Silva, M.L.F., Ballin, P.R., Camoleze, Z. Projeto Alto do Rodrigues. (1984). PETROBRAS/DEBAR/CENPES. (Relatório Interno).

[4] Nolla, F.R. (1992). Atualização do estudo dos arenitos reservatórios da unidade 3 da Formação Açu, Campo de Alto do Rodrigues, Bacia Potiguar Emersa. Natal: PETROBRAS/DEBAR/SELAG. Nota técnica 001/92, (Relatório Interno).

[5] Garcia, L. M. & Gonçalves, I. G. (2021). Implementação da modelagem implícita na graduação. In: Anais do 13º Salão Internacional de Ensino, Pesquisa e Extensão da UNIPAMPA, 13(1).

[6] Lane, R. (2015). Why Implicit Modelling. In: SEEQUENT/BENTLEY. Available in https://www.seequent.com/why-implicit-modelling. Accessed on: January 2022.

[7] Vasconcelos, E.P. & Lima Neto, F. & Roos, S. (1990). Unidades de correlação da Formação Açu-Bacia Potiguar. In: 36 Congresso Brasileiro de Geologia, Natal, Anais..., São Paulo: SBG. V1, 227-240.