

Facies Simulation Model Construction Implementing Lithological Logging For The Sacha Field Formations

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Abstract

This project will evaluate data from 10 wells of the Sacha field, which contain wellheads, facies logs, electric logs, tops and bases of formations and additional information, which will be attached and integrated into Openworks software to create a database and work in individual sessions in Decision Space Geoscience. From this program, the field data will be interpreted by geological analysis, and vertical relationship curves and the geostatistical grid of the field will be built. Furthermore, the variographic study will be carried out to obtain the real trend of each geological stratum. Several facies models will be reproduced using two different types of simulation algorithms, the sequential simulation algorithm of indicators and the plurigaussian simulation algorithm, with the results of these models, The development of the study proceeded to evaluate each of the formations to verify which of these algorithms reproduced the reservoir in a better way and the zones where there are no wells will be evaluated to find new possible locations where there are good quality clean sands to find hydrocarbons.

I. INTRODUCTION

Most of the country's existing hydrocarbon reservoirs are at a mature stage due to the exploitation of the fields several years ago. Therefore, the characterization of these reservoirs constitutes an advance in the search for new well locations to maintain production quotas.

Electrical logs, facies maps or structural maps of the producing formations of the field allow the generation of three-dimensional models of stratigraphic facies to have a clearer view of how they are distributed throughout the region, for this specialized software is used in the field, the simulation allows building high definition models using interpolation algorithms such as the Plurigaussian simulation algorithm (PS) or the sequential indicator simulation algorithm (SIS).

To perform the simulation, the process includes 4 stages: quality control of available data (data from 10 wells corresponding to the Sacha field region will be used), lithological interpretation of field data (using logs such as Gamma Ray or Spontaneous Potential to obtain clay volume), data input to simulation software (well coordinates, facies codes, structural maps, tops and bases of formations) and finally lithological modeling of all producing formations (using a sequential indicator and plurigaussian algorithms).

II. METHODOLOGY

A. Simulation methods

In order to carry out a good simulation project within an oil reservoir, it is necessary to develop a method that is the most convenient to define its properties correctly. The best-known simulation methods are:

- Cell-based simulation
- Object-based simulation
- Multipoint - Training image

The cell-based simulation methodology will be used for the present study, which is explained below.

B. Cell-based simulation

The cell-based simulation methodology is a technique in which the reservoir can be divided into multiple cells as considered; within each cell, the properties they contain will be homogeneous, and better-detailed information can be obtained if much finer cells are defined, interpolation methods of the whole information available are used [1].

Static and dynamic information, multivariate spatial relationships or multiple attributes are techniques limited by the univariate and bivariate way reservoir properties are distributed.

The main limitation of this type of method is that all reservoir properties are described as cell structures, which is not entirely true since reservoirs have complex shapes and sizes and certain geological objects. This methodology facilitates the simulation of continuous variables, for example, porosity, water saturation, clay volume, permeability, etc., and of categorical variables, for example, facies, electrifies, lithotypes, etc. A cell-based simulation is visualized in Figure 1 [1].

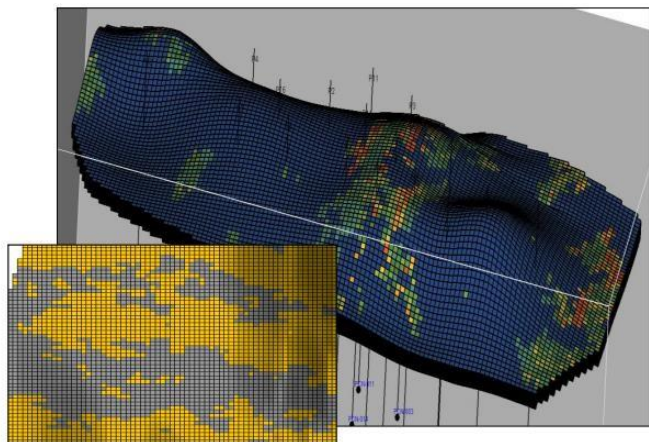


Fig.1 Cell-based simulation Source: Ganan J. (2014)

C. Definition of the facies model

The geostatistical facies model is constructed on the grid using information from variograms, the depositional field environment and vertical ratio curves. Since the simulations must be stochastic, a certain number of facies modeling runs must be chosen, called realizations. Simulation software generally presents two algorithms to generate the facies model, which are explained below:

D. Sequential Simulation Model Indicator

The indicator sequential simulation algorithm using the interpolation method known as kriging is very efficient since it allows for predicting the local probability distribution function. This estimator needs the variogram models in each stratigraphic unit, or the

cut-off variogram obtained corresponding to the median, although this alternative is less accurate [2]. Figure 2 shows 3D (left) and 2D (right) reproductions of a porous stratum simulated by the sequential indicator algorithm.

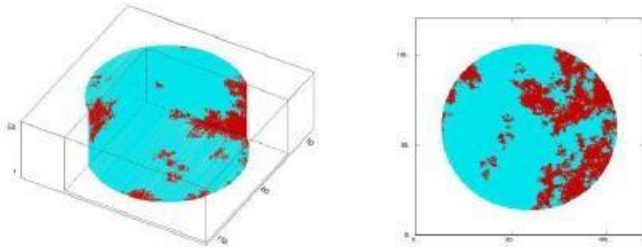


Fig. 2 2D and 3D view of a simulation with the sequential indicator algorithm Source: Diaz & Casar (2004)

E. Plurigaussian Simulation Model

The multi-Gaussian simulation algorithm is considered a generalization of the truncated Gaussian simulation method because several truncations of several random functions $Y(x)$ must be defined at the same time:

$$I(x; y_1, y_2) = \begin{cases} 1 & \text{si } y_1(x) < y_1 \\ 2 & \text{si } y_1(x) \geq y_1 \text{ e } y_2(x) < y_2 \\ 3 & \text{si } y_1(x) \geq y_1 \text{ e } y_2(x) \geq y_2 \end{cases}$$

The simulation methodology is very important due to the influence that the calculation of variograms has on this type of Gaussian variables. Figure 3 shows how the model realizations vary depending on the calculated variograms approaching the origin. On the left side is shown a reproduction of a parabolic variogram at the origin, while on the right side is presented the reproduction of a linear variogram at the origin [3].

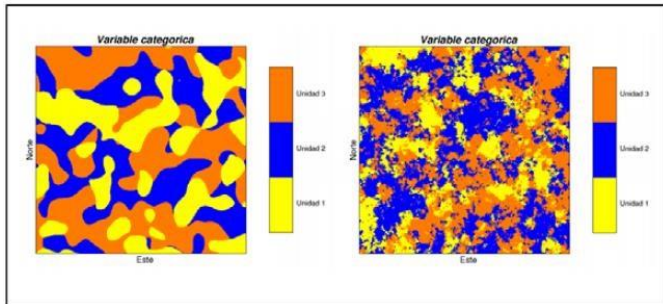


Fig. 3 Influence of the variograms on the plurigaussian algorithm Source: Hurtado S. (2009)

In order to generate plurigaussian simulation models, the following main steps must be followed:

- Interpret the data of the parameters to be modeled (calculation of variograms of Gaussians and thresholds).
- Simulation at sampling locations of Gaussian random functions.
- Simulation in the rest of the space of Gaussian random functions using the rotating bands methodology or the sequential Gaussian method.
- Define truncation flags [3].

It is necessary to define certain parameters for the construction of the Plurigaussian model, which are as follows:

The truncation flag which directly influences between geologic strata contacts and their hierarchies.

The thresholds since they have an impact on the fractions of space occupied by all existing geological strata. The calculation of variograms of Gaussians because they affect the variogram indicator for each lithological stratum [3].

Figure 4 shows how truncation flags are defined for each lithological stratum in the reservoirs:

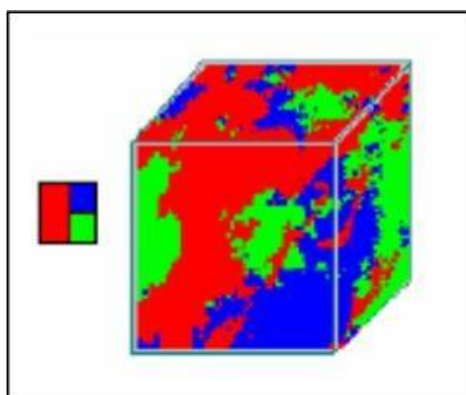


Fig. 4 Definition of truncation flags in the plurigaussian algorithm Source: Hurtado S. (2009).

III. MODELING DEVELOPMENT

A. Analysis of available information

The information available for the preparation of this project must undergo the necessary quality control to corroborate the veracity of the data and thus reduce the level of uncertainty of the results as much as possible.

- The data correspond to 10 wells in the Sacha field of the Ecuadorian Amazon district, which, for reasons of confidentiality of the information, will be described in a synthetic way (with other names and coordinates, but with the same logs and formational tops); thus the information provided contains:
 - Wellheaders: in .xlsx format (4 kb)
 - Training caps: in .xlsx format (23kb)
 - Lithofacies record: in .LAS format (6.6 Mb)
 - Electrical records: in .LAS format (18.6 Mb)
 - Additional information: in .docx format (15.5 Mb)

B. Data collection in the software

The first step after verifying all the information is to create the database for the project; the Openworks platform is used to generate a new project which will manage all the information generated in the Decision Space, parameters such as the project name, the range of coordinates of the field or region to be evaluated, the size of the project, etc. are specified.

C. Up of wells

Data for the 10 wells were loaded using the Decision Space "Well Data Manage" tool. The nomenclature of the wells is explained in Table 1 where data such as X, Y coordinates, rotary table elevation and true vertical depth are presented.

TABLE I INPUT DATA FOR CREATING WELLHEADERS

UWI	WELL NAME	X	Y	KB	TVD
001	WELL001	909959,72	32713350,71	1077	10180

002	POZO002	912133,77	32714498,08	1063	9800
003	POZO003	912485,41	32711520,79	1045	9900
004	POZO004	912584,46	32717486,36	1037	9920
005	POZO005	909328,98	32710644,12	961	9820
006	POZO006	910058,08	32715596,15	1081	9965
007	POZO007	909507,10	32707955,74	935	9796
008	POZO008	909467,60	32706038,98	943	9827
009	POZO009	910218,15	32717489,22	1027	10039
010	POZO010	911130,92	32709695,07	1060	10030

In addition, Figure 5 shows a DSG visualization of the good data entered in a three-dimensional cube on the left and a two-dimensional map on the right.

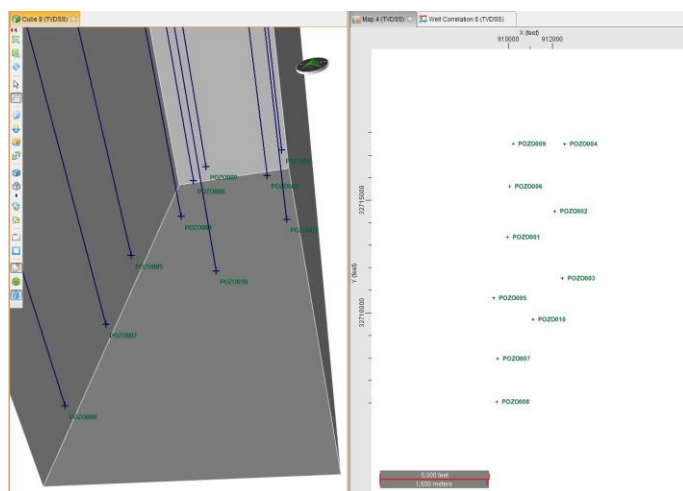


Fig. 5 General view of well locations
Source: DSG Software

D. Facies record uploading

The sedimentary facies of each well were loaded through the “Data Import” tool of the Openworks software; the view of a facies log through the “Well Correlation” window of the DSG where color has been assigned for each sedimentary facies in each well.

E. Raising of electrical registers

The electrical well logs and facies logs are uploaded through the “Data Import” tool of Openworks. In this case, since not all the logs will be used, only the Gamma Ray (GR), Resistivity (RM), Porosity (PHI) and water saturation (Sw) logs were uploaded to the project, mainly to facilitate the interpretation of the data in the areas of interest.

F. Determination of training caps

Formational tops were located well by well in the “Well Correlation” window using the “Well Pick Interpretatio” tool; for each top and base, a color was designated, the respective nomenclature and depth, which are explained in table 2, in this case, the example is shown for two wells (POZO001 and POZO002).

TABLE II DATA ON FORMATION BUFFERS

WELL	TOPE	DEPTH	COLOR
WELL001	Tope_Basal_Tena	8666	

WELL001	Base_Basal Tena	8680.94	
WELL001	Upper_U_Stop	9346.2	
WELL001	Lower_U_Stop	9388	
WELL001	Lower_U_Base	9433.29	
WELL001	Top_T_T_Stop	9589	
WELL001	Lower_T_T_Stop	9634	
WELL001	Base_T_Bottom	9688.65	
WELL001	Top_Hollin_Top	9770.11	
WELL001	Bottom_Hollin_Stopper	9781	
WELL001	Base_Hollin_Bottom	9815.44	
POZO002	Tope_Basal_Tena	8662.44	
POZO002	Base_Basal Tena	8695.83	
POZO002	Upper_U_Stop	9336.41	
POZO002	Lower_U_Stop	9378	
POZO002	Lower_U_Base	9423.18	
POZO002	Top_T_T_Stop	9576.23	
POZO002	Lower_T_T_Stop	9619	
POZO002	Base_T_Bottom	9677.87	
POZO002	Top_Hollin_Top	9762	
POZO002	Bottom_Hollin_Stopper	9770.76	
POZO002	Base_Hollin_Bottom	9814.35	

Figure 6 shows a view of all formation tops in a “Well Correlation” view on the left and a 3D cube on the right.

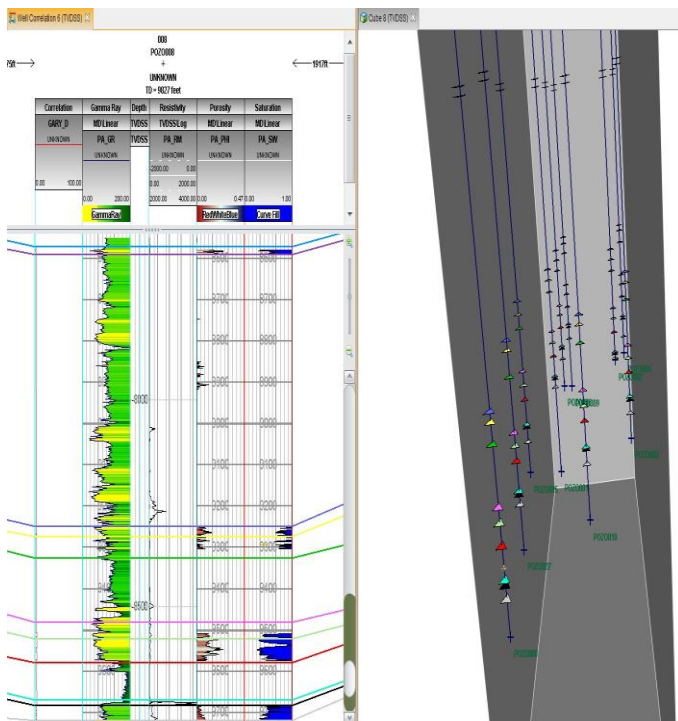


Fig. 7 Lithological correlation of wells Source: DSG software

H. Stratigraphic correlation of the field

Figure 7 shows the lithological correlation of the 10 wells in the evaluated field, showing the logs described above and the tops and bottoms of each geological formation, thus providing a more detailed view of the formations to be modeled.

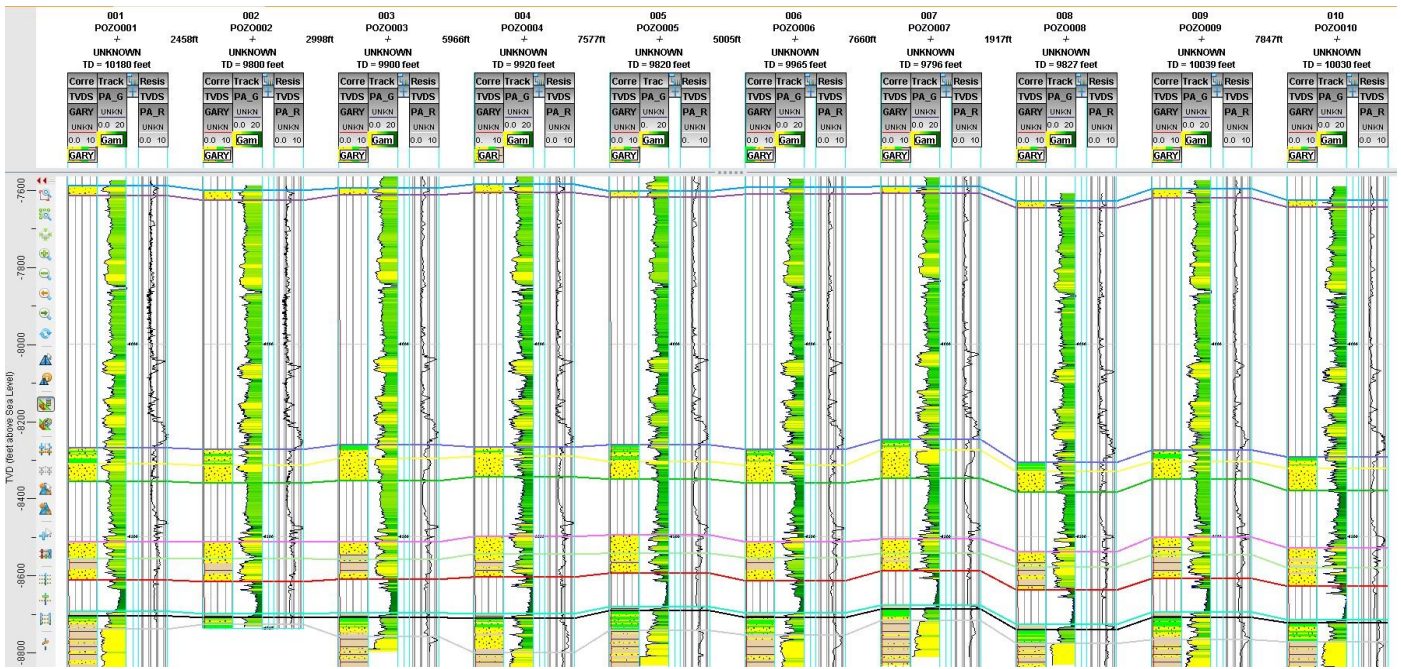


Fig. 7 Lithological correlation of wells Source: DSG software

I. Field surfaces

The polygon of the region in which the facies models are to be generated was constructed with the tool Surfaces or horizons are created from the top part of “Polygons and Centerlines” of the DSG considering an existing formational region using the tool “Grid and Contour” in which all the wells are integrated as shown. Once the surfaces are created and integrated into a polygon in Figure 9. The polygon will allow concentrating the analysis in “frame,” which will be useful when generating the grid, the region within the yellow box, which was created for each of the existing tops and bases. The surface for the Tope Basal Tena formation, and its respective depth scale, this procedure was performed with geostatistics. Figure 8 shows an example of how the area of interest will be named.

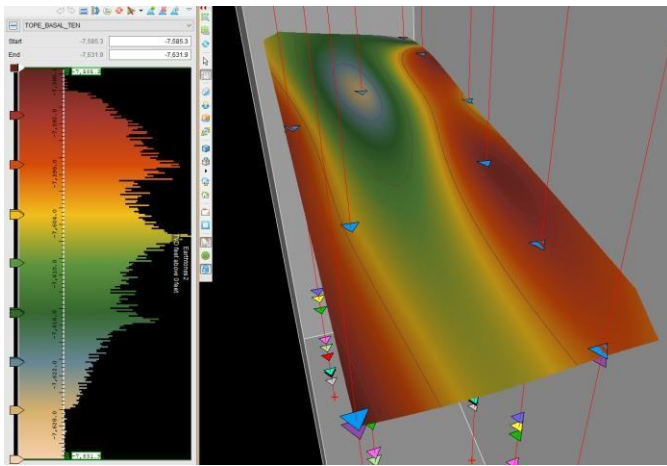


Fig. 8 Surface of Basal Top Tena
Source: DSG Software

J. Construction of the polygon

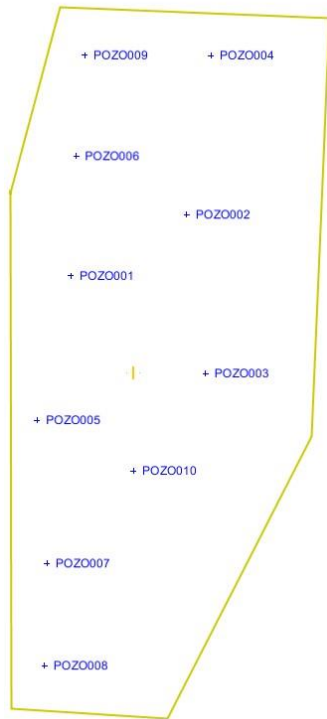


Fig. 9 Area of the field polygon
Source: DSG Software

K. Grid construction

The geostatistical grid was constructed considering that the region to be evaluated covers all the wells, so an analysis of the variograms in all directions can be carried out. In order to build it, the constructed framework and the polygon are taken into consideration, that is, all the surfaces of the field which allow obtaining the sand intervals, which are detailed in Table 3.

TABLE III GEOSTATISTICAL GRID INTERVALS

Interv	Layer style	# Layers	Thickness	Surface stop	Surface base	Average thickness
1	Proportional	41	0.502	Basal Cap Tena	Basis Basis Tena	20.596
2	Proportional	1	649.511	Basis Basis Tena	Upper U Stop	649.511
3	Proportional	33	0.997	Upper U Stop	U Stop Inferior	32.903
4	Proportional	110	0.502	U Stop Inferior	Base U Inferior	55.187
5	Proportional	1	152.869	Base U Inferior	Upper T Stop	152.869
6	Proportional	45	1.004	Upper T Stop	T stop Inferior	45.177
7	Proportional	104	0.503	T stop Inferior	Base T Inferior	52.287
8	Proportional	1	86.745	Base T Inferior	Stop Soot Superior	86.745
9	Proportional	10	1.082	Stop Soot Superior	Stop Soot Inferior	10.823
10	Proportional	82	0.512	Stop Soot Inferior	Base Soot Inferior	41.99

Thus, as detailed in Table 3, a total of 10 intervals were obtained, where intervals 1, 3, 4, 6, 7, 9 and 10 are considered. Interval 1 represents the Basal Tena formation; interval 3 corresponds to the Upper U formation, interval 4 to the Lower U formation, interval 6 to the Upper T sand, interval 7 to the Lower T sand, interval 9 to the Upper Soot formation and interval 10 to the Lower Soot sand.

Intervals 2, 5 and 8 will not be considered for facies modeling; therefore, their properties will not be described because they do not correspond to sands of interest.

In addition, Table 3 details parameters such as the number of layers in each interval, the thickness of the layers, the tops and bottoms of each interval and the average thickness of each formation.

Other parameters necessary for constructing the geostatistical grid must also be specified, such as cell origin coordinates, cell size and the number of cells; these data are shown in Table 4.

TABLE IV CELLS OF THE GEOSTATISTICAL GRID

	X (Feet)	Y (Feet)
Origin	908,513.062	32,705,182
Cell size		
Number of cells	46	

With all this information, it is possible to reproduce the geostatistical grid which consisted of 2'520,064 cells distributed in 46 cells in the X coordinate, 128 cells in the Y coordinate and 428 cells with respect to the vertical direction, figure 10 shows the constructed grid visualized in a three-dimensional cube which will be used for the generation of the proposed models.

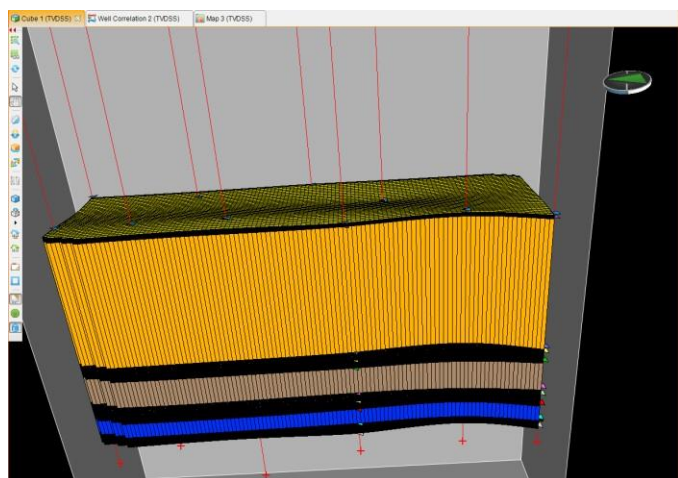


Fig. 10 . Three-dimensional view of the geostatistical grid of the field
Source DSG software

Definition of lithotypes

The geological study of the evaluated region identified as a result of 20 rock classes which were classified according to their characteristics and quality as reservoir rock. In total, the different types of rocks were divided into 4 lithotypes described in Table 5 where a code and a different color identify each one.

TABLE V LITHOTYPE CODE DATA

Lithotype Code	Name	Color
1	Fine Sand	Yellow
	Arena Media	Green
	Glaucanite	Light Green
	Lutite	Grey

A quick statistical analysis was performed with the lithotype information considering the totality of the facies records for each formation or interval; in Figure 11, a scale between the intervals vs. the percentage of each existing lithotype as previously configured is observed, in them, it is observed that those with better sand quality are intervals 1, 4, 6 and 7 corresponding to the Basal Tena, Lower U, Upper T and Lower T sands respectively.

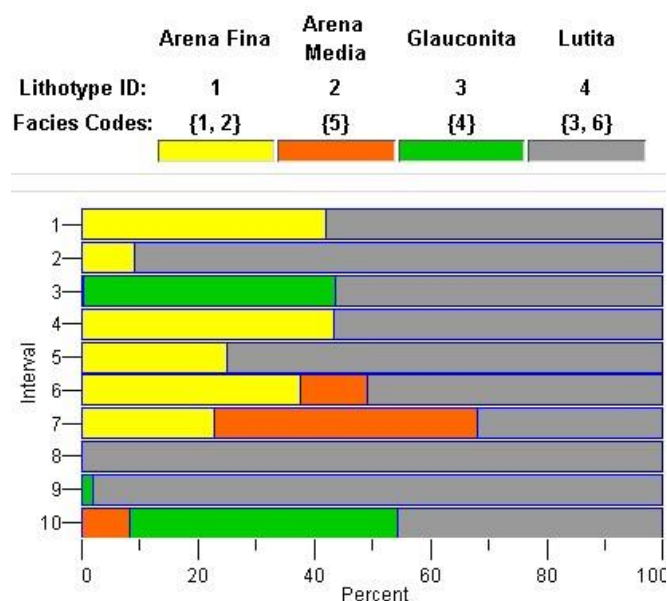


Fig. 11 Interval scale vs. percentage of each lithotype.

Source: DSG Software

M. Vertical proportion curves

The vertical proportion curves (VPC) of the formations were generated using the facies logs and the scaled information obtained from the coding of the lithotypes; the following figures show the representation of each VPC in-depth scale; in Figure 12, the Basal Tena formation contains the lithotypes of fine sand in great proportion and shale.

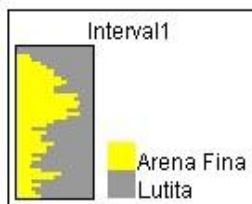


Fig. 12 CPV of the Basal Tena Formation

Source: DSG Software

Interval 3, corresponding to the Upper U sandstone, is shown in Figure 13, and it shows two different lithologies, glauconite and shale, distributed throughout the region.

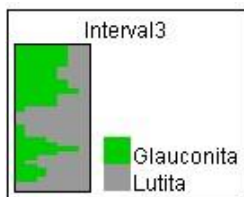


Fig. 13 CPV of the Upper U formation

Source: DSG Software

Interval 4 or Lower U sand, shows a large proportion of sand in the upper part of the graph, as shown in Figure 14, while the lower part shows a greater presence of shale.

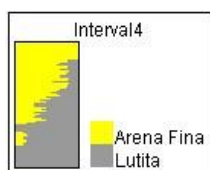


Fig. 14 CPV of the Lower U Formation

Source: DSG Software

For the Upper T sand or interval 6, 3 different lithotypes were obtained, showing a high percentage of fine sand, shale and medium sand, to a lesser extent, as shown in Figure 15.

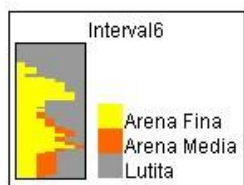


Fig. 15 CPV of the Upper T formation

Source: DSG Software

In interval 7 or lower T sand, 3 lithotypes were obtained as in interval 6; in this case, there is a higher proportion of medium sand in the upper part, a higher percentage of fine sand in the lower part and shale in a lower percentage as shown in Figure 16.

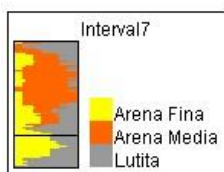


Fig. 16 CPV of the Lower T Formation
Source: DSG Software

In the Upper Soot formation or interval 9, Figure 17 shows the very little percentage of glauconite in the lower part, while almost entirely shale is shown.

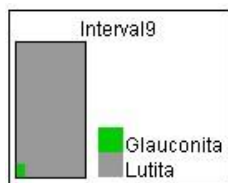


Fig. 17 CPV of the Upper Soot Formation
Source: DSG Software

Interval 10 or Lower Soot sand has a large percentage of glauconite, as shown in Figure 18, plus a small proportion of medium sand in the lower part and shale also in a large proportion.

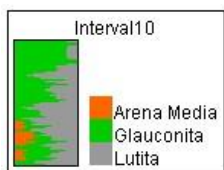


Fig. 18 CPV of the Lower Soot Formation
Source: DSG Software

N. Calculation of variograms

The variogram study is performed for each interval to be modeled, where the vertical variogram and the calculation of variograms in the directions of 0°, 45°, 90° and 135° are taken into consideration. In addition, parameters such as lag, lag tolerance, angular tolerance, bandwidth, and variogram model are specified so that by adjusting these parameters, the best possible variogram is obtained to obtain the ranges that allow the construction of the anisotropy ellipses.

Ñ. Construction of the anisotropy ellipses

The anisotropic ellipses were constructed using the Microsoft Excel platform with the information on all the ranges obtained from the variographic analysis. Figure 19 shows the ellipses obtained from each stratigraphic formation.



Fig. 19 Ellipses of anisotropy of the stratigraphic units
Source: Microsoft Excel Software

IV. RESULTS OBTAINED

A. Construction of the facies model

To generate the facies models, the “Facies Modeling and Simulation” tool is used; from this window, you can choose the type of algorithm to be used for modeling, condition the models to be created with the calculated variograms, reproduce several realizations, model by intervals, etc.

For the present project, the models will be generated using the sequential indicator simulation algorithms and the plurigaussian simulation algorithm to observe how each reproduces the reservoir in the different stratigraphic formations.

B. Construction of the facies model with SIS algorithm.

The facies model with the Sequential Indicator Simulation (SIS) algorithm takes into account the results of the variograms for each interval of interest, also conditions them with the vertical ratio curves and allows to choose a certain number of realizations, which in this case 20 were chosen.

Figures 20 and 21 show two examples of the results obtained for each geological formation evaluated, 10 random realizations were placed to observe how each one shows a different distribution of the lithotypes but without losing the stratigraphic sequence, the shot was chosen at different layer thicknesses.

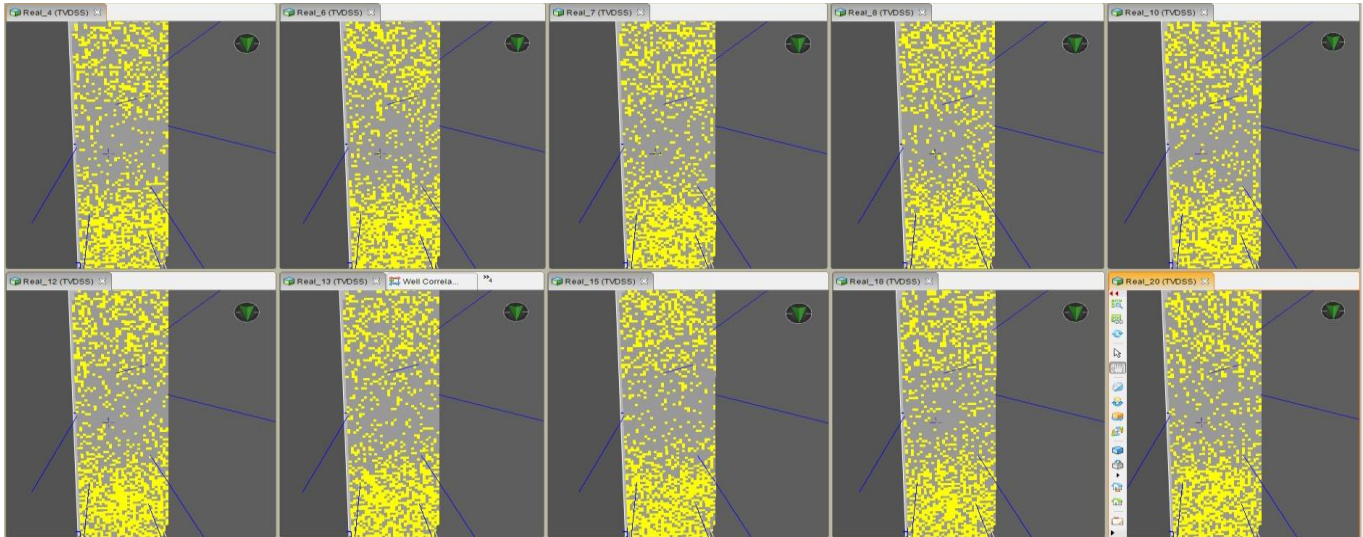


Fig. 20 Facies Model - SIS Algorithm - Tena Basal Sand - Layer
Source: DSG Software

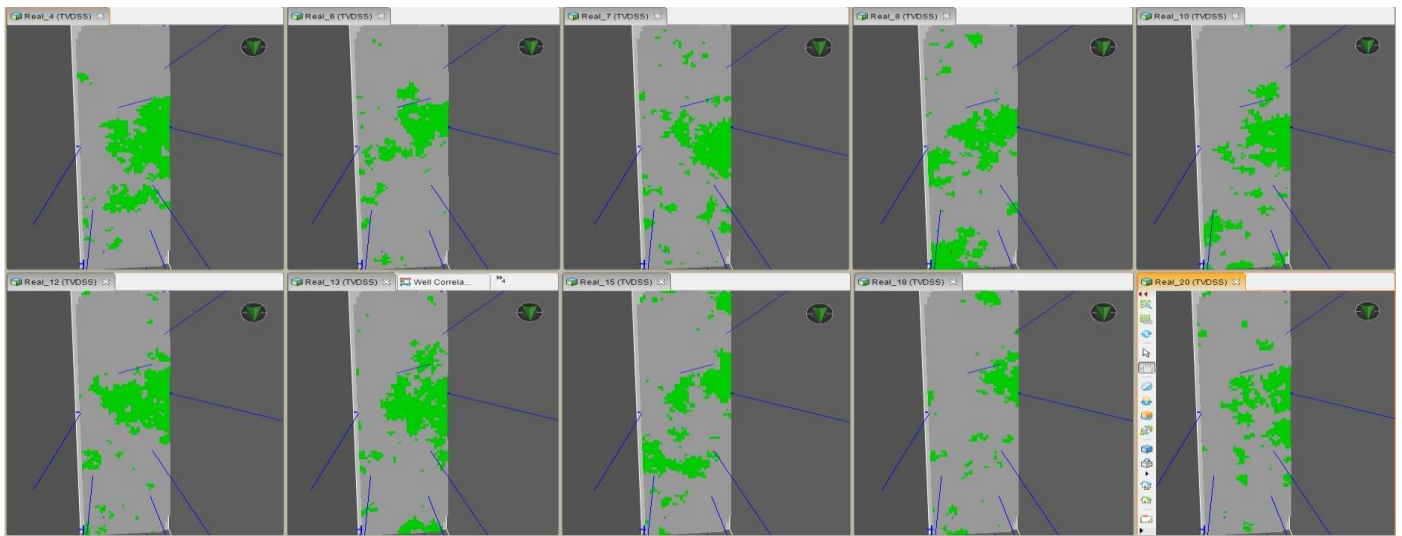


Fig. 21 Facies Model - SIS Algorithm - Upper U Sand - Layer 57 Source: DSG Software

C. Construction of the facies model with PS algorithm.

To build the facies models using the Plurigaussian Simulation (PS) algorithm, the calculation of variograms of each interval to be modeled is taken into account, the depositional environment of each stratigraphic formation is specified, the truncation flags of each lithotype are defined and the number of realizations is chosen, which like the previous algorithm was chosen to be 20.

Figures 22 AND 23 visualize 10 realizations of the facies model using the plurigaussian simulation algorithm at the same layer scale used for the sequential indicator algorithm in two stratigraphic formation examples.

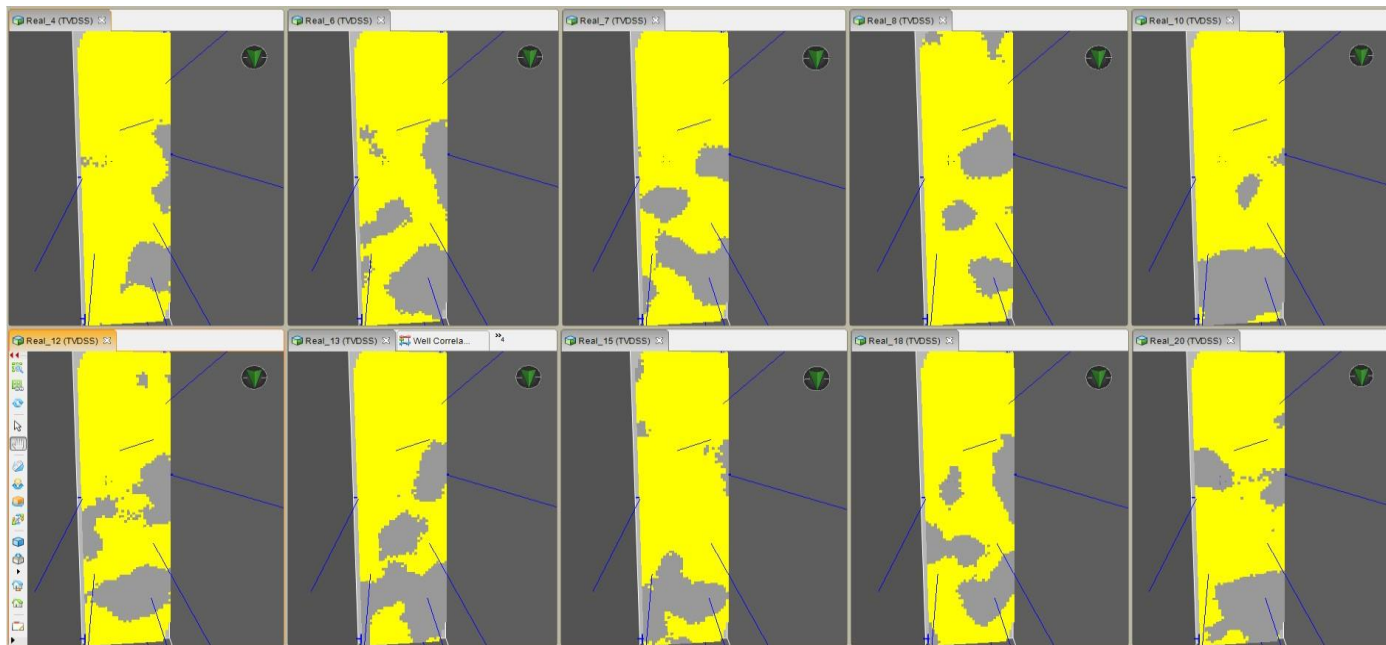


Fig. 22 Facies Model - PS Algorithm - Lower U Sand - Layer 98
Source: DSG Software

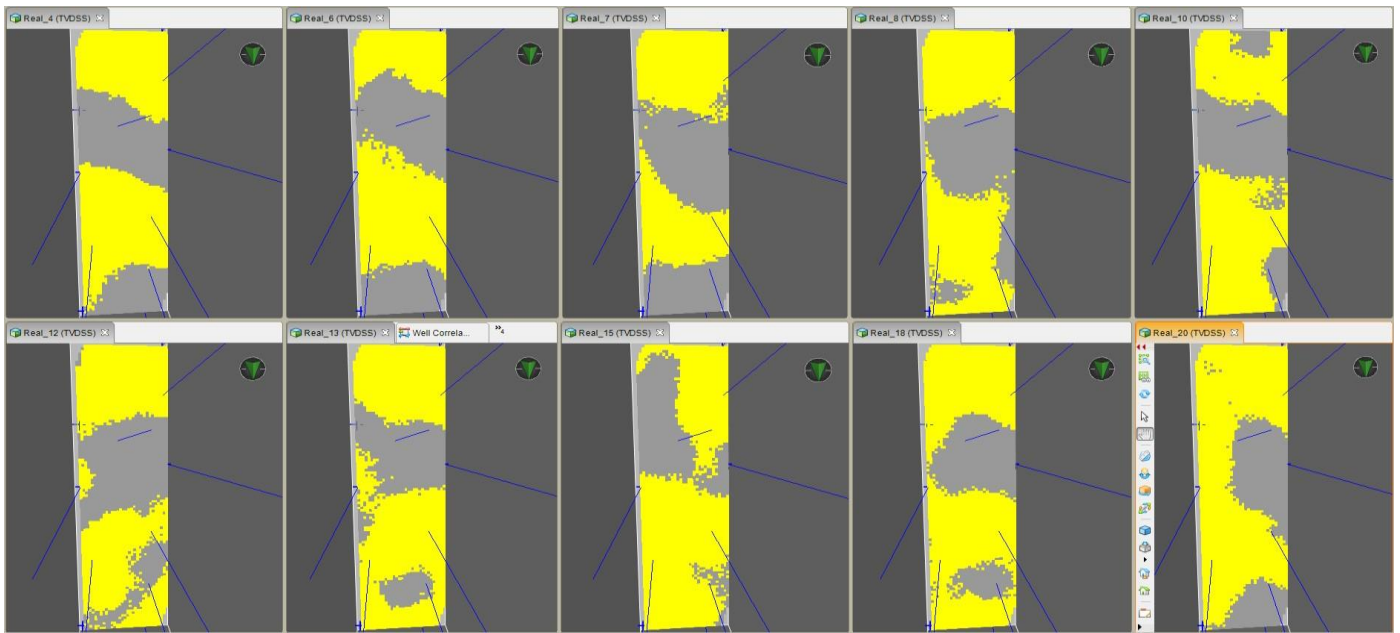


Fig. 23 Facies Model - PS Algorithm - Upper T Sand - Layer 199 Source: SG software

D. Analysis of results

According to the results, the model that best defined lithologic facies was the algorithm, since it groups of lithotypes in the different units in a better way.

Figures 24,25 and 26 show some of the differences of the lithotypes using both algorithms of simulation in Lower U, Lower T and Soot formations inferiors respectively.

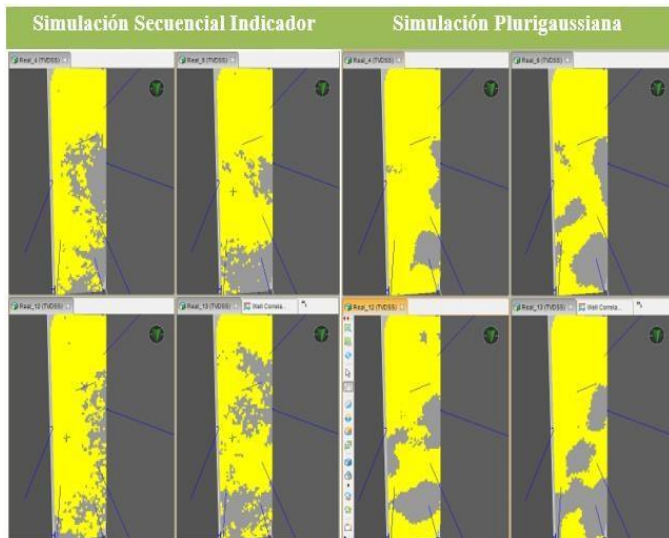


Fig. 24 Difference between SIS (left) and PS algorithms (right) Area Lower U

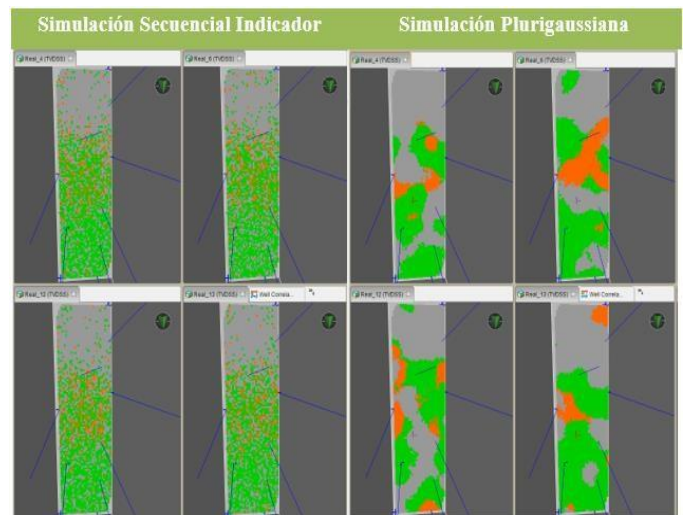


Fig. 26 Difference between SIS (left) and PS algorithms
Hollín Inferior
Fuente: Software DSG

The analysis of the geologic bodies that were performed interpreting facies records and facies models. The results obtained allowed to identify 3 areas where the proportion of sand find a in several of the formations stratigraphic, which may be an indication of zones productive areas where new wells could be drilled.

Table VI show the coordinates of the locations of possible wells.

Source: DSG Software

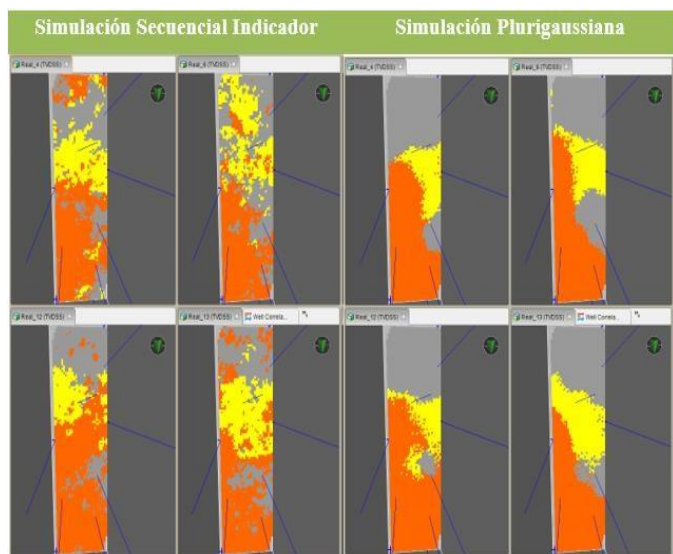


Fig. 25 Difference between the SIS (left) and PS (right) algorithms Lower T Sand. Source: DSG Software

TABLA VI
COORDENADAS DE POSIBLES NUEVOS POZOS

WELL	X-Coordinate	Y coordinate
POZO011	911760.39	32708154.06
POZO012	910716.38	32711966.28
POZO013	912453.40	32715810.13

In addition, Figure 27 shows the location of these potential new wells on a two-dimensional map.

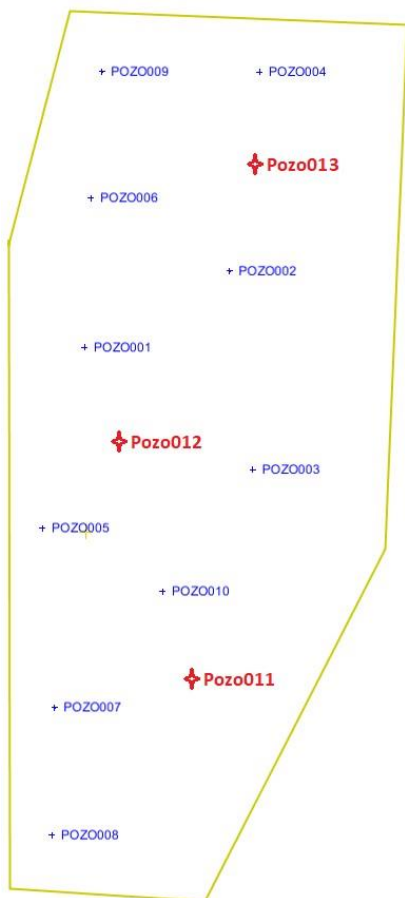


Fig. 27 2D map view of potential new well locations **Source:** DSG software

CONCLUSIONS

The analysis of the lithological information from the field allowed obtaining 20 different rock types present in all the evaluated formations, which due to their characteristics, were reduced to 4 geological bodies or lithotypes according to similarities in their characteristics, are fine sand, medium sand, glauconite and shale.

The surfaces or structural horizons of the field were created from the tops and bases of the existing formations in order to obtain the sand intervals that separate each formation or stratigraphic unit.

The field's geostatistical grid was constructed considering a reasonable number of cells to avoid losing or distorting the existing information. Thus the grid consisted of 2'520,064 cells distributed in 46 cells in the X coordinate, 128 cells in the Y coordinate and 428 cells for the vertical direction.

Vertical proportion curves were constructed for the interpretation of the distribution of the lithotypes in the 7 intervals of interest generated by the geostatistical grid; thanks to this analysis, it was taken into account that the intervals of greatest interest are the Basal Tena Sand, Lower U Sand, Upper T Sand and Lower T Sand.

Twenty realizations were reproduced using two facies simulation algorithms, the Sequential Indicator Simulation (SIS) algorithm and the Plurigaussian Simulation (PS) algorithm, for each of which the created variograms and vertical ratio curves were conditioned in the SIS algorithm and the depositional environments for the PS algorithm.

The analysis of each modeled formation verifying all the realizations allows us to conclude that the model that best reproduced the facies was the Plurigaussian Simulation algorithm since it demonstrates the grouping of the lithotypes in a better-defined way.

The study and interpretation of the facies logs and the constructed models allowed the identification of three possible new zones for drilling wells, as shown in Table 6.

ACKNOWLEDGMENT

Thanks to...

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