Multiple-Point Simulation Applied to Uncertainty Analysis of Reservoirs Related to High Sinuosity Fluvial Systems: Mina El Carmen Formation, San Jorge Gulf Basin, Argentina*

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Abstract

A comparative study of several stochastic simulation methods was performed in the reservoirs of the Upper Cretaceous Mina El Carmen Formation, in Diadema Field, located in the north flank San Jorge Gulf basin, Argentina. The reservoirs belong to a meandering fluvial system showing high variability in thickness, channel width (less than well separation distance) and sinuosity parameters. The study compared the results of 30 realizations using Sequential Gaussian Simulation, Sequential Indicator Simulation, Object-Based and Multiple-point Sequential simulations (MPS) performed over the same facies data. The channel probability three-dimensional models derived from the simulations show a better and more realistic response of multiple-point methods over the previously widely used simulation methods. The SNESIM algorithm was selected from the MPS methods available to simulate channel-flood plain facies. The model used to guide the MPS simulation was built using a current high-sinuosity fluvial system, the Sanboronbom River, located in Buenos Aires province, Argentina. The training model was built by digitizing fluvial facies using satellite imagery and converted to ASCII format to be used in the SGems public software. The authors believe that the Cretaceous Mina El Carmen Formation was deposited in a low slope environment similar to the river used in the training model. After the realizations, the MPS probability model shows channels with high sinuosity, variable width, direction changes and different sizes on the same stratigraphic level. These shapes were impossible to reproduce with the other simulation methods mentioned above. Moreover, a good appraisal of a five-well forecast was made using the MPS probability model. It is concluded that the multiple-point method is most appropriate to estimate the uncertainty of high sinuosity fluvial systems with channel width less then 300 m in average, like the Mina El Carmen Formation channels.

Introduction

Diadema field is located on the north flank of San Jorge Gulf Basin, Patagonia region, southern Argentina. The field has produced since 1920 from the Upper Cretaceous El Trebol, Comodoro Rivadavia and Mina El Carmen formations. The uppermost formations (El Trebol and Comodoro Rivadavia) are currently producing by secondary and tertiary recovery.

The main reserves of the field are in the meandering fluvial system beds of the Mina El Carmen Formation. From 1,500 wells drilled in the field, only 230 wells reached the Mina El Carmen Formation (Figure 1). The purpose of the study is to evaluate the probability of intersecting channels in new appraisal wells to be drilled.

Data Features

Well data present several characteristics, which make modeling jobs particularly difficult. Distribution of data-point control is irregularly spaced (clustered), an important drawback for estimation and simulation algorithm applications. Moreover, logs available have very different technologies, and only shale and sand discrimination was possible.

The reservoir sands are under seismic resolution (thickness average 5 m), and it is impossible to separate sand from shale areas using seismic attributes in time or frequency domains. Additionally, channel widths are less than the average of inter-well distance as shown in well correlation. Finally, to emphasize the modeling effort, channels belong to a high-sinuosity meandering system.

Methodology

The study was performed using a sand/shale indicator curve, derived from a normalized SP curve. The methodology used consisted of a comparison of 30 realizations results using Sequential Gaussian Simulation (SGS), Sequential Indicator Simulation (SIS), Object-Based Simulation (OBS) and Multiple-point Sequential Simulations (MPS) performed over the same facies data. Cross-validation was the criteria to evaluate the results of each modeling process.

Multiple-point stochastic sequential simulation is a statistical procedure that allows one to simulate categorical variables, particularly curvilinear facies structures, from relative frequencies observed in training images. The SNESIM algorithm (Strebelle 2002), one of the MPS methods, was used in multiple-point stochastic simulation process. The training image was built by taking a current high sinuosity meandering river, as an example of the probable sedimentary environment for the Cretaceous Mina El Carmen Formation.

The Training Model

The model used to guide the MPS simulation was built using the deposit shapes of Sanborombón meandering river, located on the east of Buenos Aires province, Argentina (Figure 2). The model was made using simple sinuous and non-regular shapes drawn by hand. After that, layer by layer were digitized and converted into a tridimensional volume in ASCII format to be used in the SGems public software (Remy, et al., 2009). The model is statistically stationary because the probability to find different shapes is approximately the same in the whole volume (Figure 3).

Simulation Details

Sequential Gaussian Simulation: It was made using SP curve normalized geometrically ranging from zero units (clean sand) to 80 units (shale). Variogram used was exponential type with N-S anisotropy ratio of 1.25.

Sequential Indicator Simulation: Indicator sand curve was made using normalized SP curve with 70-unit cut-off. Variogram used was exponential type with N-S anisotropy ratio of 1.25.

Object Based Simulation: It was made using a commercial modeling package and the geometrical parameters used (channel width, orientation, sinuosity, repulsion, thickness, etc.) was derived from geological experience in the Mina El Carmen Formation. Maximum data points honored was 90%, and convergence was difficult to reach.

Multiple Point Simulation: Several attempts were made with SNESIM algorithm of SGems software. The most satisfying results were obtained without zones, affinities changes or training image rotation. We think the training image itself keeps the most important characteristics of the meandering system.

Stochastic Simulation Results: Comparison Between Methods

Figure 4 shows the same layer of the sand probability volume after 30 realizations, estimated with above-mentioned methods. Pixel based methods (SGS and SIS) overestimated the size of sand bodies and they made an unrealistic sandy forms. Object based simulation was unable to honor the whole data, and probability sand volume is non-representative of Mina El Carmen reservoirs.

On the other hand, Multiple Point simulation represents very well the sedimentary concept assigned to the Mina El Carmen Formation; i.e., high-sinuousity meandering system with channel width less than inter-well distance in average. When we compare the probability of sand volume with the current model used, we can see correspondence between shapes, widths and sinuosities. Although we use simple shapes, simulation control of hard data and the size of search templates allowed the addition of simple curves generating more complex shapes, such as point bars (Figure 5).

Moreover, Training Image stationarity allows one to see probable changes in the channel mean directions, from N-S in the north of the field towards NW-SE in the south of the field. Appraisal wells drilled after modeling showed a very close estimation between sand probability curves (derived from MPS) and recorded SP logs (Figure 6).

Conclusions

It is possible to model high sinuosity meandering system using simple training image with the condition of stationarity satisfied in the whole volume. For data configuration and characteristics similar to those of Diadema field, SNESIM algorithm is the most simple and efficient solution.

References

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Strebelle, S., 2002, Conditional simulation of complex geological structures using multiple-point statistics: Mathematical Geology (Mathematical Geosciences), v. 34, no. 1, p.1-21.

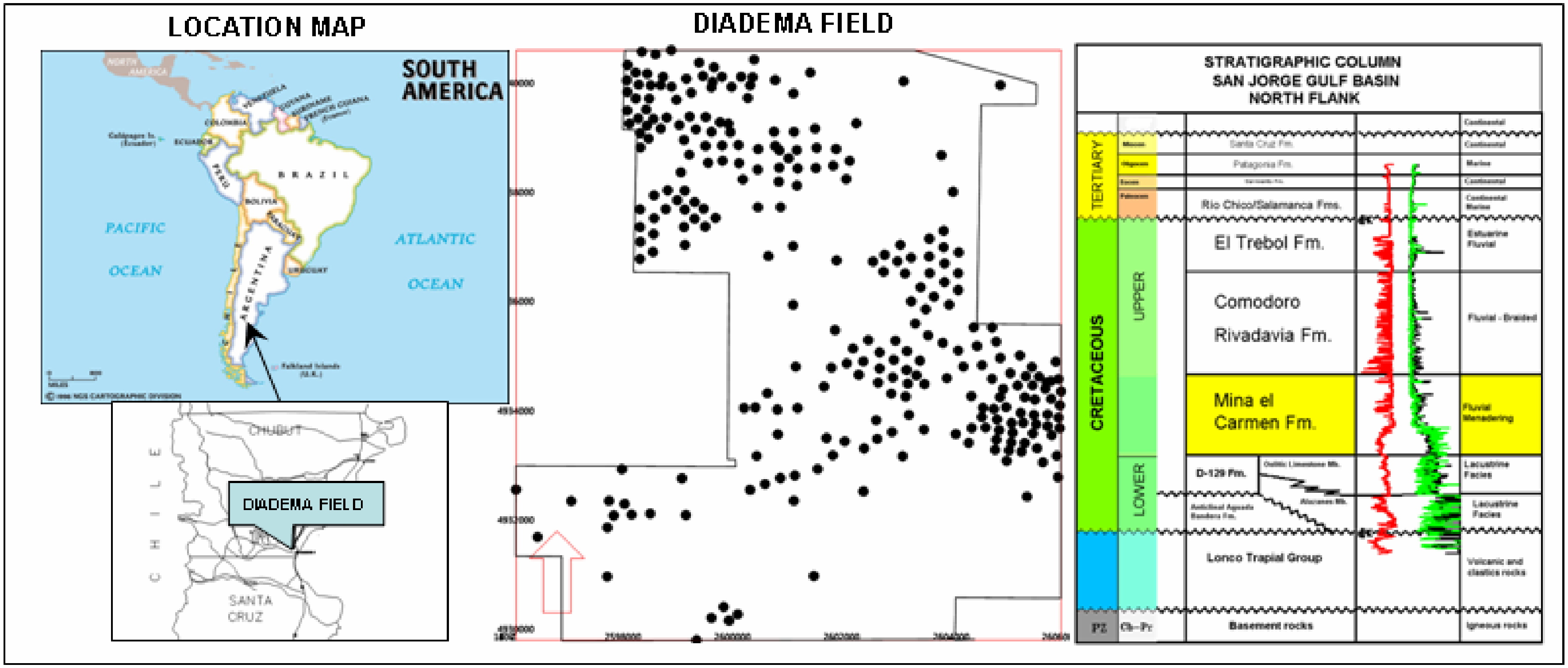

Figure 1. Location map showing wells used in the models.

Figure 2. Satellite view of San Borombón River used as model and digitized interpretation of meandering system. Drawing details show point bars as result of adding elemental chords.

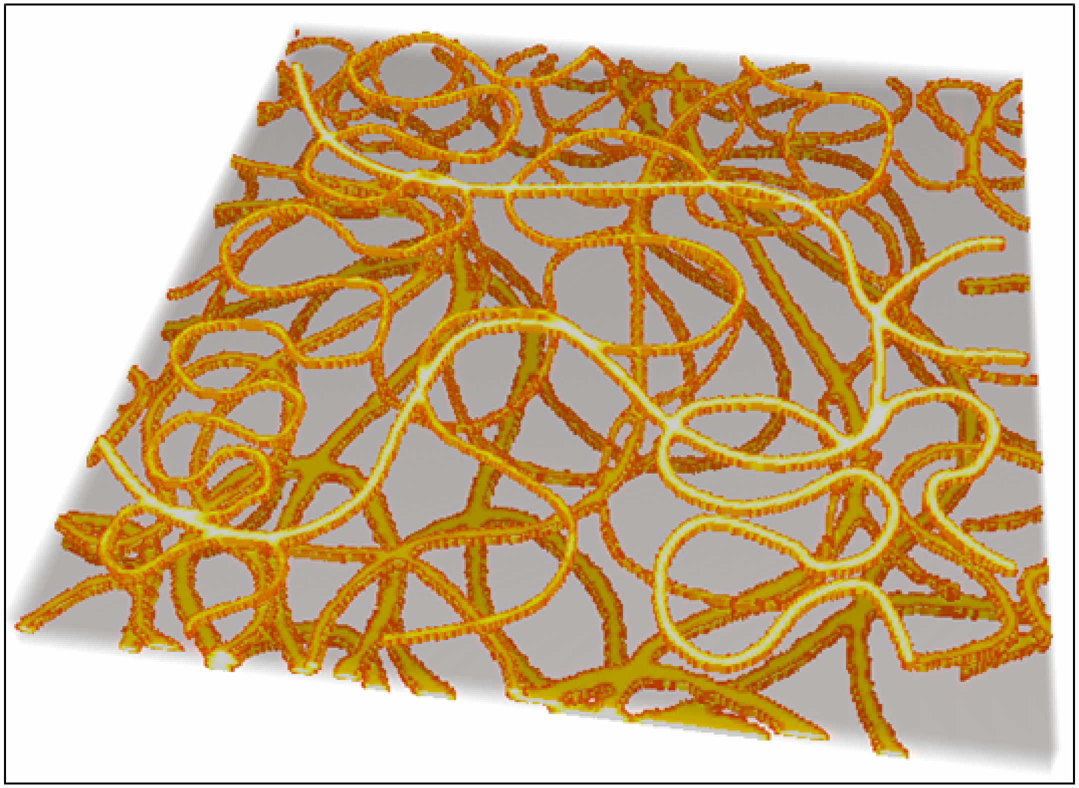

Figure 3. Part of Training Volume made with simple shapes. Grouping simple shapes will result in more complex meandering system shapes.

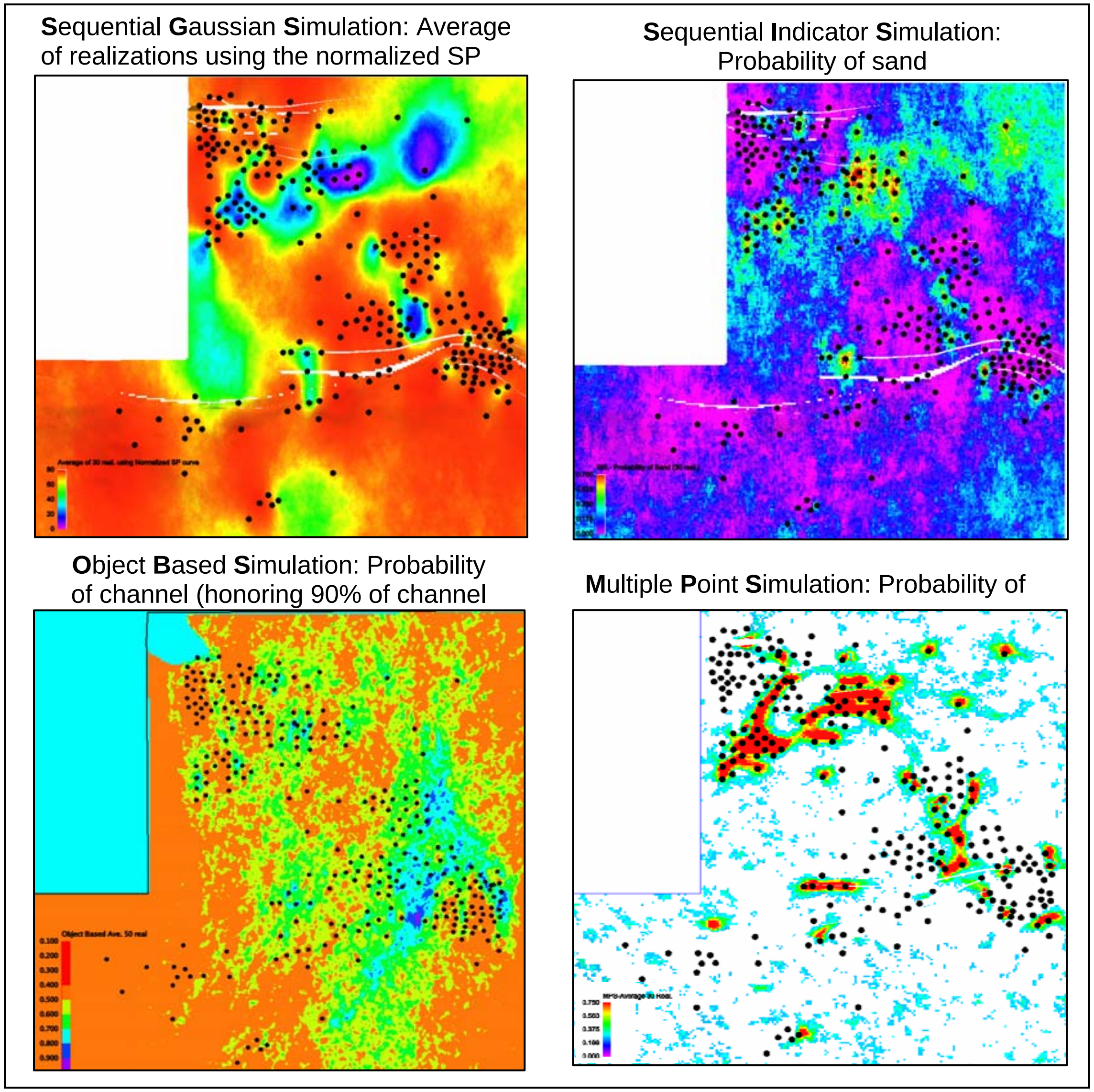

Figure 4. Stochastic simulation results after 30 realizations. Images show one layer of the resulting volume.

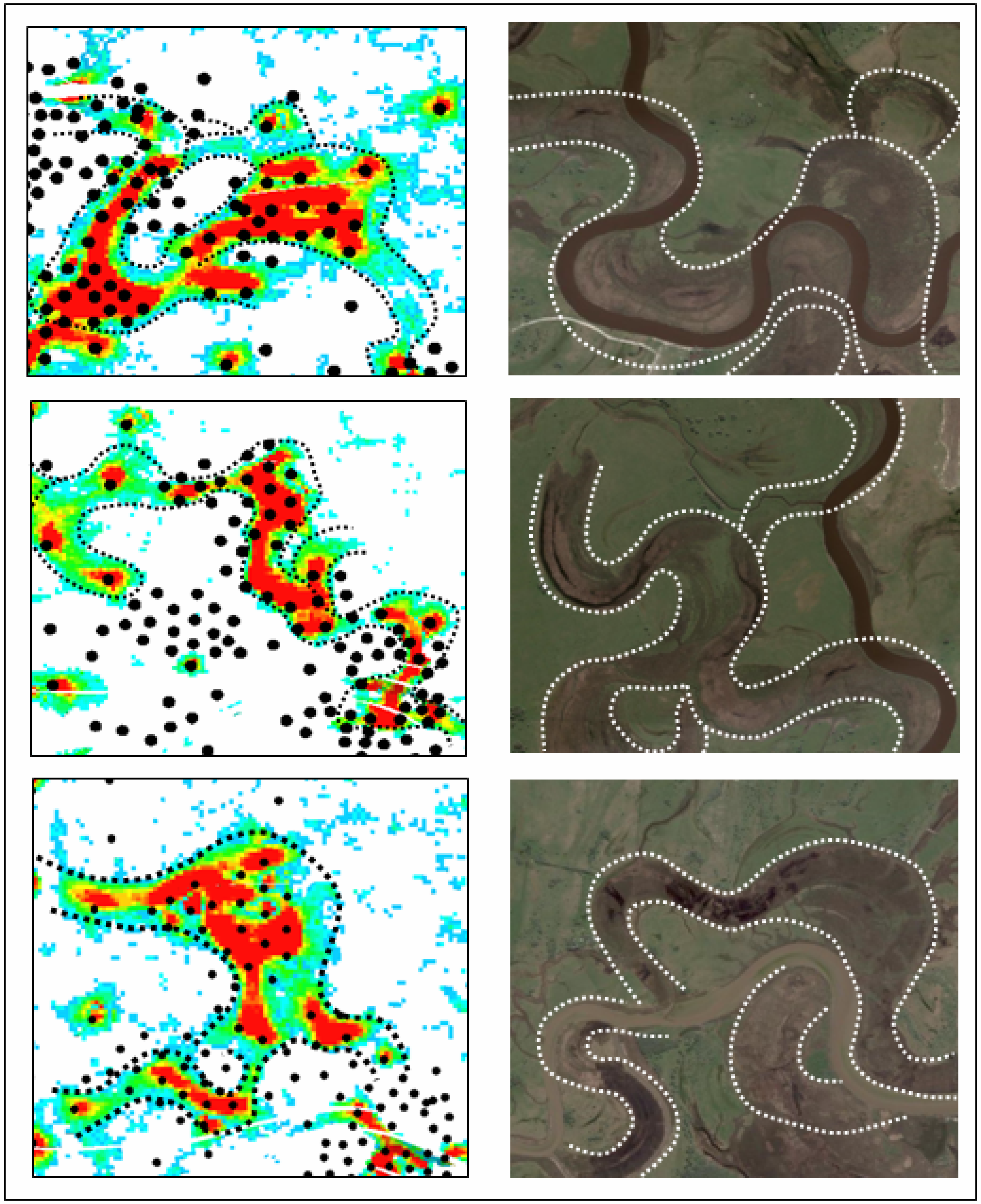

Figure 5. Multiple point simulation results. Three layers of sand probability volume compared with several views of the current model used.

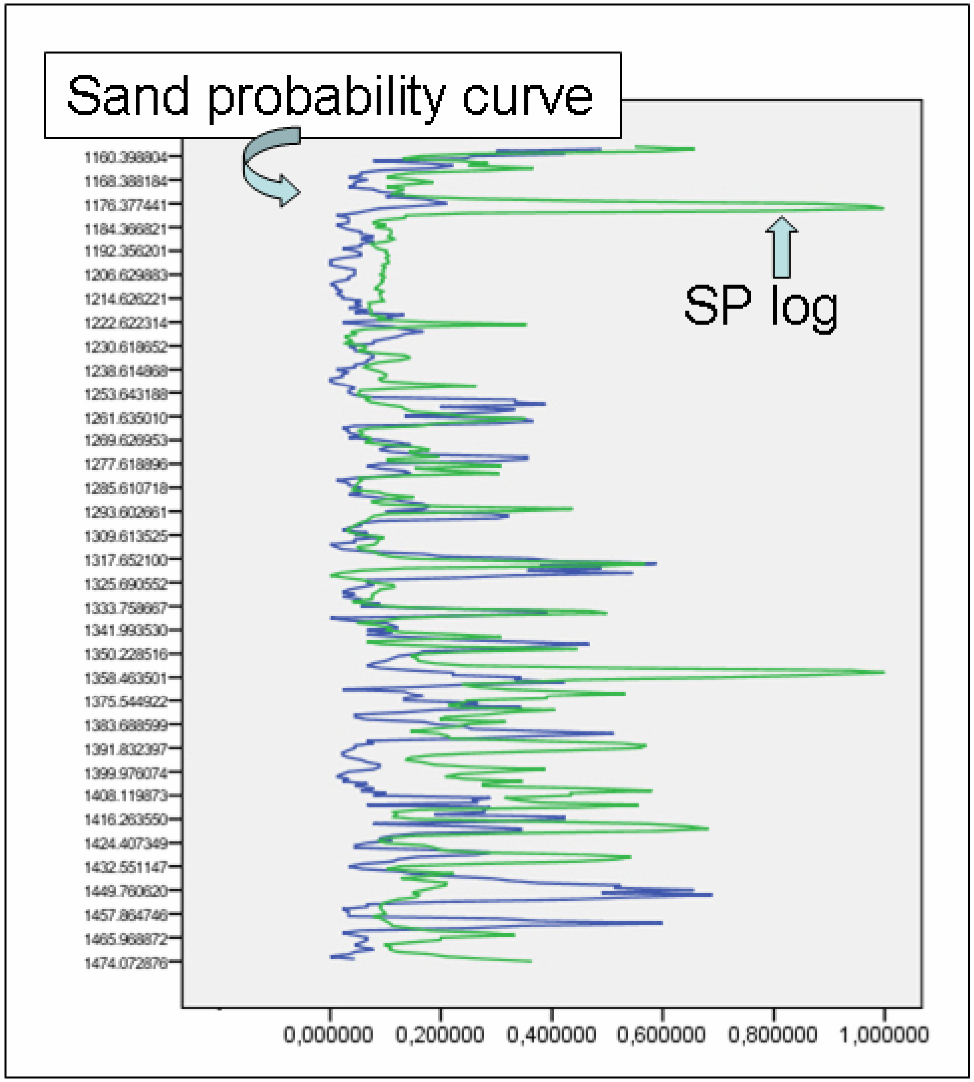

Figure 6. Appraisal well drilled after modeling. Uncertainty increases with depth due to less quantity of control data.