# Application of geologic-mathematical 3D modeling for complex structure deposits by the example of Lower-Cretaceous period depositions in Western Ust – Balykh oil field (Khanty-Mansiysk Autonomous District)

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**Abstract.** The complex structure of the Lower-Cretaceous formation by the example of the reservoir $BC_{10}^1$ in Western Ust – Balykh Oil Field (Khanty-Mansiysk Autonomous District) has been studied. Reservoir range relationships have been identified. 3D geologic-mathematical modeling technique considering the heterogeneity and variability of a natural reservoir structure has been suggested. To improve the deposit geological structure integrity methods of mathematical statistics were applied, which, in its turn, made it possible to obtain equal probability models with similar input data and to consider the formation conditions of reservoir rocks and cap rocks.

## 1. Introduction

Today, the major hydrocarbon resources in West Siberia petroleum – bearing province are related to Jurassic formations. However, due to the increased production and structure depletion of the area, more and more attention is being paid to the Neocomian formations, which, in its turn, is associated with the future reserves growth. Here, the lithologically sealed oil accumulations (clinoforms) are characterized by a complex geological structure, as well as a great variability of reservoir filtration capacity properties.

Nowadays, well drilling justification, oil-gas field development plans, hydrocarbon reserves estimation, cost-effectiveness analysis of geological and technological activities are performed in 3D modeling. In this respect, 3D geological modeling should include the heterogeneity and variability of the reservoir structure both laterally and vertically. It is known that the reliability of the simulated geological unit depends on the exploration certainty. When the information is insufficient, the stochastic approach in 3D modeling is used. It is one of the ways to increase the integrity of the geological structure for oil and gas deposits [2].

## 2. Unit characteristics and research methods

The targets are Lower-Cretaceous formations of Sortymsk series studied by the example of Western Ust – Balykh oil field located in the area of Surgut and Nefteyugansk (Khanty-Mansiysk Autonomous District). The major reservoir is $BC_{10}^{1}$ layer identified in $BC_{10}$ horizon of Sortymsk series. The stratigraphic layering profile is based on the following documents: "Regional Stratigraphic Sectional Plan of Mesozoic formations in West Siberian Plain" adopted by the $V^{th}$ Tyumen Agency Stratigraphic Meeting, May18, 1990 and approved by the International Commission on Stratigraphy, January 30, 1991 and "Resolution of the Agency Stratigraphic Meeting, for consideration and approval of Mesozoic depositions stratigraphic schemes in West Siberia territory" approved by ISC on April 2004.

Tectonically, Western Ust – Balykh oil field is divided into two parts: the eastern part is from Surgut arch and is considered to be the $I^{st}$ order structure in the range of Ust – Balykh Mamontov swell; the western part is found in Tundrinsk basin stretching northwards. Malobalykskaya mega saddle is located on the south border of the area; Salymsk megaswell is on the west.

The characteristic structure for $BC_{10}$ layers is the clinoform development of formations which is isochronous isolated system of sand bodies with variable argillization. These positionally overlap and prolongate each other towards the regressing sea forming regressive sand sheet [3].

Clinoform structure of the studied formations is confirmed by seismic data which identified that the field clinoforms have submeridional orientation, i.e. they can only be traced during the correlation of profiles from the south-east to the north-west. $BC_{10}^{1}$ layer is related to Pokachevsk clinoform of Early Cretaceous Sortymsk series.

To identify the geological structure features and reservoir range relationships correlation of $BC_{10}^{1}$ layer has been conducted, potential oil-bearing formations were mapped, as well as average porosity distribution maps.

When correlating well profiles the datum mark was the bottom of Cheuskinsk clay sequence being extended to thickness of 30-45 m and has specific geophysical characteristic, i.e. is well-identified by geophysical well logging (GIS) by high curve values of gamma logging (GL) and low values of neutron logging (NL). The layer thickness varies from 14 m to 61 m and naturally increases from the north-west to south-east. Lithologically, $BC_{10}^{1}$ layer composition is heterogeneous and characterized by sandstone layering from fine-grained to coarse–grained with clayey and aleurite-clayey layers (figure 1).

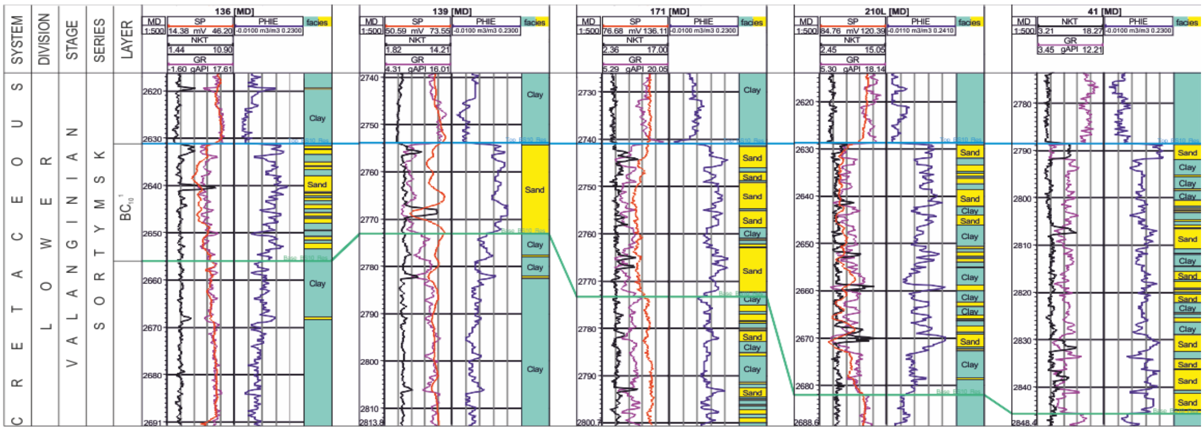


**Figure 1.** Correlation scheme from NW to SE along well lines 136-139-171-210L-41.

The reflection seismic horizon $NBC_{10}$ is confined to the bottom of Cheuskinsk clays. Taking into account seismic data quality and sufficient seismic density profiles, the reflection horizon surface $NBC_{1}$ was chosen, including drilling data. It should be noted that the wells are located irregularly, so correlation accuracy and reliability within the area would be non-identical.

Generally, Western Ust – Balykh uplift is an isometric structure extruding on the terraced slope, plunging from N-E to S-W.

As a result of studied areal geological and geophysical activities, pinching-out lithological borders of reservoirs have been identified- three deposits in $BC_{10}^{1}$ layer have been determined.

GIS interpretation of the reservoirs and their properties identification was conducted. Porosity coefficient was calculated to the GL curve as in some wells there was no SP curve or brine mud drilling (polymer drilling mud) was performed. The interpretation was made by the dual difference parameter which is equal to the difference between current and minimum GL values. The reservoirs and impermeable rocks were identified by boundary values.

Based on GIS interpretation data general strata maps, efficiency strata maps, oil-bearing strata maps and porosity mean values maps were plotted. Well log maps were used as trend surfaces both for lithology and petrophysical properties modeling [6].

The following relationships were determined: sandstones extent as submeridian strike bands, confined by the lithological layer replacement zones. Within the area reservoir thickness changes from complete pinching-out zone to 56.5 m. Maximum oil-bearing strata thickness is 50.26 m. The deposits are lithologically sealed. Maximum oil column thickness is up to 61m. Absolute OWC Vertical Depth is at 2471m according to GIS data, sampling, perforation and reservoir development data during the first operation months.

Based on porosity mean values maps, the maximum values are identified in the deposit dome, which is 18.6 % and decreases to the pinching lines up to the boundary values. In general, the porosity values of three deposits are distributed uniformly and characterized by high capacity properties.

The model structure carcass was plotted on the basis of the roof formation surface (reflection horizon $NBC_{10}$ related to drilling data) and the bottom formation surface $BC_{10}^{1}$ calculated by the strata maps. All the wells, where GIS data had determined the reservoir roof and bottom locations, were applied.

To calculate 3D grid, the optimal horizontal cell size equals 150×150 m was chosen, including the minimum distance between the wells. Vertical partitioning into layers, based on the geological structure peculiarities, was performed according to the formation roof. The optimal layer thickness was determined by the sampling distribution analysis of the facies thickness. Data presentation as histograms, functions, cross-plots, pie-charts being in compliance with factual log and seismic data analysis were applied for the distribution of properties in the borehole space. The histogram in figure 2 shows the optimal value (0.5 m) for vertical resolution.

The results of log data smoothing in the grid are given in the histogram (figure 3). It shows the comparability of re-scaled cells and GIS initial curves.

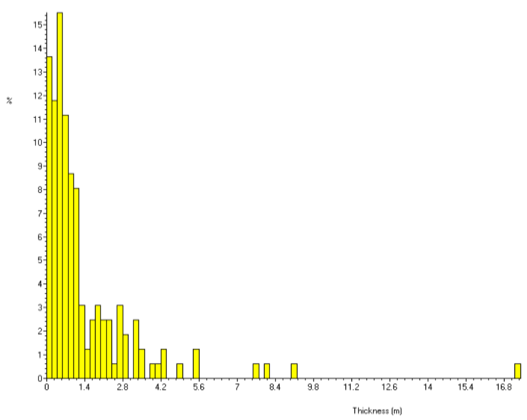


**Figure 2.** Histogram of sandstone formation layer distribution.

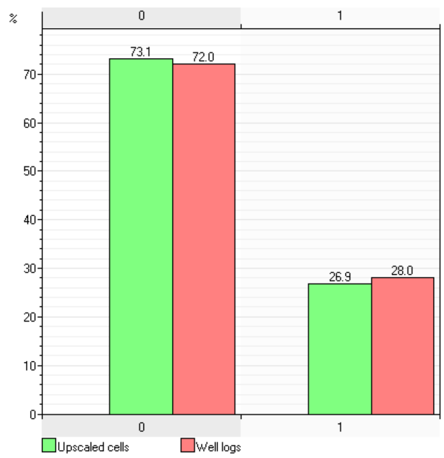


**Figure 3.** Re-scaled log diagram histogram (green color) and initial log diagram (red color).

Interpolation of properties in the borehole space is the basic and most complex stage in 3D geological modeling. In this research the mathematical statistics techniques have been applied to obtain more realistic geological models, particularly, in the well zones with low density; to obtain several equal probability models with the same input data set and to consider the reservoir rock and cap rock formation conditions. Variogram analysis was used to identify spatial correlation of geological data. It is based on the correlation bond between two values of a parameter in the adjacent points of space during the properties distribution in the borehole space. The distance increases and variation range also increases [1]. 3D modeling includes plotting the facial model, firstly, and further petrophysical modeling.

The initial parameters for variogram plotting is preset interactively via the Variogram window to the principle direction and perpendicular to the principle direction. The principle direction parameters for sandstones have the following values:

- band width – 1200 m (based on drilling – out grid);
- search radius – 4800 m (should be 0.7-1 of whole field measurement);
- tolerance angle – 32º (orienting pairs of points in chosen direction);
- number of lags– 10 (value is chosen due to the obtained histogram and lag distance delay);
- lag tolerance – 50 % (subsequent and preceding lag pairs in the interval);
- lag distance – 480 m (search radius ratio to the number of lags).

The obtained experimental variogram has the following parameters:

- Major direction– 300 º;
- Minor direction– 210 º;
- Major range – 680 m;
- Minor range – 500 m;
- Nugget – close to 0.

Nugget value close to 0 identifies good functional bond and experimental variogram data can be used for 3D modeling.

Furthermore, the experimental variogram approximated was by a smooth curve. The variogram spherical model characterized as smooth, uniform dispersion increase between the data to specific maximum was applied [4].

Firstly, the curves describing the vertical distribution of sandstone and clay facies due to the model layers were evaluated and edited by the Data Analysis. Secondly, these curves were used to control the vertical facies in the modeling distribution including the variograms.

Lithological modeling was performed by Sequential Indicator Simulation technique based on the experimental variograms and trends data. To approximate to the real geology unit the effective strata map as a horizontal trend including reservoir pinching lines was applied. As a result of obtained plots, the facial model shown in figure 4 was obtained.

For petrophysical modeling the following initial data were used: GIS interpretation results, 3D lithological model; geological relationships variability of petrophysical properties in the area: reservoir pinching polygons; porosity mean values calculated to wells data; petrophysical dependence equations.

To model the reservoir petrophysical properties semideterministic technique called Kriging providing the minimal variance of error was applied.

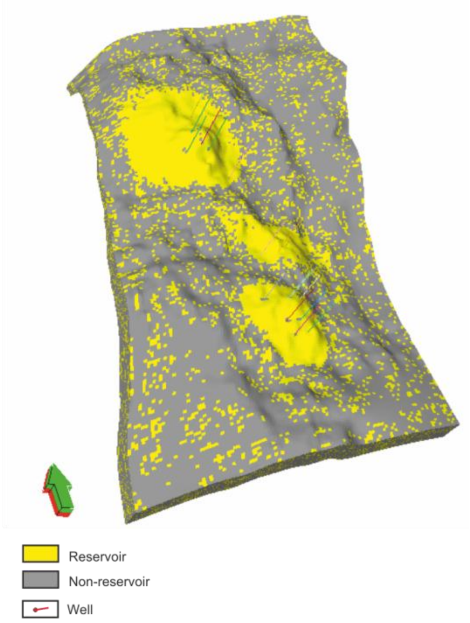


**Figure 4.** SD lithological model.

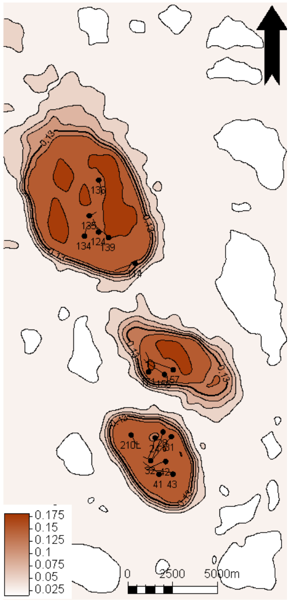


**Figure 5.** Porosity mean values map obtained from 3D model.

Reliability evaluation of geologo-mathematical model was performed on the basis of correlation values of well data and the obtained 3D geologo-mathematical model data (figure 5).

**3.Conclusion**.

Formation of $BC_{10}^{1}$ horizon sediments is related to shallow shelf environment, where the lens-convex asymmetrical bodies are formed. These are characterized by sand, impermeable clayey and aleurite-clayey rock layerings.

The total thickness increase is from the North-West to the South-East.

Three lithologically sealed oil accumulations have been identified within the field.

Reservoirs are characterized by high reservoir properties; according to A. A. Khanin classification, they are $III^{d}$ class.

3D geological model is based on geostatistics techniques.

The experimental variogram that precisely corresponds to the spherical model has been calculated for the property distribution relationship in the borehole space.

The obtained 3D geological model corresponds to the well data and represents the complex production horizon $BC_{10}$ structure.

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