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Geologic Modelling of Unconventional Field Using Geostatistics, Williston Basin, North Dakota*

Alan Alexeyev[1], Mehdi Ostadhassan[2], and Chunxiao Li[3]

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[1]Department of Petroleum Engineering, University of North Dakota, Grand Forks, ND, United States (aalexeyev@uh.edu)
[2]Northeast Petroleum University, China, Distinguished Professor of Earth Sciences
[3]University of North Dakota, Grand Forks, ND, Ph.D. Student

Abstract

Bakken formation is the unconventional shale reservoir in North Dakota. It has been a major producing formation in the USA, which led North Dakota to become the second largest oil producing state. The reservoir was discovered in 1950s, but recent technology developments such as hydraulic fracturing and horizontal drilling allowed the rapid development of this low permeability, low porosity formation. Geologic modelling is the important step in reservoir development, since by looking at the distribution of the reservoir properties the engineers can identify the spots that require further development. Geomodel of the Bakken Formation has been built using geostatistical methods. Variograms were constructed to achieve an accurate interpolation between the data from given wells. Stochastic method, like the Sequential Gaussian Simulation, was used to populate the model with reservoir properties, which included porosity, permeability, effective porosity, water saturation, and shale volume. Petrophysical analysis of this field was done previously using the well log analysis. Once the model has been constructed, the trends and the better zones could be seen and identified. Variogram maps were built to see the anisotropy direction.

Introduction

Geologic modelling allows to look at the oil reservoir from a new perspective, and to identify the zones of additional attention that were previously unavailable. The general purpose of creating the geomodels is to perform a reservoir simulation study later in order to predict the future production and to come up with the best development scenario; a history match could tell if the model is accurate or not.

Given Bakken's relatively recent rapid development, few studies had been found that focus on the geomodelling of this formation using geostatistics. In this paper, the goal is to bridge the gap between geostatistics and modelling of unconventional shale reservoir. The role of geostatistics is to predict the distribution of values in places that are unknown and that are at a distance from known values. Geostatistical modelling provides static description of petrophysical properties throughout the entire reservoir. Deutsch (2014) in his book "Geostatistical

Reservoir Modelling” describes the foundation of application of geostatistics, its purpose in reservoir modelling, and the importance of geostatistics. Geostatistical models usually honor the reservoir-specific information. (Deutsch, 2014). The input data for geomodels comes from seismic, core, logs, engineering, general knowledge of geology, and other sources.

Powerful commercial software has only become available relatively recently, coupled with recent but rapid development of the Bakken, it perhaps explains the lack of much literature available on geomodelling in the Bakken. For this reason, we believe it was important to perform a geomodelling of the producing part of the Bakken formation with hopes that this work will add some information to the reservoir’s development. Geostatistic approach is used in this case study, it has been proven to be a good tool in geomodelling. Geostatistics is the science of spatial relationship between known and unknown points; it is used to predict the values in space. This is very applicable in geomodelling, since there are only a few known values available, but the goal is to predict the values of any property at any given location in-between. Some of the most important questions to be answered after the geomodelling are – how the porosity or any other property is changing throughout the reservoir.

One of the previous geomodelling works that was done in the Williston Basin is the analysis of Winnepegosis Formation by Oster (2016). In that work, the author also used geostatistics to establish the distribution of properties, such as porosity and permeability, in addition to facies. Some of the trends have been described. That formation is deeper than Bakken, but some similarity in general trends could be noticed between the two formations. Miri (2006) performed a geomodelling on the formation in Iran using variograms and geostatistical analysis. In that study, stochastic methods were used over deterministic, since the former is better for preserving reservoir heterogeneity than the latter. To reevaluate older oilfields, Martin (2015) performed a modelling of the depleted reservoir in Illinois. That study describes the building of a model in Petrel using well logging data. It resulted in finding new spots that were overlooked during previous management of a reservoir. Similar goal was achieved in a paper by Rodriguez, et. al (2015). There, the field in South America has undergone modelling and simulation. Over 90% of geostatistical reservoir characterization uses variogram-based geostatistical modelling. Variogram reflects the understanding of geometry and continuity of the reservoir properties and can have an important effect on prediction of flow behaviour (Gringarten and Deutsch, 1999). Reservoir modeler can influence the appearance and flow behaviour of the final model through the variograms. Melton, et al. (2014), in their attempt to build a geomodel of Bakken tried to correlate the data from cores, logs, and incorporate different sources of data into one model. However, the geostatistics was not the part of that work. Almanza (2011) performed a geomodel of Bakken in Elm Coulee field. However, it also lacks the variogram inclusion. Following the lack of literature on geostatistical Bakken modelling, the need to create one arose.

General Geology

The geology of the Bakken had been extensively described in many publications found in literature. The reader should refer to publications by Webster (1984), Meissner (1991), LeFever (1991), and Gerhard (1982) to get familiar with regional geology. In recent years, various studies have been done on reservoir characterization of Middle Bakken (Alexeyev, 2017; Liu, 2016; Simenson, 2010; Sonnenberg, 2009; Alexandre, 2011; Kowalski, 2016). The general conclusions are that the porosity exhibits the range between 3 and 10%, permeability between 0.001 mD and 0.01mD, and the lithology is mainly a dolomitic sandstone, depending on the area.

Methodology

Geologic model relies on petrophysical data as the input that is acquired from well log, cores, or other sources. The petrophysical analysis of this field was done in the previous study, described in the report by Alexeyev, et al. (2017). The resultant curves of porosity, permeability, effective porosity, water saturation, and shale volume were imported into Petrel to begin the modelling. Standard workflow for geomodelling was followed that included well log upscaling, well tops picking, surface generation, and others.

Variogram analysis is the common way to measure the spatial variability and correlation for the cell-based property modelling. Variogram is the measure of variability versus the distance, it increases as the samples become more different. The essence of variogram is that it measures how much the two samples will vary as the distance between them changes. Generally, samples taken closer to each other will have a smaller variability than those taken more distance apart. More in-depth information is provided in books by Deutsch (2014) and Kelkar, et. al (2002).

There are two main ways to perform geostatistic interpolation – stochastic and deterministic. The common method for stochastic modelling is the Sequential Gaussian Simulation (SGS); this method has been used in this study. Kriging refers to deterministic method.

SGS takes an input variogram model and creates a 3D model constrained to a local data and variogram model. Geostatisticians fit variograms with specific known positive functions. Those are spherical, exponential, and Gaussian. Exponential type of variogram seemed to be fitting the best in this study. The tolerance angle was 45 degrees in most cases. Primarily, it was important to get the anisotropy direction, as depending on what direction was chosen, the number of pairs differed. For variograms, it was important to have the number of pairs decreasing as the distance increased. By selecting the appropriate range and direction, we were able to achieve the decreasing number of pairs. Thus, the determination of anisotropy direction and making sure the number of pairs are in the decreasing order appear to be a successful strategy for variograms, which should result in accurate distributions. Kriging was not chosen as the interpolation technique as its smoothing did not reflect the reservoir heterogeneity. Figure 1 and Figure 2 show the variograms for saturation and porosity.

Variogram maps

Variogram map is the variograms calculated in different directions. They allow us to know the directions of major and minor anisotropies. Variogram maps are the effective tools for trend identification in data. The color of the map shows the changes in variance (Miri, 2006). In this part of the Bakken formation, there is a Nesson Anticline exists that runs in the northwest direction. The direction is about 330 degrees azimuth. This is close to what Oster (2016) found in the Winnipegosis formation. The main purpose of creating variograms in this study was to observe the anisotropy direction amongst the properties and verify if it agrees with general geology and previous studies.

Geologic model

Surfaces were done using Kriging interpolation. This model highlights the structure of the Bakken. The relief and the surface of the Bakken are based on chosen well tops, where the main criterion for selecting them was the Gamma Ray (GR) log. It is known that GR on Lower and Upper Bakken shales is extremely high, while the Middle Bakken corresponds to a normal GR value. The surface can be seen as non-flat, and some sort of anticline and a dip present within this field. The scale on Figure 3 is slightly exaggerated vertically to highlight the unevenness of the reservoir.

For comparison purposes, four additional different types of interpolations techniques available in the software were simulated. Mainly, stochastic and deterministic methods were compared. For surfaces, it is better to use kriging because of its smoothing effects; it applies well for surface applications, such as shown in Figure 3. However, to preserve the heterogeneity, it is better to use stochastics-based interpolations, such as Sequential Gaussian Simulation. Kriging type interpolations do not show the heterogeneity. Thus, in this project we used SGS for properties interpolations and Kriging for surface interpolation. Figure 4 shows the porosity distribution after the abovementioned methodologies were applied. Most values of porosity fall within predicted range of 3-8%.

The geologic northwestern trend could be observed. The five main properties will allow seeing where the better spots for further exploration are. It would be great to combine these five modelled properties into a common model where the zones with high porosity, high permeability, low water saturation, low shale content could overlap, and that would almost certainly indicate the good locations for exploration. By looking at property distribution, the zones that appear to be favorable are in the middle of the explored area. That area also corresponds to the highest concentration of the wells drilled. The good zones appears to be around the slight dip in the middle of the field, according to a structural model, where there's an observed low water saturation, higher porosity, low shale volume (less than 10%), and thus higher effective porosity; permeability also appears to be higher, although it exhibits a very high heterogeneity throughout the reservoir and hydraulic fracturing is always used in this formation.

This concludes the geomodelling process of a reservoir. The next steps would be to improve the input data or to export the model for simulation studies.

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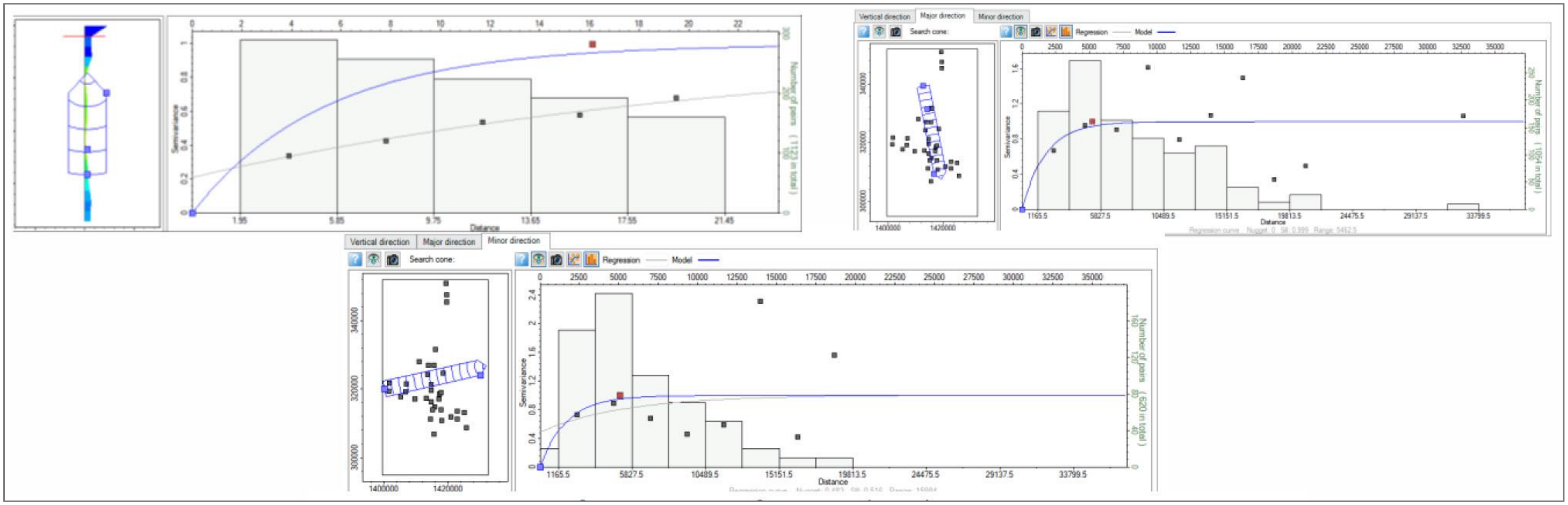

Figure 1. Variograms of saturation. Left: vertical. Right: major. Bottom: minor.

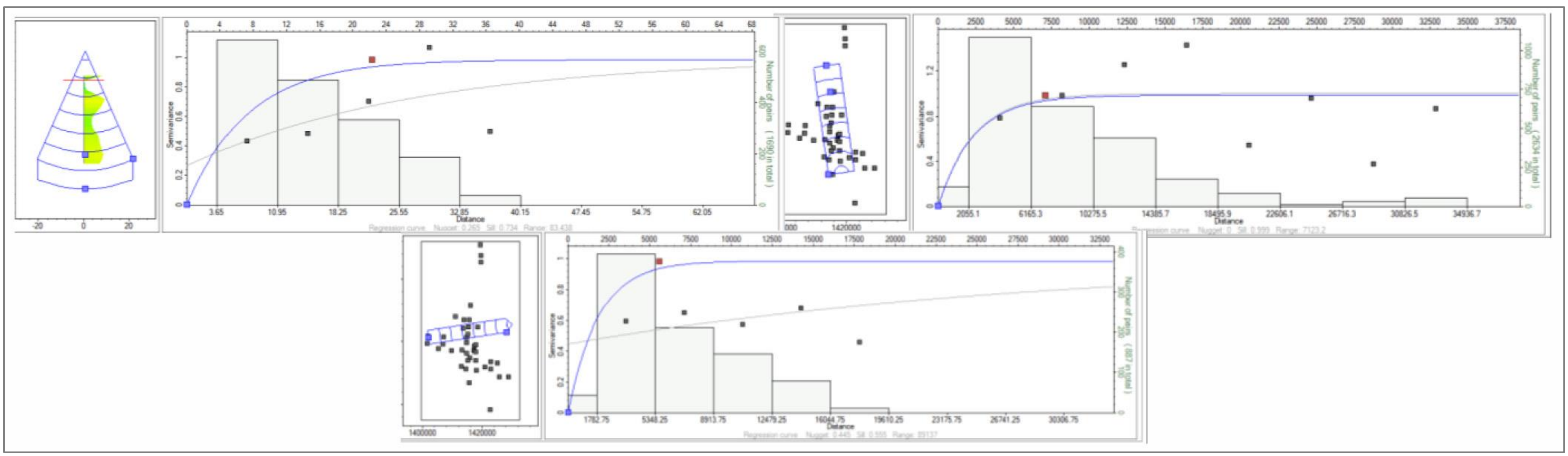

Figure 2. Variograms of porosity. Left: vertical. Right: major. Bottom: minor.

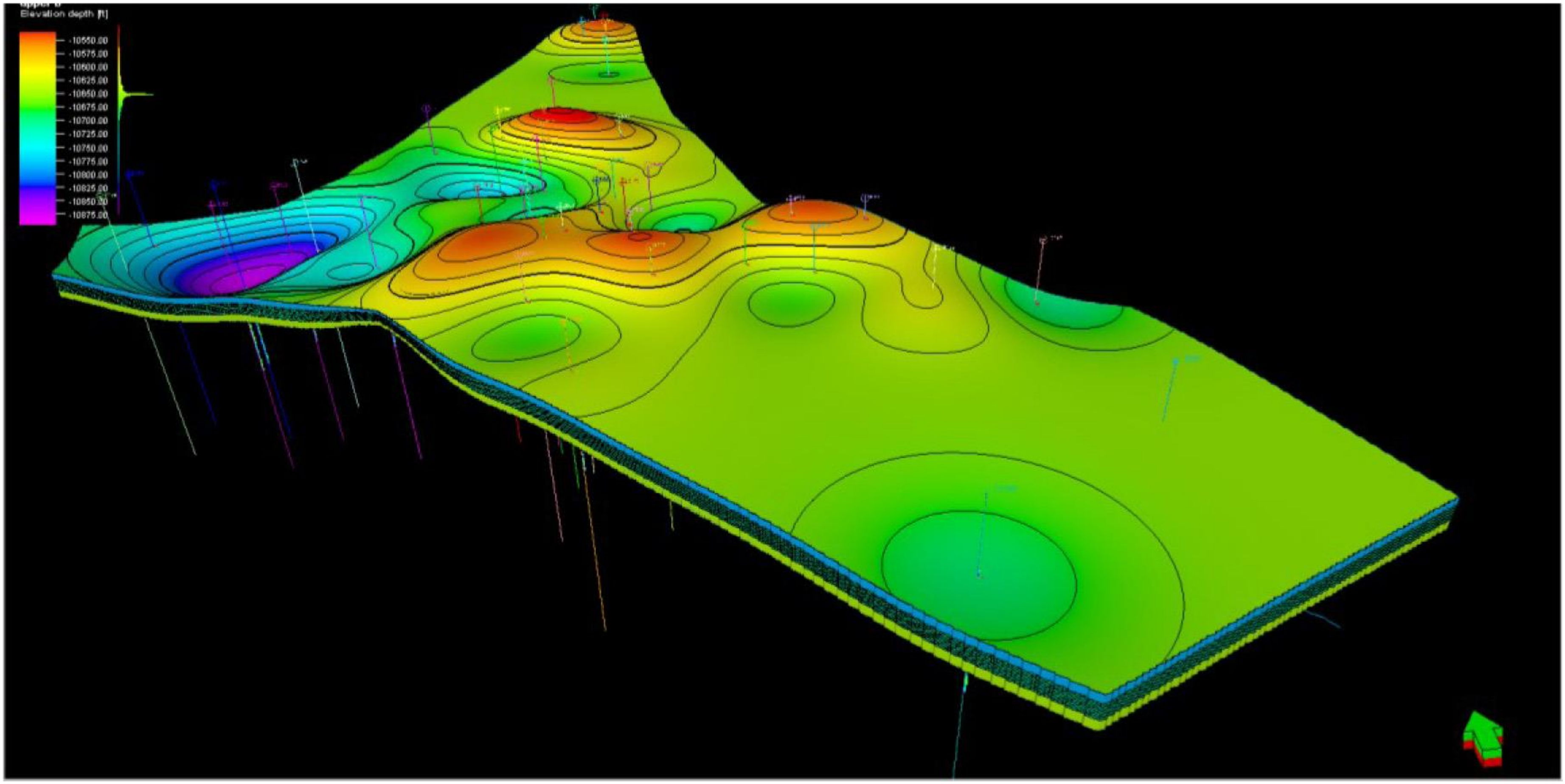

Figure 3. An overview of the geologic model of the Blue Buttes Field.

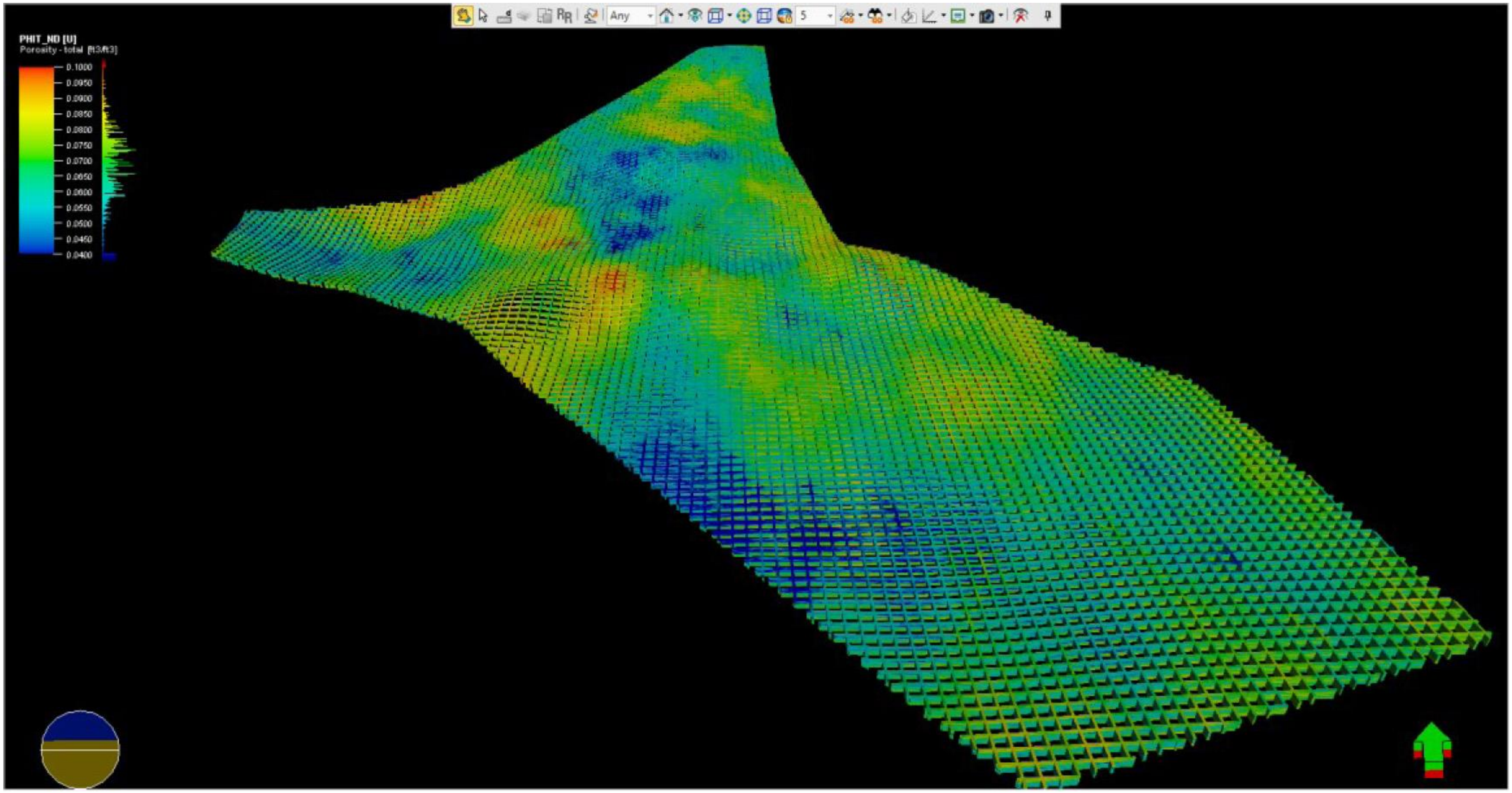

Figure 4. Porosity distribution.