O PROCESSO DE MODELAGEM GEOLÓGICA NA NOTAÇÃO "IDEF0"

THE PROCESS OF GEOLOGICAL MODELING IN THE NOTATION "IDEF0"

ПРОЦЕСС ГЕОЛОГИЧЕСКОГО МОДЕЛИРОВАНИЯ В НОТАЦИИ "IDEF0"

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Received 18 June 2018; received in revised form 30 November 2018; accepted 03 December 2018

RESUMO

O artigo analisa o processo de modelagem geológica. A novidade deste artigo reside no fato de que o tópico da modelagem geológica tridimensional usando a metodologia IDEF0 ainda não foi totalmente desenvolvido e não está consagrado no nível legislativo. Os autores mostram, que é promissor para otimização do processo de modelagem geológica. Para construir modelos geológicos, os sistemas de software foram utilizados durante este estudo (Petrel, Irap RMS, DV-Geo, Geoplat, JewelSuite, SKUA-GOCAD, Nedra, PanTerra e muitos outros). Um modelo deste processo foi construído na notação "IDEF0" e decomposto no primeiro nível, os dados de entrada e saída para cada estágio são apresentados, e os módulos do programa utilizados em cada estágio são indicados. O funcional do pacote de software Irap RMS é considerado e detalhados modelos geológicos tridimensionais de depósitos jurássicos de um dos campos da região de Tomsk são construídos, consistindo de uma grade geométrica, cubos de parâmetros de litologia, porosidade, permeabilidade, saturação de gás e óleo, índice de saturação, reservas geológicas iniciais.

Palavras-chave: *modelagem geológica, sedimentos jurássicos, IDEFO, formações produtivas.*

ABSTRACT

The article analyzes the process of geological modeling. The novelty of this article is in the fact that the topic of three-dimensional geological modeling using the methodology "IDEF0" has not yet been fully disclosed and has not been fixed at the legislative level. The authors show how promising it is to optimize the process of geological modeling. To build a geological models the software complexes are used during research (Petrel, Irap RMS, DV-Geo, Geoplat, JewelSuite, SKUA-GOCAD, Nedra, PanTerra and many others). The model of this process is constructed in the notation "IDEF0" and is decomposed into the first level, the input and output data for each stage are denoted, the program modules used at each stage are indicated. The function of the software

DOI: 10.52571/PTQ.SI1.2018.263_PeriodicoES.pdf

complex "Irap RMS" was considered and detailed 3D geological models of the Jurassic deposits of one of the Tomsk region deposits were reconstructed. They consisted of a geometrical grid, cubes of lithology parameters, porosity, permeability, gas and oil saturation, saturation index, initial geological reserves.

Keywords: *geological modeling, Jurassic sediments, IDEFO, productive layers.*

АННОТАЦИЯ

Статья анализирует процесс геологического моделирования. Новизна данной статьи заключается в том, что до сих пор до конца не раскрыта тема трехмерного геологического моделирования с использованием методологии "IDEF0" и не закреплена на законодательном уровне. Авторы показывают, насколько она перспективна для оптимизации процесса геологического моделирования. Для построения геологических моделей использовались программные комплексы во время данного исследования ("Petrel", "Irap RMS", "DV-Geo", "Geoplat", "JewelSuite", "SKUA-GOCAD", "Недра", "PanTerra" и многие другие). Построена модель этого процесса в нотации "IDEF0" и декомпозирована на первый уровень, обозначены входные и выходные данные для каждого этапа, указаны программные модули, используемые на каждом этапе. Рассмотрен функционал программного комплекса "Irap RMS" и построены детальные трехмерные геологические модели юрских отложений одного из месторождений Томской области, состоящие из геометрической сетки, кубов параметров литологии, пористости, проницаемости, газо- и нефтенасыщенности, индекса насыщенности, начальных геологических запасов.

Ключевые слова: *геологическое моделирование, юрские отложения, IDEFO, продуктивные пласты.*

INTRODUCTION

Modeling is a method of research and forecasting, based on the imitation of the object. The result of the simulation is the model. A model is a representation of a real object or process in some form different from the actual one, revealing the interconnections of the elements of the object. A real model is a tool for research and forecasting.

Models are divided into two classes: isomorphic and homomorphic. Isomorphic models represent the total equivalent of a simulated system. However, it is almost impossible to construct an isomorphic model due to the incompleteness and imperfection of knowledge about the real system and the insufficient adequacy of the methods and tools of such modeling. Therefore, almost all models are homomorphic, which are models similar to the displayed object only in relationships that are characteristic and important for the modeling process. Other aspects of the structure and functioning of homomorphic modeling are ignored. A geological model is a collection of data on a geological object, which includes: structural maps, borehole data, a three-dimensional grid filled with parameters, contours, etc. (Zakrevsky, 2009; Zakrevsky *et al*., 2008; Bolotnik *et al*., 2001; Rybnikov and Sarkisov, 2001; Aranov, 1990; Belkina *et al*., Baimakhan *et al*., 2009; 2015; Ababkov *et al*., 2010; Baranov *et al*., 2012).

The existing technologies for building 3D-geological models to a large extent allow automating the process of constructing the model (Wu *et al*., 2005; Lelliott *et al*., 2009; Kurchikov and Borodkin, 2011; Don *et al*., 2018). However, the 3D model remains an expression of the author's presentation of the geologist-modeler about the geological structure of the deposit. This idea is developed by the geologist-modeler both in the process of studying geological and geophysical data and in the process of constant communication with specialists of other related specialties - seismic explorers, petrophysicists, hydrodynamics, etc. The views of these specialists may not coincide and contradict each other. Since the geological model must take into account all the circumstances in a maximum and consistent manner, the process of constructing the model is the search for justified compromises (Kontorovich *et al*., 2013; Dias *et al*., 2016; Khakimova, 2016).

The professional skill of the geologist-modeler naturally grows with the experience of modeling various geological situations, as well as with the development of various software products (Gladkov, 2012; Abakhov *et al*., 2010; Kharakhinov and Shlenkin, 2012). An extremely important role is played by the enrichment of the experience of other specialists, which can be found at specialized conferences and exhibitions, in specialized journals and books.

MATERIALS AND METHODS

To build a geological model, a huge amount of data is used, the detailed analysis and use of which takes a large amount of time. The software complexes of geological modeling (Petrel, Irap RMS, DV-Geo, Geoplat, JewelSuite, SKUA-GOCAD, Nedra, PanTerra and many others) help automate this process (Weng *et al.*, 2012; Vidyakin *et al.*, 2011; Erofeev and Orekhov, 2014).

Based on the three-dimensional geological model, a set of maps has been constructed for each productive layer:

1) structural maps of the roof and bottom for each layer;

2) maps of the roof and the bottom of the reservoir for each layer;

3) maps of effective thicknesses of the formation;

4) maps of gas-saturated and oil-saturated thicknesses of the formation.

The "IDEF0" ("Integration Definition for Function Modeling") standard is a graphical modeling notation used to create a functional model that reflects the structure and functions of the system, as well as information flows and material objects that connect these functions (Smirnov *et al.*, 2009; Gogonenkov, 2007; Baishev and Kuznetsova, 2010).

The process of geological modeling was analyzed, as a result of the analysis, a process model was constructed using the "IDEF0" notation using the software "BPWin" of the "All Fusion" line of the company "Computer Associates" (Figures 1 and 2).

Within the framework of this work, 2D and 3D geological modeling of Jurassic reservoirs have been performed (Halimov, 2012; Kuznetsov *et al.*, 2010; Golovin *et al.*, 2016). As a starting point for geological modeling, a single digital database of geological and geophysical data has been prepared that includes:

1) maps of the surfaces of the main reflecting horizons based on seismic survey results;

2) fracture lines;

3) coordinates of wellheads and altitudes of the rotor table;

4) stripping of stratigraphic boundaries of counting objects;

5) well survey data;

6) initial GIS diagrams;

7) the results of the geological and geophysical interpretation of the well sections by the definition of the lithology of the section, the separation of reservoirs, the nature of their saturation, the FES;

8) perforation data, test and test results;

9) topological basis.

The construction of the three-dimensional geological model was carried out using the software complex "Irap RMS". Geological models were created in the productive strata of U_1^1, U_1^2, U_1^{3-4} and U_2^1.

CONSTRUCTION OF A GEOLOGICAL MODEL OF JURASSIC DEPOSITS:

2.1. Construction of the structural framework surfaces of the deposit

The initial stage in the construction of geological models is the construction of the structural framework of the deposit. The framework was built on the absolute marks of the stratigraphic boundaries of the strata, obtained as a result of the correlation of the well sections using the available seismic structural maps as trends for the most clearly traced reflecting seismic horizons. Correlation of well sections was carried out within the framework of this study, and seismic maps were obtained from the results of a comprehensive interpretation of 2D and 3D seismic data (Ryskin, 2016; Romashev, 2016; Zakrevsky and Kundin, 2016).

Seismic structural maps constructed on the reflecting seismic horizons "IIa" (the sole of the Bazhenov suite) and "Ib" (the upper part of the Tyumen suite) were used to construct the structural framework of the productive section of the deposit section. The method of constructing the structural framework for the productive layers of the deposit included the following stages.

First, the surfaces of the stratigraphic roof of the U_1^1 layer and the base of the U_2^1 formation were constructed, for which the structural maps for the reflecting horizons "IIa" and "Ib", respectively, were used as trends. All other horizons of the examined group of strata were sequentially stratigraphically stratified in wells using the upper and lower trends.

Quality control of constructing the surfaces of the structural framework was carried out by constructing maps of the total thickness for each reservoir. The discrepancy in the construction of stratigraphic surfaces with the values of absolute marks in the wells, the composition of the mud does not exceed ± 0.4 m. Figures 3 and 4 show the resultant surfaces of the structural framework over the deposit.

It should be specially noted that, based on the results of seismic exploration, the entire area of the field is covered by a network of tectonic disturbances. Some of these violations were considered as tectonic screens that limit the distribution of deposits in Jurassic age strata. When tectonic disturbances were included in the geological model, violations were identified that divide blocks with different fluid contact markers, as well as violations, the presence and significance of which is confirmed by data of hydro-acoustic and interaction of wells in the development process. Since there were no obvious displacements in them, the structural framework was constructed in a plicative version.

2.2. Creation of a model of fractures (disjunctives) and a stratigraphic model

Dedicated seismic data tectonic screening disruptions were digitized from the counting plans and loaded into the project. Based on these data, the surface fractures have been constructed, extending through a roof surface layer and U_1^1 sole of U_2^1. After the construction of fracture surfaces, fracture relationships were defined and unnecessary parts that appeared as a result of surface interpolation were cut off. After constructing a preliminary model of fractures, the quality control of each fracture was made, and the surface shapes and intersections were refined. The fracture model thus formed is shown in Figure 5.

The stratigraphic model of the deposit was constructed using the resulting model of fractures and previously constructed surfaces across all strata. The surfaces have previously passed the filtering process, which allows converting the original data into a set of points, with the removal of that part of them that is located in the areas adjacent to the fractures. The results of stratigraphic modeling are presented in Figures 6 and 7.

2.3. Creating a grid model (3D-Grid)

On the basis of the structural model, a grid model was constructed, which is a three-dimensional grid consisting of cell sets in X, Y, and Z coordinates (Table 1), each cell of which is characterized by a rock feature (reservoir-non-collector) and values of reservoir rock properties (initial gas or oil saturation, porosity, permeability). The choice of the sizes of meshes of three-dimensional geological models was made, proceeding from the distances between the wells. The horizontal dimension of the cells along the X and Y axes was 100 x 100 m for all the layers. The selected step is optimal with the existing grid of exploratory and production wells.

The grid is divided vertically in 3D modeling in accordance with the accepted model of sedimentation. On the considered deposit, a model with a conformal bedding of the layers relative to the roof and the base of the formation was adopted. Therefore, in our case, the volume between the structural surfaces is divided into an equal number of interlayers with a proportionally varying thickness. The average thickness of the layer was chosen as a result of an analysis of the degree of dissection of the section, the degree of reliability, so that the vertical thickness of the cell did not exceed 0.4 m, and the average value of the cell height was 0.3 m, which provides sufficient detail for the model.

It should be noted that, as already noted above, a system of tectonic disturbances was adopted along the Jurassic group of reservoirs. In this connection, in the construction of the 3D-geological grid of the Jurassic layer of beds, an option of unstructured grids was chosen. Moreover, the sides of the cells are chosen to be oriented parallel to the fault lines. Thus, the surface of tectonic disturbances is one side of adjacent cells. The other sides of the adjacent cells and the sides of the other nearest cells are not oriented parallel to these tectonic disturbances. The result of this stage of work was a rebuilt grid structure, intended for further facial and petrophysical modeling of properties.

2.4. Construction of a lithological model

The creation of a lithological model is the first step in parametric modeling. In the modeling of this deposit, two types of rocks were conventionally identified: a reservoir and a non-collector. The construction of the lithology cube was carried out for each layer in several stages:

1) By the method "lithology curve" the RIGIS data was transferred (averaged) to grid cells along the well trajectory (Figure 8).

2) Using the "Kriging interpolation" method, an "NTG" cube of sand in a 3D grid was calculated.In this case, as a horizontal trend, sand maps were used. Trend maps of sandiness were constructed for each layer by dividing the maps of the principal effective thickness into maps of common stratigraphic thicknesses obtained from the structural framework of the 3D model;

3) Using a special program (plug-in), a discrete lithology cube "LITO" was created, so that the sand maps obtained from the 3D cube corresponded to trend maps of sandiness as much as possible. At the same time, the value of the collector / non-collector cutoff was different and was selected individually for each column of the grid;

4) The cube was then smoothed to remove individual unconnected cells. The quality control of the lithology cube was made by comparing the geological and statistical sections (CSR) of the lithology cube and the "scale-up" well data, the degree of conservation in the GSR of the cube of lithology was checked for the regularities of cyclicity, the presence of bridges, the change in the share of the reservoir along the layers inherent in the GSR by the wells (Figure 9).

Also at the first stage of building a cube of lithology, the RIGIS data on porosity and oil saturation were averaged. On geological and statistical profiles for some formations, the discrepancy between the distribution curve of the reservoir over the layers in the model and the curve constructed from the RIGIS data averaged over the grid cells is observed. One of the reasons for such discrepancies is the influence of the clay zones, near which there is a decrease in effective gas-saturated thicknesses, and, consequently, an underestimation of the share of the reservoir in the model (layer U_1^2). Another reason is the uneven network of wells over the area of the field, which leads to an overestimation or underestimation of the share of the reservoir in the model in comparison with the well data due to a larger radius of distribution of the lithology parameter in areas with a low density of well placement. For example, in the U_1^1 formation (Figure 9a), the discrepancy between the GSR for the model and for the RIGIS is due to the influence of the marginal wells (Nos. 31, 8, 18, etc.) located in the low-drill areas. In this case, the wells have maximum thicknesses according to GIS, which is isolated practically along the entire thickness of the section.

In layer $U_1^{3-4,}$ there is a reverse situation with an underestimation of the reservoir fraction in the model in comparison with the GIS data. In the central part of the stratum U_1^{3-4}, a zone with small effective thickness values is traced, which is caused by the claying of the central part of the section of the U_1^{3-4} formation. In the lithology cube, these are layers 39-62 (Figure 9c). Since the distances between the wells are sufficiently large in the considered section, the radius of propagation of this zone along the area turned out to be large and the volume of the non-collector cells is comparable to the volume of the reservoir that is distributed in the area with a sufficiently dense net of wells.

In addition, the average values and behavior of isopachytes of trend charts of effective thicknesses were constructed from RIGIS data and maps obtained from the lithology cube in the model. In addition, a visual check of the cross sections of the cubes (I, J and K slices) was conducted to assess the correctness of the distribution of the reservoirs in the volume of the reservoir.

2.5. Petrophysical modeling

After the analysis of the fluid contacts, the contact surfaces for each layer were constructed and a cube of the saturation index of the reservoir rocks was created (Figure 10). For this purpose, an auxiliary cube of the height of the center of each cell relative to the surface of the interfluid contacts was originally constructed, where the cells below the contact were assigned the value "0", the remaining cells remained at altitudes. Further, if the cell with the collector (in the "Lito" cube) had a positive value according to the aforementioned auxiliary cube, the cell in the "Saturation" cube was assigned an index corresponding to the saturation of the gas or oil, otherwise the cells in the lithology cube were assigned an index, corresponding to saturation "water", cells with non-collectors - an index with the value "non-collector".

Then the cube of saturation ("Saturation ") was reviewed. In case of unreasonable pooling or distribution of deposits over the area, either the surfaces of interfluid contacts or the structural surfaces were locally corrected. A deterministic approach was used for petrophysical modeling. When interpolating; the values in the wells do not change. Interpolation never yields parameter values that go beyond the range of the original values. When interpolation is removed far from the well, the resulting parameter values will be approximately equal to the average value of the original values.

At the stage of modeling the distribution of porosity, the interpolation of parameter values was performed only for the volume of rocks determined at the stage of lithological modeling as a collector. As initial information in the simulation of the porosity parameter, GIS material processing data was used. The construction of the cube of the porosity coefficient (Figure 11) was carried out by interpolation ("Kriging interpolation") parameter in the inter-well space. As a horizontal trend, a two-dimensional porosity map was used, calculated on the basis of the averaged values of the porosity of collector layers along the wells.

An estimation of the quality of the construction of the porosity cube was carried out by visual control of the cross sections of the porosity cubes; Comparison of the minimum ("min"), maximum ("max") and average values ("mean") of the RIGIS and the model, and also by comparing the GSR of the porosity cubes and the wellbore data averaged over the grid cells (RIGIS). In addition, an assessment of the quality of averaging of RIGIS data into cube cells was performed by comparing the weighted average values of the porosity coefficient calculated from the RIGIS and obtained from the model along the well trajectory ("scale-up").

The grid model of the oil saturation and gas saturation coefficients (Figure 12) was plotted using a stochastic petrophysical modeling (Stochastic Petrophysical Modeling) module. This method is designed to generate a realistic distribution of the petrophysical parameter in the inter-well space based on borehole and seismic data, as well as the patterns of distribution of this property. The patterns of distribution are determined by the degree of spatial correlation, based on the fact that the similarity between two points in space is the greater, the smaller the distance between them. As a horizontal trend, a two-dimensional oil and gas saturation map were used, calculated on the basis of the averaged values of the saturation of reservoir strata along the wells.

CONCLUSIONS:

Geological modeling at the present stage of development with the use of computer technologies requires the formalization of a number of procedures, the correspondence of modeling techniques to general scientific approaches and principles. The complexity of the technological cycles in the creation and maintenance of digital geological models requires an assessment of the reliability of model parameters, the introduction of parameters in the model for estimating confidence intervals of parameters. The introduction to the practice of modeling probabilistic approaches allows us to formulate new requirements for the developers of computer programs both at the stages of the direct creation of models and at the stages of compiling interpreting and interpolation programs.

As a result of the performed studies, a functional model of the process of three-dimensional geological modeling using IDEF0 notation was created using the BPW in the software of the All Fusion line of Computer Associates. In the Russian Federation, the IDEF0 methodology has not yet been approved as an industry standard. Nevertheless, it is a promising direction for describing the processes of three-dimensional geological modeling. The use of this methodology makes it possible to optimize the process of geological modeling and significantly reduce the time spent on building a geological model of a specific productive object.

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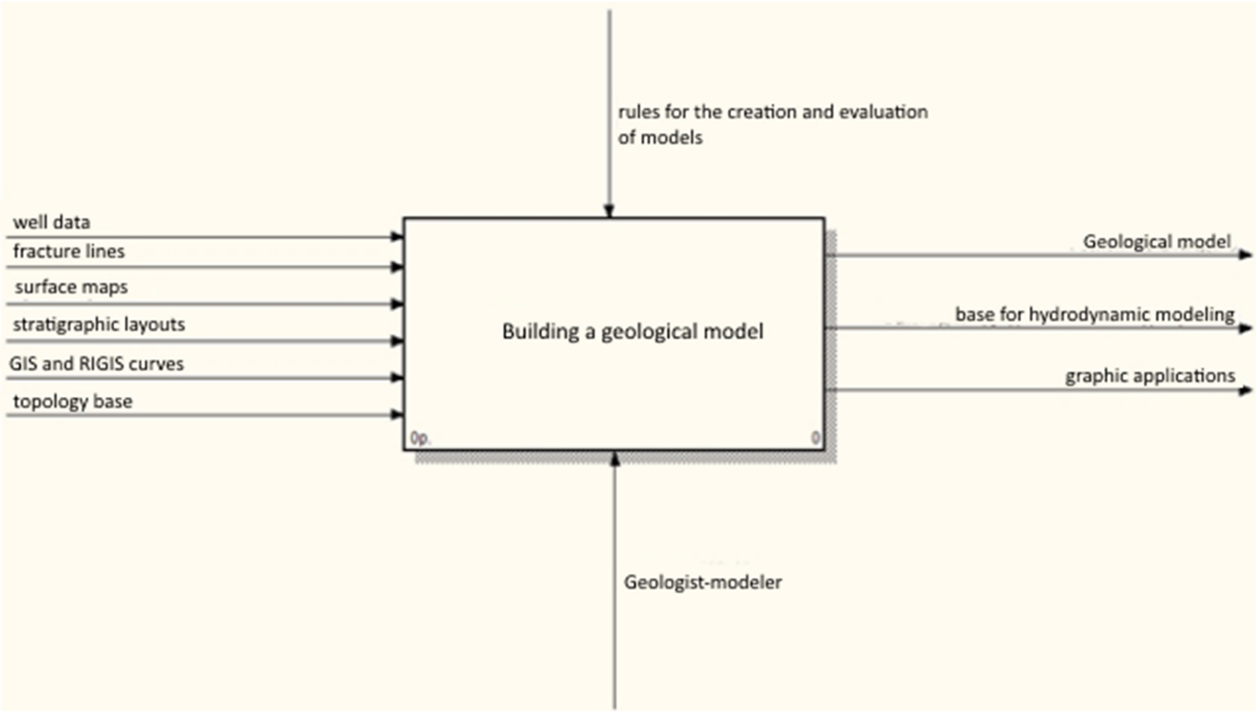

***Figure 1**. Model of the process of building a geological model*

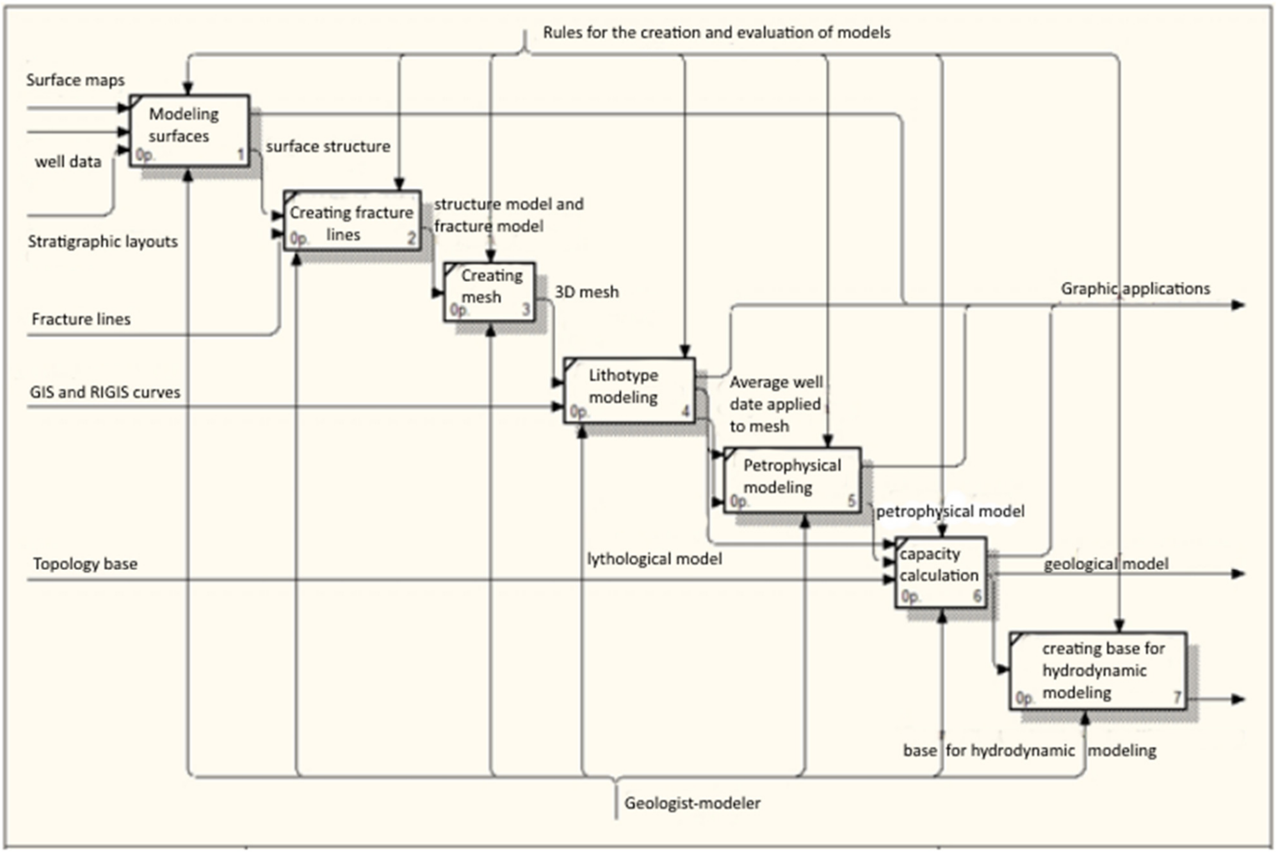

***Figure 2**. Decomposition of the block "Construct a geological model"*

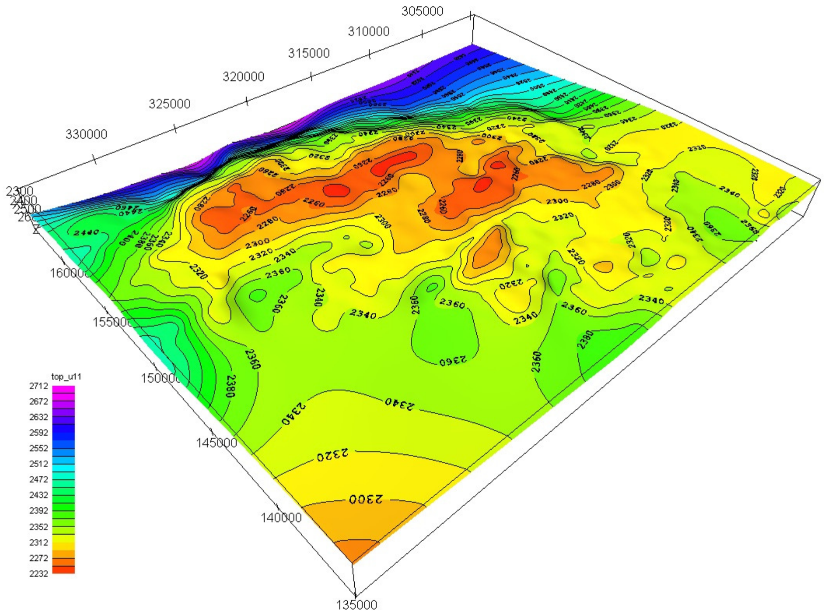

***Figure 3**. The structural map on the roof of the seam U_1^1*

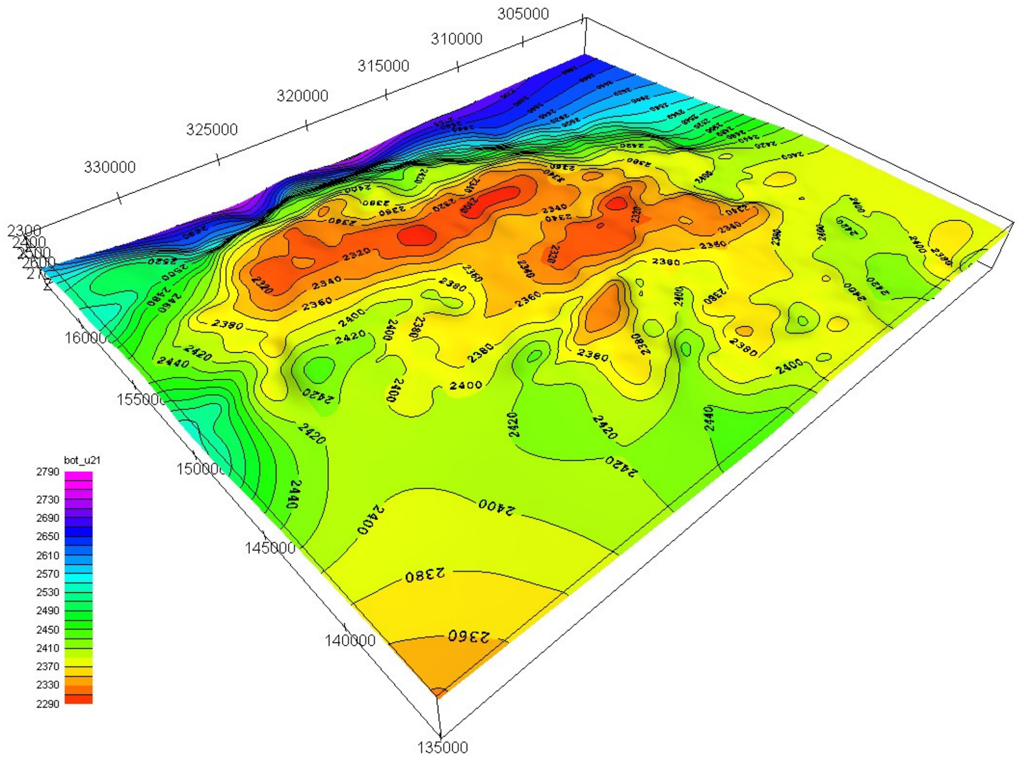

***Figure 4**. The structural map on the base of the U_2^1 formation*

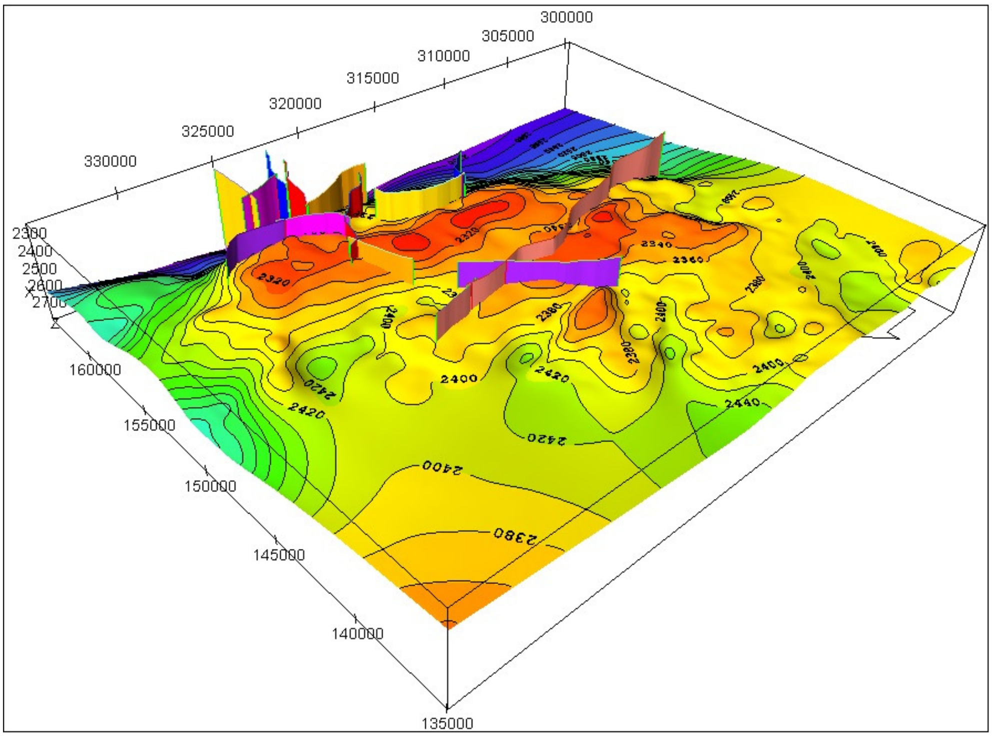

***Figure 5**. Resulting model of fractures*

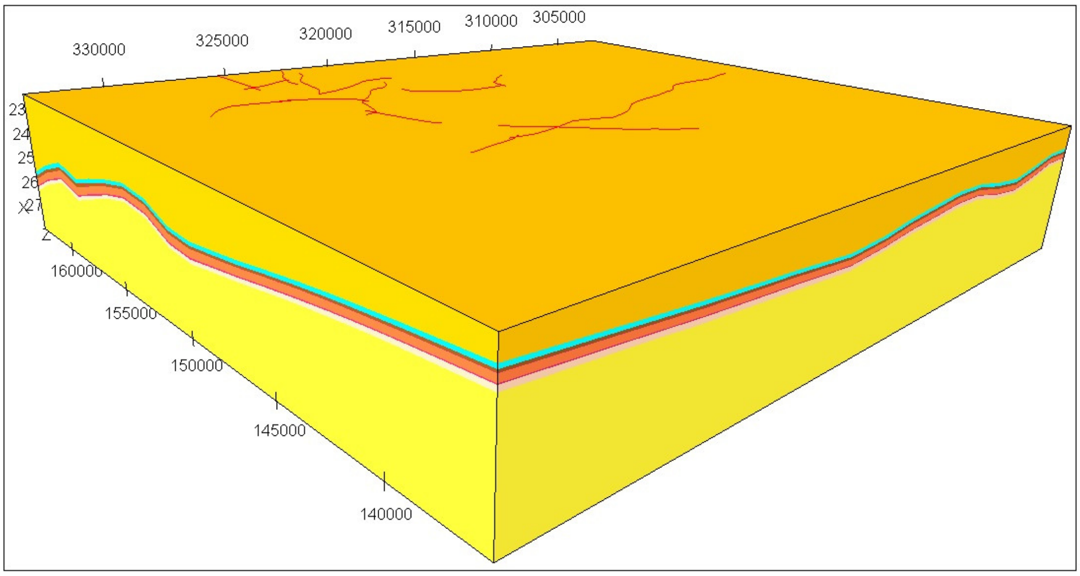

***Figure 6**. Layers of the stratigraphic model*

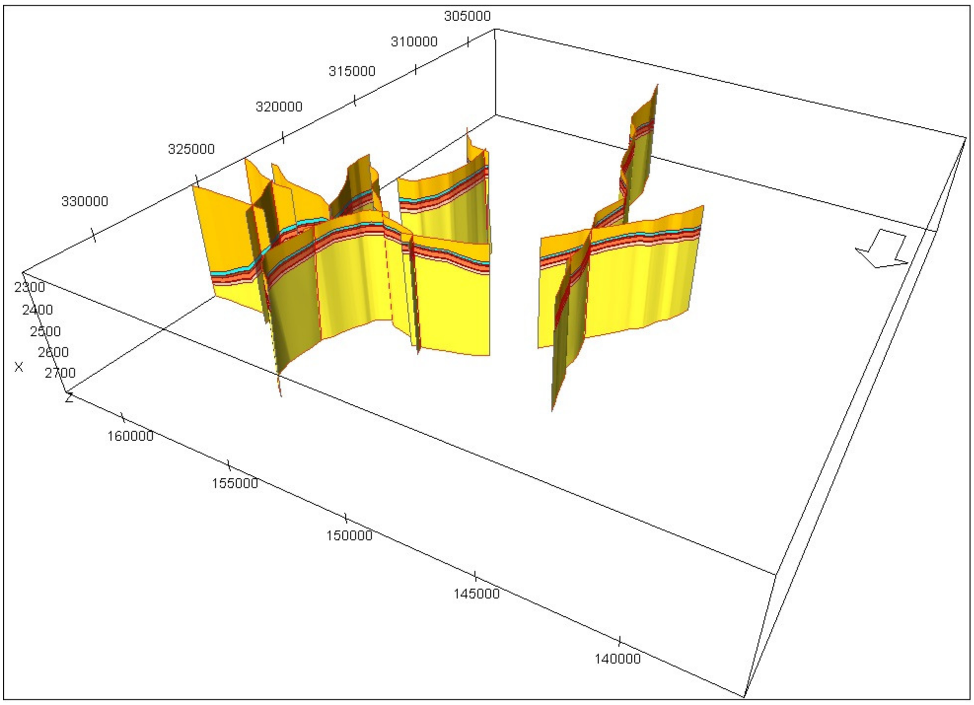

***Figure 7**. Projection layers of the stratigraphic model on the surface of fractures*

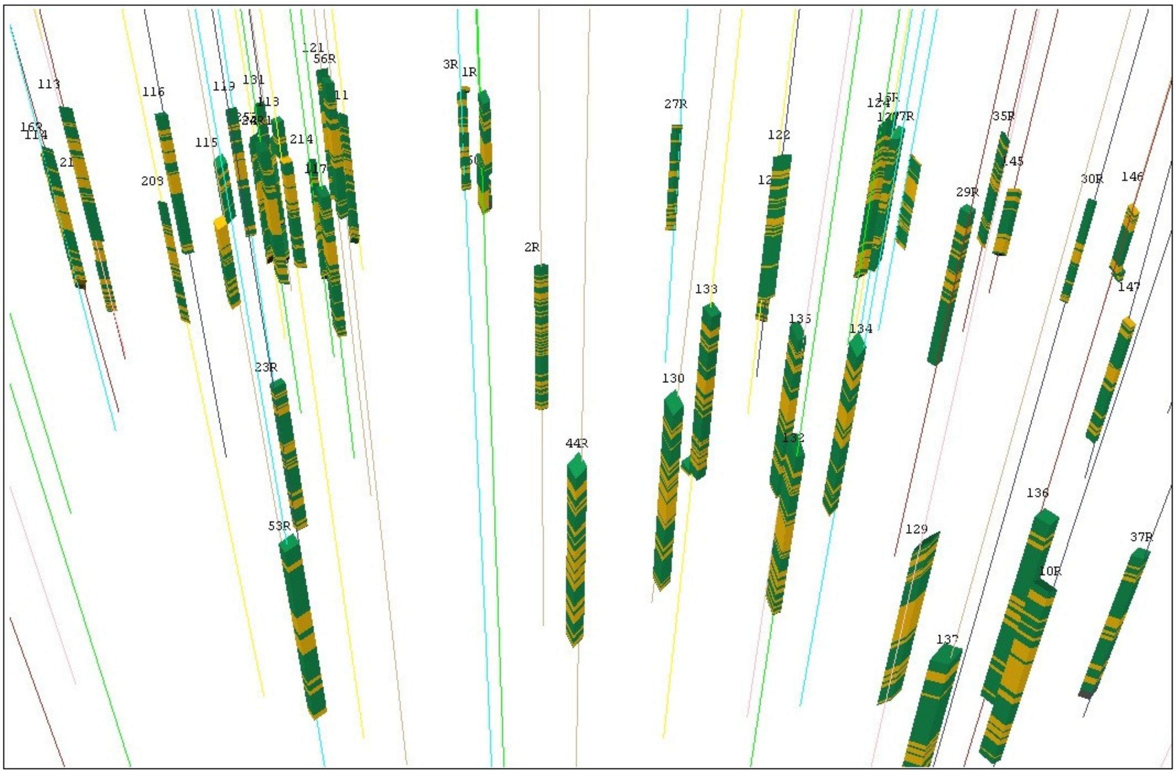

***Figure 8.** Average on the grid, the lithology curve*

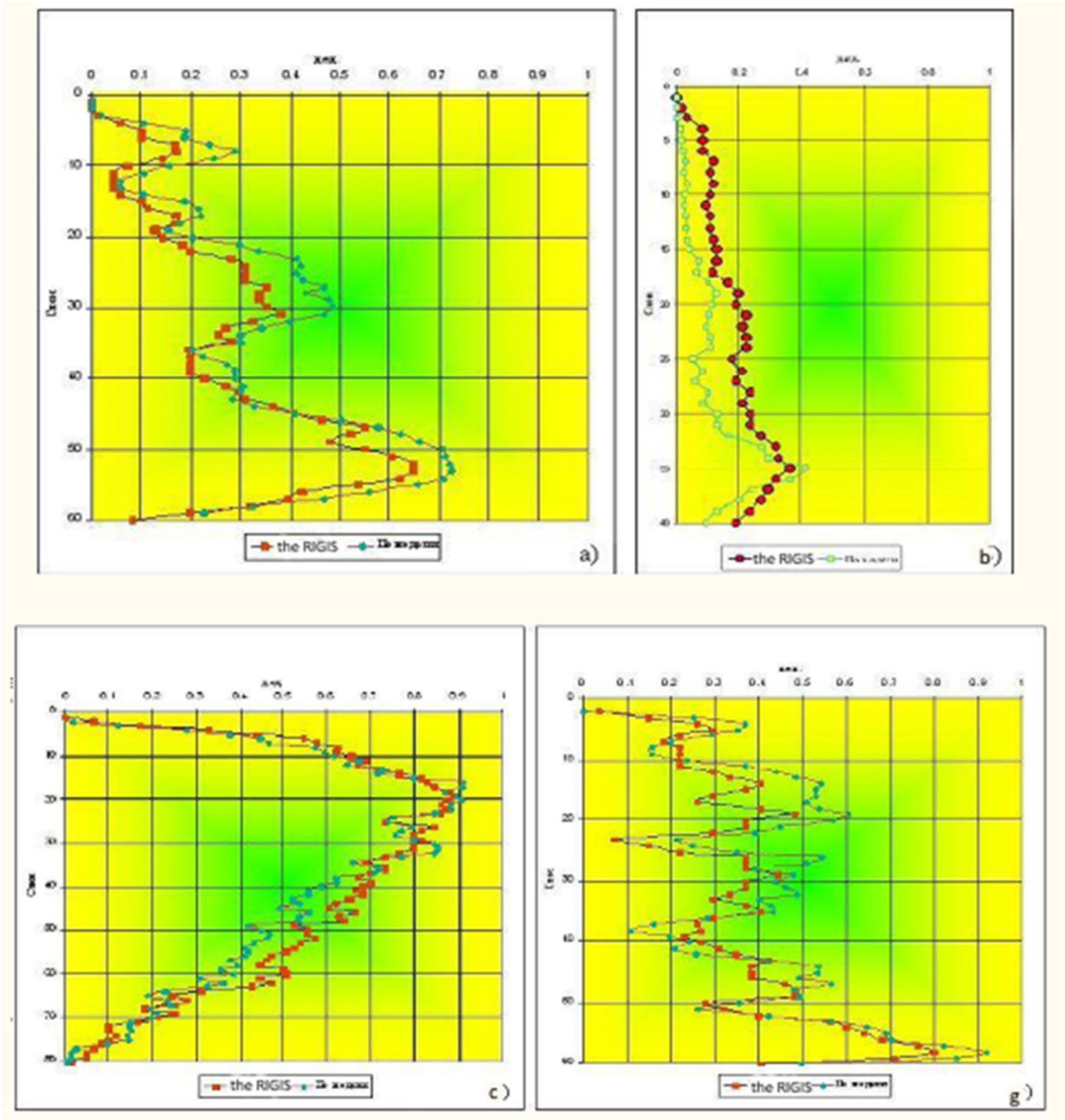

***Figure 9**. Comparison of GSR on the lithology: a – for the formation U_1^1; b – for layer U_1^2; c – for layer U_1^{3-4}; g – for layer U_2^1*

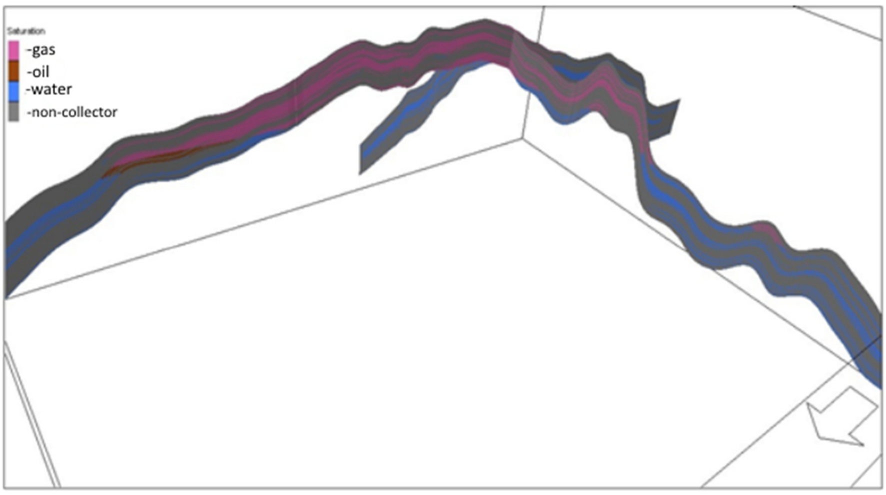

***Figure 10**. Fragment of the cube of saturation*

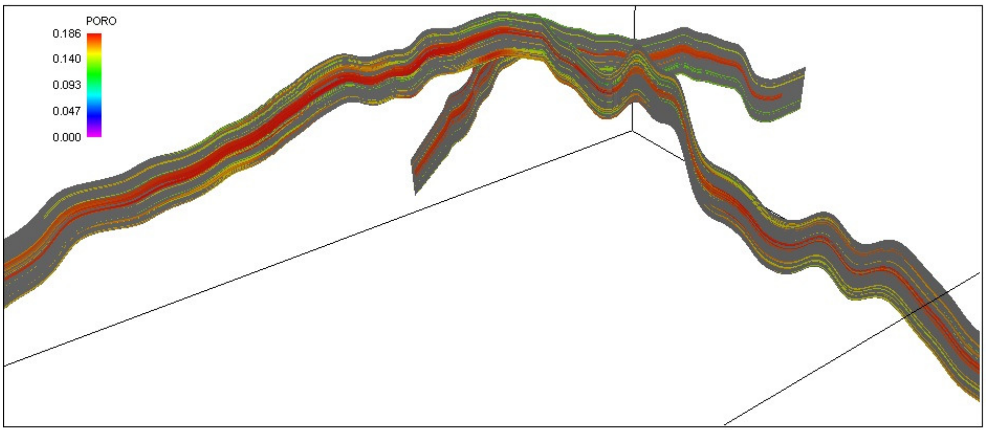

Figure 11. *Fragment of a cube of porosity*

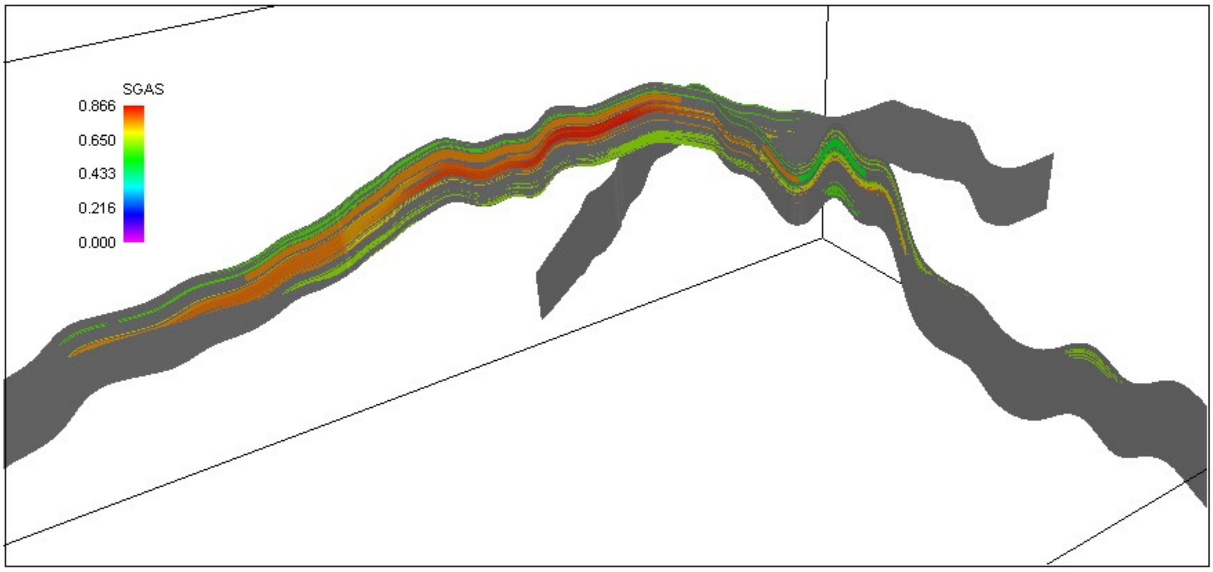

Figure 12. *Fragment of the cube of gas saturation*

Table 1. *Characteristic of the meshes of 3D geological model objects*

An object	The dimension of the grid is X × Y × Z	Number of cells
U_1^1	268 × 308 × 60	4952640
U_1^2	268 × 308 × 40	3864460
$U_1^{3\text{-}4}$	268 × 308 × 80	6603520
U_2^1	268 × 308 × 60	5040600