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Integration of a Low Gas-Saturated Zone in Creating a 3D Model of the Medvezhye Field

Artem Shirjaev[1], Yuri Vaganov[2], Vitaliya Naumenko[3]
[1,2,3]Laboratory for Workover Technologies and Well Stimulation, Tyumen Industrial University, Russia
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Abstract
3D geological modeling is an integral part of reserves estimation and project documentation for the development of gas and oil fields. The developed 3D geological model of the Cenomanian productive complex including the low gas-saturated zone of the Medvezhye field represents a combination of data from the drilling of 350 wells, the structural features of the reservoir, permeability properties determined on cores, seismic surveys, and the results of geophysical well surveys. Based on examining the available well logs recorded in the Medvezhye field wells, the low gas-saturated zone is integrated into the construction of the 3D geological model of the Medvezhye field of the Cenomanian productive complex. A total of three models are constructed, and a 400*400*0.4 m grid is recommended for further hydrodynamic modeling. A comparison of the three grids suggests that a more detailed model delivers more thorough results, however, heavy models cannot be applied to hydrodynamic modeling. Resource estimations do not differ across the three grids significantly.

Keywords: 3D geological modeling, gas, Cenomanian deposits, low-pressure gas

1. Introduction

Cenomanian deposits in the north of West Siberia contain Russia's largest gas reserves (Ulmasvai et al., 2008). Fields unique by their reserves, such as the Vyngapurovskoye, Medvezhye, Yamburg, Urengoy, Komsomolsk, and other fields of the Nadym-Pur oil and gas bearing area, are in the final stages of development. The factors complicating production in these fields are outlined by A. A. Khakimov and I. I. Gurbanov (2016). Using the development of the Urengoy field as an example, it is demonstrated (Evlikova et al., 2014) that despite the efficiency of the adopted system and correct technological and technical solutions, the issues of reaching maximum gas recovery still stand. Importantly, the rational use of subsoils is among the mandatory aspects of performing extraction in the Russian Federation (Supreme Council of the Russian Federation, 1992, Article 23), and low-pressure gas is becoming one of the leading directions in the energy sector. Low-pressure gas refers to gas that is unprofitable to extract and transport. A detailed examination of the varying interpretations of this concept is presented in several studies (Avilenko, 2018; Kusov & Savenok, 2020; Sarancha & Sarancha, 2014). The reserves of this gas are extensive, which is why its extraction is drawing increased attention. We consider the identified low gas-saturated zone as a type of low-pressure gas.

The relevance of the study is determined by the broad use of geological modeling as a method of studying oil and gas fields. At present, per methodological recommendations, all project documentation for the development of oil and gas fields in Russia needs to be prepared on 3D geotechnological models (Zakrevskii & Popov, 2021). This is also the case in other countries (Görz et al., 2017; Meulen et al., 2013). In addition, models are used not only for resource estimation but also for identifying problems in the drilling and development of the fields (Radwan, 2022). 3D geological models are a digital representation of the structure and properties of subsoils (Nurgatin & Lysov, 2014; Wang et al., 2018). The study of geological structure with the construction of 3D geological models of exploration areas based on generalized data of analog fields, seismic data, and lithological and facies analysis is relevant and economically viable (Zakrevskii et al., 2008).

The purpose of this study is to integrate a low gas-saturated zone in creating a 3D geological model of the Cenomanian productive complex of the Medvezhye field.

2. Methods

Identification of the Low Gas-Saturated Zone

In the study of materials on the Medvezhye field, some data were discovered indicating the presence of a low gas-saturated zone in several wells. Geological and geophysical characterization of the Cenomanian productive strata of well No. 30H of the Medvezhye field established the presence of a low gas-saturated zone with induction logging at ρ_f=4.8 in the depth interval along the borehole between 1,164.5 m and 1,169.9 m. At ρ_f=3.5 there is saturation with water. However, collectors at the depth of 1,152.5-1,164.5m with similar induction probe readings and ρ_f=4.6-4.8 showed no low gas-saturated zones.

Analysis of data for well 10P of the Medvezhye field from the geological section, where the test intervals were plotted, showed that gas flow was obtained from the interval of 1,142.2-1,145.7m, confined to the water-saturated zone, 3 m below the accepted gas-water contact. Reserve estimations suggest that this owes to a gas breakthrough from an interval above. No water inflow was obtained. However, the gas inflow was several times lower (104.29 thousand m^3/day, while in neighboring wells, the inflow rate was over 1,000 thousand m^3/day). We attribute this fact to the presence of a low gas-saturated zone in the section. The border of the low-gas saturated zone can be taken based on the upper mark of perforation and updated when new a priori information is obtained. The thickness of the low gas-saturated zone in this well can be assumed to be 10.2 m. The reserves estimation data indicate a deterioration of permeability properties at the contact boundaries (the presence of clay interlayers was detected). The gas-water contact boundary was at 1,127-1,142 m, which also indirectly indicates the presence of a low gas-saturated zone in the section.

In well 12 of the Medvezhye field, the bottom of the maximum gas-saturated zone was marked at a depth of 1,131.8 m, the roof of the low gas-saturated zone – at 1,132.2 m, the bottom of the low gas-saturated zone – at 1,134.4 m, while the roof of water-saturated reservoirs was marked at 1,143.6 m. Thus, the thickness of the low gas-saturated zone according to the well data can be considered from 2.2 to 11.8m. In well 835, the bottom of the maximum gas-saturated zone was allocated at a depth of 1,139.4 m, the roof of the low gas-saturated zone was accepted at 1,139.8 m, and its bottom – at 1,141 m, along with the roof of water-saturated reservoirs. The thickness of the low gas-saturated zone can thus be taken to be 1.2-1.6 m. In well 425, the thickness of the zone was 1.4m. In well 84M, characterized by qualitative geological and geophysical data, the thickness of the low gas-saturated zone was 29.4m . Well 16M is characterized by studies showing that the thickness of the low gas-saturated zone amounted to 2 m. Thus, having analyzed all the materials, we concluded that it is possible to integrate the low gas-saturated zone into the 3D geological model. The thickness of the zone should be assumed to be equal to the weighted average value of 18.2 m. Due to the possible error in inclinometry, which is normal even in well drilling and geophysical well surveys to this day, given that at the time of drilling the wells in question the technologies were far from modern and due to the low resolution of logging devices, the real thickness of the low gas-saturated zone can be estimated to be somewhat greater than indicated by the examined reserves estimation.

The character of resistance change with depth to the gas-water contact level can be estimated by the methods of lateral logging, apparent resistivity (1.05 m), and induction logging if relevant measurements can be made in the well. Considering the variation of resistivity with depth in the Cenomanian deposits, the available logging diagrams show a tendency of decreasing resistivity towards the zone in which the resistivity is higher than the boundary resistivity (set in the potential probe), but the value of which stands out significantly in comparison with the resistivity of overlying rocks. An example of such a zone is highlighted in Figure 1, and this zone can be defined as low gas-saturated.

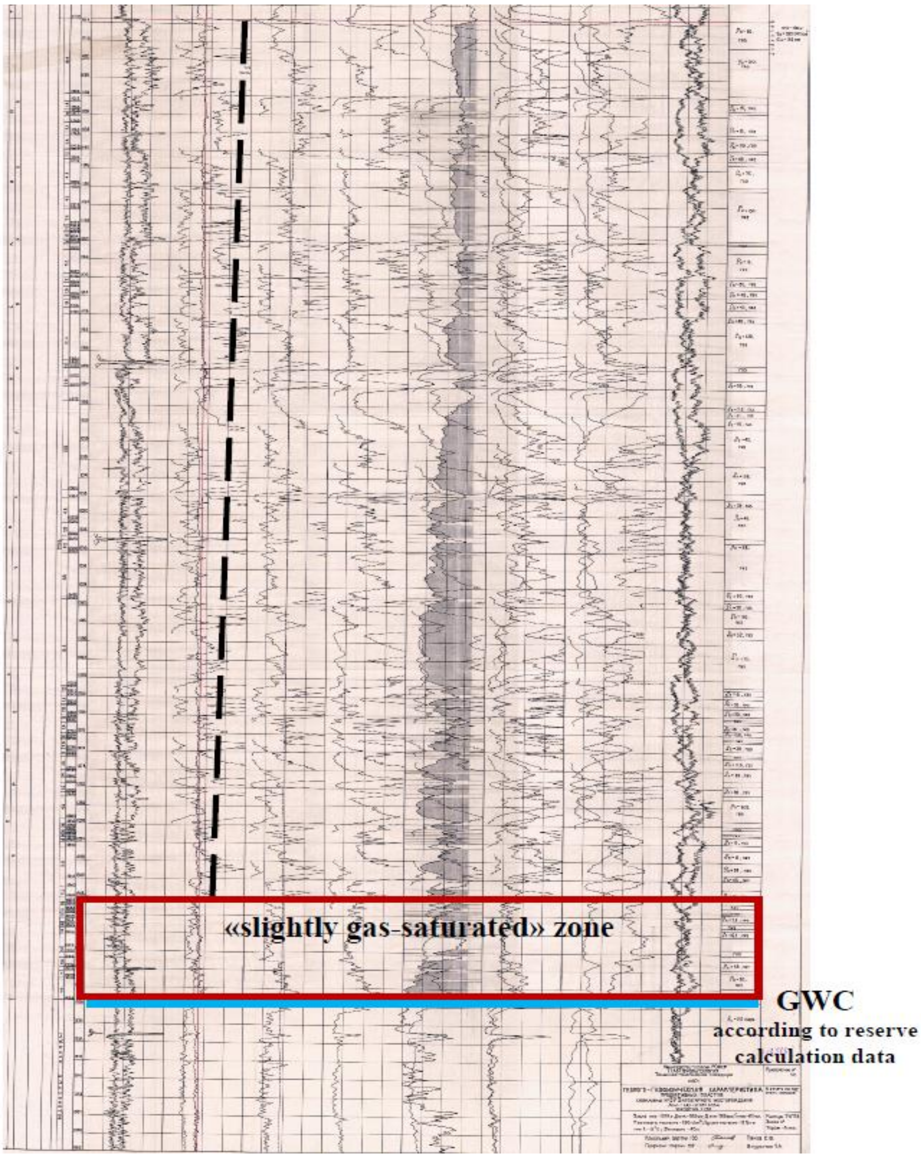

Figure 1. An example of identifying a low gas-saturated zone from the data of electrical GIS methods. The black line is the trend of resistivity change with depth

Analysis of Initial Data and the Methodology of Modeling

Based on the analysis of available information, it was decided to form the database for modeling using the data from the reserves estimation, which undoubtedly entails certain limitations in terms of the completeness of the volume of data for research and processing. For example, there was no numerical data at our disposal but only indirect data presented in tabular and graphical form. As pointed out by D. A. Kazanskaya et al. (2019), any indirect information other than the a priori information available should be considered for model construction. Some model accuracy can also be achieved from indirect information since some of the information is reflected in reserve estimates.

The available data show that only six wells have penetrated the section below the Cenomanian bottom, which will further complicate the construction of the 3D geological model. Also important for the subsequent modeling is the fact that the considered stratum has a rapid change of clay-silt-sand sediments, which is an aspect that complicates correlation. Based on these data, it was decided not to distinguish the strata within the Cenomanian productive complex when building the 3D geological model, and when modeling the structural framework, the roof of the Cenomanian sediments was taken as a basis without considering the position of the bottom of the Cenomanian sediments stratigraphy, as it is located significantly lower than the position of the gas-water contact in absolute elevations. In addition, data on the opening marks of the bottom of the Cenomanian stratigraphy are available for a much smaller number of wells than were drilled at the time of compiling the materials for the reserve's estimation. Given the needs of the subsequent hydrodynamic modeling, the base of the structural framework was built conformally to the roof of the Cenomanian sediments so that the thickness of the water-saturated reservoir was no less than 20 m.

Due to the lack of information on the presence and position of disjunctive dislocations, information on tectonics in the Medvezhye field has not been considered and analyzed. Regarding seismic studies, the reflecting horizon G is confined to the roof of productive sediments, and a map of the reservoir roof was constructed based on the interpretation of seismic studies of the investigated area and well-drilling data. In this connection, seismic surveys have not been analyzed separately either.

Based on the analysis of well drilling data in the absence of inclinometry information, a decision was made to build the 3D geological model using absolute marks. According to the available data (both the measured depth and absolute marks) on the roof stratigraphy of the Cenomanian productive complex and its reservoir roof, the collector in the Cenomanian starts from the reservoir roof. This fact is well-correlated across wells and is traced by the drop in gamma-ray log values and confirmed by micro-logging data, i.e., the presence of increments between micro-gradient probing and micro-potential probing data.

Proceeding from the works by theorists and practitioners and from our own experience of geological modeling, we made preliminary conclusions about the possibility of creating a model in the conditions of limited geological and geophysical information (Fadeev, 2022; Ladeishchikov et al., 2022; Zakrevskii, 2009). It is necessary to obtain wellhead coordinates, inclinometry, well geophysical survey curves, interpretations of geophysical surveys, well-by-well breakdowns of stratigraphy and collector roof and bottom, and gas-water contact marks (this study will identify the bottom of the maximum gas-saturated zone, the roof of the low gas-saturated zone, and the roof of the water-saturated zone). These data are the minimum set of information for creating the structural and permeability components of the 3D geological model. In addition, modeling can use the results of seismic studies interpretation, core studies, saturation contour polygons, and average sandiness, porosity, saturation, and trend maps. The condition for this is that it is not the first time that reserves have been estimated for this model, or no new wells have been drilled and/or no re-interpretation of previous seismic well surveys has been performed since the previous reserves estimation, or it may be performed again and to a fuller extent with more accurate modern instruments, based on the interpretation of which the permeability characteristics of the rocks and, therefore, the volume of hydrocarbon reserves, may change.

3. Creation of the 3D Geological Model

Structural Framework

The structural model is the first step in building the geological model. It is a set of interconnected surface maps of the studied horizons (Bulygin et al., 2011). For modeling the structural framework, tabular and graphical data from the reserve's estimation were taken as a basis. As a result, a structural map of the Cenomanian sediments roof was obtained, which will serve as a basis for further construction of the structure (Figure 2). The position of the gas-water contact was determined based on the results of the materials review and data on stratigraphic intersections. The stratigraphic roof map was built in the Mapping module using the Local B-spline method.

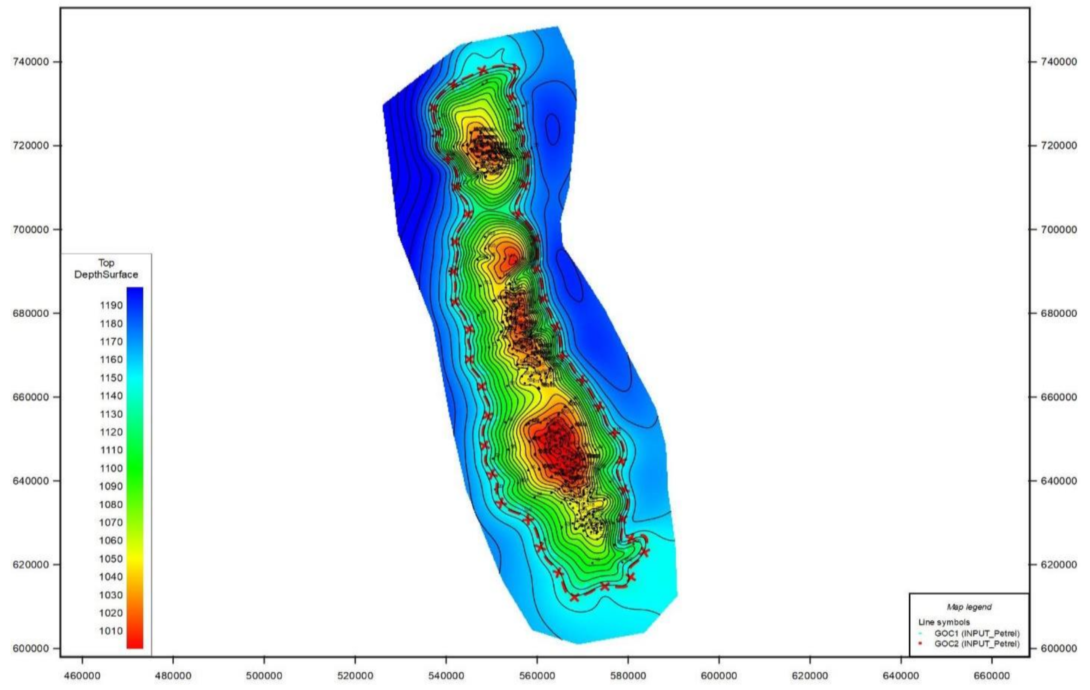

Figure 2. Fragment of the roof map of the stratigraphy of the Cenomanian productive complex of the Medvezhye field

The structural framework is built based on previously constructed stratigraphic surfaces in the stratigraphic framework module (Figure 3). The modeling boundary for further optimization of the creation of the 3D geological model in terms of the number of cells was defined as 2 km from the gas deposit of the Cenomanian productive complex of the Medvezhye field. Structural analysis indicates an uplift in the northern part of the deposit, two small uplifts are observed in the central part, and the highest amplitude structural uplift is dislocated in the southern part of the gas deposit. Thus, it can be concluded that the largest gas-saturated thicknesses of the Cenomanian gas deposit are confined to these structural elements, which can be classified as anticlinal folds.

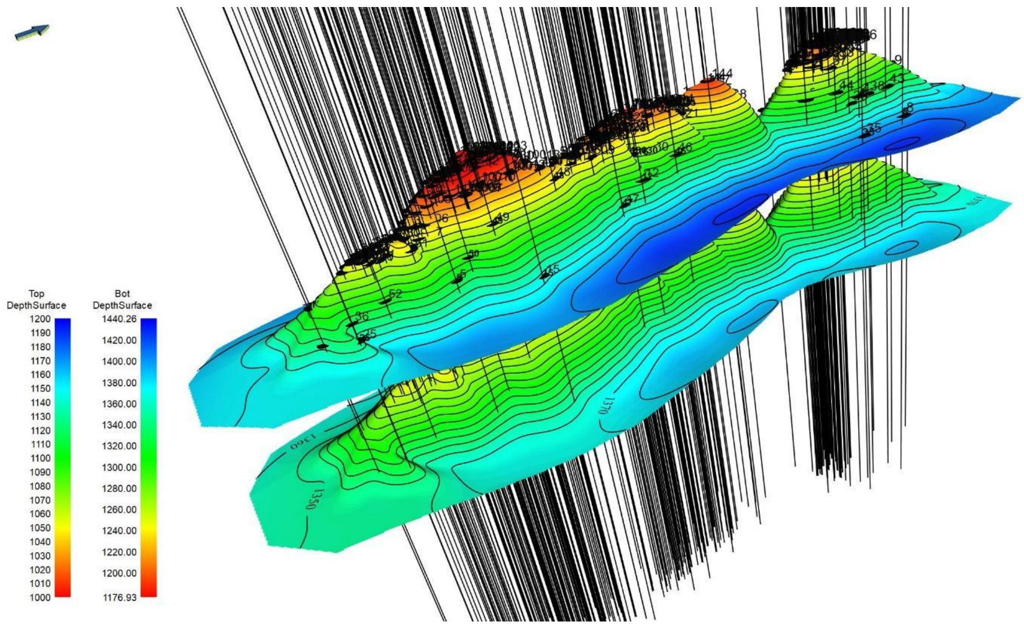

Figure 3. Structural framework of the Medvezhye field and drilled wells considered when creating the 3D geological model

Lithology Cube

After the construction of the structural framework and grid slicing, a probability cube was constructed based on the data on the lithologic features of the gas accumulation in the Cenomanian productive complex of the Medvezhye field. Information from the reserve's estimation suggests that the Cenomanian productive complex of the Medvezhye field is represented by frequent interlacing of predominantly sandy and silty-clay layers. In addition, sandy lenses are also encountered. These factors were considered in lithology modeling (Figure 4).

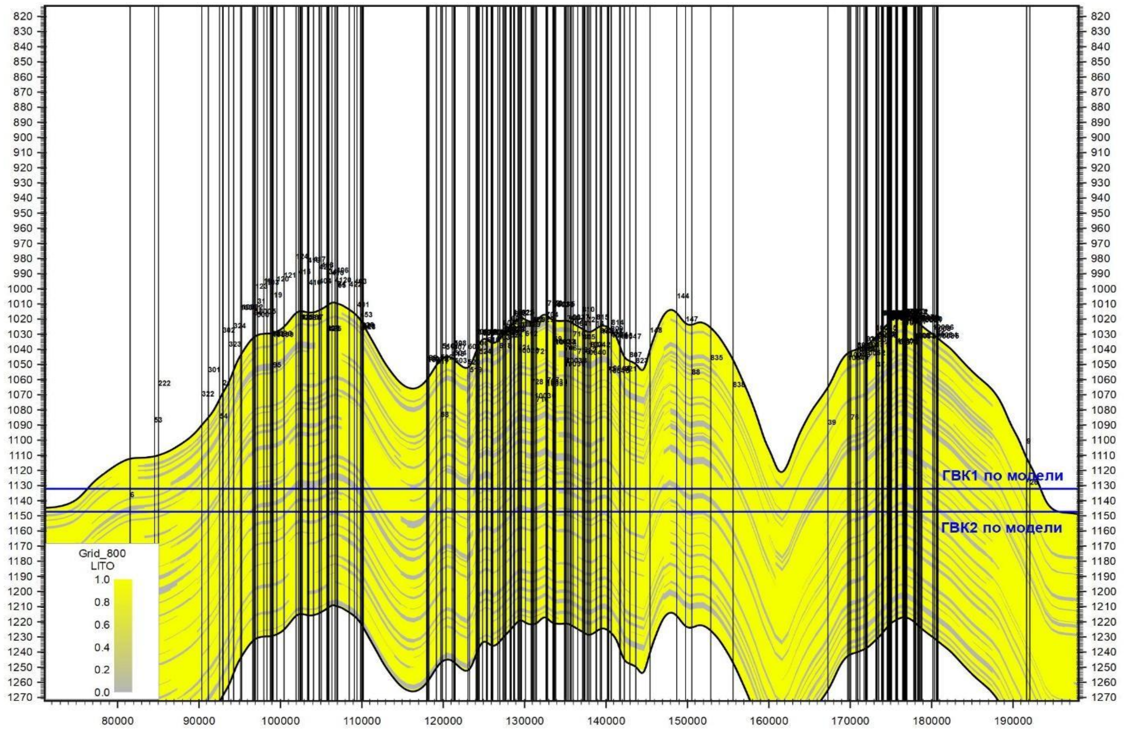

Figure 4. South-north section of the lithology cube through the areas of highest stratigraphic roof elevations from the 3D geological model of the Medvezhye field

Porosity Cube

To preserve the character of porosity distribution over the deposit, a porosity map was constructed in the mapping module using the Global B-Spline method, since the drilled wells are located at a sufficiently large distance from each other with a large area of the deposit to be used as a trend for the construction of the porosity cube (Figure 5).

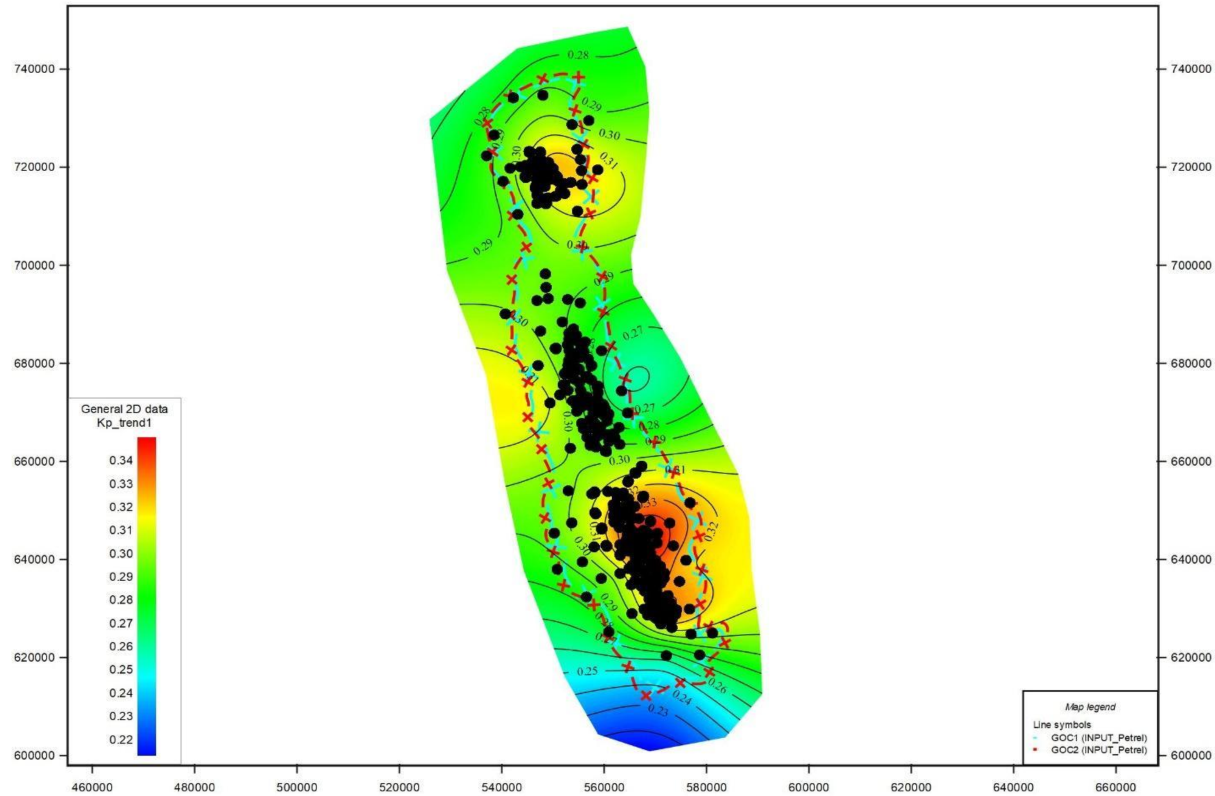

Figure 5. Porosity trend map

The results indicate no change in porosity from south to north or west to east. The maximum porosity values are attached to the northern and southern elevations. In the southern part of the reservoir, the map shows a value of porosity less than 0.22, which is below the border value. However, it is possible to limit the maximum and minimum values in modeling the porosity cube it is possible to limit the minimum and maximum values, which will exclude this discrepancy. It was decided to recognize the porosity trend map as the correct one to be used as a trend for further construction.

Porosity cube modeling was performed in the Petrophysical modeling module. To obtain the most accurate hydrodynamic links between collector interlayers, given the high discontinuity of the section, as well as frequent interbedding of the interlayers with collector permeability properties and the interlayers unable to accumulate and filter fluids, we chose a stochastic method to distribute the data in the uncertainty zone. Analysis of the available geological and geophysical information shows that the maximum and minimum porosity boundary values are 0.2608 and 0.3492, respectively, which is reflected in the module settings in the figure. The average porosity for the Cenomanian productive complex of the Medvezhye field, determined through the analysis of reserves estimation to be 0.31, is also considered. The 2D trend is the porosity map based on the calculated weighted averages of the wells, and the 3D trend is a 3D cube of the elevation above the gas-water contact. The ranks of variograms were chosen based on well drilling data so that the data distribution occupied the entire area of the uncertainty zone, namely, not less than 25 km along the stratification plane and 0.1 m vertically, to thoroughly consider the reservoir discontinuity while avoiding the mutual influence of the interpretations of vertical geophysical studies of the wells. Thus, the 3D porosity cube constructed with consideration of the entire set of geological and geophysical information and multiplied by the previously constructed lithology cube to consider non-collector interlayers not only meets all the requirements of normative documents but contains the entire set of available studies and can be used in resource estimation, in further permeability calculations, etc. (Figure 6).

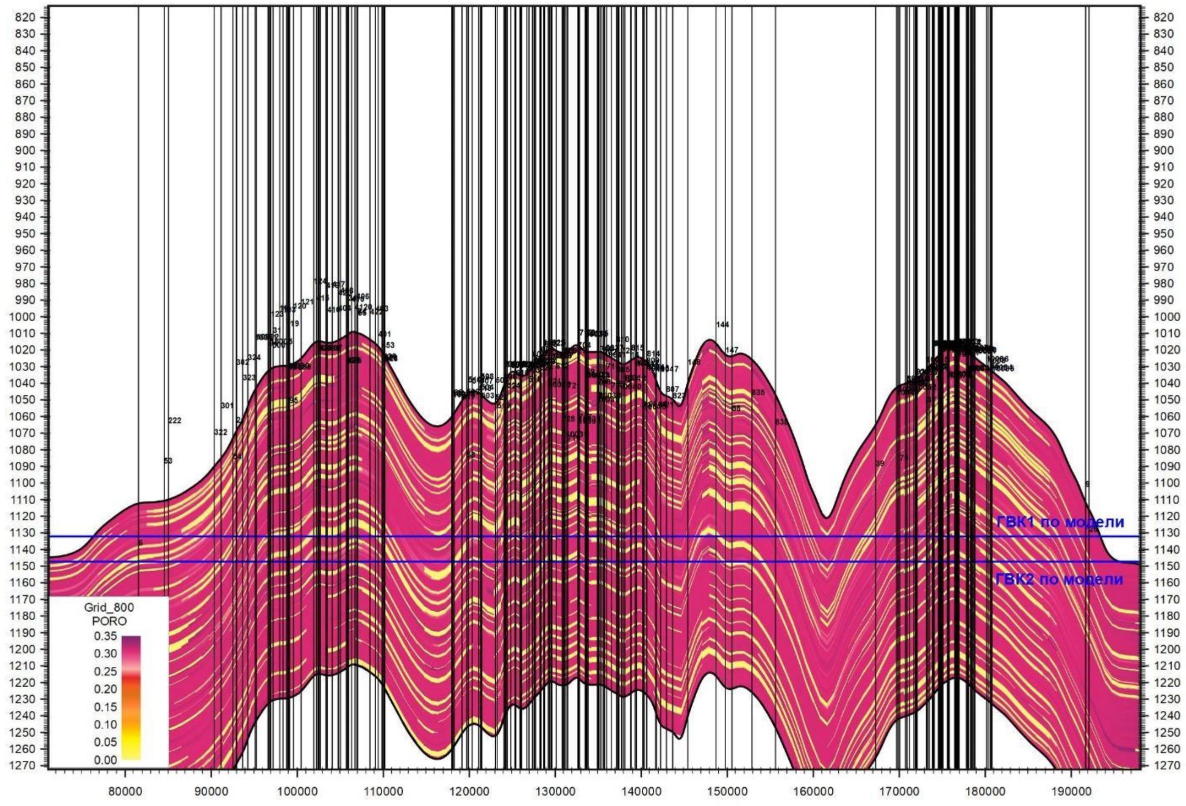

Figure 6. North-south porosity cube section from the 3D geological model of the Medvezhye field

Gas Saturation Cube

Modeling of gas saturation in the 3D geological model of the Medvezhye field is based on the results of the interpretation of geophysical well surveys and core studies. The need to model the low gas-saturated zone is determined by scientific exploration in the unconventional distribution of reservoir rocks of the Cenomanian productive complex. The identification and thickness of the low gas-saturated zone have been described above. Data on residual water saturation were not available, so water saturation was recalculated into gas saturation by formula:

$$Sgas=1-Sw \quad (1)$$

For each well, weighted average values per collector thickness were calculated. A general gas saturation map without differentiation into zones was constructed from the available data (Figure 7). The resulting 2D surface was subsequently used as a trend in gas saturation modeling.

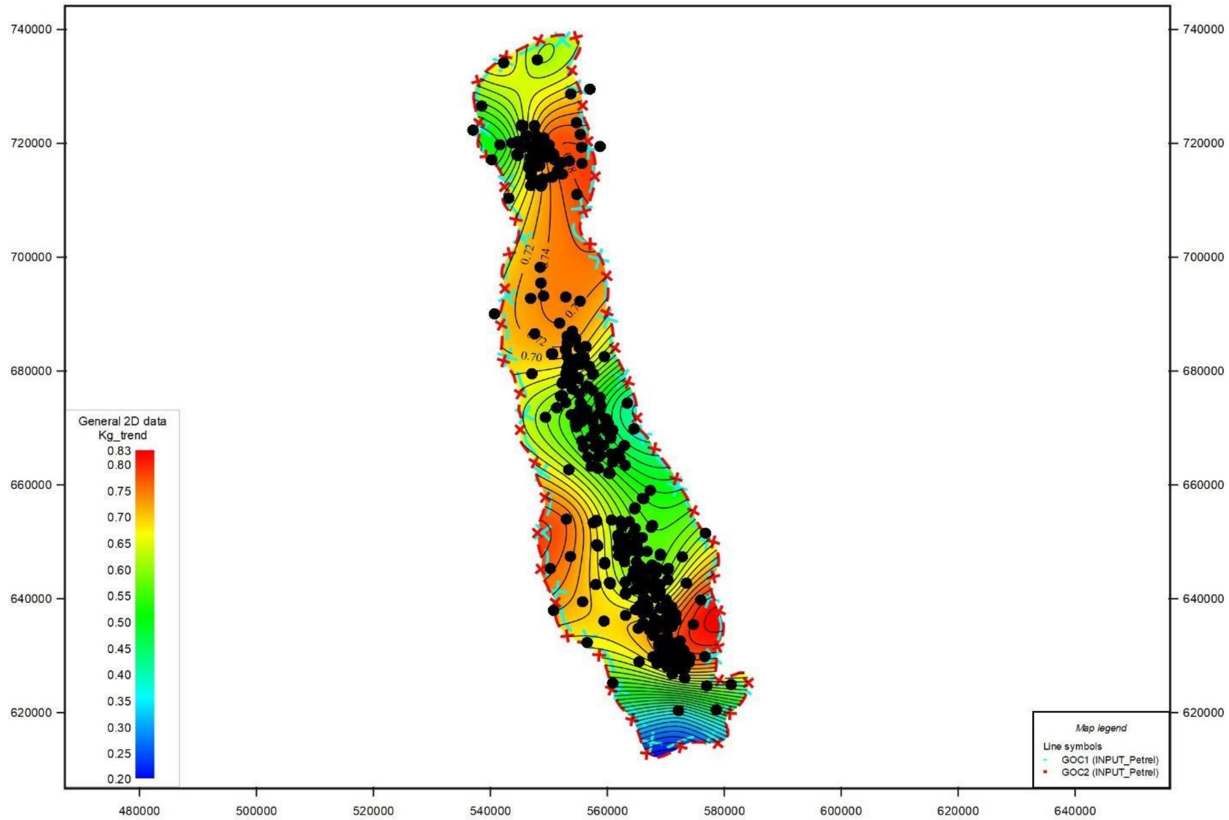

Figure 7. Gas saturation trend map based on available data on gas saturation in the wells of the Medvezhye field

The map shows elevated gas saturation values at the edges of the deposit at the contact boundary, which undoubtedly raises doubts about its accuracy. The southern part of the deposit has values near 0.2, which is below the boundary values. However, this map is constructed without accounting for gas saturation distribution along the section. Nevertheless, this map can be used as a trend with trimming on the boundary values when constructing the gas saturation cube. Gas saturation was modeled in the Petrophysical Modeling module. Variogram ranks were chosen similarly to porosity modeling. The distribution of the saturation parameter was performed using stochastic modeling. In modeling the saturation parameter in the uncertainty zone, the boundary values [0.39; 0.79] were considered. According to the reserve's estimation data, the weighted average gas saturation value is 0.747, which was also considered when creating the saturation cube. The cube of height above the gas-water contact and a 2D trend in the form of the previously constructed map were used as a trend. The low gas-saturated zone has no values in the calculation of reserves. It was decided to take the gas saturation coefficient for the low gas-saturated zone equal to 0.47, similar to the Yamburg field, which has similar sedimentation conditions, and also proceeding from the fact that the Cenomanian Stage in the Nadym-Pur oil and gas bearing area is accepted as a single object of search for gas deposits.

As a result of modeling, the gas saturation cube was obtained considering 2D and 3D trends (Figure 8).

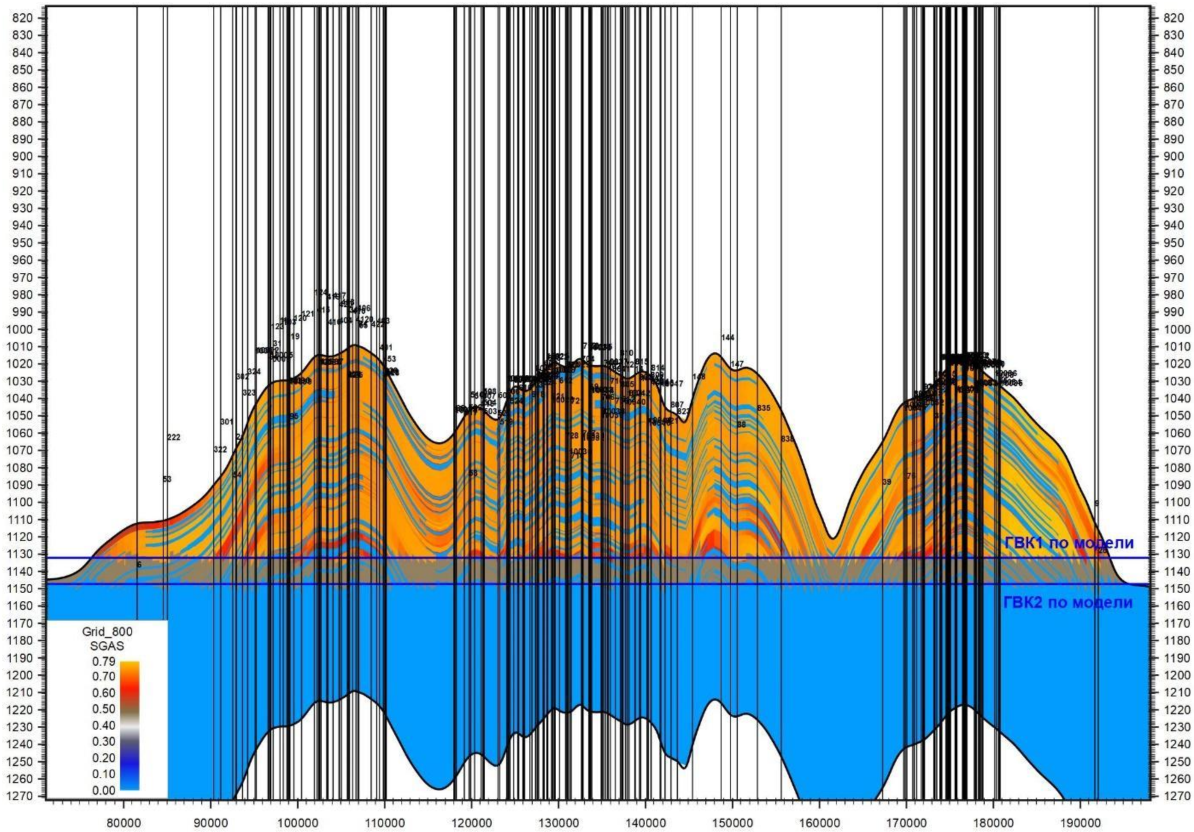

Figure 8. North-south gas saturation cube section of the gas reservoir of the Medvezhye field Cenomanian productive complex

The section shows the result of 3D gas saturation cube construction, considering all available geological and geophysical information on the Medvezhye field. The low gas-saturated zone is located between Gas-Water Contact 1 and Gas-Water Contact 2, where minimal gas saturation values are observed.

Since there was no need for permeability analysis, as this parameter is more correctly calculated by hydrodynamic modeling specialists, permeability was not described within the framework of building the 3D geological model.

4. Alternative Constructions

In the process of work on building the 3D geological model of the Cenomanian productive complex of the Medvezhye field, a total of three models were constructed. The first one, as described above, was built proceeding from the capacities of computational equipment for geological and filtration modeling. It uses cells of the size of 800*800*0.4 m, which is necessary and sufficient to achieve the established objective. However, to test the validity of the model, alternative grids were created – with a cell size of 100*100*0.3 m and its upscaled version with 400*400*0.6 m cells. With identical input data as a single set of a priori information, the results slightly differ. With an increased number of cells in the second model, the greatest hydrodynamic connection of the collectors is achieved, especially in the low gas-saturated zone. While the previous model has 7.492.500 cells, the given grid surpasses it by more than 95 times, which is unacceptable for further filtration modeling. To verify the algorithm for reducing the number of cells, the grid was upscaled to the size of 400*400*0.6 m to further transfer it for filtration modeling to hydrodynamics specialists. A full-fledged model with all the permeability properties has been created, accompanied by many intermediate and indicator cubes, as in the case of the first model. All three models have a common structural framework for modeling, common contact surfaces, well data, and formation breakdowns. To optimize the information space, the other cubes are not given in this paper, but they are built on the same data as the first model, with the same settings and in full volume.

As a result of upscaling the model with the basic permeability parameters and indicator cubes, a grid of 400*400*0.6 m was obtained to optimize the information flow, and only this one is given in this paper. The section of the gas saturation cube shows the corrected result (Figure 9).

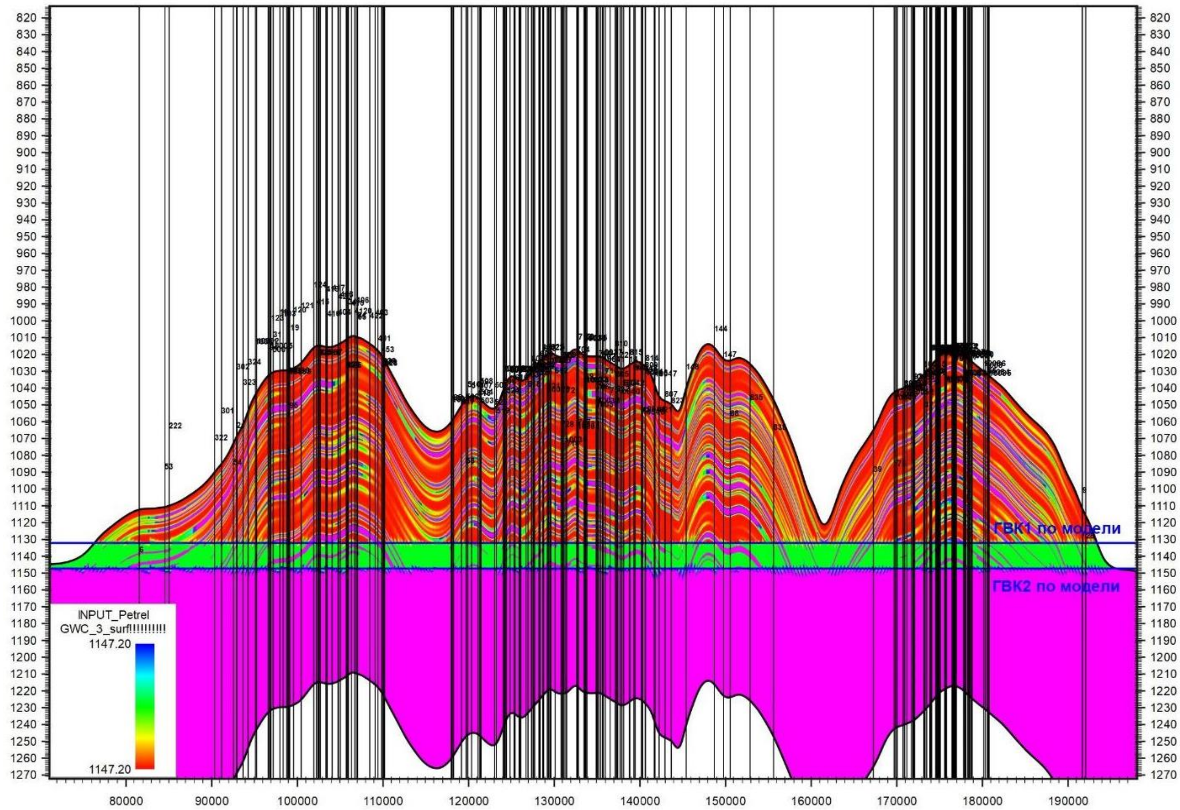

Figure 9. Statistical characteristics of an upscaled 3D geological model of the Cenomanian productive complex, cell size 400*400*0.6 m

For further modeling of analogous fields, it is reasonable to use this grid, except for the vertical dimension, which per the regulations should be 0.2-0.4 m. Otherwise, the number of cells 22.416.750 is the most optimal and will allow not only to consider in more detail the geological features of the Cenomanian productive complex but also to optimize the work of specialists in filtration modeling.

Table 1 below presents a comparison of the gas reserves of the Cenomanian productive complex of the Medvezhye field in different grids, as described above.

Table 1. Comparison of Calculation Parameters Using Different Grids in 3D Geological Models of the Cenomanian Productive Complex of the Medvezhye Field

					800*800*0.4						
YEAR IC		**S, km3**	**h, m**	**V, million m3**	**C_s**	**C_{gs}**	**P_I, atm**	**P_f, atm**	**Correction for gas properties**	**Correction for temperature**	**Q, billion m3**
1987.00		2,062.55	45.31	93,464.93	0.31	0.75	113.40	1.05	1.17	0.96	2,722.12
2023.00	pred	2,271.06	48.26	108,959.25	0.31	0.72	113.40	1.05	1.17	0.96	3,091.06
	low	2,493.01	12.07	29,403.02	0.31	0.47	113.40	1.05	1.17	0.96	550.21
%		**120.87**	**133.15**	**148.04**	**0.04**	**20.21**					**133.77**
					100*100*0.3						
YEAR IC		**S, km3**	**h, m**	**V, million m3**	**C_s**	**C_{gs}**	**P_I, atm**	**P_f, atm**	**Correction for gas properties**	**Correction for temperature**	**Q, billion m3**
1987.00		2,062.55	45.31	93,464.93	0.31	0.75	113.40	1.05	1.17	0.96	2,722.12
2023.00	pred	2,271.06	50.94	115,552.03	0.31	0.75	113.40	1.05	1.17	0.96	3,425.19
	low	2,493.01	12.98	33,984.46	0.31	0.47	113.40	1.05	1.17	0.96	590.51
%		120.87	141.07	159.99	-0.75	18.67					147.52
					400*400*0.6						
YEAR IC		**S, km3**	**h, m**	**V, million m3**	**C_s**	**C_{gs}**	**P_I, atm**	**P_f, atm**	**Correction for gas properties**	**Correction for temperature**	**Q, billion m3**
1987.00		2,062.55	45.31	93,464.93	0.31	0.75	113.40	1.05	1.17	0.96	2,722.12
2023.00	pred	2,271.06	48.84	110,502.78	0.32	0.75	113.40	1.05	1.17	0.96	3,343.55
	low	2,493.01	12.52	31,756.97	0.31	0.47	113.40	1.05	1.17	0.96	575.30
%		**120.87**	**135.42**	**152.21**	**-2.26**	**18.64**					**143.96**

IC - inventory calculation; C_s - sandiness coefficient; C_{gs} - gas saturation coefficient; P_I - initial pressure; P_f - final pressure

The provided resource estimates show that the first model estimates the reserves of the low gas-saturated zone at 550 billion m^3, the second, more detailed model – at 590 billion m^3, and the third, most optimal model – at 575 billion m^3. The most detailed model delivered the most precise estimation of reserves. However, this model cannot be used for further calculations. The estimated volumes of reserves do not differ significantly, although the more detailed the model, the more accurate the calculations.

4. Conclusions

Three geological models were built based on the results of geological modeling of the gas deposit of the Cenomanian productive complex. Analysis of the geological and geophysical information obtained from reserves estimation proves the presence of a low gas-saturated zone in the section. Initial geological reserves of gas from the maximum and low gas-saturated zones have been calculated. All the information necessary for further filtration modeling has been transferred. For further modeling of the Cenomanian productive complex, it is recommended to use a 400*400*0.4 m grid, or a grid with about 20 million cells, which is optimal based on the aspects described above. The given constructions, calculations, and judgments are based on the results of analyzing geological and geophysical information. The obtained results of geological modeling do not contradict current regulations (Ministry of Energy of the Russian Federation, 2000) and can be recommended as the methodology for building 3D geological models of the Cenomanian productive complex of fields in the Nadym-Purov oil and gas bearing region with an integrated low gas-saturated zone.

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Data availability

Data will be made available on request.

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