Russian Journal of Earth Sciences

Special Issue: "Fundamental and Applied Aspects of Geology, Geophysics and Geoecology"

Geological Filtration Model of the Layers of Nizovsky Field of Volga-Ural Oil and Gas Province

M. A. Meretukov[1], R. A. Toroyan[1], M. K. Bedanokov[1], R. B. Kokhuzheva[1], A. M. Artamonov [1]

[1]Maykop State Technological University, Maykop, Russian Federation

* **Correspondence to:** R. A. Toroyan, rubenet@mail.ru

Abstract: The article presents the results of modeling a three-dimensional digital geological filtration model. The substantiation of the volumetric grids of the model is given and the analysis of the distribution of filtration-capacitance properties of layers and models of reservoir saturation with fluids is carried out. Based on the constructed three-dimensional model of Nizovsky field, the reliability of revealing hydrocarbon reserves at the field has been confirmed.

Keywords: Digital three-dimensional geological model, filtration and capacitance properties, porosity coefficient, reservoir thickness, well logging.

Citation: Meretukov M. A., Toroyan R. A., Bedanokov M. K., Kokhuzheva R. B., Artamonov A. M. (2023), Geological Filtration Model of the Layers of Nizovsky Field of Volga-Ural Oil and Gas Province, *Russian Journal of Earth Sciences*, Vol. 23, ES0217, https://doi.org/10.2205/2023ES02SI17

1. Introduction

Nizovsky oil field is located in Kinelsky district of Samara region, 5 km east of Domashka village, in the aisles of Nizovsky license area. In tectonic terms, the deposit is confined to the southwestern side of the Buzuluk depression (the structure of the I order) and in the zone of its gradual transition to the Zhiguli vault (the structure of the I order).

The industrial oil content of the field is set in four productive layers: A-4 - the Bashkir tier of the middle carboniferous (C2b), B-2 – the Bobrikov horizon of the Visei tier (C1v), C-1 – the Tournaisian tier (C1t) of the lower carboniferous and D-I' – the Pashian horizon of the Fransk tier of the Upper Devonian, containing four oil deposits.

The deposit is considered to be small according to the size of the initial recoverable hydrocarbon reserves and complex according to the complexity of the geological structure.

The deposit of the A4 formation of the Bashkir tier (C 2b) is massive, arched. The size of the deposit is 1.7×1.1 km and the height is 14.7 m. 6–10 permeable dense layers of carbonates 0.4–0.6 m thick represent the formation, separated by dense layers 0.4–0.11 m thick. The oil-water contact was defined at absolute mark of 1564.2 m.

The C1v formation of the Visean tier is a reservoir, arched. The size of the deposit is 1.6×1.2 km and the height is 38 m. The oil-water contact was defined at absolute mark of 2143.3 m.

C1t Tournaisian, formation C-1. The deposit is massive, arched. The size of the deposit is 1.3×0.8 km and the height is 32.5 m. Conventionally, the calculated level of the deposit was taken at absolute mark of 2168.2 m along the sole of the oil-saturated interlayer.

D3f Fransk, layer D-I'. The reservoir is a vaulted reservoir, lithologically limited from the north. The dimensions are 2.0×0.3 km and the height is 34.3 m. The oil-water contact is conditionally defined at absolute mark of 3038.8 m along the sole of the oil–saturated reservoir [*Expert commission of the Volga-Ural branch of the FBU GKZ*, 2019; *Toroyan and Meretukov*, 2023].

The technical and economic advantages of setting and operating three-dimensional geological and technological models with existing operational facilities of gas and oil

Research Article

Received: 20 October 2023
Accepted: 27 November 2023
Published: 15 December 2023

fields are undeniable. The efficiency consists in increasing the oil recovery coefficient to 10% from low-yielding deposits, reducing associated water production. Thus, the setting and the use of geological and technical models of oil and gas and oil deposits, as well as permanent operational facilities, makes it possible to solve topical issues of current and future hydrocarbon production planning [*Baturin*, 2007].

2. Object of research and methods

The objects of geological modeling of the Nizovsky deposit are A-4 layers of the Bashkir tier, B-2 of the Bobrikov horizon, C-1 of the Tournaisian tier of the lower Carboniferous and the formation D-I' of the Pashian horizon of the Upper Devonian. The justification of the geological model consists in constructing a model in the form of a three-dimensional grid [*Raspopov and Mordvinov*, 2010], in which each cell is represented by a hexagon with quadrangular faces, tied in space using a coordinate system. The number of grid cells is usually from several million to about a billion.

To create a three-dimensional digital model of the formations of the deposit in question, a grid with the geometry of a corner point was used [*Gaisina*, 2010], with a horizontal cell size of 25×25 m [*Zakrevsky*, 2009]. The vertical pitch of the grid varies in the interval:

- 0.04–0.34 m with an average estimate of 0.19 m for deposits of the A-4 formation of the Bashkir tier;
- 0.03–0.38 m with an average estimate of 0.16 m for the deposits of the B-2 formation of the Bobrikov horizon;
- 0.04–0.35 m with an average estimate of 0.21 m for the deposits of the C-1 formation of the Tournaisian tier;
- 0.04–0.34 m with an average estimate of 0.14 m for the deposits of the D-1 formation of the Pashian horizon.

The chosen grid scheme takes into account the vertical (internal) and lateral heterogeneity of the deposits of the Nizovsky deposit [*Gladkov and Gladkova*, 2011].

The size of the grid objects is as follows:

$160 \times 149 = 3814400$ cells (A4 formation model);

$160 \times 118 = 3020800$ cells (B-2 reservoir model);

$160 \times 113 = 2892800$ cells (C-1 formation model);

$160 \times 152 \times 75 = 1824000$ cells (D-I' reservoir model).

The spatial distribution of the reservoirs of the Nizovsky deposit was performed using the deterministic Geomod model of the IRAP RMS complex [*Tikhomirova*, 2020]. The deterministic modeling technology includes 3-dimensional stratigraphic interpolation taking into account a priori given 2-dimensional distribution of sandiness.

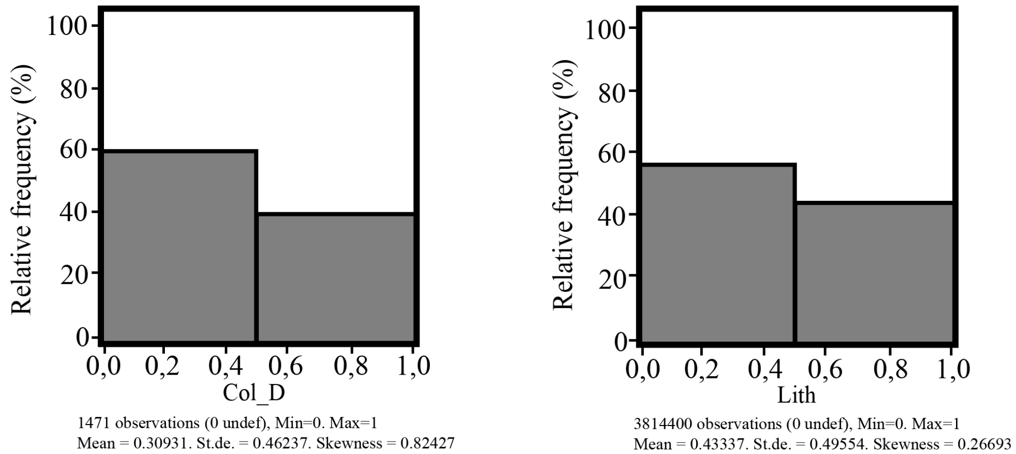
The result of constructing a lithology cube of productive layers of the Nizovsky deposit is the spatial distribution of reservoirs, describing their geological heterogeneity in section and area.

3. Results and discussion

The constructed lithological model is satisfactorily consistent with the concept of the structure of deposits, at the level of maps of effective and initial oil-saturated thicknesses. Based on the constructed lithological models for all productive formations, the volume of oil-saturated rocks was estimated. When estimating the volumes of oil-saturated rocks, the lithological model does not exceed 5% according to these deposits, which indirectly confirms the validity of estimates of the volumes of these rocks by counting objects.

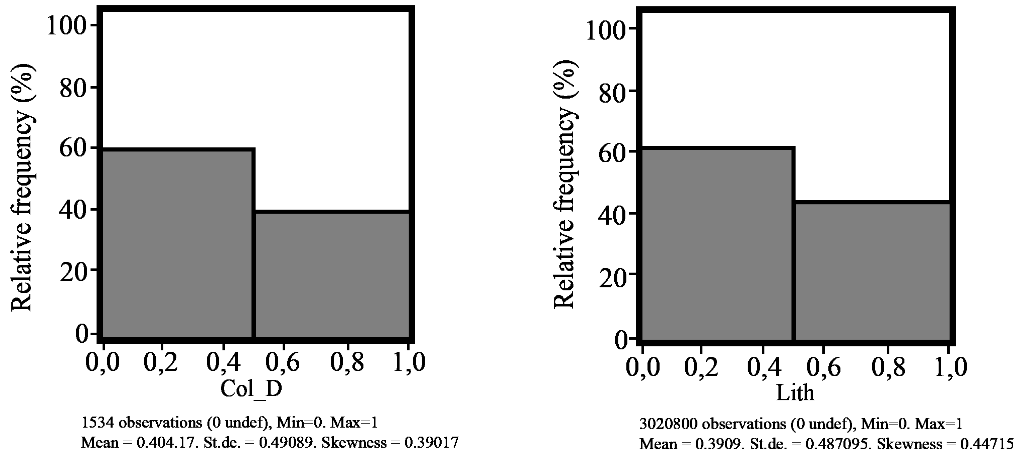
The proportion of reservoirs of the simulated objects for wells and for the reservoir as a whole is shown in histograms on Figures 1–4.

The porosity cube for all productive layers is constructed by interpolating the value of the porosity coefficient calculated from the results of well logging along the borehole. The



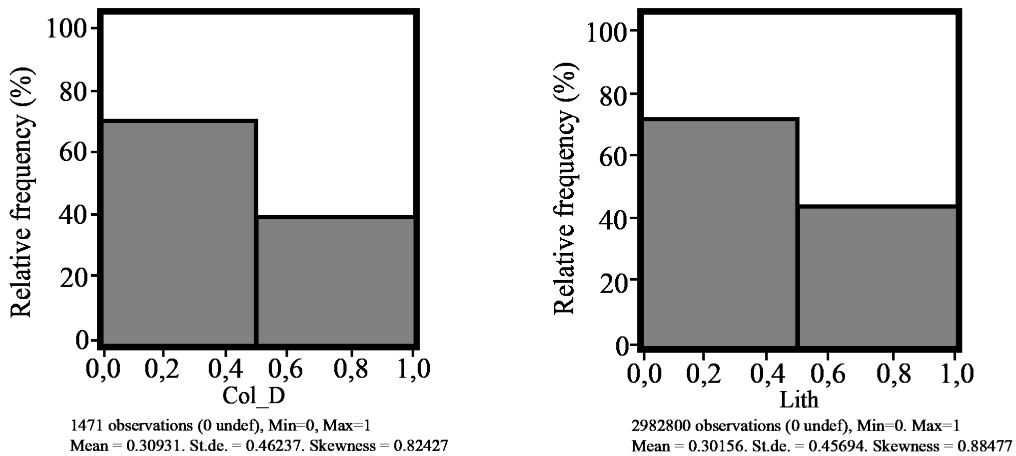
(a) **(b)**

Figure 1. Comparison of the proportion of the collector and non-collector of A4 formation in wells (a) and in the reservoir as a whole (b).



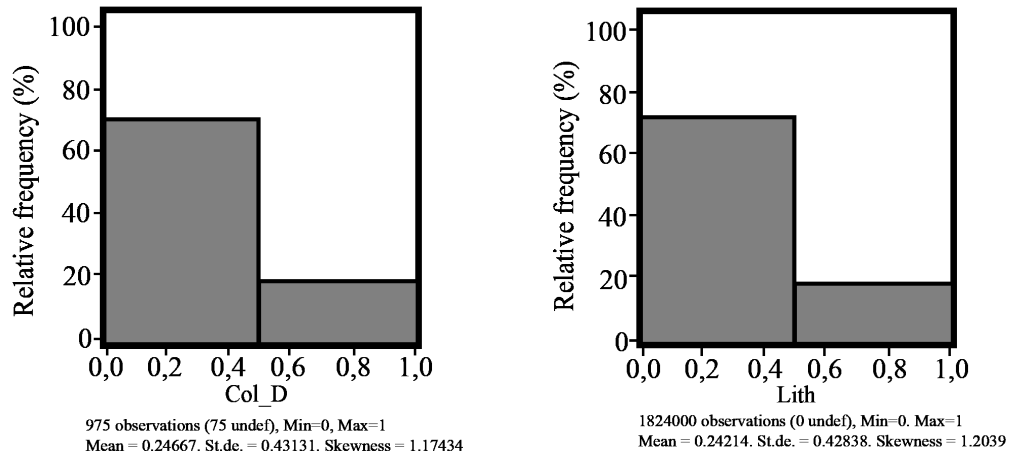
(a) **(b)**

Figure 2. Comparison of the reservoir and non-reservoir shares of B-2 formation in wells (a) and in the reservoir as a whole (b).



(a) **(b)**

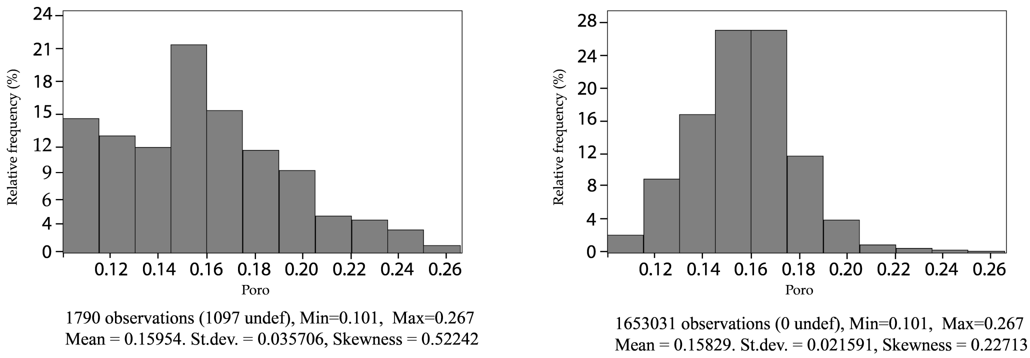
Figure 3. Comparison of the share of collector and non-collector C-1 in wells (a) and in the reservoir as a whole (b).



(a) **(b)**

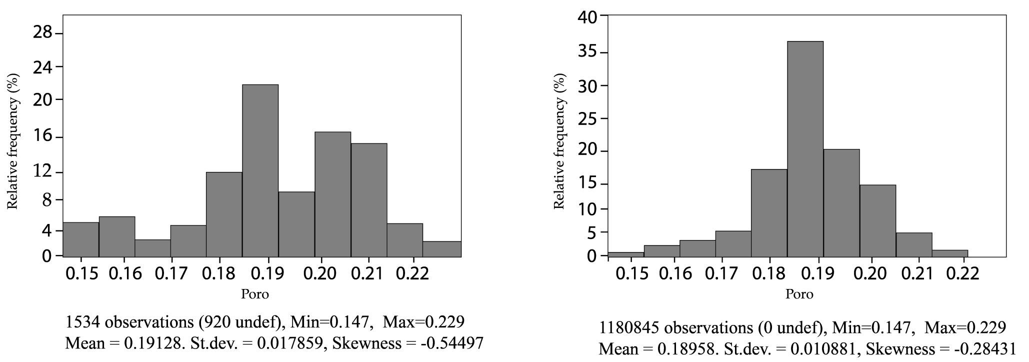
Figure 4. Comparison of the proportion of the collector and non-collector D-I' in wells (a) and in the reservoir as a whole (b).

distribution of porosity values in the reservoirs of productive formations according to the initial data and for the reservoir as a whole are shown in histograms on Figures 5–8.



(a) **(b)**

Figure 5. Porosity distribution of A-4 formation in wells (a) and in the formation as a whole (b).

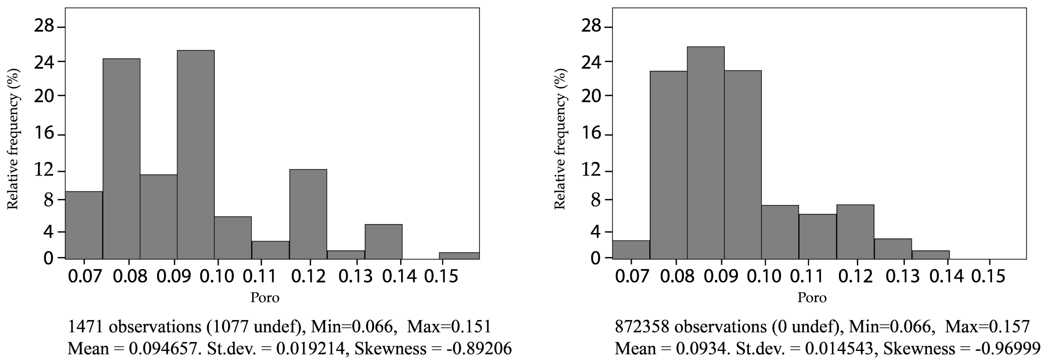


(a) **(b)**

Figure 6. Porosity distribution of B-2 formation in wells (a) and in the formation as a whole (b).

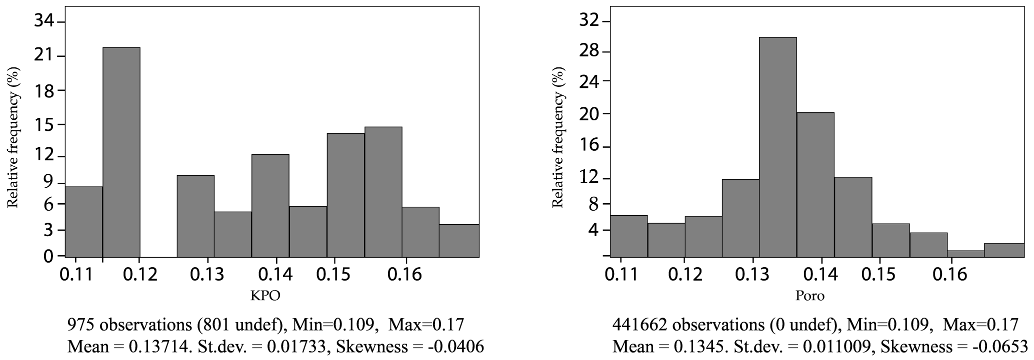
The average porosity estimates in the model for all deposits (with an accuracy from 0% to 3.1%) are consistent with the proposed values of the parameter under consideration.

To restore the permeability fields, information on the filtration-capacitance properties of the core material was used in the form of correlations between porosity and permeability parallel to the Kp–Kpr stratification, given below. The permeability cubes are calculated by recalculating the 3D distribution of Kp according to the Kp – Kpr correlation dependencies.



(a) **(b)**

Figure 7. Porosity distribution of C-1 formation in wells (a) and in the formation as a whole (b).



(a) **(b)**

Figure 8. Distribution of the porosity of D-I' formation in wells (a) and in the formation as a whole (b).

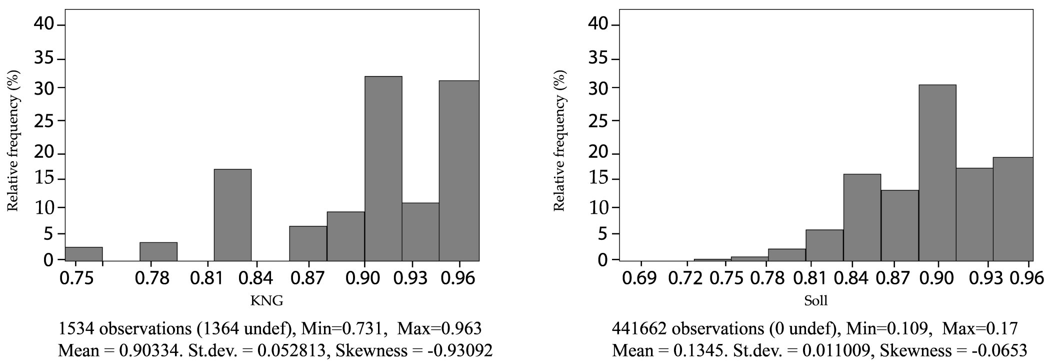
Kpr = 9225.7 × Kp – 6.3951 – for A-4 formation;;

Kpr = 101794 × Kp – 7.2317 – for B-2 formation;

lgKpr = 29.301 × Kp – 5.5686 – for C-1 formation;

Kpr = 5754.4 × Kp – 5.783 – for D-I formation'.

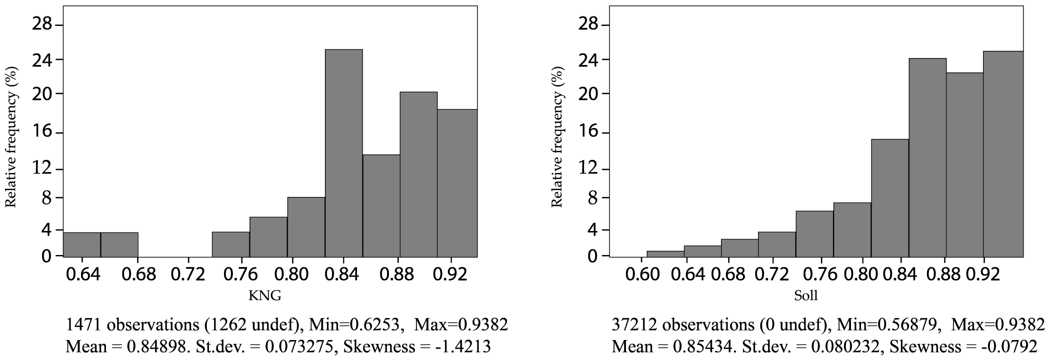
The distribution of oil saturation values in the reservoir of productive formations by source and by formations as a whole is shown in histograms on Figures 9–11.



(a) **(b)**

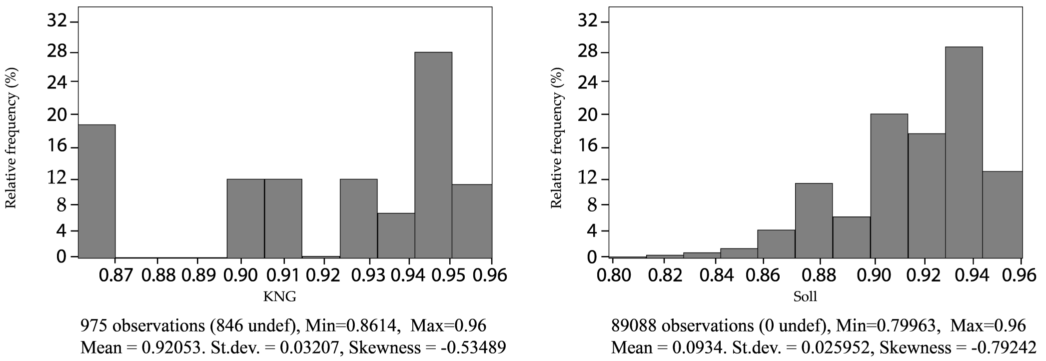
Figure 9. Distribution of oil saturation of B-2 formation in wells (a) and in the reservoir as a whole (b).

The results of geological hydrocarbon reserves were obtained based on the constructed three-dimensional geological model of the Nizovsky field [*Expert commission of the Volga-Ural branch of the FBU GKZ*, 2019].



(a) **(b)**

Figure 10. Distribution of oil saturation of C-1 formation in wells (a) and in the reservoir as a whole (b).



(a) **(b)**

Figure 11. Distribution of oil saturation of D-I' formation in wells (a) and in the reservoir as a whole (b).

Table 1 shows an assessment of the reliability of the created geological model by comparing the initial geological reserves of hydrocarbons, the volume of oil-saturated rocks, the area of oil-bearing capacity, the average effective thickness, the average porosity coefficient and the average coefficient of initial oil saturation.

Based on the authors' statement [*Davydov et al.*, 2017], terrigenous layer with increased porosity and having differences in lithological structure can be easily identified in the seismic field.

There are fewer terrigenous formations at the Nuzovsky deposit and they are heterogeneous in their composition and are often replaced. These layers can be barely identified.

There are similar problems with the identifying of carbonate formations and less powerful formations. This is because the layers have a large dissection and are located in the thickness of the same carbonate rocks with the same properties, which leads to difficulties in their identification.

Thus, geological models have been constructed for all the objects of calculation listed on the state balance sheet. The reserves deviation does not exceed 5%, which meets the requirements. Deviations of the calculated parameters from the approved ones are also within the framework of the regulations.

Digital geological models (GM) [*Meretukov et al.*, 2023] were used as the basis for a filtration model of the studied productive layers and were created by TRAP RMS software package, while digital hydrodynamic models (GDM) and modeling of the filtration process of the deposit layers were made by Eclipse software calculation complex.

The grids of filtration models were created using the procedure of rescaling the grid of geological models. The linear dimensions of the grid cells along the direction of the X and Y axes were chosen 50×50 m. Horizontal layers are variable power layers. The main

Table 1. Comparison of calculated parameters and oil reserves listed on the state balance sheet with those calculated in the geological model.

Layer	Oil-bearing area	Average oil-saturated thickness	Volume of oil-saturated rocks	Coefficients			Oil density	Initial geological oil reserves
				Open porosity	Oil saturation	Recalculated		
A-4	thousand m^2	metre	thousand m^3	decimal fraction	decimal fraction	decimal fraction	g/cm^3	thousand tons
State balance	1395	3.8	5347	0.16	0.77			649
Geomodel	1414	3.9	54.51	0.165	0.764	0.926	0.839	648.2
% discrep-ancies	1.4	1.5	1.9	3.1	−0.8			0.12
B-2								
State balance	1246	5.9	7352	0.19	0.9			993
Geomodel	1249	6.1	7568.8	0.1903	0.899	0.937	0.843	1022.9
% discrep-ancies	0.2	2.7	2.9	0.2	−0.1			3.0
C-1								
State balance	788	7.8	6158	0.1	0.86			413
Geomodel	799	7.8	6208.5	0.1	0.862	0.942	0.827	417.8
% discrep-ancies	1.4	−0.4	0.8	0.0	0.2			1.3
D-I'								
State balance	2806	2.6	7398	0.14	0.92			655
Geomodel	2818	2.7	7518.8	0.14	0.92	0.81	0.849	667.8
% discrep-ancies	0.4	2.6	1.6	0.0	0.0			1.9

characteristics of filtration models of productive layers of the deposit are presented in Table 2.

The procedure for transferring data from geological models (GM) to filtration models (FM) was carried out correctly, as evidenced by the satisfactory convergence of the calculated parameters and oil reserves to the parameters of geological models and oil reserves listed on the state balance sheet (Table 3).

As can be seen from Table 1, deviations do not exceed the limits of 5% allowed by the regulations.

Since there is no gas cap at objects A-4, B-2, C-1, D-I', the development of deposits is assumed at a reservoir pressure above the saturation pressure. Therefore, the creation of filtration models is carried out within the framework of the theory of isothermal two-phase filtration [*Basniev et al.*, 1993; *Buckley and Leverett*, 1942].

The initial distribution of oil saturation of reservoirs was calculated according to digital geological models. The pressure in the formation was distributed depending on the depth and the known initial reservoir pressure at the reduction boundary (OWC).

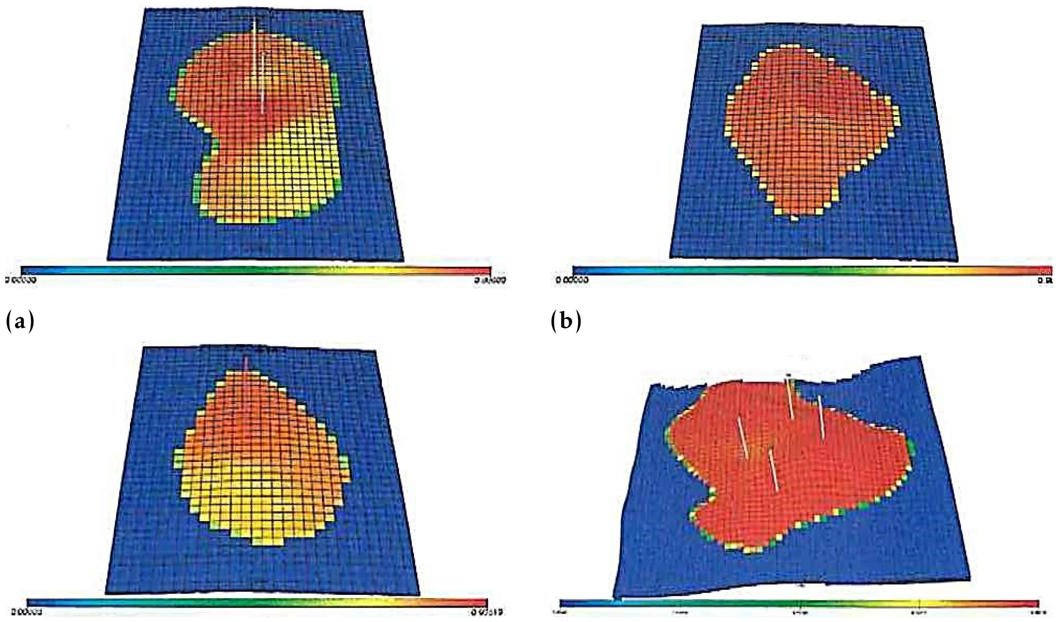
The volumetric representation of the filtration models is shown in Figure 12.

Table 2. The main characteristics of filtration models of productive layers of the field.

Model	Number of grid blocks by direction			Horizontal dimensions of the grid block, m	Vertical dimensions of the grid block, m	Total number of blocks	Number of active model blocks
	NX	NY	NZ				
1	2	3	4	5	6	7	8
				Layer A-4			
GDM	33	47	20	50×50	0.13–1.3	31020	23883
				Layer B-2			
GDM	34	43	27	50×50	0.11–1.26	39474	26032
				Layer C-I			
GDM	28	36	23	50×50	0.33–2.71	23184	13172
				Layer D-I'			
GDM				50×50	0.18–1	29700	21464

Table 3. Comparison of initial geological reserves of hydrocarbons listed on the state balance sheet and calculated on the basis of three-dimensional GM and FM.

Layer	Initial geological oil reserves, thousand tons			Discrepancy, %	
	State balance	GM	GDM	State balance – GDM	GM-GDM
A–4	649	648.2	647.3	−0.26	−0.14
B–2	993	1022.9	1013.2	+2.03	−0.95
C–1	413	417.8	418.5	+1.34	+0.18
D–I'	655	667.8	658.0	+0.46	−1.46



(a) (b) (c) (d)

Figure 12. Volumetric representation of filtration models of the Nizovsky field: a) A-4 formation; b) B-2 formation; c) C-1 formation; d) D-I' formation, Oil saturation as of 01.01.2019.

The modeling of the water-pressure system of the modeling objects of the Nizovsky field was carried out by connecting the Fetkovich analytical aquifer [*Yagafarov et al.*, 2011; *Yu et al.*, 2021].

The diagrams of the relative permeability were used for the layers similar to Zapadno-Kommunarskoye field such as the deposits of Bashkir, Turiyeysky tiers and Pashiysky horizon. As for Bobrikovsky horizon deposits the research data on a composite model of 10 core samples of B-2 formation from well 25 Sovetsky field was used.

The graphs of relative permeability used in the models of the Nizovsky field are shown in Figure 13.

The option of scaling the end points of the tables from saturation was used in the models.

The values of displacement coefficients for deposits of A-4, B-2, C-1, D-I' formations of Nizovsky field were calculated using correlation petrophysical dependences of residual oil saturation on permeability, established according to the data of the core of analog formations.

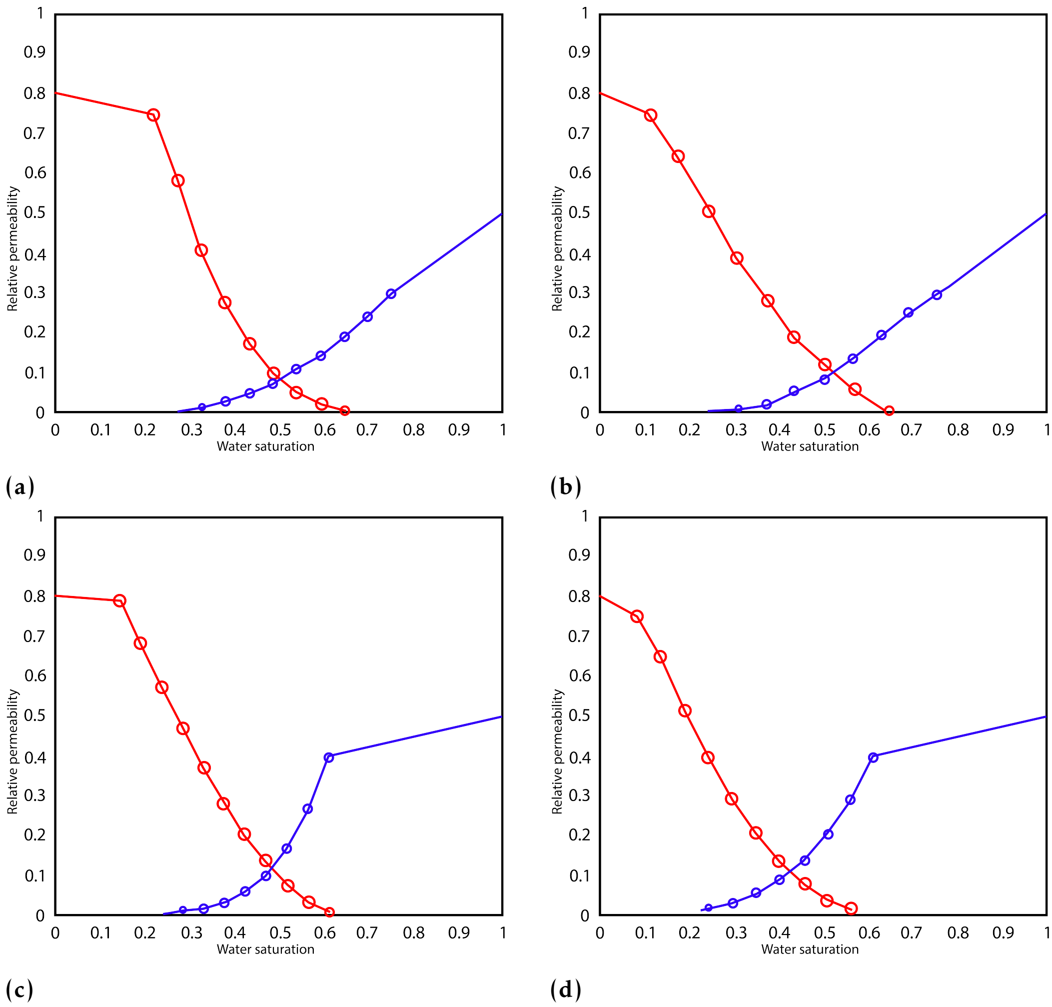


Figure 13. Relative permeability of the layers of Nizovsky deposit.

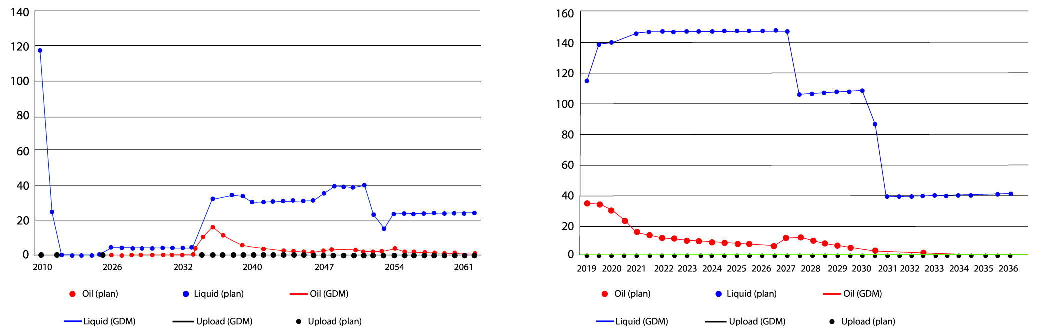
The displacement coefficients obtained by modeling layers A-4, B- 2, C-1, D-I' correspond to reasonable values (Table 4).

The adaptation of the history of the field development was carried out as of 01.01.2019 for all simulated objects with a history of the development.

The results of predictive calculations of technological indicators of development are presented in Figures 14–15. The figures show comparisons of oil, liquid and injection production levels according to models and those presented in state balance sheets according to the recommended option.

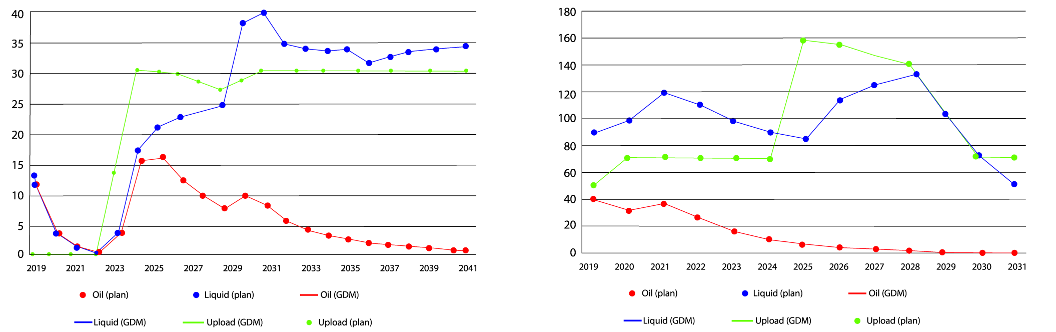
Table 4. Comparison of displacement coefficients for layers A-4, B-2, C-1, D-I' of Nizovsky deposit.

Layer	Accepted displacement coefficient	FM	Discrepancy, %
A-4	0.674	0.674	0.0
B-2	0.724	0.724	0.0
C-1	0.543	0.543	0.0
D-I'	0.572	0.572	0.0



(a) **(b)**

Figure 14. The graph of compliance of model calculations and state plan tables for A-4 and B-2 layers.



(a) **(b)**

Figure 15. The graph of compliance of model calculations and state plan tables for C-1 and D-I' formations.

4. Conclusions

1. The presented filtration model of A-4, B-2, C-1, D-I' formations allows predicting the behavior of productive formations and tracking the dynamics of changes in the production indicators of project wells under a given operating mode.
2. The results obtained and their correspondence with the expected parameters confirmed the realism of the forecast, which is ensured by using exclusively physical tools for model adaptation.
3. The basic properties of reservoir fluids and the values of initial reservoir pressures set in the GDM correspond to the basic parameters for Nizovsky field.
4. The forecast indicators of oil, liquid and injection production correspond to the indicators obtained using hydrodynamic models.

References

Basniev, K. S., I. N. Kochina, and V. M. Maksimov (1993), *Underground hydromechanics: textbook for universities*, 416 pp., Nedra, Moscow (in Russian).

Baturin, A. Y. (2007), Geological and technological justification of the design of the development of oil and gas-oil fields, candthesis, Tyumen (in Russian).

Buckley, S. E., and M. C. Leverett (1942), Mechanism of Fluid Displacement in Sands, *Transactions of the AIME*, *146*(01), 107–116, https://doi.org/10.2118/942107-g.

Davydov, A. A., A. M. Pligin, I. A. Levin, and M. A. Istomova (2017), Accuracy estimation of the dynamic analysis of oil and gas-bearing complex in Samara region, *International Research Journal*, (08(62)), https://doi.org/10.23670/IRJ.2017.62.077 (in Russian).

Expert commission of the Volga-Ural branch of the FBU GKZ (2019), Technological project for the development of the Nizovsky oil field in the Samara region. The user of the subsoil of Samaraneftegaz JSC (in Russian).

Gaisina, G. F. (2010), Geologic modeling the Malyshev field oil pool with using the Norway program RMS 9.0.7, *Neftegasovaâ geologiâ. Teoriâ i practika*, *5* (in Russian).

Gladkov, E. A., and E. E. Gladkova (2011), Methodology for creating a three-dimensional geological model of technology in the fields with a history of the development over 50 years, *Bureniye i neft'*, (1), 32–35 (in Russian).

Meretukov, M. A., R. A. Toroyan, M. K. Bedanokov, R. B. Kohuzheva, and A. M. Artamonov (2023), Assessment of the quality of constructing a geological filtration model of the Nizovsky deposit formation of the Samara region, in *FUNDAMENTAL AND APPLIED ASPECTSOF GEOLOGY, GEOPHYSICS AND GEOECOLOGY USING MODERN INFORMATION TECHNOLOGIES. VII International Scientific and Practical Conference. Part 2*, pp. 66–73, Kucherenko V.O., Maykop (in Russian).

Raspopov, A. V., and V. A. Mordvinov (2010), *Designing the development of oil and gas fields: a textbook*, 87 pp., Perm State Technical University, Perm (in Russian).

Tikhomirova, E. A. (2020), Methods of oil saturation modeling and their application in IRAP RMS, *Herald of Tver State University. Series: Geography and Geoecology*, (1(29)), 69–78, https://doi.org/10.26456/2226-7719-1-2020-69-78 (in Russian).

Toroyan, R. A., and M. A. Meretukov (2023), Analysis of Circulation Losses Behavior during Wells Drilling at the Nizovskoye Field in the Samara Region, *Science and Technology in the Gas Industry*, *1*(93), 22–29 (in Russian).

Yagafarov, A. K., I. I. Kleshchenko, and V. A. Korotenko (2011), *Geology and development of oil and gas fields in Western Siberia*, TSOGU, Tyumen (in Russian).

Yu, J., L. Zhuo, Y. Chen, W. Sun, and Y. Liu (2021), Production Performance Analysis of Class II Hydrate-Bearing Layers Based on an Analytic Aquifer Model, *Frontiers in Energy Research*, *9*, https://doi.org/10.3389/fenrg.2021.702456.

Zakrevsky, K. E. (2009), *Geological 3D modeling textbook*, 376 pp., Maska, Moscow (in Russian).