# THE MAIN FEATURES OF THE GEOLOGICAL MODELING PROCESS OF A SHALLOW DEPOSIT OF SUPER-VISCOUS OIL IN ASPECT OF DEVELOPMENT STRATEGY PLANNING WITH THE USE OF STEAM-ASSISTED GRAVITY DRAINAGE METHOD

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**Abstract**. Deficiency of fossil minerals, limited reserves of conventional hydrocarbon raw materials indicates the need to involve in the fuel and energy complex of other sources of hydrocarbons. Fields of super-viscous oil are one of the sources.

This article is devoted to the study of sediments of the Permian sedimentary complex containing super-viscous oil deposits. The geological structure of the Lower Kazanian and Ufimian deposits is considered. A characteristic of the Sheshmian sandstone pack is given. The analysis of the set of geophysical studies is presented. Modeling of a shallow super-viscous oil deposit based on the lithologic-technological types of the productive formation was carried out, based on the results of drilling, core material and logging. The features of constructing the structural framework of a three-dimensional grid, and a lithological-technological model are highlighted. The distribution of porosity, permeability and oil saturation is described.

**Keywords**: Permian sedimentary complex, super-viscous oil, geological modeling, Sheshmian horizon

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The reduction of prospected oil reserves, reduction of its production and the complexity of hydrocarbon extraction at the present stage of development, requires an assessment of developing unconventional hydrocarbon raw materials, such as super-viscous oil. There is a need to find the most optimal ways of extracting and processing super-viscous oil. Today, the development and production of super-viscous oil is an urgent task in the oil industry, solved using innovative technologies of Tatneft PJSC.

The Lower Karmalsky uplift, which controls the deposit of super-viscous oil of the Cheremshansky oil field is territorially confined to the western Zakamye. In tectonic terms, it is located on the western slope of the South Tatar arch, which is a sloping monocline, step-wise submerging in the direction of the Melekess depression.

Geological-tectonic development is associated with the late formation period of the Paleozoic sedimentary strata. In accordance with the allocated lithologic-stratigraphic complexes of rocks, the Permian system of this period is subdivided into three series – Priuralian, Biarmian and Tatarian (bottom-up) and 8 stages (Table 1 (Cohen et al., 2013)).

Permian deposits on the territory of the Republic of Tatarstan include four petroleum bituminous complexes: locally petroleum bituminous Lower Permian carbonate, zonally petroleum bituminous Ufimian terrigenous, Lower Kazanian terrigenous-carbonate and Upper Kazanian carbonate-terrigenous (Muslimov et al., 2012).

The article focuses on the Lower Kazanian and Ufimian deposits.

The relief of the South Tatar arch in the structural plan of the Kungurian time was weakly expressed, this created conditions for the generation of the Ufimian formation. With distance from the Urals and moving westward, this formation underwent certain lithologic-facies changes, which manifested in changes of the main rock complexes. These lithologic-facies changes are associated with the change of the boundaries to the east of the desalinated basin during the Sheshmian period under the influence of smooth oscillations arising under the influence of early tectonogenesis of the Urals. As a result, the Sheshmian sedimentation basin gradually regressed to the east. However, there

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| Age | System | Series | Stage | Substage | Horizon |
|---|---|---|---|---|---|
| Paleozoic | Permian | Tatarian ($P_3$) | Vyatskian | | |
| | | | Severodvinskian | | |
| | | Biarmian ($P_2$) | Urzhumskian | | |
| | | | Kazanian | Upper | |
| | | | | Lower | Barbashinskian |
| | | | | | Kamyshlinskian |
| | | | | | Baytuganskian |
| | | Priuralian ($P_1$) | Ufimian | | Sheshmian |
| | | | | | Solikamskian |
| | | | Kungurian | | Irenkinskian |
| | | | | | Fillipovskian |
| | | | Artinskian | | |
| | | | Sacmarian | | Sterlitamakskian |
| | | | | | Tastubskian |
| | | | Asselian | | |

*Table 1. General stratigraphic chart as of 2016*

was no complete regression of the Sheshmian basin on the territory of the Zakamye of Tatarstan. During regression, it was preserved in the most submerged part of the Sheshminsky paleo depression – in the basin of the river Sheshma. In near-shore conditions, bottom currents within the basin have developed the shoestring bodies of sandstones in the upper pack of the Ufimian tier (Petrov, 2000).

The unconcordant bedding of a sandy pack of the Sheshmian horizon on bedding rocks indicates that the formation of accumulative bodies rising above the bottom of the basin was proceeding (Uspensky, Valeeva, 2008).

The Ufimian stage ($P_1u$) belongs to the Priuralian series of the Permian system. Within the Lower Karmalsky deposit of the Cheremshansky field, the stage is represented by the Sheshmian horizon (P1u-ss, Figure 1), consisting of a lower sandy-clay pack and an upper sandstone pack (Akishev, Shalin, 1977; Nurgalieva et al., 2016).

The Sheshmian sandstone pack of the Ufimian stage is the main stratum containing hydrocarbons. The pack is composed of sands and sandstones with different degree of cementation with small interlayers of siltstones. The thickness of the pack varies from 3 to 10 meters on the slopes and up to 45 meters in the arch of the structure (Figure 2).

In the Permian sediments, shielding seals of regional, zonal and local distribution are distinguished. On the territory under consideration, the zonal impermeable layer is the clay rocks of the Baytuganskian horizon of the Kazanian stage (P2kz1), which is divided into two packs (Geologiya Tatarstana..., 2003).

The lower pack, lying on the deposits of Sheshmian sandstone pack of the Ufimian stage, is composed of clays, dark gray, with a bluish tinge and is a reliable impermeable layer (reference horizon – "lingula clays"). The thickness of the lower pack of the Baytuganskian horizon varies from 6 to 8 meters in the arched parts of the sand formations of the Ufimian stage. On the slopes of sand formations the thickness is up to 26 meters.

The upper pack, lying over the "lingula clays", is composed of limestones, bluish-gray, dark gray, steel-gray, porous, cavernous, fractured, with a mass of brachiopod and spirifer residues, in the bottom with frequent remains of bryozoans with inclusions of pyrite (reference horizon – "Medium-spirifer limestone"). Its thickness is from 2 to 4 meters.

The thickness of the Baytuganskian horizon varies from 8 to 30 meters.

Like all deposits of super-viscous oil, Nizhne-Karmalsky deposit is located on the western slope of the South Tatar arch. It is confined to the Ufimian bituminous complex, to a sand pack of the Sheshmian horizon of the Permian system. It is controlled by the Upper Permian uplifts of the third order of sedimentary genesis allocated along the top of the Ufimian stage. The studied uplift is part of the group of uplifts of the Yamashino-Cheremshansky structural zone of the second order, its south-eastern part.

The Lower Karmalsky positive structural form is an integral part in the ridge of elongated sand bodies of the northwest strike. Sand bodies are paleobars; they have the form of local sedimentary domes of the brachiantical type. The chains of the uplifts are separated from each other by sections of reduced thickness of the sand pack. The sand pack is covered with "lingula clays" of the Baytuganskian horizon.

The arching part of the uplift is complicated by six domes with the maximum thickness of the Ufimian sandstone pack from 34 to 46 m. The amplitude of the domes varies from 25 to 40 meters.

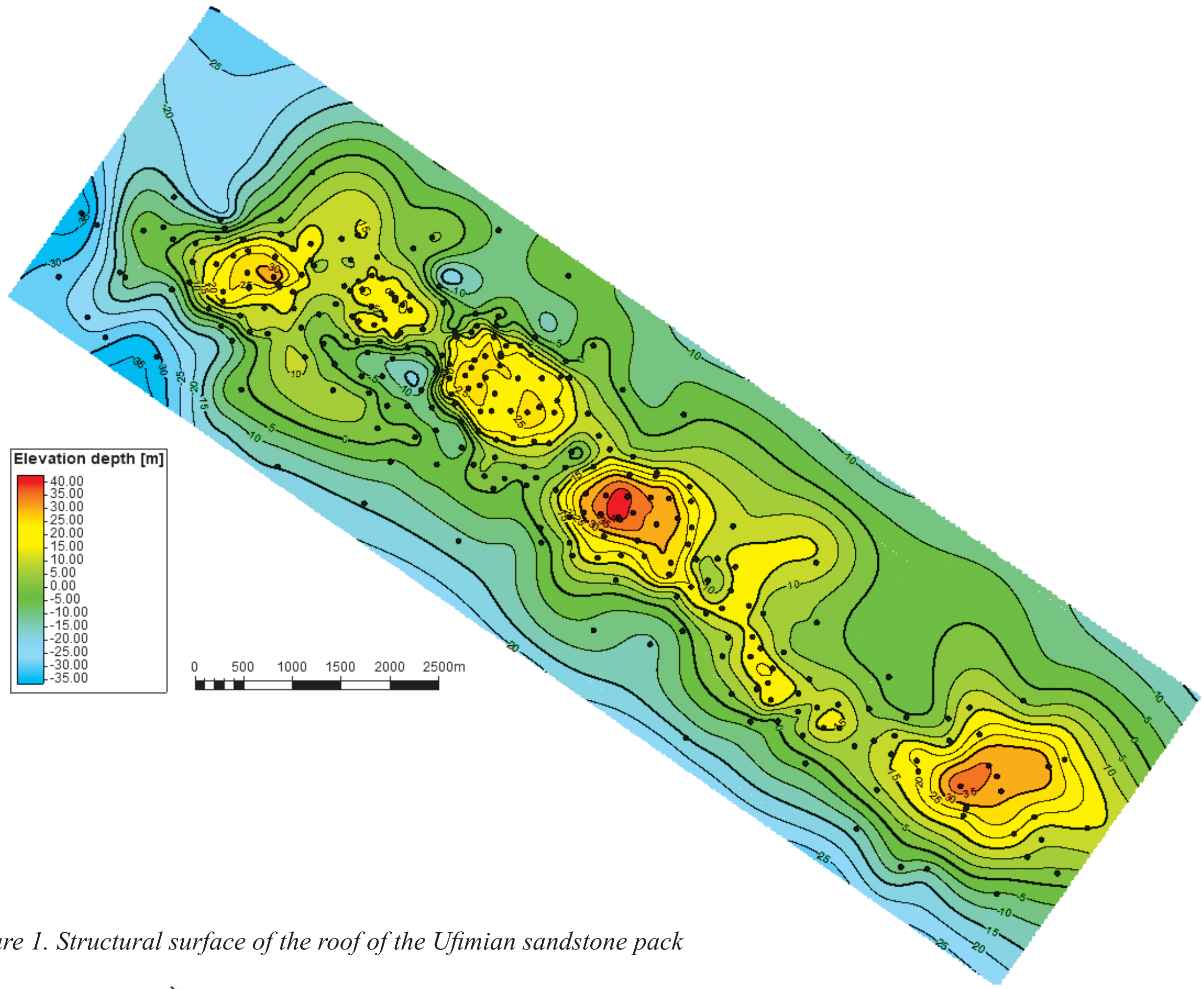


*Figure 1. Structural surface of the roof of the Ufimian sandstone pack*

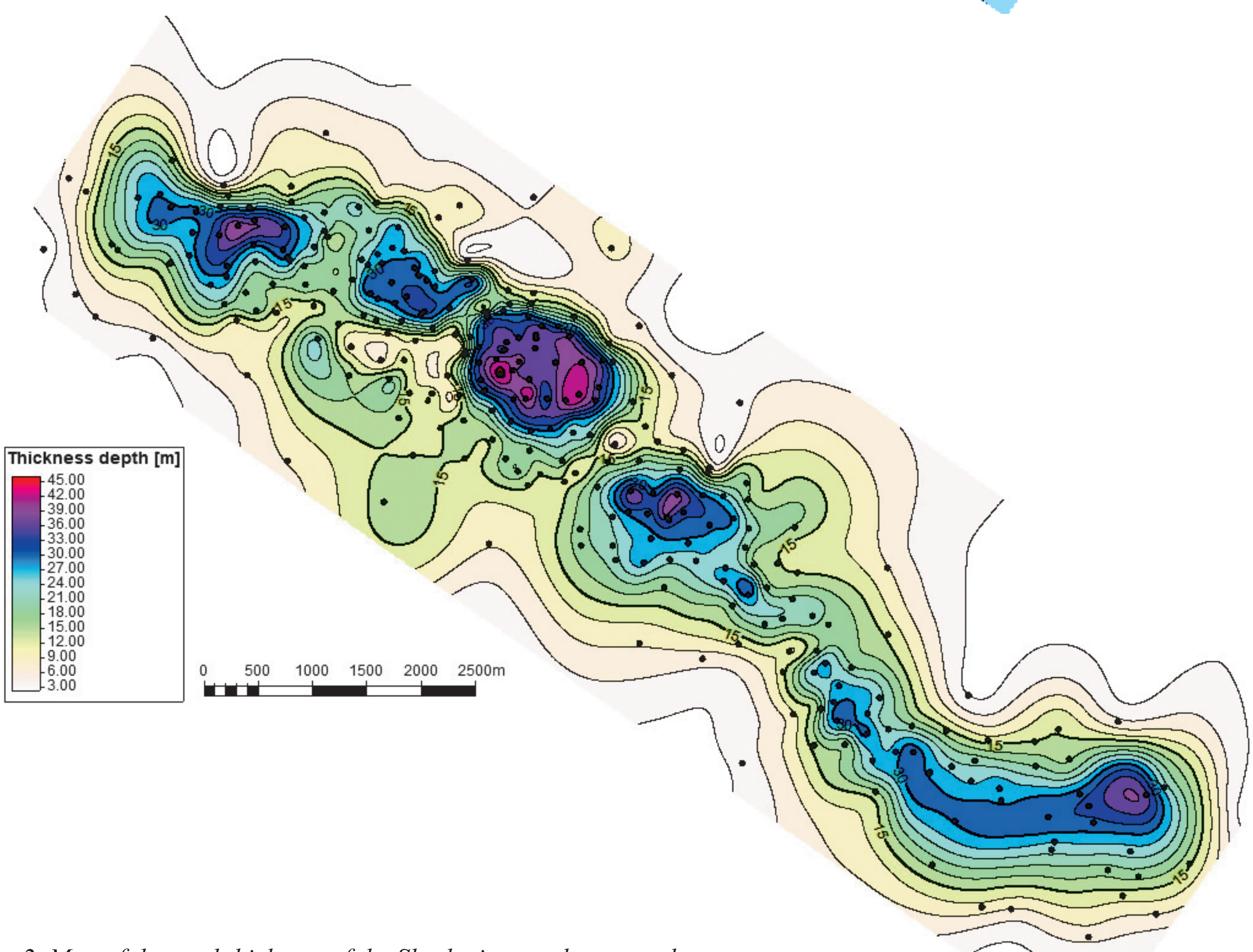


*Figure 2. Map of the total thickness of the Sheshmian sandstone pack*

The uplift is controlled by a closed isohypsum with absolute elevations of 0 meters. The thickness of the sandstone pack in the troughs decreases to 8 meters. The dimensions of the Lower Karmalsky uplift are 12.3 x 2.4 km.

The sections with the maximum thickness of the Sheshmian sandstones correspond to the minimum thickness of the "lingula clays" pack of the Lower Kazanian substage (Figure 3).

Structural plans for the Lower Kazanian and Upper Kazanian sediments basically repeat the structural plan for the top of the Ufimian deposits, but the slopes of the local uplifts in the Kazanian deposits are more gentle due to accumulation of "lingula clays" (Figure 4).

Taking into account the peculiarities of the studied section and the conditions for carrying out the well log survey, the developed **set of geophysical methods** now includes: self-potential logging, apparent resistivity logging, lateral logging sounding, lateral logging, inductive logging, electromagnetic propagation logging, neutron gamma-ray logging, gamma-ray logging, compensated neutron logging, cavernometry, resistivimetry. Correlation of deposits was carried out on 173 wells.

In exploratory wells drilled on Ufimian deposits, according to logging data, two main reference horizons are well distinguished: "medium-spirifer limestone" and "lingula clays". In the wells of structural drilling in addition to those named, tight limestones of the Sakmarian stage are applied (Syurin, 2017). But P1-ass layer was the main reference horizon in structural and deep drilling, including in wells of super-viscous oil deposit (Pavlov, Petrov, 1974).

## Construction of a structural framework of three-dimensional grid

A peculiarity in structural constructions of a shallow deposit is the specificity of processing and interpretation of seismic data in the upper part of the section, which does not allow obtaining sufficiently accurate data about structures in the inter-well space. This is due to the low speed zone and, consequently, the poor resolving capacity of seismic exploration in the upper part of the section (~ 300 m). Exploration wells in the investigated deposit have been drilled with a close spacing, and therefore structural constructions based on well data are more accurate.

When constructing a grid model, a smaller grid should be defined than in traditional models in order to characterize the heterogeneity of a closely drilled reservoir and also to describe the process of steam-assisted gravity drainage (SAGD) in reservoir modeling, if the SAGD method is planned to be used during the deposit development. Rotation of the grid should be chosen from the calculation of its orientation, not only along the strike of the geological structures, but also in the cross of the main mass of the horizontal boreholes.

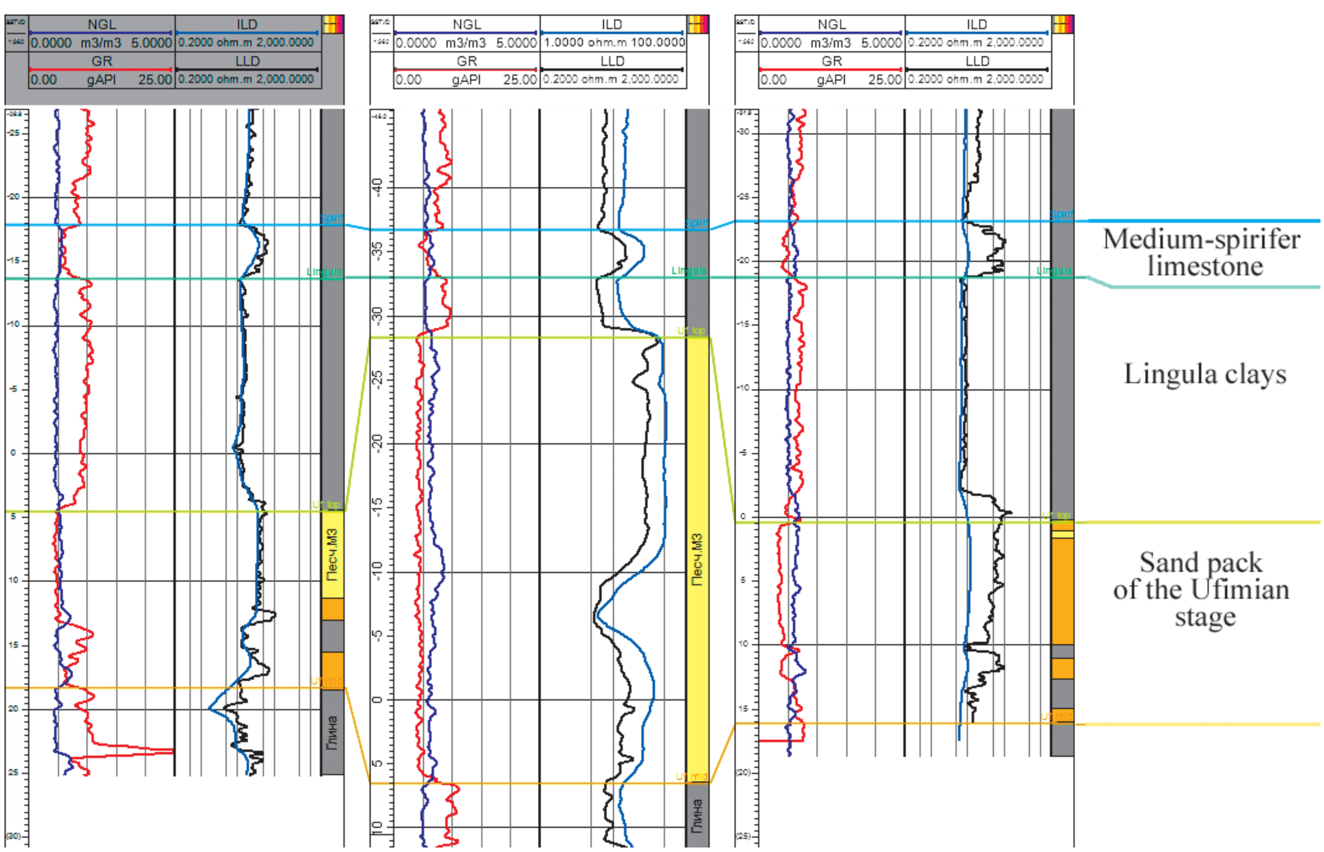


*Figure 3. The correlation scheme*

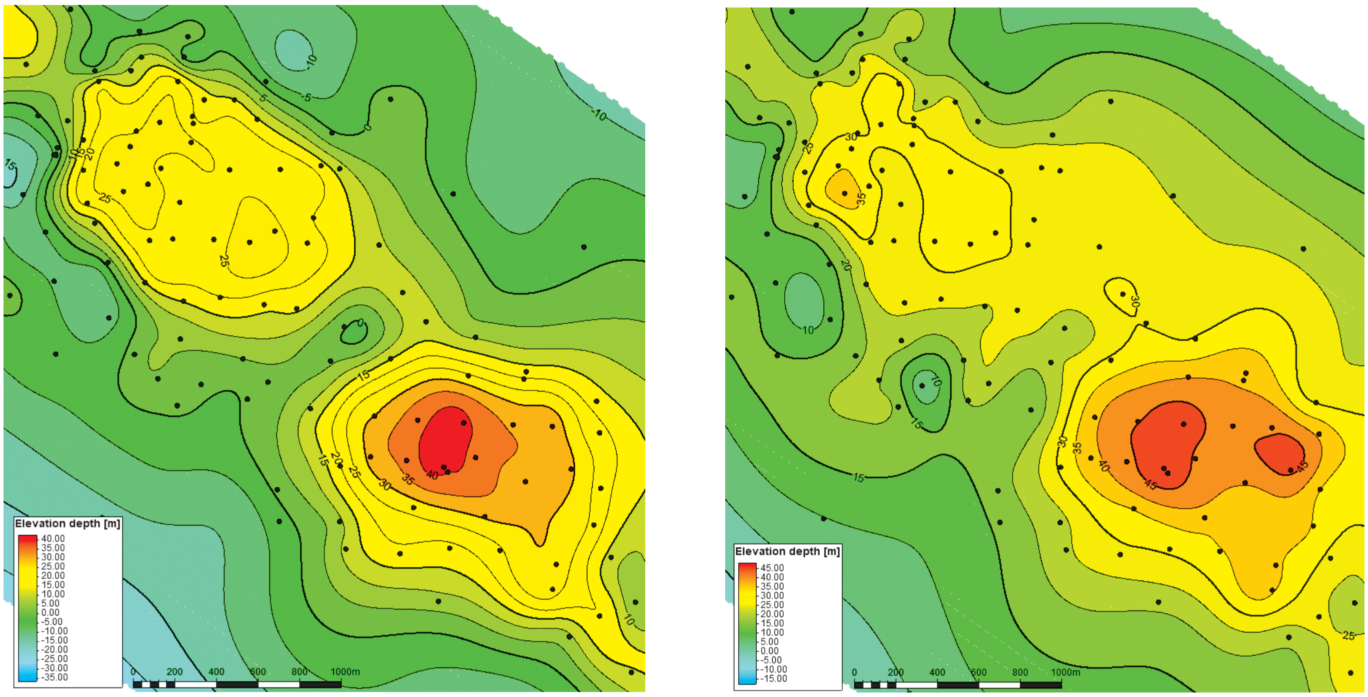


*Figure 4. Structural maps: a – for the roof of lingula clays; b – for the roof of the Ufimian stage*

## Construction of a lithologic-technological model

The difference from working with the traditional model is the presence of a large volume of core material from prospecting, exploration, structural wells. The use of core data as the main geological document in the macro description up to the definition of the reservoir properties makes it possible to expand the resolving capacity of logging methods and produce a more detailed breakdown of rocks into lithological differences (Figure 5).

Based on the concept of the bar structure of the studied deposit, the construction of the lithologic-technological model was carried out in two stages. At the first stage of the construction, the sand body was modeled with boundaries defined by the parametric wells. For this, the Truncated Gaussian with trends algorithm was used, which allows to set geometric trends in the constructions (Figure 6). At the second stage, 4 lithological-technological types of sandstones (fine-grained loose sandstone, fine-grained firm sandstone, medium-grained loose sandstone and medium-grained firm sandstone) were spread in the volume of the sand "body" obtained from the investigations carried out using the geostatistical methods and the Sequential indicator simulation algorithm.

When geostatistical methods are used, the distribution of lithological-technological types of rocks in the vertical section should be used as a trend. For this purpose, an analysis of the vertical proportion curve was performed on the set of wells (Figure 7). The upper part of the section, composed of clayey rocks (lingula clays), the middle part of the section, mainly composed of loose fine-grained sandstones (the top of the sand pack of the Ufimian stage) and the lower part of the section, represented by tight sandstones (the bottom of the sand pack of the Ufimian stage) are well traced along the vertical proportion curve.

Since the construction of the lithological-technological model was carried out by stochastic algorithms, the formation of unrelated volumes, "noise", is unavoidable. Quality control of the lithological-technological model was carried out by the method of connected volumes

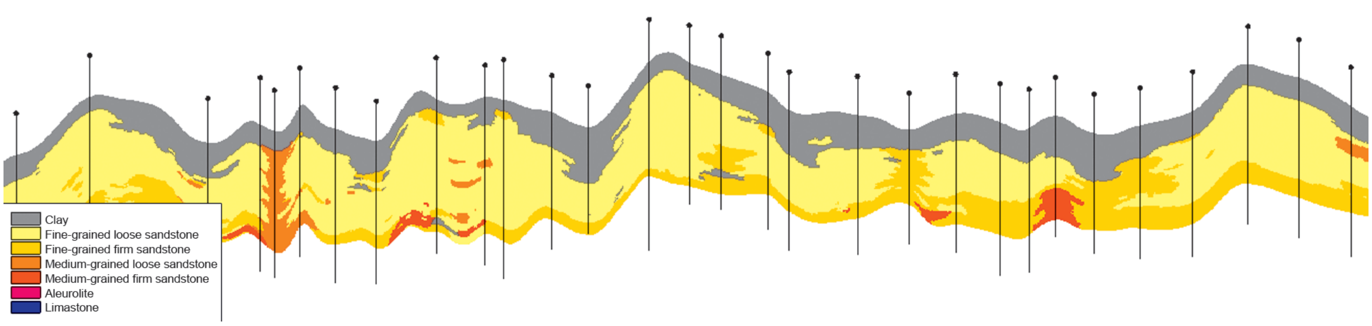


*Figure 5. Profile. Lithological model*

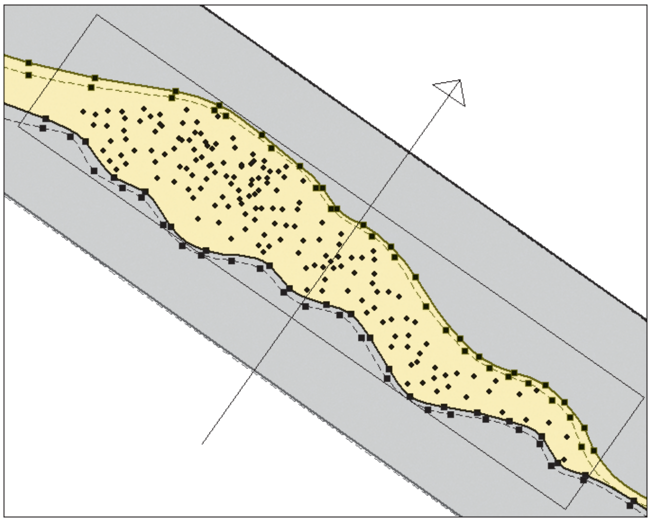

*Figure 6. Boundary of the sand body*

and analysis of distribution histograms of lithological-technological types of rocks (Zakrevsky, 2009). Further, the removal of clusters of cells not connected with the main body of the deposit and not justified by borehole data was carried out (Figure 8). This operation was carried out proceeding from the notion that the reservoir rocks within the bar body should be well connected in the consequence of sedimentation.

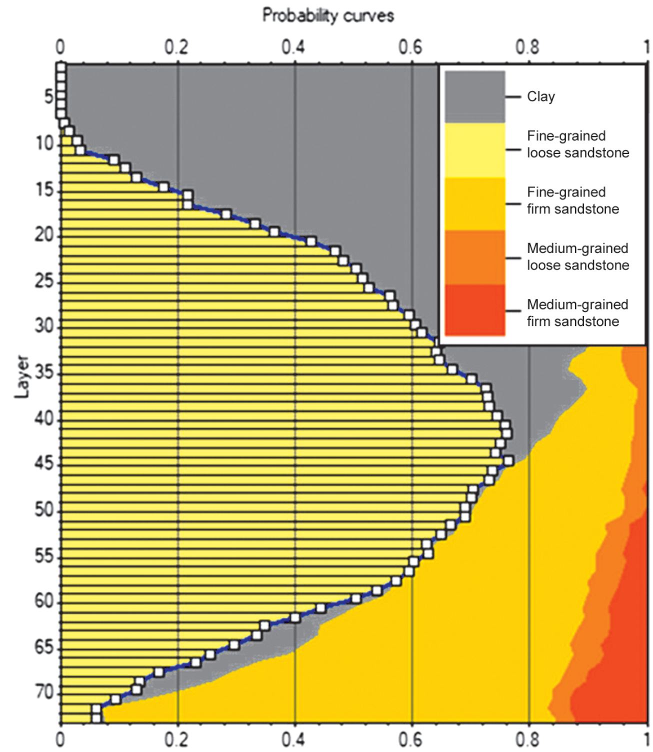


*Figure 7. Vertical proportion curve*

## Distribution of porosity and permeability parameters

As a basis for the distribution of porosity, the model uses well log interpretation data that are correlated with the values obtained from core studies (reservoir properties). The porosity distribution methods do not differ from the work with the traditional model (Figures 9, 10). The distribution of porosity in the reservoirs was performed by Gaussian random function simulation method for each lithological-technological type of reservoir.

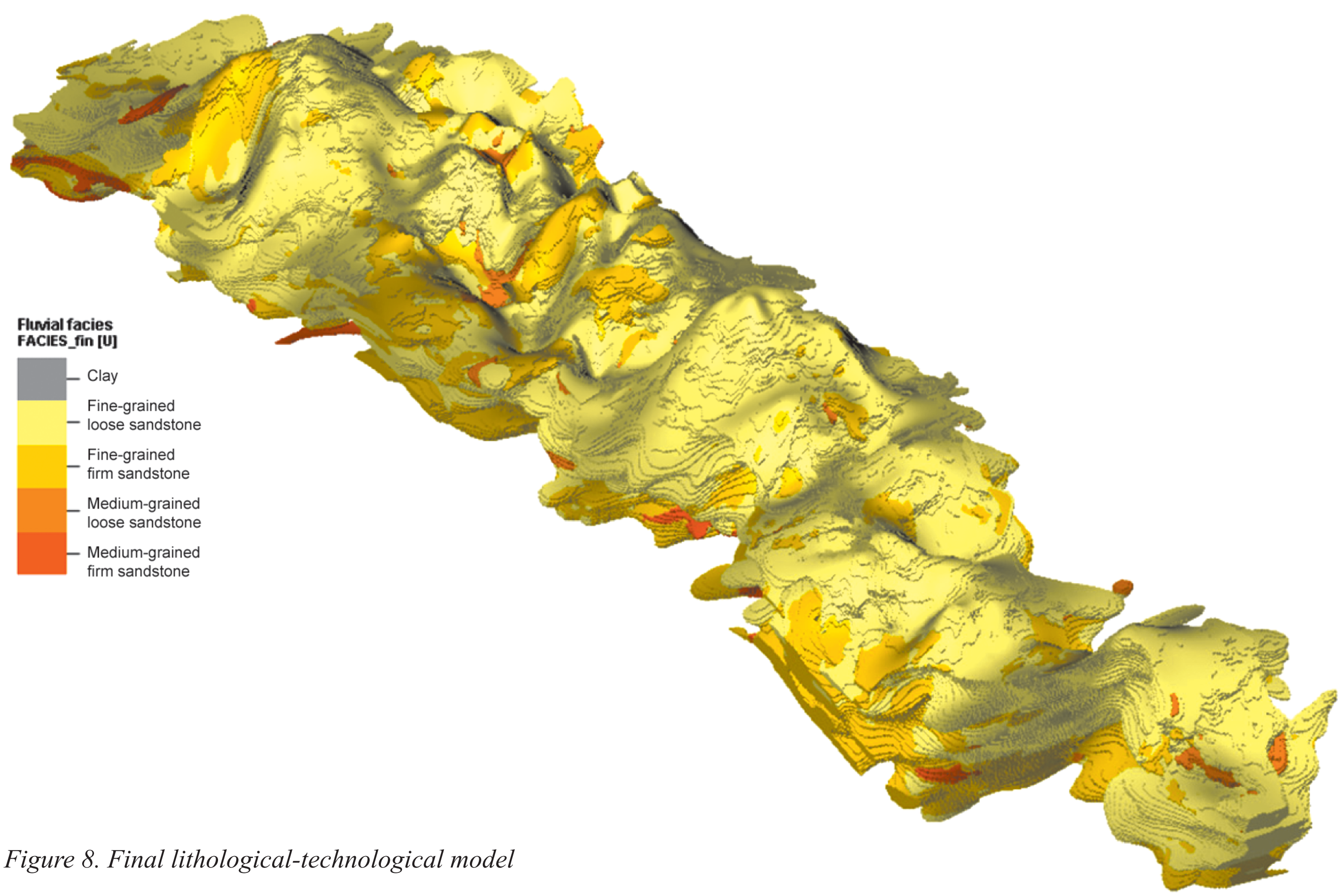


*Figure 8. Final lithological-technological model*

The permeability cube is calculated from the porosity-permeability dependences determined from the core data for each lithologic-technological type of rocks.

## Distribution of saturation and justification of the bottom of the deposit

As a method for distributing oil saturation, we applied layered interpolation by means of Kriging method, using, as a trend, the dependence of saturation on depth (Figures 11, 12) (Zakrevsky, 2009).

Unlike conventional deposits, the investigated deposit from a top to a bottom of formation to some extent contains residual water in the bound volume of a layer, and sometimes also in the form of bypassed water.

The bottom of the oil-saturated zone was taken as the oil-water contact (the values of conditional limits were taken from the report on the reserves calculation), determined by the quantitative and qualitative characteristics of the laboratory studies of core and well logging survey (Figure 13). In the electric logging diagrams, this boundary is repulsed by the sharp drop in the apparent resistivity curve.

Often, the apparent resistivity curve shows a double decline. The latter characterizes the ancient oil-water contact (paleo oil-water contact).

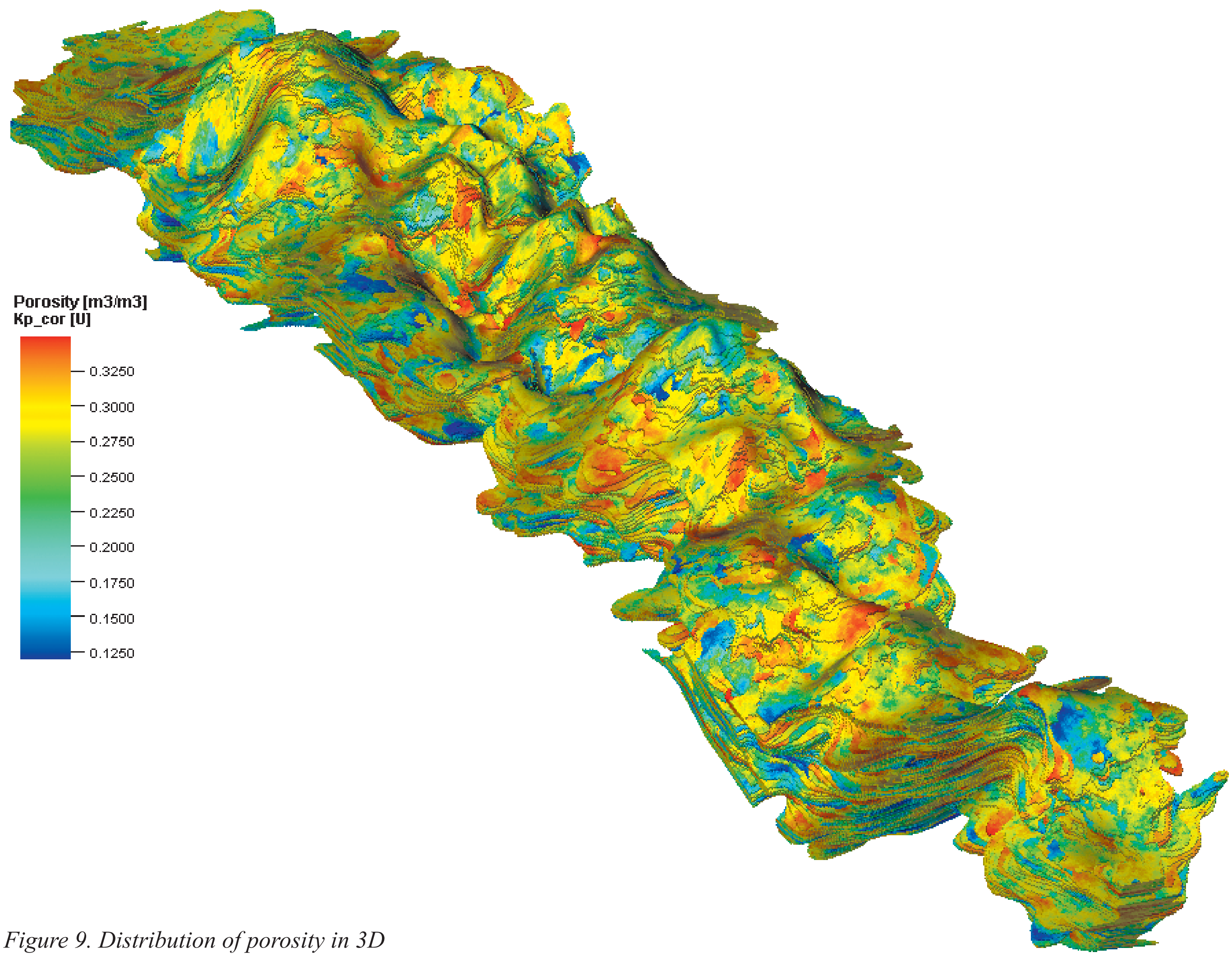


*Figure 9. Distribution of porosity in 3D*

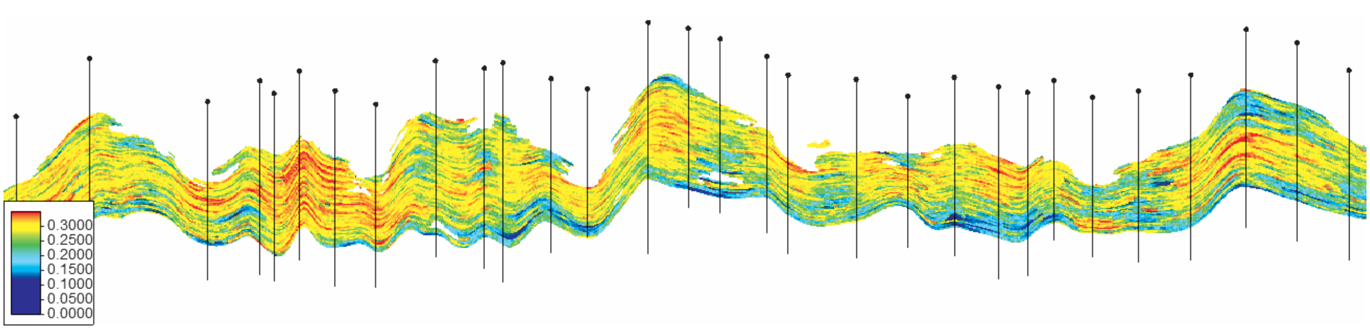


*Figure 10. Distribution of porosity in the section*

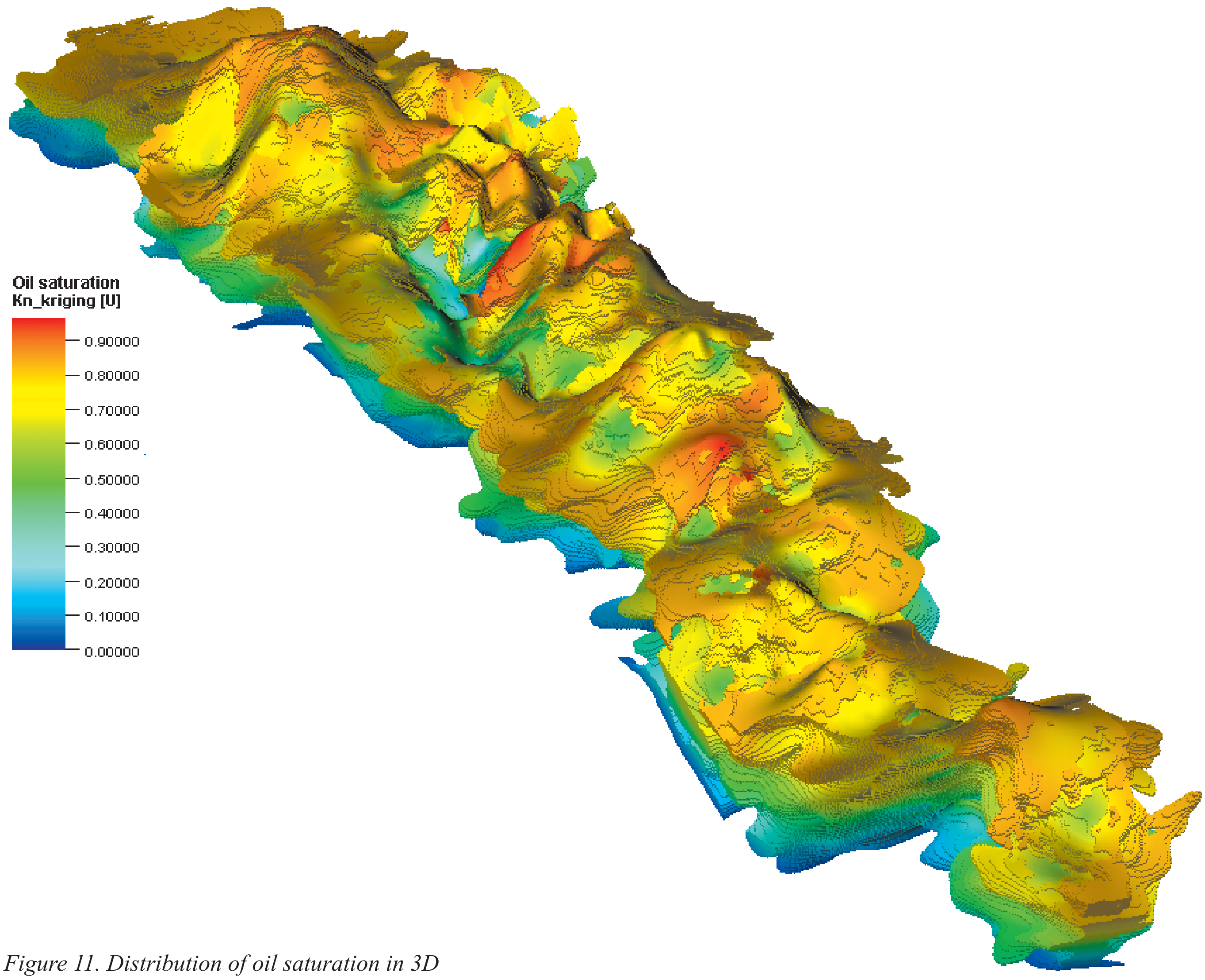


*Figure 11. Distribution of oil saturation in 3D*

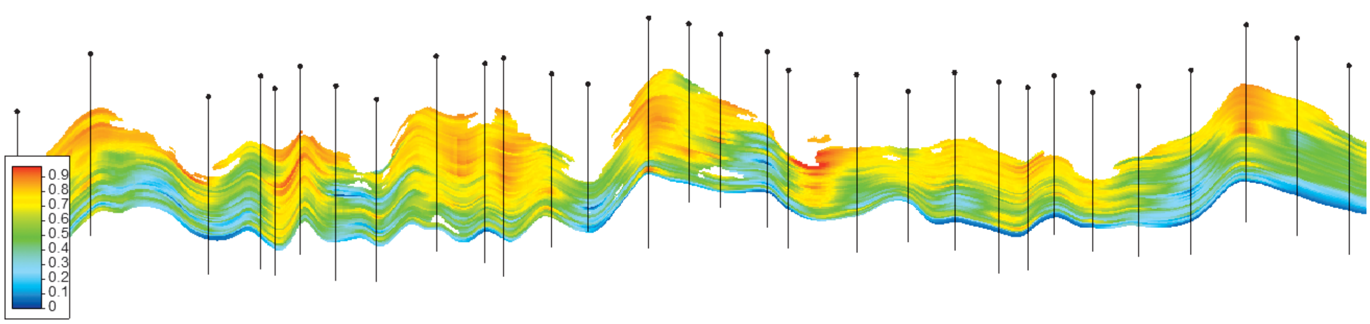


*Figure 12. Distribution of oil saturation in the section*

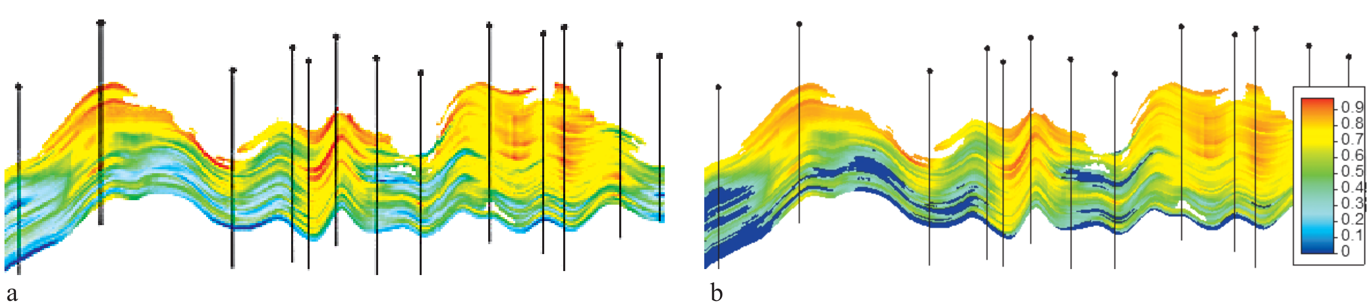


*Figure 13. Oil saturation profile: a – the initial, b – the below-zero conditioning limit*

To monitor the processes occurring in the formation, an original set of geophysical methods was used, including special electrical survey and seismic survey (Sudakov, 2016).

### The main features of the geological model construction of shallow super-viscous oil deposit

In the process of analysis and preparation of the initial data and, subsequently, the geological model construction of the super-viscous oil deposit, the following features of the construction and the main differences from the conventional deposits were revealed.

1. The presence of a large volume of core material can serve as a source of data allowing to expand the resolution of logging methods and to produce a more detailed breakdown of rocks into lithological differences.

2. The complexity, and often the impossibility of processing and interpreting seismic data in the upper part of the section do not allow us to obtain sufficiently accurate data on structures in the inter-well space. In the case of close spacing of drilled wells, structural constructions for well data will be more accurate.

3. When constructing a grid model, a smaller grid should be made than in traditional models, in order to more accurately characterize the heterogeneity of a closely drilled reservoir, and also to describe the SAGD process. Rotation of the grid should be chosen from the calculation of its orientation not only along the strike of structures, but also in the cross of the main mass of horizontal well trunks.

4. The lower boundary of oil saturation is considered to be the bottom of the oil-saturated zone (the values of the conditional limits are taken from the report on the reserves calculation), determined by the quantitative and qualitative characteristics of laboratory studies of core and logging.

The spatial distribution of super-viscous oil deposits in the Permian system is controlled by the spread of lithofacies. Due to the variety of lithofacies, these deposits are characterized by incontinence and intermittent propagation. The detailed correlation of the section, the separation of reservoirs, the sealing layers and traps as a whole, as well as the considered features of the logging methods in combination with the core data and the completeness of this set, made it possible to construct a geological model of the field. The method of constructing geological model of a shallow deposit of super-viscous oil is presented; approaches and techniques in the arrangement of works for practical applications without considering periclinal zones are shown.

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