Updating the petrophysical model of a thin-layered clay reservoir, taking into account the identified lithofacies features

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Abstract. The article presents a study on the establishment of geological and facies conditions for the formation of a sandy-silty-clayey reservoir based on core analysis and linking the information obtained with neighboring areas. Previously used petrophysical relationships were generalized with underlying objects composed of thick monolithic sandstones and did not allow correctly assessing the properties of the reservoir under consideration. The work made it possible to clarify the idea of lithofacies features to substantiate their own petrophysical dependencies, which make it possible to differentiate thin-layered clay reservoirs in the section and determine their properties. The results obtained during the study made it possible to refine the petrophysical model, previously generalized to all the layers of the group. The revision of the boundary values and dependencies helped to justify the increase in reservoir oil reserves and became the basis for subsequent work to increase the profitability of putting the facility into commercial development.

1 Introduction

Today, there is a noticeable change in the resource base of oil companies in Russia. The oil and gas fields of Western Siberia, put into development in the 70-80s of the XX century, are at the final stages of exploitation, characterized by a decrease in the level of production [1-2]. At the same time, it should be noted that the share of hard-to-recover reserves (TRIZ) associated with low-permeability reservoirs of the Achimov, Bazhenov, Tyumen, and Domanik suites is increasing in the production profile. The increased interest in these objects is additionally due to the possibility of obtaining tax benefits for the extraction of hard-to-recover reserves [3-4]. The use of existing wells and surface infrastructure allows minimizing capital costs, due to which the involvement in the development of previously abandoned objects with low porosity and permeability properties (PRP) gives a "second life" to old fields and increases the profitability of their operation.

An example of an "abandoned" object in a group of fields in the West Siberian oil and gas province is a reservoir, which is a thin layered interbedding of sand and clay

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interlayers, characterized by high anisotropy in reservoir properties both lateral and vertical. In commercial practice, due to the textural features of the reservoirs, it is called "hazel grouse". Initially, it was considered unpromising due to the low density of reserves and the lack of technology for their development. However, the results of the study provided an opportunity to take a fresh look at previously low-margin reserves. The rejection of the previously accepted generalized petrophysical model, built on the basis of self-polarization potential (IP) logging, and the substantiation of our own petrophysical model, taking into account the newly sampled core, based on the radioactive logging complex, made it possible to identify productive intervals previously attributed to non-reservoir. This made it possible to justify an increase in the initial geological reserves by more than 50%. The reassessment of the average reservoir properties made it possible to justify obtaining a preferential tax rate for the extraction of hard-to-recover oil reserves, which increased the profitability of putting the facility into operation [5].

2 Materials and methods

Refinement of the geological and lithological structure of the object was based on the study of the facies conditions of the formation of the object [6-7]. A description of the characteristics of core samples was made: color, texture, mineralogical and granulometric composition, laboratory determinations of the porosity and permeability properties of the rocks that make it up. With the use of geophysical well surveys (GWS), the lithological composition in wells was indirectly established without core sampling. According to the nature of the curves of geophysical studies of wells, the regularities of changes in lithology and reservoir properties along the section were established [8]. As a result of statistical processing, boundary values were set for section differentiation on the basis of "reservoir/non-reservoir" and a connection was established between "core-geophysical studies of wells" to determine the main petrophysical properties.

3 Results

Existing regional studies refer the area under consideration to shallow marine sedimentation conditions [6-9]. Based on the performed analysis, determination of the textural and lithological features of the core, and the patterns of rock distribution along the section, a transition was made to a detailed examination of the object. According to the refined model, the reservoir was formed under the conditions of a pro-delta slope, which is a marine section of the delta complex, under the conditions of which thin-layered interbedding of clays and silts is formed [10-11]. The prodelta deposits are characterized by thin-layered lenticular-wavy interbedding of fine-grained sandstones and siltstones with a low content of sandy material and high clay content. Rocks were typified according to the parameters of permeability, porosity and mass clay content. Table 1 presents the reservoir properties of the lithotypes that make up the reservoir of the object under consideration [12].

Table 1. Lithotypes of deposits of the "grouse" type formation.

Type of hazel grouse	Clay content, %	Porosity, %	Permeability, mD
Sanded hazel grouse	5-30	23.6-26.2	5-23.
Actually hazel grouse	30-55	20.9-23.6	1-5
Clay grouse	55-80	18.1-20.9	<1

The sandy hazel grouse consists of sandy-silty lenses and interlayers composed of well-sorted silty sandstone with clayey cement. The rocks represented in the lithotype proper "grouse" are characterized by an increase in clay layers and a more pronounced manifestation of a layered structure. The reservoirs are predominantly composed of highly clayey fine-to-coarse-grained siltstone. Clay "grouse" is characterized by the maximum number of clay layers and a clear manifestation of obliquely wavy texture. The most permeable intervals are fine-grained clayey siltstone.

The studies carried out to identify the regularities in the distribution of the selected lithotypes showed that the thickest and most consistent interlayers are predominantly located in the proximal part of the area under consideration. In the western direction, there is a deterioration in reservoir properties, a decrease in the consistency and thickness of permeable interlayers. There is an increase in the proportion of clayey siltstones and mudstones (Figure 1). Despite significant differences in reservoir properties, analysis of the distribution of the results of determining the properties of the core showed that all types of rocks are described by the same dependencies and differ only in the ranges of values.

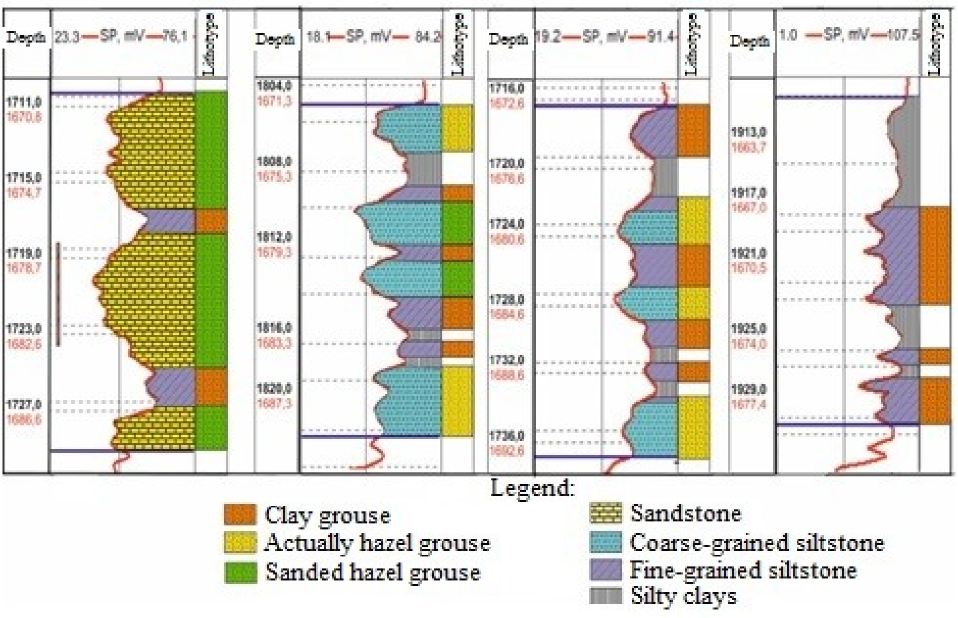

Fig. 1. Distribution of formation lithotypes in the direction from east to west.

The construction of petrophysical dependencies to determine reservoir properties in the fields of Western Siberia, as a rule, is carried out using the self-polarization curve. For the object under consideration, this approach cannot be used due to the smoothed shape and small amplitude of the curve, which is due to the low permeability and high clay content of the reservoirs. Under the conditions of a layered anisotropic reservoir, the differentiation of the section is possible using the double difference parameter GK (ΔIγ), which has a higher resolution:

$$\Delta I\gamma = \frac{I\gamma - I\gamma^{min}}{I\gamma^{max^{min}}} \quad (1)$$

According to the mineralogical analysis, silty sandstones are predominantly composed of quartz components, their share is about 70%. This makes it possible to use the GC data without making corrections to take into account the influence of clay components. As the reference intervals of the maximum and minimum values of ΔIγ, the clay member of the Koshai clays and the underlying layer, composed of thick mature sandstones with maximum porosity and permeability, respectively, were chosen.

The determination of the boundary value for the allocation of permeable intervals was made by constructing integral distributions [13] for the array of core information and the compared value of ΔIγ for reservoirs and non-reservoirs. According to the constructions carried out, the boundary of the reservoirs corresponds to the value ΔIγ = 0.59 (Figure 2).

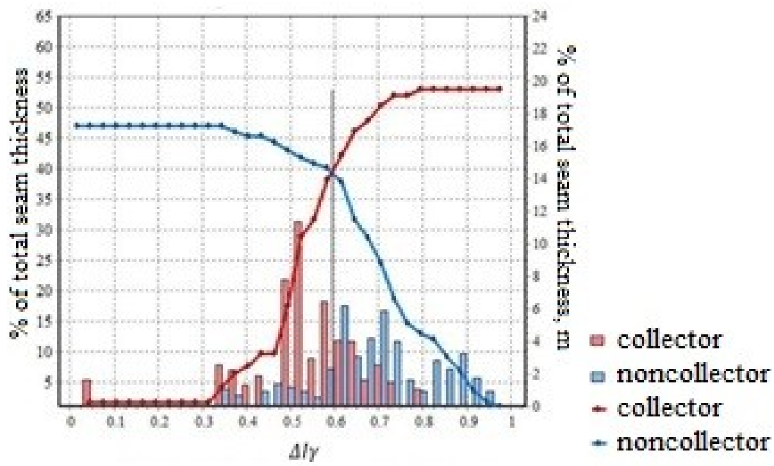

Fig. 2. Justification of the boundary value ΔIγ.

In order to identify and exclude dense, low-porous, impermeable interlayers, the normalized hydrogen content was calculated on the basis of curves of stationary neutron logging.

The applicability of various well logging methods for calculating porosity was assessed. The assessment was carried out according to two key criteria - the convergence of core and calculated parameters and the coverage of the well stock by the method of well logging [14]. The best correlation between the calculated and core porosity was shown by the GK method (Figure 3), and an indisputable advantage is that it is recorded in almost all wells.

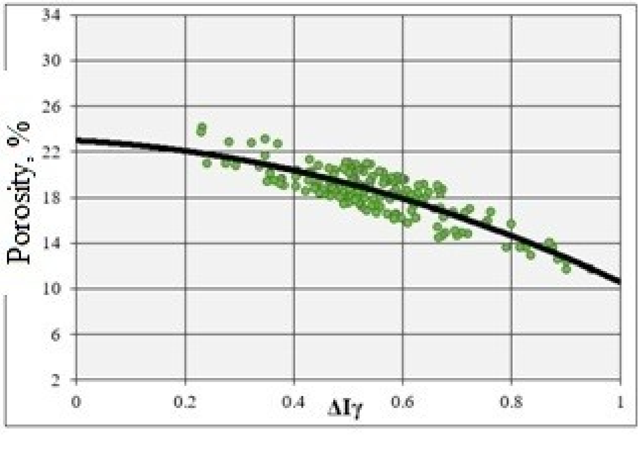

Fig. 3. Dependence of the porosity coefficient on the double difference parameter ΔIγ.

In accordance with the rock types described above, the relationship between porosity and permeability was assessed (Figure 4). The analysis showed that a significant spread in the values of reservoir properties of low-productive samples (cluster 1) is associated with dense siltstone samples containing a significant amount of carbonate cement in the pore space. Such intervals are confidently distinguished by the complex of well logging and are not reservoirs. These samples were excluded from the construction of the dependence, which made it possible to significantly increase the correlation coefficient. As can be seen from Figure 4, the selected clusters of lithotypes are not isolated and overlap each other, thus forming a single trend. This makes it possible to build and apply unified petrophysical relationships for the entire sample, without building relationships for each lithotype.

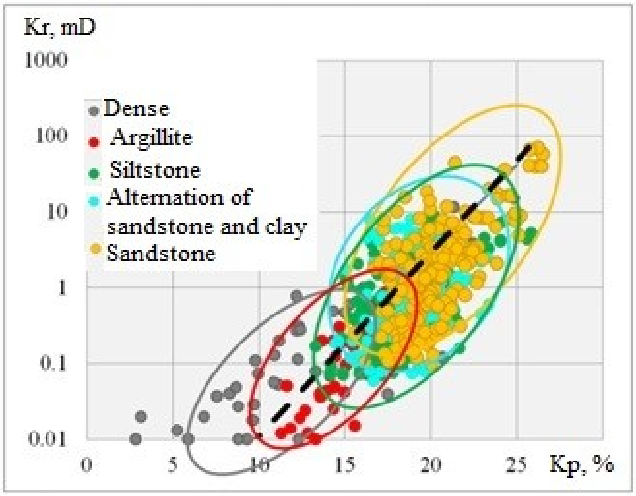

Fig. 4. Dependence of permeability on the coefficient of porosity with the selection of lithotypes.

4 Discussion

The results of a comparative analysis of the updated petrophysical dependencies based on core data taken throughout the reservoir section, including intervals with degraded reservoir properties, with those generalized for the entire group of reservoirs demonstrate a significant discrepancy in all main parameters (Figure 5). Despite the fact that, traditionally for the fields of the West Siberian oil and gas province, the determination of porosity is based on acoustic, gamma-gamma-density and neutron methods of well logging, it is not always possible to use them due to poor standardization and poor coverage of the well stock of well logging. [15].

The calculation of the oil saturation factor was made according to the standard method using the Archi-Dakhnov equation [16-17]. The dependences for determining the parameters of porosity and saturation were obtained from studies of rock samples. The value of the electrical resistivity of formation water is taken based on the mineralization of water and the average temperature of the formation, taking into account data on neighboring fields. Salinity and temperature are determined based on samples and measurements obtained from reservoir testing. The decrease in electrical resistance in productive interlayers is due to the significant content of loosely bound water in the pore space of heavily clayey reservoirs [17-19].

 https://doi.org/10.1051/e3sconf/202341101018

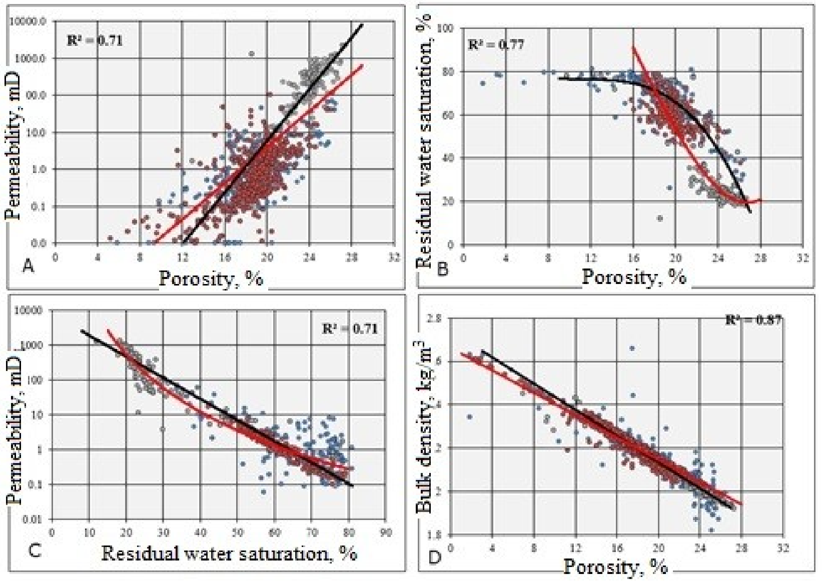

Fig. 5. Comparison of updated and previously used petrophysical relationships: A) permeability versus porosity; B) residual water saturation from porosity C) permeability from residual water saturation ; D) bulk density of rocks from porosity.

5 Conclusion

The result of the studies was the identification of key factors in the formation of the reservoir, which made a significant impact on its lithological features and distribution of reservoir properties. The key role in this was played by the use of rock samples taken from shale intervals of the section to assess the main petrophysical parameters and their relationship, and the exclusion of data from other reservoirs of the group from the statistical sample. The recalculation of geological oil reserves, carried out using a geological model, showed their increase by more than 50%. The main factor in the growth of reserves is the increase in effective thicknesses and oil-bearing area (Figure 6).

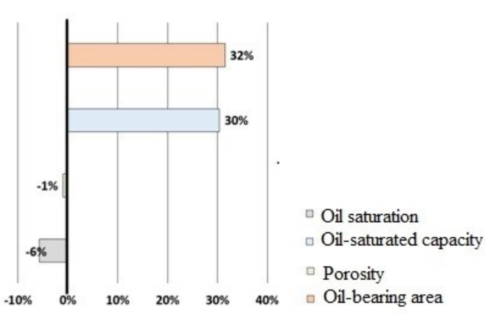

Fig. 6. Factor analysis of changes in stocks.

The use of an updated petrophysical model made it possible to identify productive intervals that were previously classified as non-reservoir due to the overestimated due to more permeable formations of the group of boundary values. Also, due to the allocation of additional effective thicknesses, local replacement zones of the reservoir, uncharacteristic for this type of sedimentation, were excluded, which made it possible to increase the oil-bearing area by 32%.

The decrease in porosity is associated with the separation of thicknesses in the section of the reservoir with degraded porosity and permeability properties, which were previously attributed to a non-reservoir. The decrease in average oil saturation is due to an increase in clay content and residual water saturation relative to previously accepted values.

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