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Abstract. Authors of the article identified the influence of sedimentation conditions on reservoir thickness and the patterns of change in reservoir properties of superviscous oil field from the following three zones of the sandstone sequence of the Sheshminsky horizon: Northern, Southern and Central identified by PJSC Tatneft and prepared for initial development. The following relationships have been investigated: open porosity relation with bitumen content (by weight and by volume), open porosity relation with carbonate content, open porosity relation with bulk density, carbonate content relation with bulk density, bitumen content (by weight and by volume) relation with carbonate content, and also bitumen content relation with their depth. The revealed patterns of changes in reservoir properties and bitumen content within the sandstone sequence can be the result of not only changing conditions of sedimentation, but also the result of post-sedimentation processes resulting in calcitization or redistribution of carbonate cement in the rock under the influence of aggressive products (oxidation, biodegradation) of oil deposits destruction.

1. Introduction

The study of reservoirs formation processes and patterns of the reservoirs distribution as well as study of associated with them traps of oil and bitumen-bearing rocks traditionally involves the forecast and the search for oil and gas fields. In this work, the main emphasis is made on identifying the influence of sandstone-aleuritic sediments formation conditions on the structure and reservoir properties of bitumen (oil) containing sediments. The object of the study are sandstone-aleuritic sediments of the Sheshminian horizon, Ufimian Stage. The zone consisting of hydrocarbon-saturated rocks is at least 200 km in length. The conditions of the hydrocarbons formation are polyfacial, however this question is interpreted ambiguously by different researchers (Forsh N.N., Miropolsky L.M., Ellern S.S., Shalin P.A., Uspensky B.V., Petrov G.A. and others [1, 2]. This is due to the fact that in the areas of oil and bitumen-containing sediments distribution there are channel, delta (distal and proximal parts) and bar facies, as a rule, without specific boundaries of mutual transitions of one facies zone to another. Most of the authors identify only one type of facies. However, each type corresponds to specific and particular sizes of traps, thickness of sediment containing hydrocarbon deposits, particle size distribution and reservoir properties, varying both along strike and along the vertical section. In this regard, knowledge of the detailed geological structure of reservoirs of specific fields, their relation to certain facies zones is extremely important when developing predictive criteria for the search for hydrocarbons, as well as when choosing methods to increase oil recovery using secondary and tertiary methods.

2. Methodology

Analysis of the applied Russian and international technologies of ultra-viscous oil (UVO) and natural bitumen (NB) production showed that there are no clear criteria for their applicability to specific oilfields. Each technology should be individually adapted taking into account the geological and geochemical conditions of the ultra-viscous oil and natural bitumen reservoirs formation. Examples of recommended criteria for the applicability of technologies for the production of ultra-viscous oil and natural bitumen, depending on their physicochemical properties and the reservoir geological characteristics from [3] are given in Table 1.

Table 1. Criteria for the selection of objects recommended to develop by in-situ combustion[1] and steam injection[2]

Parameters	Recommended Values[1]	Recommended Values[2]
Depth, m	< 2100	up to 1200
Reservoir thickness, m	> 3	> 6
Porosity,% for terrigenous rocks for carbonate rocks	 > 18 > 12	 > 18 -
Oil saturation to the start of the process, %	> 40	> 40
Permeability, μm^2	> 0.1	> 0.1
Viscosity of reservoir oil (bitumen), MPa·s	> 10	> 1000
Density of reservoir oil (bitumen), kg/m^3	> 870	> 900

From the above data, it follows that most of the recommended parameters (reservoir thickness, porosity, permeability, bitumen content, viscosity and bitumen density) for selecting development criteria by these methods depend on the reservoirs and hydrocarbon deposits formation conditions. In order to ensure proper reservoir development, construction of horizontal wells, use of enhanced oil recovery methods, besides the listed criteria, it is important to know the morphology and size of traps, direction of change in reservoir properties, which is also a consequence of sedimentation processes.

In order to develop and improve the concepts of the search for, production and refining of ultra-viscous oil and natural bitumen, this article summarizes and interprets the results of actual geological, geophysical and production data, laboratory petrophysical and geophysical research data performed at the Department of Oil and Gas Geology of Kazan (Volga Region) Federal University. Based on the fundamental studies of the reservoirs' geological structure and their formation conditions, according to the authors of [2, 4], there are four facial zones in this area: channel, delta, avandelta and bar.

3. Results and Discussions

There were studied a sandstone (Ashalchinskaya) sequence of the Sheshminsky horizon, Ufimian stage and associated ultra-viscous oil and natural bitumen reservoirs. The core material analyzed in this section describes individual deposits of super-viscous oil and natural bitumen confined to three main groups: the northern, central and southern Cheremshan-Bastryk zone [3] located on the western slope of the South Tatar arch (Fig.1.). Specialists of PJSC Tatneft performed the classification of the

ultra-viscous oil reservoirs by zones in order to prepare these reservoirs for pilot commercial development.

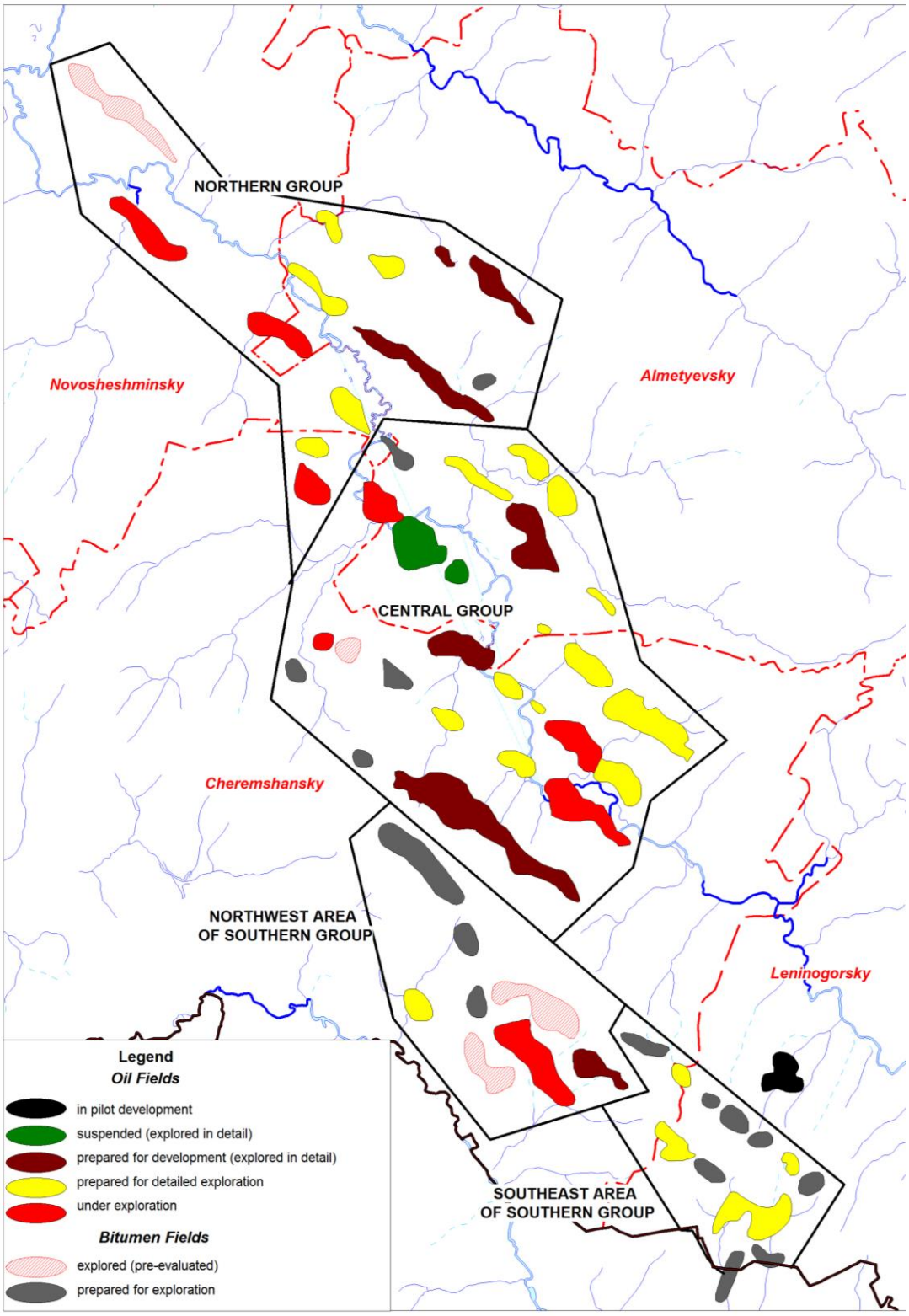

Figure 1. Cheremshan-Bastryk zone of super-viscous oil and natural bitumen

The Northern Group includes ultra-viscous oil reservoirs located between the Ashalchinsky and Arkhangelsky deposits. The Central group includes ultra-viscous oil reservoirs located between the Upper Karmalsky and South Ashalchinsky oil deposits. The Southern group includes oil reservoirs located between the Oikino-Altuninskoye and Sofievskoye oil deposits.

Reservoir properties and bitumen content of the rocks vary widely within the selected zones. Thus, in the fields of the Northern group, the open porosity of rocks varies from 3.3 to 33.9% (an average of 13.8%), carbonate content varies from 0 to 33% (an average of 16.5%), mineralogical density ranges from $2.5 \cdot 10^{-3}$ to $3.6 \cdot 10^{-3}$ kg/m^3 (on average $2.7 \cdot 10^{-3}$ kg /m^3), bulk density varies from $1.7 \cdot 10^{-3}$ to $3.3 \cdot 10^{-3}$ kg/m^3 (average $2.3 \cdot 10^{-3}$ kg/m^3), bitumen content by weight varies from 0.1 to 16.3% (average 5.5%), bitumen content by volume varies from 4.4 to 88.6 % (average 41%).

In the areas of the Central Group, the open porosity of rocks varies from 2.4 to 44.5% (average 23%), carbonate content varies from 0.6 to 46.2% (average 15.9%), mineralogical density varies from $2.3 \cdot 10^{3}$ to $3.3 \cdot 10^{-3}$ kg/m^3 (on average $2.7 \cdot 10^{-3}$ kg/m^3), bulk density varies from $1.4 \cdot 10^{-3}$ to $3 \cdot 10^{-3}$ kg/m^3 (on average $2.2 \cdot 10^{-3}$ kg/m^3), bitumen content by weight varies from 0.1 to 14.9% (on average 5.0%), bitumen content by volume varies from 2.5 to 96.8% (average 39.2%).

In terms of reservoir properties and bitumen content, the rocks from the productive reservoirs of the southern group of deposits are close to the rocks of the northern group of deposits. The open porosity of rocks varies from 0.9 to 38.7% (17.4% on average), carbonate content varies from 0.0 to 46.5% (average 16.7%), mineralogical density ranges from $2.2 \cdot 10^{-3}$ to $3.5 \cdot 10^{-3}$ kg/m^3 (on average $2.7 \cdot 10^{-3}$ kg/m^3), bulk density ranges from $1.6 \cdot 10^{-3}$ to $3.4 \cdot 10^{-3}$ kg/m^3 (on average $2.3 \cdot 10^{-3}$ kg/m^3), bitumen content by weight varies from 0 to 15.5% (average 4.5%),bitumen content by volume varies from 0 to 97.9% (average 40%).

Relationships between various reservoir parameters of the sandstone sequence within oil deposits from all three selected groups were investigated for a more in-depth study of the reservoir properties of Sheshminsky sediments. The following relationships have been studied: open porosity relation with bitumen content (by weight and by volume), open porosity relation with carbonate content, open porosity relation with bulk density, carbonate content relation with bulk density, bitumen content (by weight and by volume) relation with carbonate content [5, 6]. This paper presents the most informative correlation dependencies. The northern group is represented by the Olympiadovsky oil field, the Central group is represented by the Melnikovskoye oil field, and the Southern group is represented by the Verkhne-Karmalskoye oil field. The reservoir properties of the Olympiadovsky oil field are presented in table 2.

The correlation dependences between the parameters characterizing the reservoir properties of the Olimpiadovsky field, as well as of the Melnikovsky, Verkhne-Karmalsky and other fields referred to the Central and Southern groups are presented in Figure 2. Analysis of reservoir properties in the well section of individual oil fields showed a good direct correlation between the following indicators: porosity and bitumen content (by weight and by volume) with a correlation coefficient from 0.5 to

0.78. A clear inverse relationship appears between porosity and bulk density with a fairly high correlation coefficient from minus 0.71 to minus 0.95. There is a good inverse correlation of open

Table 2. Reservoir properties of Olympiadovsky super-viscous oil field (Northern group): min, max, x are the minimum, maximum and average values of the parameter, respectively

Objects of research		Porosity %		Bitumen content, %				Carbonate content, %	
				by weight		by volume			
		min / max	**X**	**min / max**	**X**	**min / max**	**X**	**min / max**	**X**
Rocks from individual wells	246	4.9 / 25.8	10.5	0.5 / 8.6	27.0	27.0 / 72.0	40.7	2.8 / 22.7	14.5
	248	7.9 / 22.1	12.4	1.2 / 3.2	25.2	25.2 / 66.2	42.5	9.2 / 33.0	19.7
	251	4.1 / 23.8	15.4	0.5 / 8.5	6.6	6.6 / 74.2	39.6	3.0 / 20.0	12.6
	247	4.3 / 23.2	11.2	0.5 / 7.5	12.5	12.5 / 83.5	47.8	3.0 / 30.6	14.3
	256	3.3 / 20.5	11.4	1.3 / 10.5	29.4	29.4 / 97.6	67.8	3.9 / 24.5	15.7
	748	4.9 / 26.0	12.9	0.3 / 11.6	9.0	9.0 / 69.3	44.3	6.4 / 32.4	23.0
	790	7.0 / 24.0	15.9	0.3 / 9.3	7.7	7.7 / 68.1	42.5	23.6 / 30.0	26.7
	258	5.1 / 32.6	13.8	0.2 / 16.3	4.1	4.1 / 93.0	43.1	0.0 / 26.6	9.9
Formtion in general		**3.3 / 32.6**	**12.9**	**0.2 / 16.3**	**4.6**	**4.1 / 97.6**	**46.5**	**0.0 / 33.0**	**18.1**

porosity with carbonate content (correlation coefficient varies from minus 0.6 to minus 0.7) There is also a reverse correlation between carbonate and bitumen content (by weight and by volume) with a correlation coefficient from minus 0.55 to minus 0.8. In general, the obtained correlation dependences indicate that the concentrations of hydrocarbons in the Permian sediments are confined to highly porous reservoirs, which are characterized by rather high bitumen content and low carbonate content.

Earlier [4], a connection was found between the thickness of a sandstone pack and its lithological features. It has been identified that the degree of the reservoir's clastic rocks homogeneity (the increase in degree of sorting and increase in average grain size) also increases with an increase in the reservoir thickness, which, in turn, is related to the dynamics of sedimentation. The areas of increased sandstone sequence thickness correspond to more coarse-grained rocks accumulated in the center of the stream (channel), rocks from these areas have better sorting and minimal clay and carbonate content.

The vertical section of the sandstone sequence of the Ufimian Stage is characterized by a strong pattern of changes in reservoir properties with depth.

The open porosity as well as the bitumen content of the rocks, both by weight and by volume decreases with an increase in the depth of the sandstone sequence. The lower parts of the section

within deposits are usually composed of tightly and moderately cemented weakly porous (5-12%) sandstones. Weakly and moderately cemented porous (porosity from 25 to 42%) rocks are developed in the upper part of the sequence. This leads to a higher degree of their oil saturation. The middle part of the reservoir is represented by compacted calcareous sandstones with a porosity of 12-24%. In this part of the section, changes in open porosity with depth are not so sharp, although the tendency to decrease in its values is maintained, while bitumen content of rocks decreases with depth similarly to the upper and lower parts of the formation.

4. Conclusions

Thus, the conditions of sandstone sequence rocks formation were decisive in the distribution of their reservoir properties and the degree of their saturation with hydrocarbons. Relationships between various reservoir parameters of the sandstone sequence within oil deposits from three groups of fields (Northern, Southern and Central) identified by PJSC Tatneft and prepared for initial development were investigated for a more in-depth study of the reservoir properties of Sheshminsky sediments. The following relationships have been identified: open porosity relation with bitumen content (by weight and by volume), open porosity relation with carbonate content, open porosity relation with bulk density, carbonate content relation with bulk density, bitumen content (by weight and by volume) relation with carbonate content, and also bitumen content relation with their depth. The revealed patterns of changes in reservoir properties and bitumen content within the sandstone sequence can be the result of not only changing conditions of sedimentation, but also the result of the influence (perhaps even more) of post-sedimentation processes resulting in calcitization or redistribution of carbonate cement in the rock under the influence of aggressive products (oxidation, biodegradation) of the initial oil deposits destruction.

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