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Estimation of porosity of carbonate reservoirs of Cambrian suprasalt deposits according to well logging and core data

The article considers a method for evaluating the capacitance properties of mixed-type carbonate reservoirs. The carbonate rocks (dolomites) of the suprasalt deposits of the Metegerskaya, Icherskaya and Charskaya formations of the Vostochno-Alinsky deposit were studied. To determine the porosity by well-logging methods, various methods were used: neutron, acoustic and lateral (according to the resistance of the reservoir and reservoir water). The density curve (Gardner's equation) is determined from the empirical dependence of reservoir velocities. It is established that the porosity spread has an uneven character, which is usually characteristic of a fractured or mixed type of reservoir. Nevertheless, the quantitative values determined by different methods are close to each other. The obtained data may be relevant for the assessment of groundwater reserves at hydrocarbon deposits in this region.

Keywords: East Siberia, Vostochno-Alinsky field, well-logging, secondary porosity, carbonate reservoir

The active phase of the development of oil and gas condensate fields in Eastern Siberia, exactly the provision with industrial water affects on the need to study the suprasalt deposits. According to annual report of PJSC Surgutneftegaz, in 2020 production was increased by 5.8 % to 9.9 % million tons, reaching the maximum annual production for the entire development period. Currently, PJSC Surgutneftegaz is developing seven fields in Eastern Siberia [1]. The main interest here is the productive horizons-Osinsky and Khamakinsky, focused on oil production, and the aquifer that provides the field with technical water is confined to the Lower-Middle Cambrian deposits. As an example, section of the suprasalt formation of the Vostochno-Alinsky field, opened by one of the drilled wells is given below.

Lithological and petrophysical characteristics of sediments

Stratigraphically, the Lower Middle Cambrian aquifer complex consists of the Charskaya, Icherskaya and Metegerskaya formations. The Charskaya formation is represented by brownish-gray, dark gray, dense dolomites, sometimes fractured, strongly anhydritized areas, sometimes saline. The section of the Icherskaya formation is made by a homogeneous thickness of dolomites with interlayers of mudstones. The Metegerskaya formation is represented by dense dolomites, with interlayers of mudstones and marls. The rocks are fractured, sometimes overgrown both in area and in section.

The void-pore space formed in carbonate rocks, in comparison with sandstone voids, is very diverse, both in origin and distribution in the rock matrix, and in morphology. It is formed at all stages of lithogenesis and especially during extra-radial processes and can be primary and secondary.

Primary voids are found mainly in clastic rocks (inter-clastic pores), oolitic, lumpy-clot and organogenic.

Secondary voids as intercrystalline and cavernous pores, cavities and cracks were formed as a result of recrystallization, dissolution, and cracking process.

Cavernous pores are represented by small (less than 2 mm in size) voids of dissolution. They develop along intercrystalline pores, along small cracks and weakened zones due to solutions introduced from outside.

Cavities are formed as a result of the chemical dissolution of calcite of limestones, as well as due to the processes of dolomitization, accompanied by the removal of dissolved components. The caverns may be empty, partially or completely filled with later minerals. The characteristics of cavities include: uniformity of distribution in the rock matrix, morphology, size, structure and degree of mineral filling, percentage content in relation to the volume of the rock as a whole.

Cracks are formed in rocks at the stage of diagenesis, catagenesis and at any stages of lithogenesis process during tectonic activity [5, 6].

Due to the high degree of heterogeneity of reservoir rocks, where primary and secondary voids (in the form of cavities, cracks and intercrystalline pores) contribute to the overall porosity, the porosity of mixed-type reservoirs exists.

Characteristics of rocks by core

Core was taken from one of the water intake wells of the Vostochno-Alinsky field, in fact, this well is one of the few where OGPD Talakanneft conducted core studies in the above-salt complex.

The conducted studies on the core indicate the presence of secondary voids, in which there is no regularity in the distribution of the values of the measured porosity from their type. In addition, it is worth noting that the limited number of studies in the section of this well does not allow us to make reliable petrophysical relations. In this regard, the calculation parameters for estimating reserves were determined by standard approaches to interpretation according to the well logging data, which was carried out in the same well where the core was taken.

Well logging interpretation methodology

A complex of well logging studies was carried out in the well under consideration, which made it possible to determine the porosity by several methods [2, 4, 8]. Moreover, the porosity was determined by neutron logging (TRNP).

The value of porosity based on the sonic logging data was calculated using the standard formula:

$$\mathrm{Por}_{sonic} = \frac{\Delta t - 143}{680 - 143}$$

where, Δt – transit time by sonic, 143 us/m – transit time in limestone, 680 us/m – transit time in mud filtrate for well conditions (temperature, mineralization and depth).

The porosity coefficient can be calculated using the Archi-Dakhnov equation, despite the fact that the value of water saturation in this interval is 100 % [7].

$$\mathrm{Por}_{res} = \sqrt[2.18]{\frac{\sqrt{R_{mf}}}{R_t}}$$

where, R_t – the resistance of the formation in the study area by lateral logging. The resistivity of mud filtrate and reservoir water in the study area by lateral logging is on average 7-8 Ohmm, R_{mf} – mud filtrate resistivity (1,2 Ohmm).

Secondary porosity is the difference of certain coefficients:

$$\mathbf{Por_{sec} = Por_{total} – Por_{sonic}}$$

The total porosity determined by the Rt method reaches a maximum value of 15 %, while the sonic method shows an excess of 20 % and limited by the condition of the absence of cavities in the formation.

The dependence graph shows that the main range of porosity variations is 4-12 %, and the secondary porosity is on average 5-7 %, which should also be taken into account when assessing water reserves. At the same time, according to the known subsalt productive horizon values the of porosity cut-off is 5 %. It should also be noted that some voids may be subject to post-sedimentation processes filled with calcite or halite (that is more applies to the reservoirs of the Charskaya formation) [3].

Recovery density data

Due to the fact that there are no density logging measurements in the logging cased wells, therefore, it was decided to recover this information in one of the known ways. Usually, the restoration of the logging record is carried out for the tasks of seismic exploration, however, the calculations were carried out in order to give the most complete characteristic of the rocks composing the section [9]. In this case, the Gardner equation was used to synthesize the data:

RHO=a*m*log10(DT)

where, a, m – empirical constants, DT – sonic travel time.

The resulting density curve has a good correlation with the core data. Thus, it is possible to get a knowledge of the density of rocks throughout the section and use this data to assess the value of porosity and other strength properties of rocks

Core depth 80,0-95,0 м (Metegerskaya formation)

80,18 m	Dolomite is calcareous, gray-brown. Dense, with numerous leaching voids.
81,82 m	Clay dolomite with uneven breccia-like inclusions (up to 7 cm with rare small inclusions of whitish-gray anhydrite, up to 3 mm in size. Leaching voids are observed along the layer. Cracked. The breed is dense, strong.

Core depth 155,0-160,0 м (Icherskaya formation)

155,7 m	Dolomite is gray. Cracked. The cracks are made of anhydrite. In the upper part with deep leaching voids. In some places it is destroyed to the size of rubble.
155,6 m	Dolomite is beige. Cracked. Cracks of various directions. With breccia-like inclusions of gray dolomite up to 5 cm in size.

Core depth 199,0-201,9 м (Charskaya formation)

199,3 m	Dolomite is beige, sometimes brown, of a uniform texture. With a small number of multidirectional cracks up to 2 mm, made with calcite.

Table 1.
Classification of carbonate reservoirs according to I.A. Konyukhov.

Group, effective porosity	Grade	Permeability, 10^{-15} м^2. Effective porosity, %	Lithological members
A. Classes of the highest capacity. Effective porosity >15 %	I	>1000 >25	Limestones and dolomites are skeletal, large-cavernous
	II	1000-500 25-20	Biomorphic, cavernous limestones and dolomites
	III	500-300 20-15	Cavernous and organogenic-clastic limestones and dolomites
B. Classes of medium capacity. Effective porosity from 15 to 5 %	IV	300-100 15-10	Limestones and dolomites are coarse-grained pore-cavernous
	V	100-50 10-5	Limestones and dolomites are medium-and fine-grained pore-cavernous

Table 2.
Results of core sample studies

Formation	Sample	Description	Core depth, m	Reservior properties		Density	
				Porosity (via water and helium), u.f.	Helium permeability, mD	Martix density, g/c^3	Bulk density, g/c^3
mt	5998-13	Dolomite	82.50	7.57	0.31	2.82	2.59
mt	5999-13	Dolomite	83.25	6.45	2.65	2.79	2.52
mt	6000-13	Dolomite	83.90	2.75	0.02	2.72	2.65
mt	6001-13	Dolomite	84.00	2.30	0.03	2.73	2.67
ic	6002-13	Shaly dolomite	140.30	4.24	0.01	2.68	2.57
ic	6003-13	Fractured dolomite	140.65	3.40	4.39	2.67	2.57
ic	6004-13	Fractured dolomite	141.20	0.25	<0.01	2.69	2.68
ic	6005-13	Fractured dolomite	142.25	5.37	0.07	2.82	2.67
ic	6006-13	Fractured dolomite	142.35	2.31	0.00	2.75	2.71
ic	6007-13	Fractured dolomite	155.05	0.45	0.00	2.68	2.65
ic	6008-13	Shaly dolomite	156.00	6.24	0.03	2.77	2.61
cr	6010-13	Dolomite	199.30	7.07	0.01	2.83	2.61
cr	6011-13	Shaly dolomite	201.95	1.54	<0.01	2.73	2.7
cr	6012-13	Dolomite	202.25	10.86	32.20	2.77	2.46
cr	6013-13	Dolomite	202.50	5.34	0.07	2.81	2.63
cr	6015-13	Fractured dolomite	229.60	5.88	0.02	2.86	2.68
cr	6016-13	Fractured dolomite	229.95	8.69	0.01	2.85	2.59
cr	6017-13	Fractured dolomite	230.45	2.05	<0.01	2.74	2.65

in the Lower and Middle Cambrian sediments, for instance, in order to drilling new wells.

Conclusion

The Lower Middle Cambrian aquifer complex contains on the mixed type reservoir rocks. Secondary processes can occur unevenly in the rock. As a result, the properties of the reservoir will differ significantly at different points, and two wells drilled in close proximity to each other can show a completely different values of flow rate. There is a relationship between the amount of cracks and the volume of reservoir water contained in them.

It is necessary to understand which reservoir intervals has secondary porosity and which ones have matrix porosity during the interpretation. This knowledge influences on choice of a method for determining the porosity coefficient, since only results of the acoustic method can offer to estimate of the cavernous-fractured volume of the reservoir. Due to the fact that crack porosity is a factor in assessing the reservoir capacity, it is recommended to apply the logging data processing approach given above in order to determine the calculation parameters.

Within the framework of this article, the characteristics of the host reservoir rocks of the Lower Middle Cambrian aquifer complex at the field were given. The method of estimating porosity by logging data was tested in several ways and the results were obtained that are in good correlation with the data of core analysis. The synthesis of density logging, which can be used in solving geological and technical issues, was carried out.

The study of secondary porosity gives a knowledge of the structure and properties of the reservoir, and can also be used as a factor in order to increase groundwater reserves. XXI

Fig. 1.

Cross-plot based on resistivity and sonic porosity to determine the presence of intervals with secondary porosity.

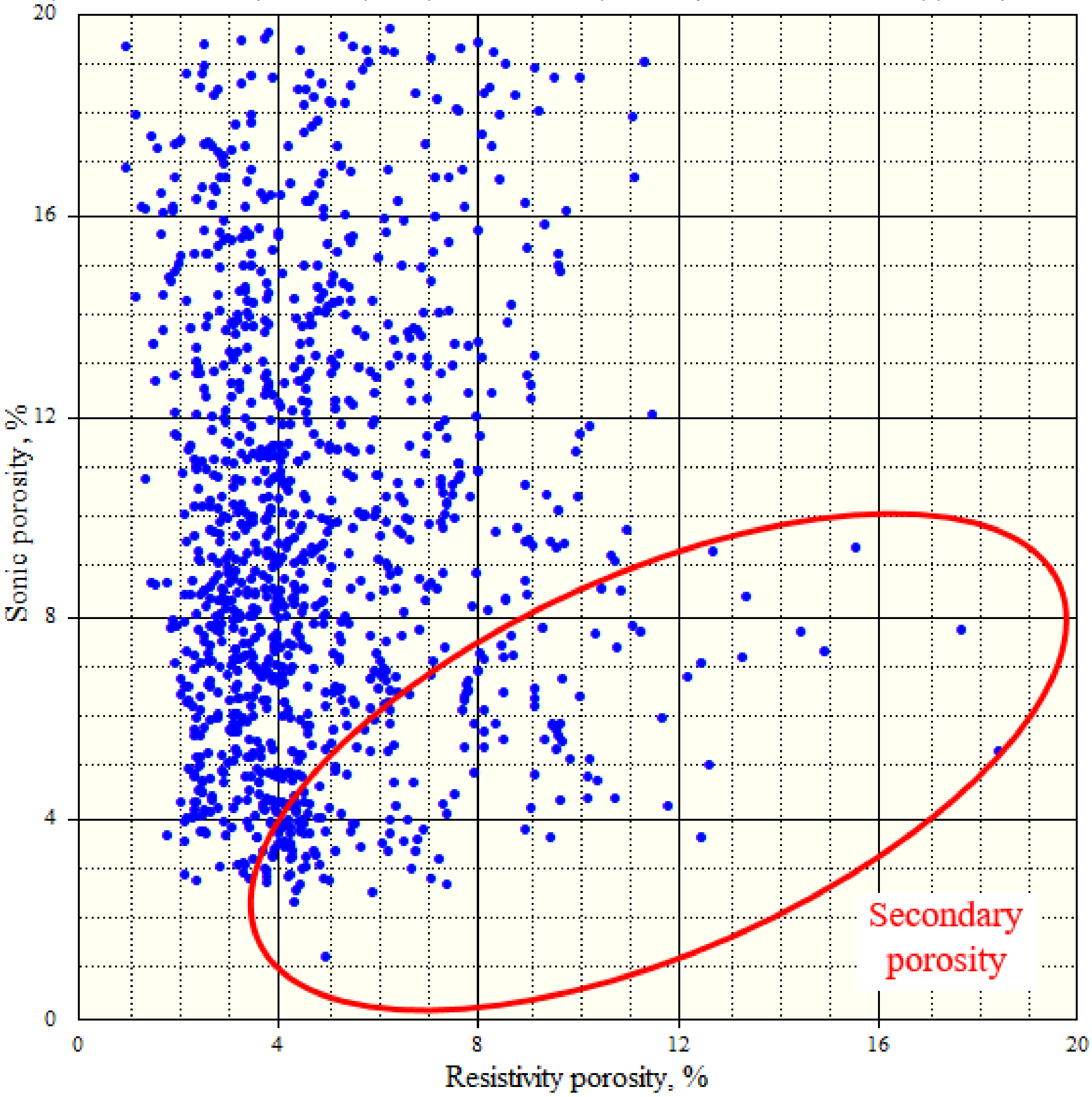

Fig. 2.
Composite log of water-saturated carbonate deposits of the studied well