CRITERIA FOR LOCAL FORECAST OF RESERVOIR FORMATIONS IN CARBONATE VENDIAN-CAMBRIAN DEPOSITS OF THE UST-KUTSKIAN HORIZON

M.N. Lemeshko[1,2], A.A. Potseluev[1], M.V. Shaldybin[1,2], D.I. Lemeshko[2]*
[1]National Research Tomsk Polytechnic University, Tomsk, Russia
[2]TomskNIPIneft, Tomsk, Russia
[*]Corresponding author: Mariya N. Lemeshko, e-mail: lemeshkomn@tomsknipi.ru

Abstract. The article presents a lithogenetic typification of the rocks of the Ust-Kutskian horizon of the Teterian formation in the central part of the Nepa-Botuobin anteclise. A generalized scheme-model of their formation is drawn up. Granular dolomites have been identified as the most promising lithogenetic type to allocate zones with improved reservoir properties. The structure of the void space of the Ust-Kutskian horizon is characterized. Based on the quantitative assessment of pores and caverns, the presence of salts in them, a correlation was established between these parameters and the reservoir properties of the rocks.

The connection with post-sedimentation processes is shown. The conditions for the formation of the Ust-Kutskian depositsare reconstructed with the use of geochemical indicators for element-impurities. As a result of the studies, a set of criteria for local forecasting of reservoirs for setting up the first stage of exploration and development has been developed.

Keywords: dolomite, reservoir rocks, criteria, lithogenetic types, Ust-Kutskian horizon
DOI: http://doi.org/10.18599/grs.19.2.6

For citation: Lemeshko M.N., Potseluev A.A., Shaldybin M.V., Lemeshko D.I. Criteria for local forecast of reservoir formations in carbonate Vendian-Cambrian deposits of the Ust-Kutskian horizon. *Georesursy = Georesources*. 2017. V. 19. No. 2. Pp. 122-128. DOI: http://doi.org/10.18599/grs.19.2.6

Introduction

The main prospects for the discovery of new hydrocarbon fields in the Nepa-Botuobin oil and gas region are associated with carbonate Vendian-Cambrian deposits. One of the productive horizons is the Ust-Kutskian horizon, the study of which is incomplete (Gurova, 1988; Shemin, 2007; Melnikov, 2009, etc.).

A feature of the horizon is the wide distribution of post-sedimentation processes, which introduced heterogeneity in the distribution of reservoir properties both in area and in the section and caused a very low permeability of oil-bearing deposits.

The use of standard methods for studying weakly permeable carbonate deposits does not allow localization of areas that provide significant inflows of oil from the layers. Increase in oil inflows is often achieved with the help of intensification methods, which require knowledge of lithology and structure of the void space. In this connection, it became necessary to study lithological features, reservoir properties, facies and geochemical conditions for the formation of horizon, to develop criteria for the allocation of reservoirs for effective prediction of zones with improved reservoir properties. This will allow localizing the favorable zones in the carbonate rocks of the studied horizon, as well as in rocks with similar structure of the reservoirs.

The research area is located in the west, northwest of the Nepa arch in the central part of the Nepa-Botuobin oil and gas bearing area, confined to the eponymous anteclise (Fig. 1).

To achieve the goal, the following investigations were carried out: lithogenetic types of carbonate deposits of the Ust-Kutskian horizon (Lemeshko, 2013) were identified, their spatial position in the sedimentary basin was determined, reservoir properties were studied, and geochemical conditions of sedimentation accumulation conditions were analyzed.

Research Methods

In recent years, a wide range of researches have been carried out to study in detail the carbonate reservoirs and fluids of the East Siberian region. In this paper, the results of complex core studies of the Ust-Kutskian horizon were used (Table 1).

Analyzes were performed by the laboratory of sedimentology, formation physics, geochemistry of OJSC TomskNIPIneft (M.N. Lemeshko, Ya.N. Roshchina, E.D. Polumogina, Yu.M. Lopushnyak, N.V. Oblasov, R.S. Kashapov, E.G. Achkasova and others), INGG SB RAS (I.V. Varaksina, E.M. Khabarov, etc.), OJSC NPTs Tvergeofizika (A.N. Nikitin, N.V. Konyukhova and others), FGUP VNIGNI (G.V. Agafonova). Core material and research results are the property of Rosneft Oil Company.

General characteristic of the section

In the studied sections of wells drilled in 2009-2012 in the central part of the Nepa-Botuobin anteclise, the Ust-Kutskian horizon has a structure similar to that described in the works of N.V. Melnikova, G.G.

Georesursy = Georesources. 2017. V. 19. No. 2. Pp. 122-128

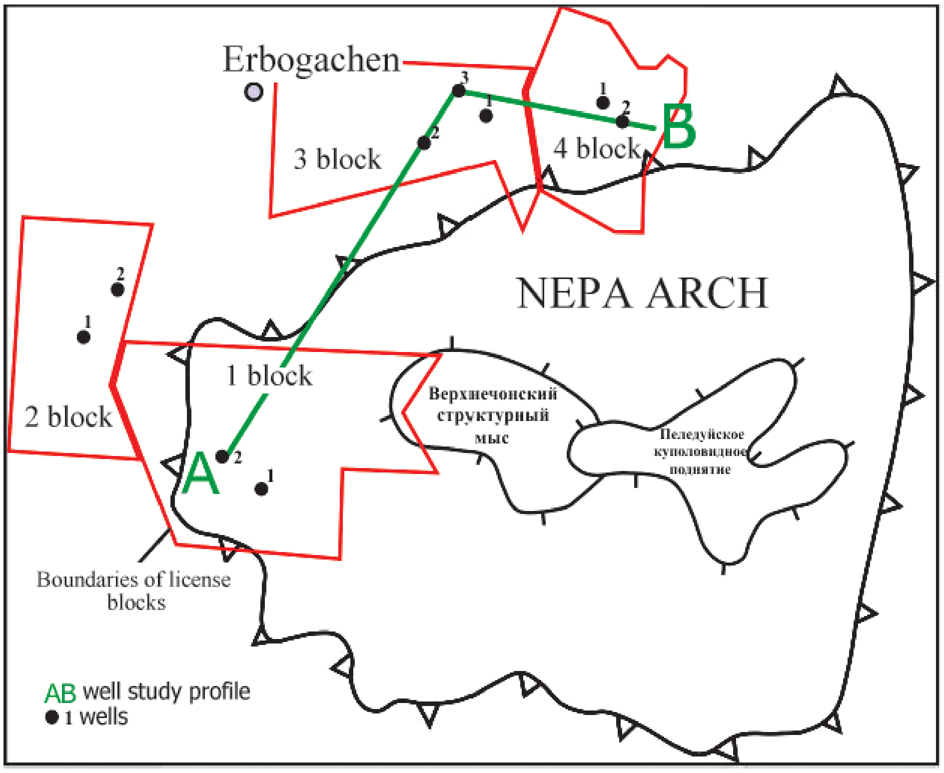

Fig. 1. Overview map of the research area

Analysis Type	Total of samples (for 9 wells)
Detailed core macro-description, m	542.19
Facies, m	542.19
Petrographic	419
X-ray diffraction (XRD)	506
Luminescent-microscopic	500
X-ray energy-dispersive microanalysis	150
Inductively coupled plasma mass spectrometry ICP-MS	11
Calcimetry	173
Study of the reservoir properties (determination of porosity and gas permeability)	1323

Table 1. List of completed studies

Shemina, T.I. Gurova et al. for different regions of the Siberian platform (Melnikov, 2009; Shemin, 2007; Gurova, 1988). Two layers are distinguished in the Ust-Kutskian horizon – the upper (B_{3-4}) and lower (B_5), separated by a clay-carbonate-sulfate bridge with a thickness of 3 ... 7 m. The thickness of the Ust-Kutskian horizon varies within 28 ... 82.67 m.

Impermeable beds of the upper layer are the halogen-carbonate deposits of the Usolskian formation, along the bottom of which the upper boundary of the Ust-Kutskian horizon is located. The mineralogical composition of the rocks is established by X-ray phase and petrographic analysis in the thin sections. The main rocks of the horizon are dolomites, less often there are dolomites with a small admixture of calcite and a different content of insoluble residue (Fig. 2). The dolomites are secondary; it is assumed that they were formed as a result of the limestones replacement. The dolomites are cryptocrystalline and clearly crystalline (from thin to large), light gray, dark gray, cream-colored, brown (oil-saturated varieties), dense and very strong. In macro- and microscopic studies of dolomites, the textures are often poorly preserved due to repeated recrystallization of rocks. Clay-carbonate rocks (marls, calcareous clays) with different percentages of clay components and argillites are less widespread in the section. Clay rocks often represent a bridge between reservoir rocks. The anhydrite (less often gypsum) is clearly distinguished in macro description, with bluish-gray and whitish colors of several generations in the form of spots, interlayers, radiant-pentagonal aggregates, needle crystals, as well as continuous masses filling pores and cracks. Galite occurs mainly in the upper half of the section and performs voids.

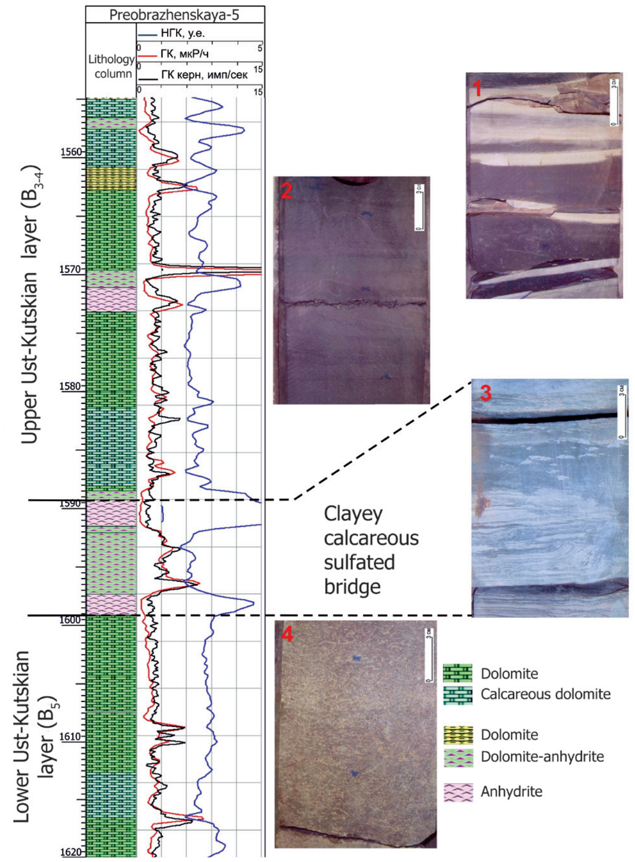

Fig. 2. The section of Ust-Kutskian horizon on the example of well Preobrazhenskaya-5. Pictures: 1 – Microcrystalline dolomite, oil-saturated porous with a layered silica; 2 – Fine-crystalline dolomite, homogeneously oil-saturated porous; 3 – Dolomite-anhydrite rock; 4 – Fine-grained dolomite, oil-saturated porous-cavernous.

The discussion of the results

Executed studies have made it possible to identify the group of criteria that, in various combinations, should be applied expeditiously in carrying out prospect evaluation and exploration work.

Lithologica criteria. Lithological criteria were identified using a macro and microscopic study of the core. Based on the results of the petrographic analysis, the lithogenetic types of the Ust-Kutskian horizon were identified and described (Lemeshko, 2013). The classification of lithotypes was based on the classification of E.M. Khabarov and R. Dunham (Khabarov, 1985, Dunham, 1962) (Table 2).

Favorable structural and textural features are attributed to granular dolomites and dolomites completely recrystallized with increased porosity relative to other rocks. Granular dolomites with a low content of micrite material form bar bodies, their primary structure is favorable for the formation of the reservoir.

Microstructural criteria are determined by the results of petrographic analysis and scanning electron microscopy. The hollow space structure of reservoir rocks is a heterogeneous and complex with the predominance of voids formed as a result of post-sedimentation processes. Thus, caverns and pores of leaching have a wide distribution in rocks. Their number reaches 10-25% of the rock volume in granular dolomites,. However, these voids are filled with pores of recrystallization and residual sedimentation pores. In completely recrystallized rocks, which, like granular dolomites, also have enhanced reservoir properties, the recrystallization pores form the bulk of the void space. Thus, favorable microstructural features of reservoir rocks are defined, including primary and secondary porosity (recrystallization, leaching, residual intergranular sedimentary pores), and also the communicability of pores and caverns. Low permeability indexes of oil reservoir rocks indicate the presence of isolated and sealed pores and caverns, which refers to unfavorable criteria.

Post-sedimentation processes have made significant changes in the structure of the hollow space of reservoirs. The influence of these processes was studied in the macro- and micro-description of core and petrographic analysis of thin sections. The evaluation of the influence

Lithogenetic types		Reservoir properties		Number of samples
		Porosity (gas), % average	Permeability (gas), $\mu m^2 * 10^{-3}$ average	
A Granular and mircrite crystalline dolomites	A1 Oolitic and oolitic-like	5,38	1,22	50
	A2 Clotted-lumpy (peloidal)	3,62	0,53	32
	A3 Intraclasts, detrital	4,04	0,27	12
	A4 Unevenly completely recrystallized (spotted)	4,61	4,55	64
B Micrite (crystalline) dolomite	B1 Micrite and micro-fine crystalline with admixture of clay substance	1,60	0,10	52
	B2 Uniformly completely recrystallized (homogeneous)	3,88	0,82	47
C Dolomite-anhydrite rocks (anhydrite content above 30%)		0,99	0,24	29
D Stromatolite dolomites		1,79	0,08	6

Table 2. Lithogenetic types of the Ust-Kutskian horizon in the central part of the Nepa-Botuobin anteclise

of post-sedimentation processes on the porosity and permeability of rocks has shown that recrystallization and leaching contributed to the improvement of reservoir properties. The processes associated with the formation of minerals-sulfatization, galitization (salination), silicification (Lemeshko, 2014), negatively affected the reservoir properties of rocks. The application of quantitative evaluation of the content of anhydrite and halite in the sections of pores and caverns, made it possible to evaluate the effect of secondary processes on the reservoir properties. For this purpose, quantitative characteristics were calculated: pores of recrystallization, open and "healed" pores and leaching cavities in thin sections, anhydrite and halite in rocks. To determine the positive or negative relationship between these parameters and the coefficients of porosity and permeability, rank correlation coefficients were used, which made it possible to estimate the influence of some secondary processes on the total rock capacity. Positive rank correlation coefficients indicate a direct proportional relationship of the parameters, negative – the inverse (Table 3).

The influence of the recrystallization pores on the reservoir properties is positive (Table 3). In the granular rocks, uneven recrystallization of uniform elements and intergranular space is well manifested. In micrite dolomites with an unfavorable primary structure, uniformly distributed pores of recrystallization in the crystalline mass provide good porosity to these rocks.

The influence of open caverns on the reservoir properties is positive. A significant volume of caverns in granular dolomites exceeds intercrystalline porosity. Cavities are often inherited from sedimentation voids, and also developed within the grains of primary shaped elements and recrystallization void spaces. Cavity formation is one of the main positive processes in the dolomites of the Ust-Kutskian horizon to form a good reservoir. However, the capacity of the reservoir is partially lost because of the "printing" of caverns with mineral salts – gallite and anhydrite.

The influence of healed caverns, anhydrite, and halite on the reservoir properties is negative. Most of the caverns have undergone sealing, which adversely affects the reservoir capacity. Sulphate mineralization and salinization, as a rule, lead to deterioration in porosity, but in some cases, due to the partial filling of pores and cavities, the open porosity remains.

Petrophysical parameters were used to characterize reservoir rocks. Studies of the coefficients of permeability and porosity in helium were performed on the AP-608 Core test systems. The calculation of the average values of the reservoir properties for each lithogenetic type showed that dolomites completely recrystallized, in which the primary structure did not survive, have the highest porosity and permeability with respect to other types of rocks, in addition to granular dolomites (Table 2). Low rates of reservoir properties are mainly associated with salinization. After the removal of rock samples from salts, a significant (2-3 times) improvement in reservoir properties is established.

Intervals with increased porosity and permeability are most often composed of granular dolomite and are accompanied by strong oil saturation and high bitumen content. The heterogeneous distribution of reservoir properties within each lithogenetic type is unfavorable.

Facies criteria. Facies criteria are determined by performing a lithological-facial analysis. Formation of sediments in shallow-water conditions at high hydrodynamic activity of the environment under the influence of tidal currents with the formation of baryonic systems and stromatolite structures is a favorable criterion for the formation of reservoirs (Fig. 3).

The formation of deposits in a calm regime is an unfavorable factor, which contributes to the accumulation of clay material and lowers the reservoir properties. Thus, the granular dolomites of the Ust-Kutskian horizon can be potential reservoirs, since they form bar systems with a favorable primary structure and low content of micrite.

Geochemical criteria. The geochemical characteristics of sedimentation were based on the data of the ICP-MS analysis. Based on the calculated geochemical parameters, the sedimentogenesis was reconstructed, which confirmed the results of the lithological-facies analysis. This makes it possible to use geochemical criteria in complex with lithologic-facies as predictions for determining zones of promising carbonate reservoirs in the deposits of the Ust-Kutskian horizon.

The authors have calculated the basic relationships of chemical elements to determine the depth of the sedimentation, salinity, oxidation-reduction features, etc.

RP	Recrystallization (pores)	Leaching (caverns)			Sulfatisation (anhydrite)	Salinization (halite)
		All	Open	Leached		
K_{por}	**0.37**	0.07	**0.35**	**-0.22**	**-0.20**	-0.11
K_{per}	**0.30**	0.03	**0.41**	-0.17	-0.14	-0.07

Table 3. Coefficients of rank correlation, reflecting the influence of post-sedimentation processes on the reservoir properties (RP). Sampling contains 102 samples. The critical value of the Spearman correlation coefficient is 0.18 (at P <0.05); significant values are in bold type

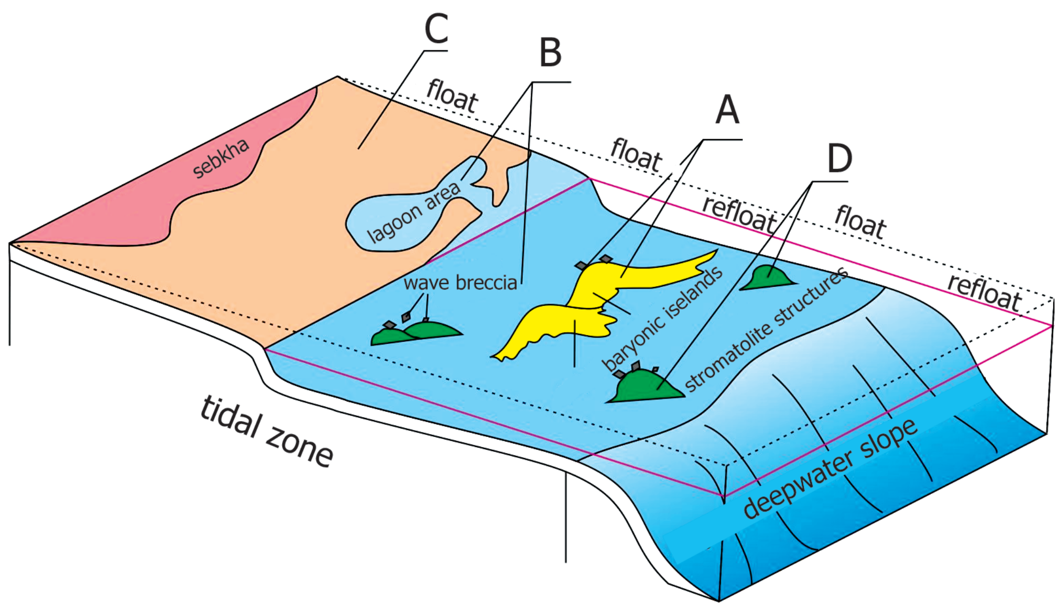

Fig. 3. A generalized scheme-model for the formation of lithogenetic types of rocks of the Ust-Kutkskian horizon (A, B, C, D – zones of lithogenetic types development)

by the methods of A.V. Maslova, Ya.E. Yudovich, E.F. Letnikova (Maslov et al., 2003; Maslov, 2005; Yudovich, Ketris, 2011; Letnikova 2005, 2008).

In the carbonate sediments of the Ust-Kutskian horizon, the main typomorphic elements have a similar distribution with subplatform deposits of ancient continental blocks and microcontinents, which were deposited in shallow conditions. According to E.F. Letnikova, the range of the Ust-Kutskian horizon corresponds to the formation of sediments in the shallow-water basin (Letnikova, 2005).

A small amount of Ti and Zr shows that the formation of deposits took place at a considerable distance from land in a basin with a passive tectonic regime. The values of Sr below the clark indicate the formation of granular dolomites under conditions of increased hydrodynamic activity of waters, at which Sr could be carried out. The distribution of typomorphic elements (Ti, Mn, Zr, Sr, Ba) corresponds to the shallow conditions of deposits formation. The content of impurity elements (Cr, Ni, Co, Cu, Be) shows the proximity of the provenance area of the basic and acidic composition.

We can judge the geodynamic situation of sedimentation according to the TR content. To reconstruct the conditions of sedimentogenesis of carbonate rocks, we can use the ratio of light rare earth elements (LREE) to heavy ones (HREE).

In the carbonate deposits of the Ust-Kutskian horizon, the LREE/HREE ratio varies in a fairly wide range (from 4 or more) and corresponds to the passive continental margin.

One indicator of the paleoclimate is the relation $\Sigma Ce/\Sigma Y$ (ratio of cerium to yttrium rare earth elements). In the considered deposits, the value of the index varies from 2 to 4 (Figure 4), which corresponds to the semi-arid climate.

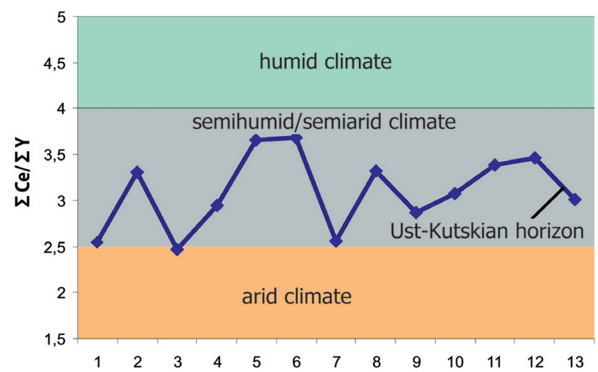

Fig. 4. The ratio $\Sigma Ce/\Sigma Y$ as an indicator of the paleoclimate

With respect to Sr/Ba in sediments of the same age, it is possible to trace the transition from freshwater to marine depositions. In the first, the ratio of Sr/Ba is less than 1, in the second – more than 1. This ratio can be used as an indicator of aridity (Martynov, Nadenenko, 1980). For most of the samples of the Ust-Kutskian horizon, the Sr/Ba ratio is much greater than unity, which corresponds to the marine sedimentation conditions (Fig. 5).

For Precambrian deposits altered by secondary processes, the use of various methods for the reconstruction of oxidation-reduction environments is difficult. Therefore, the conclusion was made as a result of comparison of the calculated geochemical indices of the Ust-Kutskian horizon with the data of Yu.O. Gavrilova et al. (2002), A.V. Maslova et al. (2003).

To assess the oxidation-reduction conditions of the Ust-Kutskian horizon, the most informative geochemical indices were used (Fig. 6).

Fig. 6 shows the predominance of indices, which correspond to the conditions of a well-aerated basin, constantly enriched with oxygen. We cannot exclude the presence of moderately anoxic environments. Most

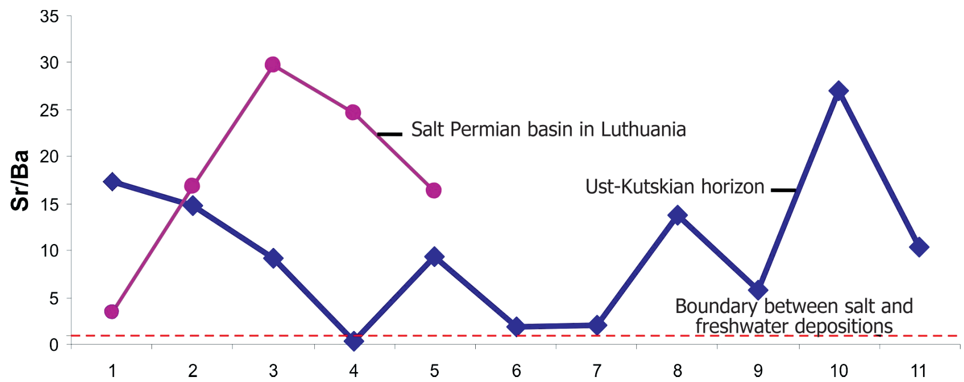

Fig. 5. Sr/Ba ratio as a measure of salinity

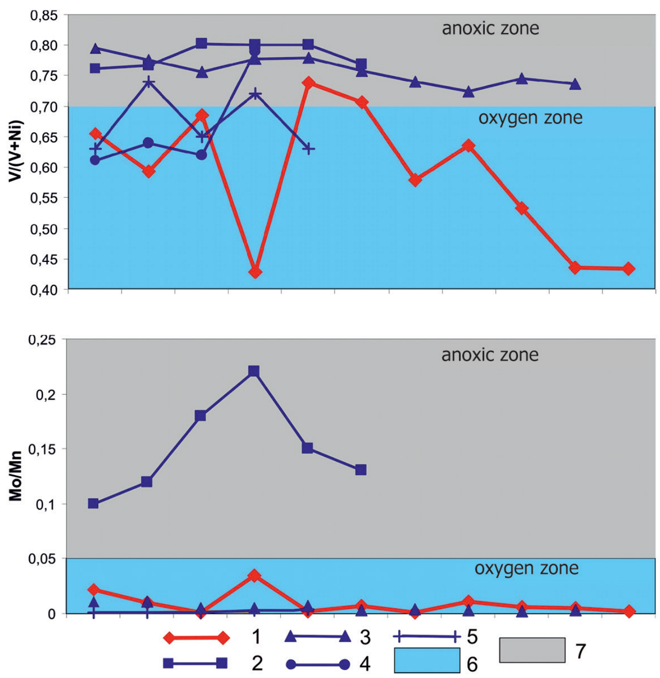

Fig. 6. Basic geochemical relations characterizing oxidation-reduction conditions. 1 – Ust-Kutskian horizon; 2 – Nizhneaptsky bituminous shales of the central regions of the Russian plate; 3 – Nizhneaptsky non-bituminous clayey rocks of the central regions of the Russian plate; 4 – Lower Vendian of the western slope of the Middle Urals; 5 – Middle Riphean of the western slope of the Middle Urals; 6 – zone of a well aerated basin – oxidizing conditions; 7 – anoxic zone – reducing conditions (Jones, Manning, 1994; Holodov, Nedumov, 1991; Ernst, 1976; Hatch, Leventhal, 1992)

often, samples falling into the anoxic-free zone are represented by clayey dolomites and clay-carbonate-sulfate deposits (litho-genetic type B and C).

The above features of carbonate reservoirs can be combined and used as a set of predictive criteria for probable placement of rocks with improved reservoir properties in carbonate sediments of the Ust-Kutskian horizon. Sites of the most probable deposition of rocks with improved reservoir properties can be considered as zones promising for revealing oil deposits, determining the most effective direction of prospecting, evaluation and exploration operations both in well-drilled areas and beyond.

References

Dunham R.J. Classification of carbonate rocks according to depositional texture. *Classification of carbonate rocks, American Association of Petroleum Geologists Memoir*. Ed. W.E.Ham. 1962. V.l. Pp. 108-121.

Ernst V. Geochemical analysis of facies. Leningrad: Nedra. 1976. 126 p.

Gavrilov Yu.O. Dynamics of formation of the Jurassic terrigenous complex of the Greater Caucasus: sedimentology, geochemistry, post-sedimentation transformations: *Avtoref. Diss. dokt. geol.-min. nauk* [Abstract Dr. geol. and min. sci. diss.]. Moscow: MGU. 2002. 52 p. (In Russ.)

Gurova T.I., Chernova L.S., Potlova M.M. et al. Lithology and conditions for the formation of oil and gas reservoirs of the Siberian Platform. Moscow: Nedra. 1988. 254 p. (In Russ.)

Hatch J.R., Leventhal J.S. Relationship between inferred redox potential of the depositional environment and geochemistry of the Upper Pennsylvanian (Missourian) Stark Shale Member of the Dermis Limestone, Wabaunsee County, Kansas, U.S.A. *Chem. Geol*. 1992. V. 99. Pp. 65-82.

Jones B., Manning D.A.C. Comparison of geochemical indices used for the interpretation of palaeoredox conditions in ancient mudstones. *Chem. Geol*. 1994. V. 111. Pp. 111-129.

Khabarov E.M. Comparative characteristics of the Late Precambrian reefogenic formations. Novosibirsk: Nauka. 1985. 125 p. (In Russ.)

Kholodov V.N, Nedumov R.I. On the geochemical criteria for the occurrence of hydrogen sulfide contamination in the waters of ancient reservoirs. *Izv. AN SSSR. Ser. geol*. 1991. No. 12. Pp. 74-82. (In Russ.)

Lemeshko M.N., Zhukovskaya E.A., Varaksina I.V. Relationship between the oil saturation of carbonate reservoirs and processes of formation of a pore space (on the example of ancient deposits of Eastern Siberia). *Izvestiya Tomskogo politekhnicheskogo universiteta = Bulletin of the Tomsk Polytechnic University*. 2013. Vol. 323. No. 1. Pp. 93-99. (In Russ.)

Lemeshko M.N. The role of post-sedimentation processes in the formation of carbonate reservoirs of the Ust-Kut productive horizon in the central part of the Nepa-Botuoba anteclise. *Geologiya i mineral'no-syr'evye resursy Sibiri = Geology and Mineral Resources of Siberia*. 2014. No. 1(17). Pp. 51-58. (In Russ.)

Letnikova E.F. Geochemical specificity of carbonate deposits of various geodynamic settings of the northeastern segment of the Paleo-Asiatic Ocean. *Litosfera = Lithosphere*. 2005. No. 1. Pp. 70-81. (In Russ.)

Letnikova E.F. Geochemical types of carbonate deposits of the southern frame of the Siberian platform: *Diss. dokt. geol.-min. nauk* [Dr. geol. and min. sci. diss.]. Novosibirsk. 2008. 319 p. (In Russ.)

Martynov V.S., Nadenenko V.N. Microelements in the bottom sediments of the south of Ukraine. *Preprinty In-ta geol. nauk AN USSR*. 1980. No. 9. Pp. 33-34. (In Russ.)

Maslov A.V., Krupenin M.T., Gareev E.Z., Petrov G.A. To the assessment of the redox environments of the Riphean and Vendian basins of sedimentation of the Urals western. *Litosfera = Lithosphere*. 2003. No.2. Pp. 75-93. (In Russ.)

Maslov A.B. Sedimentary rocks: methods for studying and interpreting the data obtained. Ekaterinburg: UGGU. 2005. 289 p. (In Russ.)

Mel'nikov N.V. Vend-Cambrian salt basin of the Siberian platform (Stratigraphy, development history). Min-vo prirod. resursov RF, Sib. nauch.-issled. in-t geologii, geofiziki i mineral'nogo syr'ya. Novosibirsk: SO RAN Publ. 2009. 148 p. (In Russ.)

Shemin G.G. Geology and oil and gas potential of the Vendian and Lower Cambrian of the central regions of the Siberian platform (Nepsko-Botuobinskaya, Baikit anteclise and Katangskaya saddle). Novosibirsk: SO RAN Publ. 2007. 467 p. (In Russ.)

Yudovich Ya.E., Ketris M.P. Geochemical indicators of lithogenesis (lithological geochemistry). Syktyvkar: Geoprint. 2011. 742 p. (In Russ.)

About the Authors

Mariya N. Lemeshko – PhD student, Department of Geology and Land Management, Institute of Natural Resources, National Research Tomsk Polytechnic University; Junior Researcher of the Sedimentology Laboratory
TomskNIPIneft
Russia, 634027, Tomsk, Mira pr., 72
Phone: +7 3822 611-958, e-mail: lemeshkomn@tomsknipi.ru

Anatolii A. Potseluev – DSc in Geology and Mineralogy, Professor, Department of Geology and Land Management, Institute of Natural Resources
National Research Tomsk Polytechnic University
Russia, 634050, Tomsk, Lenina pr., 30

Mikhail V. Shaldybin – PhD in Geology and Mineralogy, Department of Geology and Land Management, Institute of Natural Resources, National Research Tomsk Polytechnic University; Head of the Lithology division
TomskNIPIneft
Russia, 634027, Tomsk, Mira pr., 72

Dmitrii I. Lemeshko – Engineer, Sedimentology Laboratory
TomskNIPIneft
Russia, 634027, Tomsk, Mira pr., 72

Manuscript received 12 December 2016;
Accepted 04 May 2017; Published 30 June 2017