Verification of the Technology of Search for Hydrocarbon Pools on the Basis of the Studies of Water-Gas Equilibria (the Southern Regions of the Ob-Irtysh Interfluve)

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Abstract. Results obtained through the analysis of water-gas equilibria in formation waters are shown to form the basis of the technology aimed at search for hydrocarbon pools. A direct dependence of a decrease in total gas saturation, the concentrations of methane homologues and water composition on the distance from water-oil contacts was established. A connection between hydrogeochemical anomalies and hydrocarbon pools was also detected. It was revealed from the nature of the equilibria that hydrocarbon pools in the Paleozoic and Mesozoic sediments of the southern parts of the Ob-Irtysh interfluve act as a conservative element of the lithosphere. Water-gas equilibria modeling revealed that the geochemical regime dominating at the major part of the territory under study is favourable for the formation and conservation of hydrocarbon pools, except for the marginal zones. Computer modeling of physicochemical equilibria and evasion-invasion processes in water-gas systems allowed us to establish the degree of groundwater saturation with gases and the nature of diffusion redistribution of gases at the boundary between hydrocarbon deposit and formation water. All waters with total gas saturation of 2.0 l/l become ultimately saturated with gases (Kg = 2.0), which means that theoretical prerequisites for the formation of hydrocarbon deposits arise. Calculations allowed us to reveal more than 30 promising objects with the high probability of detection of hydrocarbon deposits at the Bergul, Vitin, Chekovsky and other areas.

1. Introduction
Investigation of geochemical processes and physicochemical equilibria in water – gas systems is a relevant research area closely associated with the problem of formation and degradation of oil and gas pools [1, 2, 3]. At present, discovery of new hydrocarbon deposits cannot be based on structural plotting over geophysical data and analysis of geological and geochemical signs. Physicochemical equilibria in water – gas systems form an essential research area for geochemical predictions of oil and gas bearing potential and for evaluation of the productivity of local structures and fields because these equilibria gain the information about the conditions of deposit formation, retention and mass exchange with groundwater [3, 4]. Solution of these problems allows us to validate a novel search technology aimed at the detection of oil and gas pools in sedimentary basins.

Water – gas system is multicomponent, and the processes taking part in it follow different directions, which raises the problem of using conventional simplified methods to calculate the degree
of the saturation of formation waters with gas, individual fugacities of gases etc. In the present work, a practical evaluation of the procedure aimed at search for hydrocarbon pools is carried out relying on the studies of water – gas equilibria, for the southern regions of the Ob-Irtysh interfluve as an example. The procedure is implemented using the HG-32 software (Hydrogeo) developed by M. B. Bukaty [1, 3]. Factual evidence is represented by the results of tests and geochemical sampling over more than 445 objects, including 217 wells from 84 exploratory areas in the northern parts of the Novosibirsk Region and the adjacent parts of the Tomsk and Omsk Regions. The territory under investigation has been studied by means of deep-hole drilling very irregularly: the largest number of wells were drilled in the central and northern parts, while the south-eastern part is almost free of wells. The reason is in the fact that the major hydrocarbon pools occur within local elevations in the central part of the region and are associated with the Yu1 regional horizon within the boundaries of the Upper Jurassic aquifer complex. The recent studies dealing with the features of hydrogeological structure and hydrogeochemistry of oil and gas bearing sediments were considered in [1-16] (Fig. 1).

Figure 1. Location of the study area.

While hydrocarbons pass into traps and during subsequent periods, the pools are not inert from the geochemical point of view, due to their interactions with rocks and formation waters. Geochemical scattering of pool components occurs in the lateral and vertical directions in the liquid and gaseous phases into formation waters, host rocks and caps, and this process is one of the most essential parts of the interaction. One of the geochemical results of scattering processes, determined by the same factors as those controlling the composition of hydrocarbons in the pools, is the formation of the zone of rock recovery and the aqueous scattering halos of oil and gas pools. Differentiation of water components depending on their mobility points to the occurrence of diffusion processes leading to the formation of aqueous scattering halos. Gas components are characterized by the highest mobility. We established a direct dependence of a decrease in total gas saturation, the concentrations of methane homologues and water composition on the distance from water-oil contacts; a connection between hydrogeochemical anomalies and hydrocarbon pools was also detected [2, 4].
2. Results and discussion
On the basis of the results of hydrogeochemical testing and the procedure proposed by O. A. Marshaev [17], the probabilistic curves predicting the occurrence of a pool were plotted relying on the concentrations of chemical elements and methane homologues. The efficiency of recognition of productive structures was more than 80% for the concentrations of water-dissolved gases, and about 40% for microelements. On the basis of the total number of anomalies in the composition of formation waters and water-dissolved gases, as well as other characteristics, already revealed oil pools were confirmed at the Verkh-Tarskoe, Maloichskoe, Kazanskoe, Kalinovoe, Igolsko-Talovoe, Yagyl-Yakhskoe and other deposits. The most contrast halos revealing an oil pool at a distance up to 20-23 km from the oil and gas drainage boundary were established in the Upper Jurassic complex. For Lower, Middle Jurassic and Paleozoic complexes, these distances vary from 11 to 20 km for different gases (Fig. 2).

![Figure 2. Gas dispersion halos of hydrocarbon deposits in formation waters.](image)

Previous investigations over the West Siberian Sedimentary Basin revealed the regularities in the saturation of formation waters with gases for Paleozoic, Jurassic and Cretaceous complexes [2,4,6]. Formation waters in the oil and gas bearing complexes were characterized on the basis of $K_g$ as unsaturated up to completely saturated with gases. An increase in the degree of formation water saturation with gases with an increase in stratum depth and the dependence of saturation with hydrocarbon gases on the total gas saturation of formation waters were also revealed. Waters with total gas saturation more than 1,8-2,0 l/l become maximally saturated with gases ($K_g = 1,0$), and prerequisites for the formation of hydrocarbon pools arise. Quite contrary, formation waters which are unsaturated with gases are able to dissolve previously formed pools of oil and gas. A direct dependence between $K_g$ and the phase composition of pools was revealed. The zone with $K_g$ values from 0,8 to 1,0 is associated with the major gas condensate pools, while less saturated waters are confined to oil pools. It was established that at the modern stage of the evolution of water-pressure system of the Mesozoic and the upper part of the Paleozoic basement within the southern regions of the Ob-Irtysh interfluve, the marginal waters of the majority of studied hydrocarbon pools are maximally saturated with gases. In the evaluation of gas redistribution between pools and formation waters, it was determined from the ratios of individual gas fugacities that the pools are mainly in the unstable state with respect to embedding waters (Fig. 3) Scattering of methane and carbon dioxide proceed almost in all the studied pools. This is compensated by the inflow of nitrogen and the homologues of methane (in different extents) into the pools, while some pools undergo their phase
reformation in the direction of heavier-weight composition [17]. Exchange and reformation processes are most intense within the oil and gas condensate or gas condensate pools, and the lowest intensity of these processes is characteristic of oil pools. Results of calculations for the Jurassic-Cretaceous and Paleozoic sediments in the southern regions of the Ob-Irtysh interfluve confirm previous conclusions for other regions of the West Siberian oil and gas bearing province. Analysis of the changes of individual gas fugacities in hydrocarbon pools and in formation waters revealed an increase in fugacity with depth for carbon dioxide, ethane, methane, propane and other gases, which confirms the results of studies carried out previously by B.N. Ryzhenko and V. P. Volkov [18].

Figure 3. The dependence of gases fugacity in reservoir waters and hydrocarbon deposits with depth.

Modeling of the interactions in water – gas system revealed zoning of the predictive hypothetical composition of the free gas phase with depth. A regular decrease in methane and nitrogen content with depth was revealed, which is compensated by the increasing role of methane homologues, hydrogen and carbon dioxide in the pools. The heaviest composition of hypothetical predicted pools is characteristic of the Jurassic oil and gas bearing complexes, especially the Upper Jurassic one. Below, in the sediments of the Paleozoic base at a depth within the range of 2800-3700 m, the role of methane homologues decreases.

The predicted quality of pools for the region under investigation may be divided into two types with respect to the ratios \( i-C_4H_{10}/n-C_4H_{10} \), \( CH_4/\Sigma HH(heavy \ hydrocarbons) \) and \( i-C_5H_{12}/n-C_5H_{12} \). The first type includes purely oil pools and oil pools with gas caps, while the second type includes gas condensate and gas pools. In the hydrogeological section, they are differentiated in two regions. Gas
and gas condensate pools dominate in the upper part of the section, within the Neocomian complex, while the pools dominating below are oil and gas condensate, and oil pools.

3. Conclusion

Analysis of the obtained results confirmed the occurrence of already discovered pools in the studied deposits of Jurassic reservoirs: Zapadno-Karayskoe, Verkh-Tarskoe, Vostochno-Tarskoe, Kazanskoe, Elleyskoe, Vostochnoe, in NGGZK (oil and gas bearing contact zone horizon), and in Paleozoic reservoirs: in the Yagyl-Yakhskoe, Verkh-Tarskoe, Kalinovoe, Solonovskoe, Archinskoe etc., and allowed predicting more than 30 skipped pools in the northern parts of the Novosibirsk Region (see Fig. 1). Within the Neocomian sediments, the most promising strata for the discovery of gas and gas condensate pools are A\textsubscript{11-12}, B\textsubscript{16-20} at the Zapadno-Kalgachskaya area and B\textsubscript{16-20} at the Vitinskaya area. The discovery of gas and gas condensate pools is possible in the strata A\textsubscript{11-12}, B\textsubscript{8} and B\textsubscript{16-20} at the Urgulskaya area. In the Upper Jurassic complex (Y\textsubscript{U}), gas condensate pools may be discovered at the Bergulskaya, Vitinskaya, Pustovalovskaya areas, oil pools with gas caps may be detected at the Elayskaya, Zapadno-Kalgachskaya, Muravshovskaya, Chekovskaya and Yuzhno-Tarskaya areas. An oil pool may be found at the Mezhovskoe deposit, where the commercial oil and gas content of Cretaceous sediments was confirmed. In the reservoirs of the Lower and Middle Jurassic complex, the discovery of oil pools with gas caps is probable at the Riftovaya area, gas condensate pool is predicted at the Bergulskaya area, and within the boundaries of the Veselovskoe and Verkh-Tarskoe deposits, in the case of supplementary exploration of Middle Jurassic sediments. Within the Paleozoic aquifer complex, the discovery of oil pool with gas cap is probable at the Zarechnaya area.

It was revealed from the nature of the equilibria that hydrocarbon pools in the Paleozoic and Mesozoic sediments of the southern parts of the Ob-Irtysk interfluve act as a conservative element of the lithosphere. It was established on the basis of water-gas equilibria modeling that the geochemical regime dominating at the major part of the territory under study is favourable for the formation and conservation of hydrocarbon pools. An exception is the marginal zones of the West Siberian Basin where the degree of washout of the Mesozoic and Cenozoic sediments by infiltrated waters is high. The gas component of the pools is undergoing a transformation towards the change in the concentrations of non-hydrocarbon gases and an increase in the content of higher weight components. Relying on these findings, we may assume continuation of the formation, migration and accumulation of oil till the modern stage of the geochemical evolution of the system, at the background of cessation of formation and accumulation of the gases soluble in embedding waters. The results obtained by modeling the water-gas equilibria suggest that favourable conditions exist for the formation and conservation of oil and gas pools in the Paleozoic, Jurassic and Cretaceous sediments over the major part of the territory under investigation.

4. References

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