Hydrogeology and Hydrogeochemistry of the Ancient Fore-Yenisey Sedimentary Basin

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Abstract. The results of geochemical studies of groundwater and brines of the pre-jurassic complexes of the Fore-Yenisei sedimentary basin are presented. It is shown that the region under investigation is characterized by a transitional type of the hydrogeological structure of the Paleozoic and pre-Paleozoic sections between the West Siberian and Tunguska artesian basins, with all the ensuing consequences: groundwater occurrence, sedimentation, chemical and gas composition, gas saturation, vertical zoning and others. Groundwaters and brines with sodium chloride composition with the total mineralization of 48 to 209 g/dm³ are predominant in the pre-jurassic complexes. A normal type of vertical hydrogeochemical zoning is developed in the region. The upper part of the section is washed with ancient infiltrogenous waters to a depth of 2-2.5 km. Deeper lie the ancient sedimentogenous waters of the middle stage of metamorphism.

1. Introduction

The possibility for the sedimentary complexes of the Siberian platform, which may be promising for oil and gas exploration, to occur at the left bank of the Yenisey under the Mesozoic-Cenozoic cover was formulated for the first time by N.S. Shatsky in 1932. In the 30-60-es of the XX century, the existence of buried structures at the territory of the left bank of the Yenisei was reported by Belousov, Nalivkin, Sokolov, Fomichev, Yanshin and others [1-3]. In the 70-es, the oil-and-gas-bearing potential of this territory was evaluated by A.E. Kontorovich, V.S. Surkov, A.A. Trofimuk as high [4]. Later on, the same idea was formulated by V.A. Benenson, N.N. Dashkevic, V.A. Kashtanov, S.A. Stepanov [5, 6] and other researchers. The most comprehensive works depicting the existing notions concerning the geological and tectonic structure of this region are cumulative publications by A.E. Kontorovich, V.A. Kontorovich, Yu.F. Filippov, S.Yu. Belyaev, V.A. Kashtanov, A.V. Khomenko and others [7-10].

From the hydrogeological point of view, the territory of the upper Precambrian-Paleozoic Fore-Yenisey sedimentary basin (FYSB) is only weakly investigated, in spite of the fact that there are many cumulative publications dealing with the West Siberian sedimentary basin (WSSB) in general [11-20]. The situation has changed in connection with the implementation of the Vostok project during the recent years when the parametric holes Vostok-1, 3 and 4 were drilled (Fig. 1). The results of the generalization of the stored and published data form the basis of the present work.

Two structural stages are distinguished within the limits of the southern part of the Fore-Yenisey zone. The lower stage us represented by the Upper Precambrian – Paleozoic layers, which are the basement of the young West Siberian geosyncline (WSG). These layers correspond to the cover of the Siberian
Platform. The upper structural stage is Mesozoic-Cenozoic, corresponding to the cover of the WSG. The region under investigation is situated in the transient zone from the salt-bearing type of section to the salt-free one [10, 21]. For this reason, we had to carry out detailed studies of the existing hydrogeological stratification layout of the WSSB and the Siberian Platform, to propose a new layout of the hydrogeological stratification of the FESB relying on the comparison of the studied layouts and on the results of drilling and testing of wells Vostok-1, 3 and 4 (water-bearing complexes of the Precambrian-Paleozoic water-bearing stage from top to bottom): Devonian, Cambrian, Vendian and Upper Riphean. It should be stressed that the separation of the sediments under study into complexes, outlined as the first approximation, will be worked out in more detail as the new information will appear, till the allocation of separate water-bearing horizons within the boundaries of the complexes.

![Figure 1. Location of the region under investigation within West Siberia. Boundaries: 1 – administrative, 2 – Fore-Yenisey sedimentary basin; 3 – the name of the exploration area and well number.](image)

Lithologic core studies showed that the rocks are to a substantial extent consolidated; they had lost their initial porosity and permeability. For this reason, the filtration capacity characteristics of the sediments under investigation are closely connected with the secondary fracturing, cavernosity and leaching, that is, water-pressure system of fissure and fissure-vein waters with very complicated hydraulic relations are characteristic of these sediments. Porosity varies within a broad range from 0.1 to 16.2 %. Complications connected with the substantial hydraulic disconnectedness of separate water-bearing zones and their variable water abundance should also be noted. As a rule, low collecting capacity of the rocks does not give inflows of the formation fluid. This is what we actually observe within the limits of the
Precambrian-Paleozoic water-bearing stage. In the hydrodynamic respect, the studied layers are characterized by pressures close to the hydrostatic pressure and are located in the zone of normal pressure according to the anomaly factor. The anomaly factor is 1.0-1.05 (according to the results of pressure measurement with a depth pressure gauge and the results of re-interpretation of the hydrodynamic investigation of the wells) [22]. The sections of the Precambrian-Paleozoic water-bearing stage of the wells Vostok-1, 3 and 4 are comparable in their geothermal conditions with the sections of the western regions of the Baykanantclise of the Siberian Platform [22, 23].

As stated above, the Fore-Yenisey sedimentary basin is situated in the transient zone from the salt-bearing type of section of the ancient Siberian Platform to the salt-free type of the West Siberian sedimentary basin. In this connection, we carried out a comparative analysis of the composition of groundwater and brines, and gases dissolved in water (GDW) from the studied wells of the Vostok project and adjacent regions. In the FESB, groundwater and brines with total mineralization 7.5 to 280 g/dm$^3$ are widespread; their composition is mainly sodium chloride (Fig. 2.a). The normal type of vertical hydrogeochemical section is developed there, that is, an increase in total mineralization of groundwater and brines with an increase in the depth of water-bearing horizons, and also an increase in the concentrations of the main macro- and microcomponents (Fig. 2.b).

In the sediments of the Precambrian-Paleozoic water-bearing stage, 33 samples of formation water and 5 samples of GDW from the wells Vostok-1, 3 and 4 were studied. The total mineralization of formation water from the zone of contact between Mesozoic and Paleozoic in Vostok-1 well varies within the range 52.2-64.0 g/dm$^3$. The composition of water is sodium chloride with insignificant presence of calcium and magnesium cations. The total mineralization of the formation water of the Cambrian and Vendian complexes in Vostok-3 well caries within the range 47.0-97.3 g/dm$^3$. The composition of water is sodium chloride with higher calcium content than that in the studies brines from Vostok-1 well. Brines of sodium chloride composition with total mineralization 64.3 – 209.3 g/dm$^3$ were revealed in Vostok-4 well in the sediments of the Cambrian water-bearing complex. Brine mineralization increases with depth, and the brines with the highest mineralization are confined to the range 4993-5036 m in the lower part of the Cambrian complex (Usolskaya suite) (see Fig. 2b).
Figure 2. Piper diagram of the composition of groundwater of the ancient Fore-Yenisey sedimentary basin (a) and the type of the vertical hydrogeochemical zoning within its limits (b).

Water-bearing complexes: 1 – the zone of contact of the Mesozoic with Paleozoic sediments, 2 – Devonian, 3 – Paleozoic (nonsegmented), 4 – Cambrian, 5 – Vendian, 6 – Cambrian (the western regions of the Siberian platform).

Comparison with the brines of the adjacent regions of the WSSB [12, 16, 18, 24], of the western regions of the Siberian platform [25-27] and salt-dome structures of the Anabar-Khatanga basin [19, 28] revealed their relationship with the first group (I), which is clearly seen from the analysis of the distribution coefficients of rNa/rCl and Ca/Cl depending on mineralization (Fig. 3). Somewhat apart are the points related to the samples from Cambrian sediments of the Vostok-4 well (group II). They are distinguished by increased mineralization and are located closer to the ancient infiltrogenous brines of the Anabar-Khatanga basin (group III) rather than to the sedimentogenous brines of the adjacent regions of the Siberian platform (group IV). This fact is quite natural because the Cambrian brines from Vostok-4 well are also ancient infiltrogenous ones. It was established that the brines from the Vostok wells contain substantially lower concentrations of ammonium, silica, rubidium and cesium. The concentrations of iodine, bromine and lithium are at the same level with the brines from the Vezdekhodnaya area, except for the Cambrian brines from Vostok-4 well. At the territories adjacent to the region under investigation, the works aimed at testing of the section of the Precambrian-Paleozoic water-bearing stage were carried out at the Vezdekhodnaya, North-Lymbel, Vanzhyl, Averino, Eloguy and Kyksinskaya areas. The dominant part of the tested objects turned out to be “dry” (inflows were not obtained). Sole intervals at the Martovo, Nyarginskaya, North-Lymbel, Elan and Averino areas gave water inflows. 30 objects were studied at the Vezdekhodnaya area, where the inflows of formation water were obtained in 26 of them. The chemical composition of water of the sediments under investigation is mainly sodium chloride, with total mineralization varying from several grams per liter to several hundred grams per liter. A regular decrease in the total mineralization of groundwater starts from the Averino area (280 g/dm$^3$) and proceeds to the west where the total mineralization in Vostok-3 well is 64.3 – 209.3 g/dm$^3$, in Vostok-3 – 50-97 g/dm$^3$, at the Vezdekhod area it is already 60-85 g/dm$^3$, and in Vostok-1 this parameter varies from 52 to 64 g/dm$^3$.

In general, the studied groundwater of the Precambrian-Paleozoic water-bearing stage in the areas adjacent to the Vostok project may be related to weak brines of the sodium chloride composition with the mineralization more than 50 g/dm$^3$. An exception is water obtained from the North-Lymbel, Elan and Martovskaya areas, its mineralization is 13.3, 34.2 and 48.1 g/dm$^3$, respectively. The studied water from the Eloguy and Kyksinskaya areas has similar or lower mineralization: 21.4 and 7.9 g/dm$^3$. Waters unsealed at the Averino area has the highest mineralization among the studied water samples (280 g/dm$^3$). The chemical composition of water of the sediments under investigation is mainly sodium chloride, with total mineralization varying from several grams per liter to several hundred grams per liter. A regular decrease in the total mineralization of groundwater starts from the Averino area (280 g/dm$^3$) and proceeds to the west where the total mineralization in Vostok-3 well is 64.3 – 209.3 g/dm$^3$, in Vostok-3 – 50-97 g/dm$^3$, at the Vezdekhod area it is already 60-85 g/dm$^3$, and in Vostok-1 this parameter varies from 52 to 64 g/dm$^3$.

Gas saturation of the formation waters was 0.7 l/l in Vostok-1 well and much lower in the studied objects of Vostok-3 well (0.1 – 0.5 l/l). In the wells of the Vezdekhodnaya area situated to the south, gas saturation of waters from the Cambrian water-bearing complex was determined to be: in well 1 – 0.7 – 1.1 l/l and in well 3 – 0.5-0.6 l/l. GDW in Vostok-1 well is composed of methane, its content is 84.97 % vol., the content of the sum of heavy hydrocarbons is 0.65 % vol. The dominant role in the composition of GDW in Vostok-3 well within the ranges 4720-4734 and 4673-4683 m is played by nitrogen (up to 72 – 91 % vol.). Methane content does not exceed 5 %. vol. The role of hydrogen increases, especially within the range 4720-4734, where its concentration is 21.9 % vol. The total content of the homologues of methane within these intervals does not exceed 0.5 % vol. The composition of GDW from two samples
characterizing the intervals 4956-4962 and 4190-4200 is methane, with its content 85.2 and 78.0 % vol., respectively. Nitrogen content does not exceed 17.6 % vol, hydrogen 8.7 % vol. Methane homologues are present in even smaller amounts; their total content does not exceed 1.5 % vol.

Figure 3. Dependence of rNa/rCl and Ca/Cl ratios on the total mineralization of groundwater and brines within the limits of the Pre-Jurassic complexes of Siberia.

Waters and brines studied: 1 – Fore-Yenisey sedimentary basin; 2 – salt dome structures of the Anabar-Khatanga basin; 3 – western regions of the Siberian platform; 4 – adjacent regions of the West Siberian sedimentary basin. The arrow marks the direction of metamorphization of groundwater and brines.

Comparative analysis of gas saturation and composition of GDW in the adjacent regions revealed that the region under investigation is situated in the transient geochemical area between the West Siberian geosynclise and the Siberian platform, with all the consequences implied. The data on the increased concentrations of nitrogen detected in Vostok-3 well deny the leading role of air as a supplier of nitrogen and argon to the waters of the deep horizons and confirm an increase in the concentration of hydrocarbons downward along the section, which is also characteristic of the sediments of the adjacent regions of the Siberian platform under study.

Thus, the Fore-Yenisey sedimentary basin is characterized by the transient type of the hydrogeological structure of the Paleozoic and Pre-Paleozoic section between the Siberian and the Tunguska artesian basins, with the consequences: the parameters of groundwater occurrence, permeability of the sediments, chemical and gas composition, gas saturation, vertical zoning etc. The region under investigation is situated rather far from the known regions of the intrusions of infiltration water, which is exhibited, for example, at the Eloguy and Kyksinskaya areas. This circumstance decreases the probability of washing the geological structures in the region under study. In donor complexes, groundwater of sodium chloride composition with total mineralization 48 to 280 g/dm³ are widespread. The normal type of vertical geochemical zoning is developed in the region. In the section under study, methane is prevailing in the composition of the gases dissolved in water. Gas saturation of water is not high; so is the coefficient of water saturation with gases. The composition of GDW corresponds to the gas (but not gas-condensate or oil) type of the possible hydrocarbon phase in equilibrium with them. In our opinion, the low degree of water saturation with gases requires additional studies to evaluate the possibility to detect the deposits of free gases or oil in the region.
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References
[1] Bogolepov K V 1963 On the forms of the structural connection of the Siberian Platform and the West Siberian Plate Tectonics of Siberia Novosibirsk: Ed. USSR Academy of Sciences 2 pp 112-121
[2] Kosygin Yu A, Luchitsky I V 1960 On the principles of distinguishing ancient platforms and the position of marginal uplifts in the structure of the Siberian platform Geologiyaigeofizika 1 pp 52-57
[3] Nakaryakov V D 1961 The structure of the pre-Mesozoic basement of the Yenisey zone of the West Siberian plate Geologiyaigeofizika 3 pp 27-34
[4] Kontorovich A E, Nesterov I I, Salmanov F K Geology of oil and gas of Western Siberia. (Nedra, Moscow, 1975), P 680
[5] Benenson V A 1989 Geological and geophysical features of the pre-upper Paleozoic sediments of the West Siberian Plate due to their oil and gas content GeologiyaNeftei Gaza (Oil and gas Geology) 12 pp 6-10
[6] Dashkevich N N, Kashtanov V A 1990 Paleozoic platform sediments and sub-salt Precambrian complexes of the left bank of the r. Yenisei - a new object of oil and gas exploration DoklAkadNauk SSSR (DokladyAkademiiNauk SSSR) 315(5) pp 1187-1191
[7] Kontorovich A E, Kontorovich V A, Filippov V F et al. 2006 The Pre-Yenisei oil and gas bearing subprovince as a new region for petroleum exploration in Siberia Geology, geophysics and the development of oil and gas fields 5-6 pp 9-23
[8] Kontorovich V A, Kontorovich A E 2006 Geological structure of the Precambrian-Paleozoic platform sediments in the south-eastern regions of Western Siberia Otechestvennayageologiya 6 pp 62-70
[9] Filippov Y F 2016 Hydrocarbon potential of the Pre-Yenisei sedimentary basin Geology of oil and gas 6 35-45
[10] Filippov Y F 2017 The Fore-Yenisei sedimentary basin: Seismic-geological model and geodynamic history Geology and geophysics 58(3-4) 455-471 (2017).
[11] Nudner V A Hydrogeology of the USSR. T. XVI. West Siberian Plain (Tyumen, Omsk, Novosibirsk and Tomsk Regions). (Nedra, Moscow, 1970) P 368
[12] Kokh A A, Novikov D A 2014 Hydrodynamic conditions and vertical hydrogeochemicalzonality of groundwater in the Western Khantanga Artesian Basin Water Resources41(4) pp 396-405
[13] Kruglikov NM, Nelyubin VV, Yakovlev ON Hydrogeology of the West Siberian petroleum megabasin and features of formation of hydrocarbon reservoirs. (Leningrad: Nedra, 1985) P 279
[14] Matussevich V M, Ryulkov A V, Uschatsky I NGeofluidal systems and problems of oil and gas content of the West Siberian megabasin. (Oil and Gas University, Tyumen, 2005) P 340
[15] Nazarov A D Oil and gas hydrogeochemistry of the southeastern part of the West Siberian oil and gas province. (Idea-Press, Moscow, 2004) P 285
[16] Novikov D A, Lepokurov A V 2005 Hydrogeological conditions of petroleum potential deposits on the structures in the southern part of Yamalo-Karskoye depression GeologiyaNeftei Gaza (Oil and gas Geology) 5 pp 24-33
[17] Stavitsky B P, Kurchikov A R, Kontorovich A E, Plavnik A G 2004 Hydrochemical zoning of Jurassic and Cretaceous deposits of the West Siberian Basin Geologiyaigeofizika 45(7) pp 826-832
[18] Shvartsev S L, Novikov D A 2004 The nature of vertical hydrogeochemical zoning of petroleum deposits (exemplified by the Nadym-Taz interfluve, West Siberia) Geologiyaigeofizika 45(8) pp 1008–1020
[19] Novikov D A 2017 Hydrogeochemistry of the Arctic areas of Siberian petroleum basins Petroleum Exploration and Development 44(5) pp 780-788
[20] Novikov D A, Sukhorukova AF 2015 Hydrogeology of petroleum deposits in the northwestern margin of the West Siberian Artesian Basin Arabian Journal of Geosciences 8(10) pp 8703-8719
[21] Novikov D A 2017 Distribution of Cambrian salts in the western Siberian Craton (Yurubcheno-Tokhomo field, Russia) Arabian Journal of Geosciences 10(1) № 7 (2017)
[22] Novikov D A, Shvartsev S L 2009 Hydrogeological conditions of the Pre-Yenisei petroleum subprovince Russian Geology and Geophysics 50(10) pp 873–883
[23] Dultsev F F, Novikov D A 2017 Geothermal zoning of the Predenisey sedimentary basin Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering 328(11) pp 6-15
[24] Novikov D A 2017 Hydrogeological conditions for the presence of oil and gas in the western segment of the Yenisei-Khatanga regional trough Geodynamics and Tectonophysics 8(4) pp 881-901
[25] Bukaty M B 2009 Groundwater geology of the western Siberian craton (implications for petroleum exploration) Russian Geology and Geophysics 50(11) pp 930-942
[26] Trifonov N S, Novikov D A, Yamskikh A A 2015 Hydrogeological prerequisites for industrial waste injection during the development of priority area of the Yurubcheno–Tokhomo field Water Resources 42(7) pp 909–921
[27] Novikov D A, Trifonov NS 2016 Hydrogeologic Implications of Industrial Effluent Disposal of the Yurubcheno-Tokhomo Field (Siberian Craton, Russia) Arabian Journal of Geosciences 9(1) № 63
[28] Novikov D A, Saraev M M 2017 Hydrogeochemistry of the Arctic areas of Siberian petroleum basins Shiyou Kantan Yu Kaifa/Petroleum Exploration and Development 44(5) pp 737-744