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Geochemistry of water-soluble gases in the oil and gas bearing sediments of the zone of junction between the Yenisei-Khatanga and the West Siberian basins (the Arctic regions of Siberia)

D.A. Novikov[1,2], E.V. Borisov[1]*
[1]Trofimuk Institute of Petroleum Geology and Geophysics of Siberian Branch of Russian Academy of Sciences, Novosibirsk, Russian Federation
[2]Novosibirsk State University, Novosibirsk, Russian Federation

Abstract. The results of the studies of geochemical and zoning features of water-dissolved gases in the Mesozoic sediments of the junction between the Yenisei-Khatanga and the West Siberian basins are reported. The stage of industrial oil and gas content is more than 3 km thick and involves the depth range from 750 to 4000 m. Waters occurring in the region contain methane, their total gas saturation is 0.3 to 4.6 dm^3/dm^3, and CH_4 content in 88.9 to 95.4 vol. % on average. An increase in the concentrations of carbon dioxide and methane homologues is observed with an increase in the depth, which is accompanied by a regular decrease in the concentrations of methane and nitrogen. In general, water-dissolved gases from the Neocomian and Jurassic reservoirs have similar compositions ($C_1 > N_2 > C_2 > C_3 >$ n-$C_4 >$ i-$C_4 > CO_2 >$ i-$C_5 >$ n-C_5). The water-dissolved gases of the Aptian-Albian-Cenomanian sediments are distinguished by lower concentrations of methane homologues ($C_1 > N_2 > C_2 > CO_2 > C_3 >$ i-$C_4 >$ n-$C_4 >$ i-$C_5 >$ n-C_5), with the total content of heavy hydrocarbons (HHC) equal to 1.44 vol. %. Vertical zoning of the composition of water-dissolved gases is determined by the distribution of hydrocarbon pools in the Jurassic-Cretaceous section. A regular increase in the average values of the factor of enrichment with hydrocarbons (HC) (from 37 to 154) was established, along with a decrease in the ratio of CH_4/ΣHHC (from 130 to 7), C_2H_6/C_3H_8 (from 41 to 2) and i-C_4H_{10}/n-C_4H_{10} (from 2.6 to 0.6) from the Aptian-Albian-Cenomanian reservoirs to the Jurassic ones. The zone with anomalous He concentrations within the range of 0.4–0.9 vol. % was detected in the Neocomian and Middle Jurassic sediments. This zone is localized at the north-western slope of the Messoyakh inclined ridge (the Anomalnaya, Turkovskaya, Pelyatkinskaya and Sredne-Yarovskaya areas). The nature of this anomaly needs further studies.

Keywords: water-dissolved gases, methane homologues, gas saturation of groundwaters, gas zoning, the Yenisei-Khatanga basin, West Siberia, the Arctic

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Introduction

Water-dissolved gases (WDG) in the Arctic regions of West Siberia have been under investigation since the second half of the past century. The early data obtained through exploration for oil and gas were generalized in the works by M.S. Gurevich and N.N. Rostovtsev (Rostovtsev, Ravdonikas, 1958). During subsequent years, essential problems concerning the studies of the composition and zoning of WDG, diffuse scattering of gas from hydrocarbon (HC) pools, and the conditions of gas generation, the release of gases from groundwaters and the formation of gas pools were considered by N.M. Kruglikov, L.M. Zorkin, A.E. Kontorovich, B.P. Stavitskiy, A.A. Kartsev, V.M. Matusevich, A.A. Rozin and many other researchers (Kruglikov, 1964; Kontorovich, Zimin, 1968; Nudner, 1970; Kruglikov et al., 1985; Kartsev et al., 1986; Stavitskiy et al., 2004; Matusevich et al., 2005; Kurchikov, Plavnik, 2009). During the recent years, extensive studies of the geochemical features of water-dissolved gases in the oil and gas bearing sediments of Siberian sedimentary basins, in particular those under study in the present work, are carried out at the Trofimuk Institute of Petroleum Geology and Geophysics SB RAS (Kokh, Novikov, 2014; Novikov, 2017a; Novikov, 2017b; Novikov, 2018; Novikov et al., 2019).

At present, the focus of oil and gas exploration is shifting to the Arctic regions of Russia. One of these regions is the Yenisei-Khatanga sedimentary basin

*Corresponding author: Dmitry A. Novikov
E-mail: novikovda@ipgg.sbras.ru

and the adjacent territories of the West Siberian oil and gas province. The region under study has been insufficiently investigated by means of deep drilling, so the integrated interpretation of the geological and geochemical data available at research and industrial organizations becomes extremely relevant. Investigation of WDG bearing the information on the regional conditions of formation and conservation of oil and gas pools, as well as on water – gas interactions, opens the new possibilities for solving the problems connected with the prediction of oil and gas bearing potential and evaluation of the productivity of poorly studied structures and areas. In this connection, the goal of the work was to reveal the features of the lateral and vertical zoning of WSG composition on the basis of the results of hydrogeochemical testing of the wells in the region of the junction between the Yenisei-Khatanga and the West Siberian basins in the Arctic territories of Siberia.

Materials and the object of investigation

The region under investigation relates to the boundary areas of the Yamal-Nenets autonomous territory and the Krasnoyarsk Territory (Fig. 1). According to the oil-and-gas geological zoning of the West Siberian province, the major part of the territory under investigation is situated within the boundaries of the Yenisei-Khatanga and the Pur-Taz oil and gas bearing areas (OGA). The stage of industrial oil and gas content embraces the entire Mesozoic complex over the depth range from 750 to 4000 m. The major HC resources relate to the Lower Cretaceous sediments. Industrial accumulations have also been revealed in the Aptian-Albian-Cenomanian and Middle Jurassic rocks. Some pools were detected in the Lower and Upper Jurassic, as well as in the Upper Cretaceous reservoirs. At the territory under investigation, 34 fields were discovered, among which there are 12 oil and gas condensate, 9 gas condensate, 8 gas, 3 oil, and 2 gas-oil fields.

The present communication is based on the results obtained in the studies of 129 WDG samples from the sediments of the Aptian-Albian-Cenomanian (10 samples), Neocomian (90 samples), Upper Jurassic (3 samples) and Lower and Middle Jurassic (26 samples) aquifer systems, sampled at 26 areas, and the results of 114 measurements of total gas saturation of groundwaters. The reliability and quality of the factual material was checked previously (Novikov, 2018; Novikov, 2020; Novikov, Borisov, 2021).

Analysis was carried out using the following coefficients: $\Sigma HC/N_2$ – the coefficient of enrichment with hydrocarbons, $CH_4/\Sigma HC$ – dryness factor, C_2H_6/C_3H_8 – ethanation factor, and the ratio of butane isomers $i\text{-}C_4H_{10}/n\text{-}C_4H_{10}$. The formula of the composition of water-dissolved gases is presented as a sequence of individual gas components, from the highest concentration to the lowest one.

The regional impermeable layers divide the section into two aquifer stages: the lower one includes the poorly defined formations of the Paleozoic basement, Triassic, Jurassic and Cretaceous sediments, and the upper one is represented by the Upper Cretaceous and Paleogene-Quaternary sediments (Table 1). Each aquifer stage is subdivided into separate aquifer systems. Hydroigeological stratification and demarcation zoning were considered in detail previously (Novikov, 2017; Novikov, Borisov, 2020). The allocated hydrogeological complexes including eleven aquifers and eleven impermeable horizons occur not over the whole territory: a substantial part of them get out of the geological section as a consequence of ravinement within the boundaries of the Messoyakh inclined ridge (MIR) separating the Yenisei-Khatanga (YKhSB) and West Siberian (WSSB) sedimentary basins.

Results and discussion

The hydrogeological section of the Mesozoic sediments is characterized by a complex hydrogeochemical field. Inversed hydrogeochemical zoning is observed, as studied in detail previously (Ginsburg, Ivanova, 1977; Kokh, Novikov, 2014). In this situation, direct gas zoning was established, which manifests itself in an increase in the average values of total gas saturation of groundwaters with depth: from 0.3 dm^3/dm^3 in the upper part of the Aptian-Albian-Cenomanian aquifer system to 4.6 dm^3/dm^3 in the reservoirs of the lower and Middle Jurassic aquifer systems. Methane dominates among the components of WDG; an increase in the concentrations of the homologues of methane is detected from 1.44 vol.% in the Aptian-Albian-Cenomanian aquifer system to 6.66 vol.% in the Lower and Middle Jurassic complex (the average values over the complex). According to the classification proposed by L.M. Zor'kin (Zor'kin et al., 1982), the WDG of the region under study are represented by all the four hydrocarbon type classes with respect to the heavy hydrocarbon content (ΣHH), vol.%: dry ($\Sigma HH < 1$), lean ($\Sigma HH = 1–3$), semi-fat ($\Sigma HH = 3–5$), and fat ($\Sigma HH > 5$) (Fig. 2). The dominating type is the WDG of the fat hydrocarbon class, which are widespread mainly in the reservoirs of the Neocomian and Lower and Middle Jurassic aquifer complexes. The composition of WDG will be characterized now in more detail. Taking into account the fact that a great array of data on the geochemistry of water-dissolved gases has been accumulated, only typical samples are presented in Table 2.

Methane dominates in the composition of WDG of the Aptian-Albian-Cenomanian aquifer system: its concentration is 90.8–98.9 vol.%. Gases with substantial nitrogen content (up to 30 vol.% and more) were revealed in the peripheral regions. This pattern

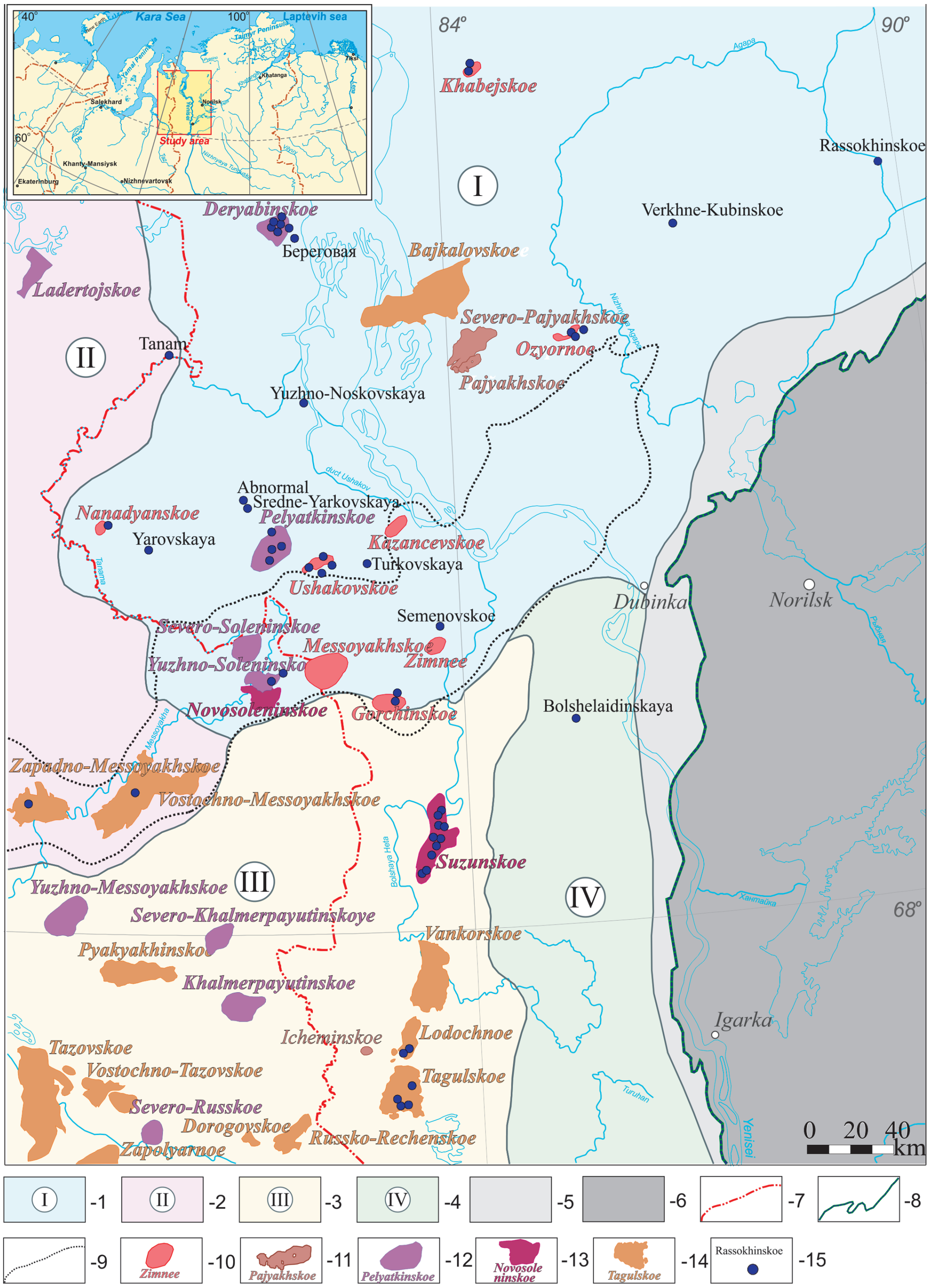

Fig. 1. Overview map of the territory under investigation. Oil and gas bearing areas: 1 – Yenisei-Khatanga, 2 – Gydan, 3 – Pur-Taz, 4 – Eloguy-Turukhansk; 5 – unpromising lands; 6 – the zone in which the Mesozoic sediments are absent; boundaries: 7 – administrative, 8 – the occurrence of Mesozoic sediments; 9 – the Messoyakh inclined ridge; fields: 10 – gas, 11 – oil, 12 – gas condensate, 13 – gas and oil, 14 – oil and gas condensate; 15 – wells with WDG sampling

is generally characteristic of the whole West Siberian sedimentary basin. For instance, within the boundaries of the Cis-Ural OGB, which is situated in the north-western part of the West Siberian basin, N_2 content reaches 10–20 vol.%, which is the evidence of the regional washing-out of these sediments by infiltrated waters in the marginal regions (Novikov, Sukhorukova, 2015). The dry hydrocarbon class with ΣHH within the WDG less than 1.0 vol.% prevails. Against this background, a few objects related to the lean hydrocarbon class were revealed at the Ozernaya area (ΣHH = 1.11–2.15 vol.%) in the YKhSB and at the Tagulskaya area (1.41 vol.%) in the WSSB; semi-fat at the Ozernaya area (3,76 vol.% in well No. 7, depth range 1170–1177 m); fat at the Lodochnaya area, with ΣHH 5.3 vol.%. It is necessary to stress that the content of methane homologues in the Arctic regions of the Nadym-Taz oil and gas area reaches higher values: 10.19 vol.% at the Severo-Iokhturskoye,

Series	Notation	Stage	Aquifer system	Notation	Hydrogeologic unit	Formatiom	Notation
Upper	$1(K_1\text{-}Q)$	Cenozoic (KZ)	Paleogene-Quaternary	8(p-Q)	Polygenetic	—	$2(P_1\text{-}Q)$
			Upper Cretaceous	$8(K_2)$	Campanian-Maastrichtian	tanamskaya K_2(tn)	$2(K_2cp_2\text{-}K_2m)$
		Mesozoic (MZ)			Lower Campanian	salpadayakhinskaya K_2(spd)	$3(K_2cp_1)$
					Middle Turonian-Santonian	nasonovskaya K_2(ns)	$2(K_2t_2\text{-}K_2st)$
Lower	9(PZ-MZ)		Aptian-Albian-Cenomanian	$8(K_1a\text{-}K_2s)$	Upper Cenomanian-Turonian	dorozhkovskaya K_1(drzh)	$4(K_2s_3\text{-} K_2t_1)$
					Middle Albian-Cenomanian	dolganskaya K_1(dlg)	$2(K_1al_2\text{-}K_2s_2)$
					Middle Aptian-Albian	yakovlevskaya K_1(jak)	$4(K_1a_2\text{-}K_1al_2)$
			Neocomian	$8(K_1v\text{-}K2a_1)$	Valanginian-Lower Aptian	K_1(nch-sd-mch) K_1(shur-bkl-mch)	$2(K_1b\text{-}K2a_1)$
			Upper Jurassic	$8(J_3)$	Kimmeridgian-Valanginian (Bathonian-cerriasian)	yanovstanskaya (J_3jnv) (golchikhinskaya (J_3gl))	$4(J_3km\text{-}K_1b_1)$ ($4(J_2bt\text{-}K_1b)$)
					Oxfordian	sigovskaya (J_3sg)	$2(J_3o)$
					Callovian	tochinskaya (J_2tch)	$4(J_2c)$
			Lower-Middle Jurassic	$8(J_{1\text{-}2})$	Upper Bajocian-Bathonian	malyshevskaya (J_2ml)	$2(J_2b_2\text{-}J_2bt)$
					Upper Bajocian	leontyevskaya (J_2ln)	$4(J_2b_2)$
					Lower Bajocian	vymskaya (J_2wm)	$2(J_2b_1)$
					Aalenian	laydinskaya (J_2ld)	$4(J_2a)$
					Upper Toarcian	nadoyakhskaya (J_1nd)	$2(J_1t_2)$
					Lower Toarcian	kiterbyutskaya (J_1kt)	$4(J_1t_1)$
					Upper Pliensbachian	sharapovskaya (J_1sh)	$2(J_1p_2)$
					Upper Pliensbachian	levinskaya (J_1lv)	$4(J_1p_2)$
					Hettangian-Lower Pliensbachian	zimnyaya (J_1zm)	$2(J_1g\text{-}J_1p_1)$
			Triassic	8(T)	Induan-Rhetian	—	$4(T_1i\text{-}T_3r)$
		Paleozoic (PZ)	Undivided Paleozoic 8(Pz)				

Table 1. Hydrogeological stratification of the zone of junction between the Yenisei-Khatanga and West Siberian basins

3.36–7.72 vol.% at the Beregovoye, and 5.21 vol.% at the Kharampurskoye fields (Shvartsev, Novikov, 2004; Novikov, 2019). The concentrations of CO_2 vary over the complex within the range 0.03–1.51 vol.%, N_2 – 0.35–3.81 vol.%, H_2 – 0.01-0.08 vol.%. The concentration of argon does not exceed 0.03 vol.%, helium is detected only in trace amounts.

The Neocomian aquifer system, similarly to the overlying Aptian-Albian-Cenomanian system, is characterized by methane-type composition of water-dissolved hydrocarbon gases. Methane content varies within a broad range from 64.4 to 99.9 vol.%. Against this background, the object detected in well No. 310 of the Nanadyan area is distinguished, because methane

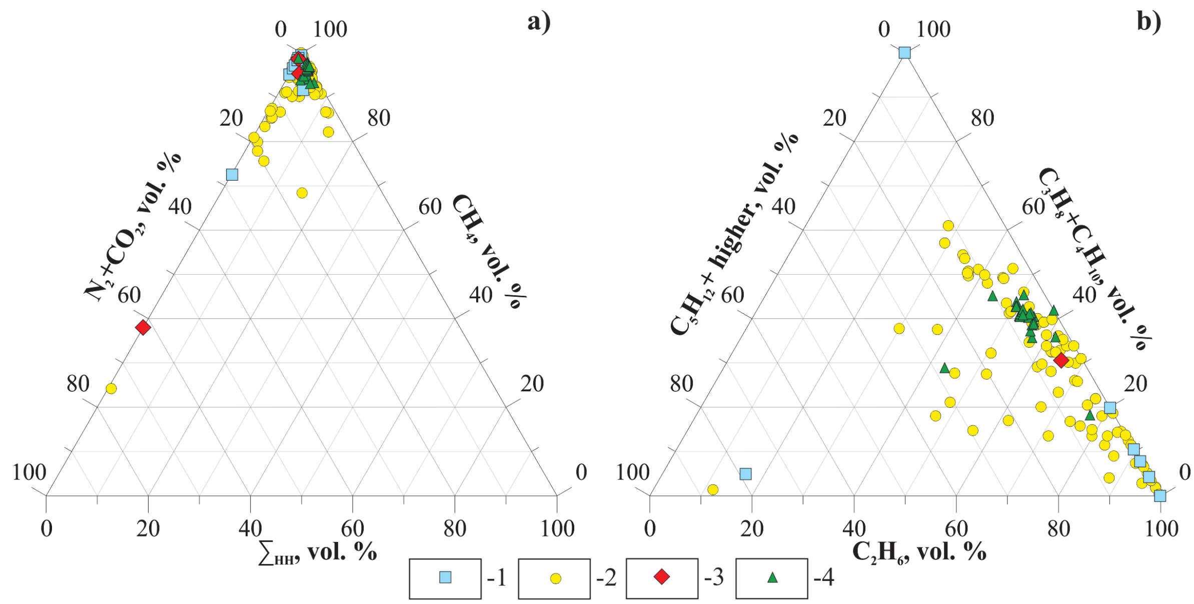

Fig. 2. The diagrams of total composition (a) and the composition of the heavy hydrocarbon fraction in WDG of the zone of junction between the Yenisei-Khatanga and West Siberian basins. Aquifer systems: 1 – the Aptian-Albian-Cenomanian, 2 – the Neocomian, 3 – the Upper Jurassic, 4 – the Lower and Middle Jurassic.

concentration in it is equal to 24.1 vol.%. In addition to rather low CH_4 content, the WDG of this area are also characterized by very low ΣHH values – not more than 0.69 vol.%, – and high N_2 content reaching 74.5 vol.%, which may be the evidence that this zone had been washed with infiltration waters. This is not detected lower along the section, and the components prevailing in WDG are hydrocarbon components with nitrogen content up to 3.2–3.7 vol.%. Semi-fat and fat hydrocarbon classes dominate, with ΣHH content in the WDG higher than 3.0 vol.%. The maximal concentrations of ΣHH were detected in the marginal waters of gas condensate and oil pools of the Pelyatkinskoye, Deryabinskoye, Suzunskoye and other oil fields, where they vary from 5.29 to 17.70 vol.%. For comparison, in the neighboring Nadym-Taz area the concentration of methane homologues reach higher values: from 27.9 to 30.9 vol.% at the Vyngayakhinskoye, 31.7-32.4 vol.% at the Tarasovkoye, 24.3–32.4 vol.% at the Zapadno-Tarkosalinskoye, 25.9-31.6 vol.% at the Ust-Kharampurskoye, 25.1–31.4 vol.% at the Komsomolskoye, and 25.8–31.6 vol.% at the Pangodinskoye fields (Shvartsev, Novikov, 2004; Novikov, 2019). In general over the complex, the average N_2 content in water-soluble gas is usually not higher than 4–6 vol.%, only within some depth ranges of the Verkhnekubinskaya, Gorchinskaya, Nanadyanskaya, Sredne-Yarovskaya, Ozernaya, Suzunskaya, Tokachinskaya and Yarovskaya areas its concentration was detected to be higher than 10 vol.%.

The concentration of CO_2 is 0.02–3.52 vol.% (most frequently several tenths of a per cent); H_2 concentration varies from trace to 2.13 vol.%, with 0.21 vol.% on average. In sole samples, argon concentration is 0.02 vol.%. Helium content in WDG is usually not higher than several hundredths of a per cent. However, detailed analysis of the available data revealed a group of objects with anomalous He concentrations from 0.5 to 0.9 vol% in a group of wells in the vicinity of the north-western slope of the MIR (the Anomalnaya, Pelyatkinskaya, and Sredne-Yarovskaya areas) (Fig. 1). The nature of this anomaly requires further investigation.

The WDG from the ***Upper Jurassic aquifer system*** in the region under investigation are only poorly investigated. By present, there are only three samples of water-dissolved gases, one of them was taken within the boundaries of YKhSB (well no. 1 of the Rassokhinskaya area), the second one – within the boundaries of the MIR (well No. 24 of the Yuzhno-Soleninskaya area), and the third one within the WSSB (well No. 1 at the Bolshelaydinskaya area). Nitrogen is the dominating gas component (61.37 vol.%) in the WDG of the Rassokhinskaya area, which is the evidence that the Upper Jurassic sediments had been washed with ancient infiltration waters. Methane dominates (92.1–98.7 vol.%) in other two samples; the concentration of N_2 is 1.30–2.56 vol.%; CO_2 0.16 vol.% (the Yuzhno-Soleninskaya area) and He 0.005–0.014 vol.%. Methane homologues were detected only in well No. 24 of the Yuzhno-Soleninskaya area; their concentration is equal to 5.15 vol.%. The available data allow us to attribute the WDG of the studies samples from the Upper Jurassic complex to the dry hydrocarbon class (well No. 1 of the Bolshelaydinskaya area) and the fat one (well No. 24 of the Yuzhno-Soleninskaya area).

Similarly to the upper sediments, WDG of methane type composition are widespread within the boundaries of the ***Lower and Middle Jurassic aquifer system***.

Area, well No.	Elemental composition, vol. %											ΣHH	$\frac{\Sigma HC}{N_2}$	$\frac{CH_4}{\Sigma HH}$	$\frac{C_2H_6}{C_3H_8}$	$\frac{iC_4H_{10}}{nC_4H_{10}}$
	CO_2	N_2	He	Ar	H_2	CH_4	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}	C_6H_{14}					
Aptian-Albian-Cenomanian aquifer system																
Vostochno-Messoyakhskaya, 35	0.00	1.73	-	0.001	-	98.9	0.00	0.018	0.01	0.00	-	0.03	57	3508	-	0.4
Gorchinskaya, 1	0.10	1.53	-	-	0.08	98.3	-	-	-	-	-	0.00	64	-	-	-
Zapadno-Messoyakhskaya, 21	0.00	0.40	0	0.001	0.00	98.9	0.61	0.14	0.01	0.00	-	0.76	286	130	4	2.7
Lodochnaya, 5	1.51	2.40	-	0.030	0.01	90.8	0.87	0.01	0.15	4.17	-	5.30	40	17	87	48.0
Ozernaya, 7	0.06	2.57	-	-	-	95.2	2.06	0.05	0.04	-	-	2.15	38	44	41	1.0
Pelyatkinskaya, 14	0.05	1.14	-	-	-	98.7	0.08	-	-	-	-	0.08	87	1234	-	-
Tagulskaya, 11	0.10	1.97	-	-	-	96.5	1.41	-	-	-	-	1.41	50	68	-	-
Neocomian aquifer system																
Verkhnekubinskaya, 2	-	14.94	0.0070	-	1.613	80.1	2.31	0.53	0.33	0.13	-	3.30	6	24	4	0.7
Gorchinskaya, 1	-	13.05	0.0110	-	0.360	83.4	1.80	0.62	0.46	0.16	-	3.19	7	26	3	0.7
Deryabinskaya, 13	0.35	9.98	0.0010	-	0.001	82.2	5.14	1.67	0.58	0.12	-	7.51	9	11	3	0.6
Lodochnaya, 6	-	0.81	-	-	0.550	95.6	1.89	0.48	0.42	0.29	-	3.08	122	31	4	3.7
Nanadyanskaya, 310	-	3.74	0.1000	-	0.400	92.8	0.89	0.29	0.83	0.81	0.15	2.97	26	31	3	3.3
Ozernaya, 4	0.65	17.65	-	-	-	78.2	2.14	0.33	0.70	0.29	-	3.46	5	23	6	3.1
Pelyatkinskaya, 5	1.43	0.93	0.1000	-	0.200	93.4	2.80	0.12	0.41	0.60	-	3.93	105	24	23	1.1
Sredne-Yarovskaya, 1	0.26	3.32	-	-	0.103	91.4	3.61	0.45	0.38	0.46	-	4.89	29	17	8	0.4
Suzunskaya, 17	0.15	1.91	0.0210	-	0.002	94.3	1.82	0.86	0.66	0.33	-	3.66	51	26	2	0.6
Yuzhno-Noskovskaya, 318	-	7.03	-	-	-	89.1	2.38	0.41	0.24	0.82	-	3.85	13	23	6	0.5
Upper Jurassic aquifer system																
Bolshelaydinskaya, 1	-	1.30	0.0140	-	-	98.7	-	-	-	-	-	0.00	76	-	-	-
Yuzhno-Soleninskaya, 24	0.16	2.56	0.0050	-	-	92.1	3.36	1.11	0.46	0.22	-	5.15	38	18	3	0.8
Lower and Middle Jurassic aquifer system																
Deryabinskaya, 5	0.52	-	-	-	0.016	92.4	3.81	1.85	0.97	0.42	-	7.05	-	13	2	0.7
Deryabinskaya, 5	0.13	-	0.0002	-	-	93.6	3.31	1.62	0.93	0.46	-	6.32	-	15	2	0.6
Semenovskaya, 2	-	-	0.0200	-	-	88.1	9.18	1.78	0.36	0.56	-	11.88	-	7	5	-
Sredne-Yarovskaya, 4	-	0.88	0.5000	-	0.400	86.0	6.72	3.30	1.60	0.57	-	12.19	112	7	2	0.7
Suzunskaya, 4	0.50	1.20	-	0.030	0.020	88.1	5.14	3.00	1.58	0.43	-	10.15	82	9	2	0.9
Turkovskaya, 2	-	0.64	0.4000	-	0.190	94.9	1.69	0.25	0.87	0.92	-	3.89	154	24	7	0.6
Ushakovskaya,1	-	0.74	-	-	1.300	91.2	3.89	1.34	1.07	0.50	-	6.80	132	13	3	0.6
Khabeyskaya, 1	0.30	2.90	-	-	-	89.4	4.57	1.55	1.10	0.19	-	7.41	33	12	3	0.3
Yuzhno-Soleninskaya, 25	1.56	-	-	-	0.007	91.1	3.29	1.79	1.52	0.75	-	7.35	-	12	2	0.8

Table 2. Typical samples of water-dissolved gases in oil and gas bearing deposits at the junction between the Yenisei-Khatanga and the West Siberian basins. Note: dash means the absence of data.

The fat WDG type with the concentration of methane homologues above 5 vol.% dominates in the region under investigation. An exception is the sample from well No. 2 of the Turkovskaya area, where ΣHH is 3.89 vol.%. Methane content varies from 86.0 to 94.9 vol.%, the average value being 92.4 vol.%. The concentrations of ΣHH vary within the range 3.89–12.19 vol.%. Themaximal values were detected at the Suzunskaya area (10.15 vol.%), Semenovskaya (11.88 vol.%) and Sredne-Yarovskaya (12.19 vol.%). For other studied objects, the average ΣHH value is 6.32 vol.%. The WDG of the Lower and Middle Jurassic reservoirs of the Nadym-Taz area are distinguished by the higher ΣHC content, which reaches 30.1 vol.% for some depth ranges (Shvartsev, Novikov, 2004; Novikov, 2019). Among heavy hydrocarbons, ethane prevails with its concentration 1.69–9.18 vol.%. The concentration of C_3H_8 does not exceed 3.30 vol.%; i-C_4H_{10} – 0.76 vol.%; n-C_4H_{10} – 0.93 vol.%; i-C_5H_{12} – 0.56 vol.%; n-C_5H_{12} – 0.80 vol.%, and C_6H_{14} – 0.16 vol.%. The concentration of N_2 varies from 0.64 to 2.9 vol.%, with the average value equal to 1.4 vol.%; CO_2 from 0.10 to 1.56 vol.%, with the average value equal to 0.37 vol.%. The concentration of H_2 in WDG varies from several pro mille to 1.3 vol.%, inert gases: He from trace amounts to 0.02 vol.%, and Ar not higher than 0.03 vol.%. Attention should be paid to anomalously high helium concentrations in the samples from the previously mentioned region at the north-western slope of the MIR (the Sredne-Yarovskaya and Turkovskaya areas), where its concentration is 0.4–0.5 vol.%.

Comparative analysis of the composition of WDG in the Jurassic – Neocomian sediments revealed similarities in the spectra of the distribution of average gas content (Fig. 3a). The WDG of the Aptian-Albian-Cenomanian sediments are characterized by lower concentrations of methane homologues. The average concentrations differ: for C_2H_6 – by a factor of 2.7; for C_3H_8 – 18.9; for i-C_4H_{10} – 4.9; for n-C_4H_{10} – 42.5, and for C_5H_{12} – by a factor of 66.6. The WDG of the Upper Jurassic reservoirs have also relatively light-weight composition of the homologues in comparison with the Lower and Middle Jurassic, and the Neocomian reservoirs. The concentrations differ by a factor varying within the range 0.95 to 2.56. This circumstance provides evidence of the higher extent of washing of the Upper Jurassic rocks by ancient infiltration waters at the eastern edge of the YKhSB (Kokh, Novikov, 2014; Borisov, 2019; Novikov, Borisov, 2021). In the axial part of the YKhSB, the Upper Jurassic complex is represented by the clays of the Golchikhinskaya formation, which served as the main oil-producing layer for upper and lower bedded Neocomian and Lower and Middle Jurassic reservoirs (Nikitenko et al., 2020), which explains the highest degree of relationship of the compositions of these complexes. The revealed regularities are confirmed by the values of the basic geochemical coefficients (Fig. 3a).

Further analysis of WDG from the Neocomian and Lower and Middle Jurassic aquifer systems showed that the available data may be divided into three uniform geochemical sets spatially confined to three largest tectonic elements of the region under investigation: The Yenisei-Khatanga regional depression, the West Siberian hemi-anteclise, and the Messoyakh inclined ridge separating the former two elements from each other. The composition of WDG from the Neocomian reservoirs of the MIR is distinguished by lower ΣHC content and increased hydrogen concentration up to 0.5 vol.% in comparison with YKhSB and WSSB (Fig. 3b). The composition of WDG of the Lower and Middle Jurassic aquifer system is generally the same over the whole territory under study. Insignificant differences are observed in the average concentrations of hydrogen and the homologues of methane (Fig. 3.c). In this situation, the waters of the WSSB contain higher concentrations of ethane, propane, and butane.

As mentioned above, the type of WDG zoning in the junction zone between the YKhSB and WSSB is normal (direct). A monotonous decrease in the concentrations of nitrogen and methane is observed with an increase in depth, which is accompanied by a regular increase in the concentrations of the homologues of methane and carbon dioxide (Fig. 4a-d). For instance, the average concentrations of methane vary from 94.0 vol.% in the Aptian-Albian-Cenomanian complex to 92.6 vol.% in the waters of the Lower and Middle Jurassic reservoirs. The minimal methane concentration equal to 88.9 vol.% is characteristic of WDG in Neocomian reservoirs. The average concentration of nitrogen varies from 4.3–5.1 vol.% in the Cretaceous complexes to 1.4–1.9 vol.% in the Jurassic ones. The average values of ΣHH increase from 1.44 vol.% in the Aptian-Albian-Cenomanian reservoirs to 6.66 vol.% in the Lower and Middle Jurassic sediments (Fig. 4d). Among the homologues of methane, ethane is the dominating component. Its average concentrations gradually increase with depth and are equal to 1.18 vol.% in the Aptian-Albian-Cenomanian complex, 2.81 vol.% in the Neocomian, 3.36 vol.% in the Upper Jurassic, and 3.64 vol.% in the Lower and Middle Jurassic. The behavior of propane, butane, pentane and hexane is more complicated: the maximal degree of enrichment with these gases is detected in the waters of the Neocomian reservoirs (Fig. 3a). A similar distribution over the section is exhibited also by the average concentrations of carbon dioxide, which vary within a narrow range 0.16–0.48 vol.%. It was established that an increase in the depth is accompanied by a regular increase in the average values of hydrocarbon enrichment factor (from 37 to 154) and

Fig. 3. Average composition of the WDG of oil and gas bearing sediments in the junction of the Yenisei-Khatanga and the West Siberian basins taking into account the main geochemical coefficients ($CH_4/\Sigma TY$, C_2H_6/C_3H_8 and $i\text{-}C_4H_{10}/n\text{-}C_4H_{10}$): a) aquifer systems: 1 – the Aptian-Albian-Cenomanian, 2 – the Neocomian, 3 – the Upper Jurassic, 4 – the Lower and Middle Jurassic; b-c) the studied regions: 1 – the Yenisei-Khatanga basin, 2 – the Messoyakh inclined ridge, 3 – the West Siberian basin.

a decrease in the ratios of $CH_4/\Sigma HHC$(from 130 to 7), C_2H_6/C_3H_8 (from 41 to 2) and $i\text{-}C_4H_{10}/n\text{-}C_4H_{10}$ (from 2.6 to 0.6) (Fig. 4e-h).

Conclusions

Thus, it was established in the studies that:

1) With an increase in occurrence depth and the age of oil and gas bearing complexes in the junction between the Yenisei-Khatanga and West Siberian sedimentary basins, the time of hydrocarbon dissemination from the pools formed at previous stages of the geochemical development of water–gas system increases. With thermobaric field hardening, the level of hydrocarbon generation is still high, which is accompanied by the shift of gas formation processes towards liquid components and methane homologues. Because of this, the detection of waters saturated with gas (up to 4.6 dm^3/dm^3) in the Lower and Middle Jurassic reservoirs is naturally determined and allows their potential to be evaluated as very promising.

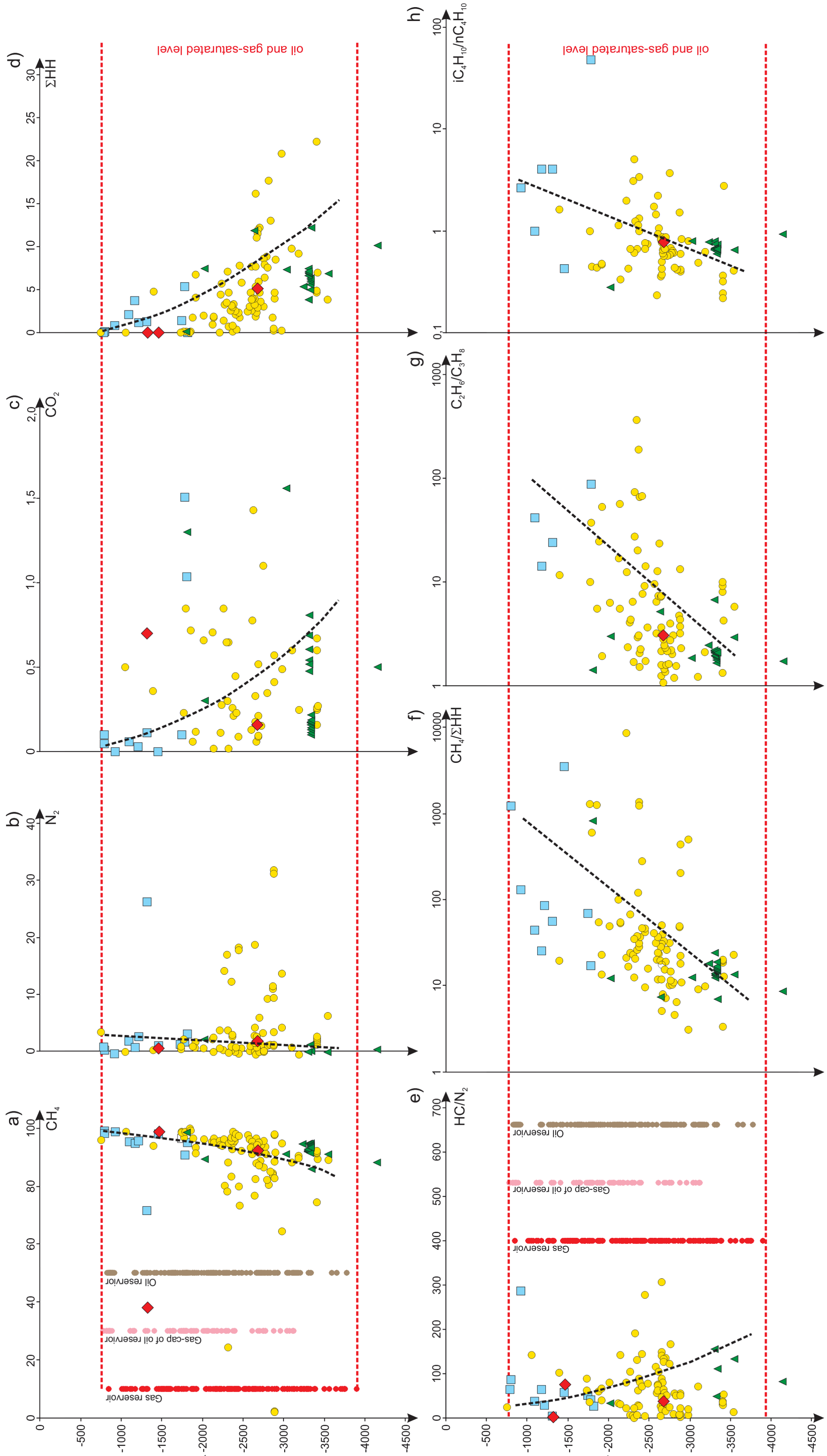

Fig. 4. Changes in the concentrations of CH_4 (a), N_2 (b), CO_2 (c), ΣHHC (d) and the coefficients: HC/N_2 (e), CH_4/ΣHHC (f), C_2H_6/C_3H_8 (g), $i\text{-}C_4H_{10}/n\text{-}C_4H_{10}$ (h) with depth in the WDG of the junction between the Yenisei-Khatanga and West Siberian basins. For designations, see Fig. 2.

2) For the region under investigation, the similarity of WDG compositions was detected for the Neocomian and Jurassic reservoirs ($C_1 > N_2 > C_2 > C_3 >$ n-$C_4 >$ i-$C_4 > CO_2 >$ i-$C_5 >$ n-C_5). The WDG of the Aptian-Albian-Neocomian sediments differ by the lower concentrations of methane homologues ($C_1 > N_2 > C_2 > CO_2 > C_3 >$ i-$C_4 >$ n-$C_4 >$ i-$C_5 >$ n-C_5), with ΣHHC equal to 1.44 vol.%. The vertical zoning of WDG composition is to a high extent determined by the paleohydrogeological history of the embedding sediments and the true distribution of hydrocarbon pools in the Jurassic-Cretaceous section.

3) A helium anomaly was revealed and localized at the north-western slope of the Messoyakh inclined ridge within a small territory limited by the Anomalnaya, Turkovskaya, Pelyatkinskaya, and Sredne-Yarovskaya areas. Helium content within the boundaries of this zone is 0.4–0.9 vol. %, which differs by several orders of magnitude from background values typical for the territory under investigation. The nature of this anomaly requires further detailed studies.

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References

Borisov E.V. (2019). Issues of correlation and indexation of productive SG strata of the Sigovskaya formation in the western part of the Yenisei-Khatanga regional trough. *Geologiya i mineral'no-syr'yevyye resursy Sibiri*, 4(40), pp. 67–79. (In Russ.). https://doi.org/10.20403/2078-0575-2019-4-67-79

Ginsburg G.D., Ivanova G.A. (1977). Some characteristic features of the geochemical zoning of groundwater in the southwestern part of the Yenisei-Khatanga trough. *Geologiya i neftegazonosnost' mezozoyskikh progibov severa Sibirskoy platformy*. Leningrad: NIIGA, pp. 70–82. (In Russ.)

Kartsev A.A., Vagin S.B., Matusevich V.M. (1986). Hydrogeology of oil and gas basins. Moscow: Nedra, 224 p. (In Russ.)

Kokh A.A., Novikov D.A. (2014). Hydrodynamic conditions and vertical hydrogeochemical zonality of groundwater in the Western Khatanga Artesian Basin. *Water Resources*, 41(4), pp. 396–405. https://doi.org/10.1134/S0097807814040083

Kontorovich A.E., Zimin Y.G. (1968). On the conditions for the formation of the chemical composition of groundwater in the West Siberian Lowland. *Trudy SNIIGGiMS*, 46, pp. 83–95. (In Russ.)

Kruglikov N.M. (1964). Hydrogeology of the northwestern side of the West Siberian artesian basin. Leningrad: Nedra, 166 p. (In Russ.)

Kruglikov N.M., Nelyubin V.V., Yakovlev O.N. (1985). Hydrogeology of the West Siberian oil and gas basin and features of the formation of hydrocarbon deposits. Leningrad: Nedra, 279 p. (In Russ.)

Kurchikov A.R., Plavnik A.G. (2009). Clustering of groundwater chemistry data with implications for reservoir appraisal in West Siberia. *Russ. Geol. Geophys.*, 50(11), pp. 943–949. https://doi.org/10.1016/j.rgg.2009.10.003

Matusevich V.M., Ryl'kov A.V., Ushatinskiy I.N. (2005). Geofluidic systems and problems of oil and gas potential of the West Siberian megabasin. Tyumen: TyumGNGU, 225 p. (In Russ.)

Nikitenko B.L., Devyatov V.P., Rodchenko A.P., Levchuk L.K., Peshchevitskaya Ye.B., Fursenko Ye.A. (2020). The Gol'chikha Formation (Upper Bathonian–Lower Boreal Berriasian) of the Yenisei–Khatanga Depression (West of the North Siberian Lowland). *Russ. Geol. Geophys.*, 61(4), pp. 412–427. https://doi.org/10.15372/RGG2019082

Novikov D.A. (2017a). Hydrogeological conditions for the presence of oil and gas in the western segment of the Yenisei-Khatanga regional trough. *Geodynamics & Tectonophysics*, 8(4), pp. 881–901. (In Russ.). https://doi.org/10.5800/GT-2017-8-4-0322

Novikov D.A. (2017b). Hydrogeochemistry of the Arctic areas of Siberian petroleum basins. *Petroleum Exploration and Development*, 44(5), pp. 780–788. https://doi.org/10.1088/1755-1315/193/1/012048

Novikov D.A. (2018). Theoretical substantiation of application of the hydrocarbon accumulation prospecting technique in Western Siberia based on the study of water-gas equilibria. *IOP Conference Series: Earth and Environmental Science*, 193(1). https://doi.org/10.1007/s12517-015-1832-5

Novikov D.A. (2019). Zonality of water-ddissolved gases in the oil-and-gas bearing sediments of the Nadym-Taz interfluve. *Interekspo GEO-Sibir*, 2(1), pp. 133–140. (In Russ.). https://doi.org/10.33764/2618-981X-2019-2-1-133-140

Novikov D.A. (2020). Analysis of water-gas system equilibria in Jurassic-Cretaceous reservoirs (by the example of the Yamal-Kara Depression). *Russian Geology and Geophysics,* 61(8), pp. 874–890. https://doi.org/10.15372/RGG2019179

Novikov D.A., Borisov E.V. (2020). Features of the hydrogeological stratification of oil and gas bearing deposits in the western part of the Yenisei-Khatanga basin. *Izvestiya VUZov. Neft' i Gaz*, 1, pp. 42–52. (In Russ.). https://doi.org/10.31660/0445-0108-2020-1-42-52

Novikov D.A., Borisov E.V. (2021). Prediction of oil and gas occurrence in the Jurassic reservoirs of the zone of junction of the Yenisei–Khatanga and West Siberian basins. *Russian Geology and Geophysics,* 62(2), pp. 216–237. https://doi.org/10.2113/RGG20194069

Novikov D.A., Sukhorukova A.F. (2015). Hydrogeology of the northwestern margin of the West Siberian Artesian Basin. *Arabian Journal of Geosciences*, 8(10), pp. 8703–8719. https://doi.org/10.1007/s12517-015-1832-5

Novikov D.A., Vakulenko L.G., Yan P.A. (2019). Lateral zoning of groundwater chemistry and authigenic mineralogy in the Oxfordian regional reservoir of the Nadym-Taz interfluve. *Russian Geology and Geophysics,* 60(6), pp. 662–674. https://doi.org/10.15372/RGG2019041

Nudner V.A. (1970). Gydrogeology of the USSR. Vol. XVI: West Siberian Plain (Tyumen, Omsk, Novosibirsk and Tomsk Regions). Moscow: Nedra, 368 p. (In Russ.)

Rostovtsev N.N., Ravdonikas O.V. (1958). Geological structure and prospects of oil and gas potential of the West Siberian lowland. Moscow: Gostoptekhizdat, 391 p. (In Russ.)

Shvartsev S.L., Novikov D.A. (2004). The nature of vertical hydrogeochemical zoning of petroleum deposits (exemplified by the Nadym-Taz interfluve, West Siberia). *Geologiya i geofizika*, 45(8), pp. 1008–1020. (In Russ.)

Stavitskiy B.P., Kurchikov A.R., Kontorovich A.E., Plavnik A.G. (2004). Hydrochemical zoning of Jurassic and Cretaceous sediments of the West Siberian basin. *Geologiya i geofizika*, 45(7), pp. 826–832. (In Russ.)

Zor'kin L.M., Subbota M.I., Stadnik E.V. (1982). Oil and gas exploration hydrogeology. Moscow: Nedra, 216 p. (In Russ.)

About the Authors

Dmitry A. Novikov – PhD (Geology and Mineralogy), Head of the Laboratory of sedimentary basins hydrogeology of Siberia, Trofimuk Institute of Petroleum Geology and Geophysics of Siberian Branch of Russian Academy of Sciences; Associate professor, Department of Geology of petroleum fields, Novosibirsk State University

3 Ac. Koptyug av., Novosibirsk, 630090, Russian Federation

Evgeny V. Borisov – Researcher, Laboratory of oil and gas of Arctic regions of Siberia, Trofimuk Institute of Petroleum Geology and Geophysics of Siberian Branch of Russian Academy of Sciences

3 Ac. Koptyug av., Novosibirsk, 630090, Russian Federation

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