Geochemistry of Water-Dissolved Gases of Oil-and-Gas Bearing Deposits in Northern and Arctic Regions of Western Siberia

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Abstract. The paper presents a pioneering attempt in the last 35 years, to summarize the accumulated data on geochemistry of water-dissolved gases of oil and gas-bearing deposits in northern and arctic regions of Western Siberia. Water-dissolved gases from all the studied oil/gas fields are characterized by absolute predominance (up to 75-99 vol.%) of the methane series hydrocarbons in their composition. The identified (after the L.M. Zorkin’s classification) four classes of hydrocarbon type of water-dissolved gases (vol.%) are designated as: dry (ΣHH < 1), lean (ΣHH = 1-3), semi-fat (ΣHH = 3-5) and fat (ΣHH > 5). The total gas saturation of groundwaters ranges from 0.3 to 5.7 L/L with CH4 concentrations averaging 95.5 vol.% in the Aptian-Albian-Cenomanian to 83.3 vol.% in the Lower-Middle Jurassic complexes. The levels of homologues ΣHH (C2H6, C3H8, C4H10, C5H12 and C6H14) tend to increase with depth: from 1.34 vol.% in the Aptian-Albian-Cenomanian to 11.67 vol.% in the Lower-Middle Jurassic complex. The maximum ΣHH concentrations reaching 30 vol.% were found at the Neocomian base in the peripheral waters of oil accumulations. CO2 levels show an increasing trend with depth, whereas N2 concentrations tend to decrease. Given the increased depths and more severe temperature conditions, the level of hydrocarbon generation remains high, however hydrocarbon series is characterized by a shift towards liquid components and methane homologues (the main zone of oil/fat gases generation). Therefore, the revealed in the Lower-Middle Jurassic complex highly gas-saturated groundwaters (up to 4.5-5.7 L/L) enriched with methane homologues allow to assess their hydrocarbon prospects as very high.

1. Introduction

The hydrocarbon prospecting and exploration, followed by detailed exploration and oil and gas fields development in the northern and arctic regions of Western Siberia have provided extensive factual material on the composition of water-dissolved gases (WDG) and gas concentrations in groundwater of oil and gas-bearing deposits.

With respect to the study area, pioneering research into water-dissolved gases (WDG) is associated with the works of M.S. Gurevich and N.N. Rostovtsev. Their research results have been of practical significance and scientific interest for more than 70 years. In the early 1950s, they introduced the concept of gas zonality of groundwater in the West Siberian artesian basin (WSAB) and stressed the importance of WDG levels (defined not only by qualitative aspects of their composition, but also by the saturation pressure) for hydrocarbon prospecting.
N.M. Kruglikov provided first insights about saturation pressure of dissolved gases, which decreases with greater distance from the gas-water contact (GWC) owing to the diffusion-driven processes of gas dispersion. While L.M. Zorkin went further and considered various conditions for gas release from groundwater and accumulation of gas pools, as potential gas generation.

This research direction has been largely contributed by A.E. Kontorovich, B.P. Stavitsky, V.M. Matusevich, A.A. Rozin, D.A. Novikov and many other researchers with the focus on different aspects of groundwater and WDGs in oil and gas deposits of the West Siberian artesian basin [1-25]. This study has made the first attempt [5] to summarize the accumulated since 1985 actual data (both from research institutions and industry) on WDG composition and concentrations in groundwater of oil and gas deposits in northern and arctic regions of WSAB. The materials are available through the electronic database comprising 2507 samples from 79 fields and prospective areas (Fig. 1).

Figure 1. Location map of oil/gas fields in northern and arctic regions of the West-Siberian artesian basin.

**Boundaries of:** 1 – West-Siberian artesian basin; 2 – Jurassic sedimentary basin; 3 – oil/gas fields: 1 – Malyginskoe, 2 – Tastyskoe, 3 – West Tarkosalinskoe, 4 – Kharatskoe, 5 – Kruzenshtern, 6 – Verkhne-Tiutey, 7 – Nerstinskoe, 8 – Arktichesko, 9 – Nuraminskoe, 10 – Khambatey, 11 – Rostovtsesko, 12 – Yamburg, 13 – Medvezhie, 14 – Urengoy, 15 – Tazovskoe, 16 – Zapolayarnoe, 17 – Russkoe, 18 – Yuzhno-Russkoe, 19 – Yubileynoe, 20 – Yamsovey, 21 – East Tarkosalinskoe, 22 – North Gubkinskoe, 23 – Gubkinskoe, 24 – Komsomolskoe, 25 – Barsukovskoe, 26 – Tarasovskoe, 27 – Ust-Kharampur, 28 – Vyngayakha, 29 – East-Vyngayakha, 30 – Yetypur, 31 – Vynga-Pur, 32 – Udmurtskoe, 33 – South Tarkosalinskoe, 34 – Kharampur, 35 – Lodochnoe, 36 – Suzun, 37 – Gorchinskoe, 38 – South Soleninskoe, 39 – Ushakovskoe, 40 – Pelyatka, 41 – Ozernoe, 42 – Deryabinskoe, 43 – Khabey, 53 – North Iokhturskoe, 54 – Sudokhodinskoe, 55 – South Tarkosalinskoe, 56 – Yumantilskoe, 57 – Tapa, 58 – Kharampur, 59 – Tektohkarampur, 60 – North Iokhturskoe, 61 –
Kholmistoe, 62 – South Udmurtskoe, 63 – Druzhnoe, 64 – Otdelnoe, 65 – Krainee, 66 – West-Purpeiskoe, 67 – Pangody, 68 – Lenzitskoe, 69 – Upper Kharlov, 70 – Palnikovskoe, 71 – Sredne-Khulymskoe, 72 – Verkhne-Kazymskoe, 73 – Sredne- Lykhminskoe, 74 – Bolshoe, 75 – Rogozhnikovskoe, 76 – Shukhtungurskoe, 77 – Serginskoe, 78 – Krasnoleninskoe, 79 – Yakhlinskoe; 4 – Prospective areas: 44 – Tanama, 45 – South-Nosok, 46 – Yar, 47 – Middle-Yar, 48 – Anomalnaya, 49 – Turku, 50 – Semenovka, 51 – Bolshaya Layda, 52 – Tokachinskaya.

2. Results and discussing
A deep genetic affinity between hydrocarbon gases in groundwater and oil and gas accumulations, as well as the depositional settings and present conditions of these mineral deposits in the water- and petroleum-bearing complexes serve as the theoretical basis for utilization of water-soluble gas indicators in assessment (both regional-scale and in-situ) of oil and gas potential. Besides, there exists a direct connection between sizes of confined aquifer-systems, potential resources of water-dissolved hydrocarbons and oil and gas reserves in the hydrocarbon accumulations [26]. Groundwaters with WDGs of methane-based composition are widespread in the hydrogeological section of the studied region (Fig. 2, a), where concentrations of methane homologues have shown an increase with depth from 1.34 vol.% (in Aptian-Albian-Cenomanian aquifer) to averaging 11.67% (in Lower-Middle Jurassic). The water-dissolved gases revealed within the Aptian-Albian-Cenomanian, Neocomian, Upper Jurassic and Lower-Middle Jurassic aquifer complexes represent all of the four hydrocarbon-type classes according to the L.M. Zorkin’s classification [27] designated as (vol.%): dry ($\Sigma$HH < 1), lean ($\Sigma$HH = 1-3), semi-fat ($\Sigma$HH = 3-5) and fat ($\Sigma$HH > 5). Heavy hydrocarbons (HH) are ubiquitously dominated by C$_2$H$_6$ (Fig. 2, b), whose concentrations can reach up to 18.3 vol.%. While $\Sigma$(C$_3$H$_6$, C$_4$H$_{10}$) is up to 16.3 vol.%, and $\Sigma$(C$_3$H$_{12}$, C$_4$H$_{14}$, C$_7$H$_{16}$) to 5.25 vol.%.

![Figure 2](image_url)  
**Figure 2.** Plots of the compositions of (a) total water-dissolved gases in oil and gas deposits in northern and arctic regions of Western Siberia and (b) heavy hydrocarbon fraction.  
Aquifer complexes: 1 – Aptian-Albian-Cenomanian, 2 – Neocomian, 3 – Upper Jurassic, 4 – Lower-Middle Jurassic

The Aptian-Albian-Cenomanian aquifer complex is characteristically prevailed by the methane-based composition of WDGs, with CH$_4$ concentrations varying from 74 to 99 vol.%, and according to the L.M. Zorkin’s classification, pertains to the hydrocarbon type. The distinctly observable regional zonality in the variability of gas composition of groundwaters is evidenced by the east-to-west trend (from the basin’s framing) of increasing values of CH$_4$, $\Sigma$HH concentrations, and gas saturation.

In respect of the identified gases of hydrocarbon types, the area is dominated by “dry” type changing to “lean” in the southwestward direction, which also allowed to reveal regions of semi-fat
and fat types (the Kharampur group in central regions of the Nadym-Taz interfluve). Thus, the maximum concentrations of $\Sigma$HH in the composition of WDG were identified in the North Iokhturskoe (10.19 vol.%), Beregovoe (3.36-7.72 vol.%) and Kharampur (5.21 vol.%) oil and gas fields. The average concentrations determined for the complex are: $\text{CO}_2$ (0.56 vol.%), $\text{N}_2$ (2.46 vol.%), $\text{H}_2$ (0.35 vol.%), He (0.012 vol.% and Ar (0.035 vol.%). Gas saturation of groundwater varies in a wide range from 0.3 to 3.0 L/L. The minimum and maximum gas saturation values were reported for the Kharampur (up to 3 L/L), and the Udmurtskoe fields (0.3-1.5 L/L), respectively. Both the Neocomian and the overlying Aptian-Albian-Cenomanian aquifer complexes are characterized by predominantly methane-based composition of WDGs (hydrocarbon type), with $\text{CH}_4$ concentrations varying widely from 61.8 to 98.8 vol.%. Given that major oil reserves are confined to the Neocomian complex, the maxima of $\Sigma$HH concentrations varying from 0.70 to 32.45 vol.% occur in the peripheral waters of oil accumulations.

Regional zonality reflected in the alteration of the gas composition of groundwaters is corroborated by the increasing content of methane homologues and by a reduction of methane levels trending from the basin’s periphery towards its central parts. In that same direction, dry hydrocarbon type changes to lean, semi-fat and fat types, with the semi-fat and fat hydrocarbon gases dominating in central and western parts of the Nadym-Taz interfluve. WDGs of the Neocomian complex have been best studied within the East Tarkosalinskoe gas field. The greatest dispersion in concentrations is reported for noble gases (He, Ar), $\text{H}_2$, $\text{CO}_2$ and $\text{N}_2$. While across the whole complex, the concentrations of $\text{N}_2$ in the composition of water-dissolved gas usually do not exceed 5-8 vol.%, only occasionally (primarily, in eastern parts of the studied region) reach more about 20 vol.% and more (Fig. 2.a).

$\text{CO}_2$ levels are around 1-2 vol.%, mostly a few tenths of a percent. Whereas $\text{He}$ concentrations vary from trace to 8.35 vol.%, averaging 0.61 vol.%. Average concentrations of He and Ar were found to be 0.025 and 0.032 vol.% respectively. The highest concentrations of heavy hydrocarbons $\Sigma$HH were reported at the Vnygayakhka (27.9-30.9 vol.%), Tarasovskoe (31.7-32.4 vol.%), Pangody (25.8-31.6 vol.%), Komsomolskoe (25.1-31.4 vol.%), Ust-Kharampur (25.9-31.6 vol.%), West Tarkosalinskoe (24.3-32.4 vol.%) and a number of other oil and gas fields. Gas saturation of groundwaters is scattered fairly widely, straddling the interval from 0.3 to 5.4 L/L, with no explicable patterns for its variability, likewise in the Aptian-Albian-Cenomanian complex. At this, the maximum values were revealed at the East Tarkosalinskoe field (up to 5.4 L/L). The Upper Jurassic aquifer complex comprises groundwaters with WDGs of methane composition (hydrocarbon type). The study area is for the most part dominated by fat hydrocarbon type of WDG, which changes to semi-fat and lean only in eastern regions. While $\text{CH}_4$ levels vary widely between 62.6 and 96.6 vol.%, averaging 81.9 vol.% (Fig. 2.a).

In the zone of regional Oxfordian reservoir development ($Y_{O1}$ bed) the content of heavy hydrocarbons is usually not more than 5-8 vol.% and reaches 10-15 vol.% only in the proximity to oil and gas condensate accumulations, rarely exceeding 20 vol.%. The highest concentrations of methane homologues were established for the Yetypur (26.6-27.4 vol.%), Kharampur (22.3-24.4 vol.%), Medvezhie (up to 22.6 vol.%), Gubkinskoe (up to 24.9 vol.%) and Tapa (26.1%) fields. $\text{N}_2$ and $\text{CO}_2$ levels in water-dissolved gas are accounted for 25 and 2.5 vol.%, respectively. Significantly lower concentrations were determined for $\text{H}_2$ (from a few thousandths of a percent to 2.8 vol.%), He (from 0.005 to 0.083 vol.%) and Ar (from 0.003 to 0.608 vol.%). The levels of gas saturation of groundwater variate inexplicably across the section and the area, varying in the range from 0.5 to 3.6 L/L. The nonuniform pattern of gas saturation changing from one structure to another, as well as within one field, is primarily controlled by the distance to hydrocarbon accumulations. The most contrasting level of gas saturation changing from 0.5 to 3.6 L/L was observed at the Kharampur gas field.

The Lower-Middle Jurassic aquifer complex is represented by groundwaters of methane composition (hydrocarbon type). As is the case with the overlying Upper Jurassic aquifer complex, the fat hydrocarbon type plays a key role in this region. The WDG composition is tending to “lighten” (changing consistently to semi-fat, lean and dry hydrocarbon types) from the basin’s periphery towards its central parts. Methane levels reach 65 vol.% and more (peaking at 95.6% for the North-Tolkino area) (Fig. 2a), while $\Sigma$HH concentrations vary in the range from 0.9 to 30.1%. The group of
heavy hydrocarbons is dominated by C₂H₆ (up to ca. 6-12%). Minor levels are reported for N₂ (not more than 10-13 vol.%, with maximum concentration (13 vol.%) at the Tektokaharampur field), and CO₂ (from 0.06 to 4.24%, averaging 0.76 vol.%). Concentrations of H₂ in WDGs range from a few thousandths of a percent to 2.2 vol.%. The fraction of noble gases includes: He (from 0.001 to 0.084) and Ar (from 0.010 to 0.108 vol.%). With the gas saturation of groundwater varying randomly from 0.9 to 5.7 L/L, its pattern is described as ambiguous. The highest values of gas-saturation (4.5-5.7 L/L) were established for the Yetypur gas field.

3. Conclusion
In conclusion, it should be noted that methane-rich groundwaters are dominantly developed within the lower hydrogeological stage comprising northern and arctic regions of Western Siberia, with methane levels averaging 95.5% in the Aptian-Albian-Cenomanian complex to 83.3% in Lower-Middle Jurassic. Its concentrations tend to decrease as the aquifers deepen. The composition of water-dissolved gases in hydrocarbon-generating structures is close to the composition of gas in HC accumulations. These differ in higher ethane-dominated methane homologues concentrations in WDGs (Fig. 2b). Dissolved gases in areas considered unproductive are also characterized by the methane-dominated composition. As noted above, the maximum concentrations of methane homologues were reported within the Neocomian complex, which is accounted for the fact that the major oil reserves are confined to its deposits. The medium concentrations of methane homologues in the aquifer complexes increase with depth: from 1.34 vol.% (Aptian-Albian-Cenomanian) to 11.67% (Lower-Middle Jurassic), and so do the levels of carbon dioxide along with the associated decrease in the heavy hydrocarbons to nitrogen ratio (from 96 for the Aptian-Albian-Cenomanian to 52 for the Lower-Middle Jurassic complex).

A natural “weighting” of WDGs of hydrocarbon (methane) type is observed in all of the all aquifers trending from the basin’s periphery towards its central parts (vol.%) and is designated as: dry (ΣHH < 1) – lean (ΣHH = 1-3) – semi-fat (ΣHH = 3-5) – fat (ΣHH > 5). The time rate of hydrocarbon dispersion tends to increase in older petroleum bearing deposits. Owing to the increased depths and more severe temperature conditions the level of hydrocarbon generation remains high, however the hydrocarbon series is characterized by a remarkable bias towards liquid components and methane homologues (the main zone of oil /fat gases generation). The revealed in Lower-Middle Jurassic sediments highly gas-saturated groundwaters (up to 4.5-5.7 L/L) enriched with methane homologues therefore allow to assess their hydrocarbon prospects as very high.

4. References
[1] Rostovtsev N N, Ravdonikas O V 1958 Geological structure and oil and gas potential of the West Siberian Lowland (Moscow: Gostoptekhizdat) 391
[2] Kruglikov N M 1964 Hydrogeology of the northwestern side of the West Siberian artesian basin (Leningrad: Nedra) 166
[3] Kontorovich A E, Zimin Yu G 1968 Tr. SNIIGGiMS 46 83-95
[4] Nudner V A 1970 Hydrogeology of the USSR. West Siberian Plain (Tyumen, Omsk, Novosibirsk and Tomsk Regions) (Moscow: Nedra) XVI 368
[5] 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
[6] Kartsev A A, Vagin S B, Matusевич V M 1986 Hydrogeology of oil and gas basins (Moscow: Nedra) 224
[7] Stavitskiy B P, Kurchikov A R, Kontorovich A E, Plavnik A G 2004 Geol. i geof. 45 826-32
[8] Matusевич V M, Rylko A V, Ushatsinskii I N 2005 Geofluid systems and oil and gas problems of the West Siberian megabasin (Tyumen: TyumGNGU) 225
[9] Novikov D A 2018 IOP Conf. Ser.: Earth and Env. Sc. 193 012048
[10] Novikov D A 2018 Neft. Khoz. Oil Ind. 4 16-21
[11] Novikov D A, Chernykh A V, Dultsev F F 2019 *J. Phys: Conf. Ser.* **1172** 012094
[12] Novikov D A 2018 *IOP Conf. Ser.: Earth and Env. Sc.* **193** 012049
[13] Novikov D A, Ryzhkova S V, Dultsev F F, Chernykh A V, Ses K V, Efimenk N A, Shokhin A E 2018 *Bull. Tomsk Pol. Univ., Geo Ass. Eng.* **329** 39-54
[14] Novikov D A, Saraev M M 2017 *Petr. Exp. and Dev.* **44** 737-44
[15] Novikov D A 2017 *Petr. Exp. and Dev.* **44** 780-8
[16] Novikov D A 2017 *Geod. and Tect.* **8** 881-901
[17] Novikov D A, Sadykova Y V, Chernykh A V, Dultsev F F, Sukhorukova A F 2018 *IOP Conf. Ser.: Earth and Env. Sc.* **193** 012051
[18] Kokh A A, Novikov D A 2014 *Wat. Res.* **41** 396-405
[19] Novikov D A 2019 *Lith. and Min. Res.* **54** 236-47
[20] Novikov D A, Sukhorukova A F 2015 *Arab. J. Geos.* **8** 8703-19
[21] Novikov D A, Shvartsev S L 2009 *Russ. Geol. and Geophys.* **50** 873-83
[22] Novikov D A, Lepokurov A V 2005 *Geol. Nef. i Gaz.* **5** 24-33
[23] Shvartsev S L, Novikov D A 2004 *Geol. i Geof.* **45** 1008-20
[24] Chernykh A V 2019 *J. Phys: Conf. Ser.* **1172** 012032
[25] Dultsev F F 2019 *J. Phys: Conf. Ser.* **1172** 012081
[26] Subbota M I, Kleymenov V F, Stadnik Ye V, Zorkin L M, Yakovlev Yu Ya 1990 *Interpretation of the results of hydrogeological studies in the search for oil and gas* (Moscow: Nedra) 221
[27] Zorkin L M, Subbota M I, Stadnik Ye V 1982 *Oil and gas hydrogeology* (Moscow: Nedra) 216

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