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**FEATURES OF FORMATION OF THE CHEMICAL COMPOSITION
OF NATURAL WATER IN THE URENGOY OIL
AND GAS PRODUCTION AREA (THE CASE OF THE URENGOY OIL
AND GAS CONDENSATE FIELD)**

SUMMARY. Nowadays the chemical composition of natural waters cannot be considered as the result of formation only by natural factors, which are defined as the processes of chemical exchange between different natural environments. Implicitly or explicitly diverse human activities have a significant impact on the formation of their chemical composition. This paper describes the main natural water-forming factors and focuses on hydrogeological characteristics of formation conditions. The authors examine the link between atmospheric, surface and ground water, which in their turn are divided into water above permafrost, subpermafrost and interpermafrost water. The paper presents the elemental chemical composition of all the considered water, and shows the change in chemical composition of the water at different depths. The research summarizes the results of two hundred chemical analyses of water samples selected directly in the oil and gas fields of Urengoy Region. Most of the results of the chemical analyses are published for the first time.

KEY WORDS. Chemical composition, conditions of formation, Urengoy field, groundwater.

Yamal–Nenets Autonomous Area, including the Urengoy oil and gas production area, is in the Arctic zone of the West Siberian Plain, with the largest part of the territory in the Arctic Circle. The territory comprises the lower reaches of the Ob River with tributaries, the Pur, the Taz and the Nadym river basins, and the Yamal, Taz and Gydan peninsulas. The area is one of the main oil and gas bearing regions in Russia. It is the source of up to 15% of all oil reserves and 91% of natural gas output in Russia [1]. The processes of developing oil, gas and gas condensate fields and putting them into production are inevitably associated with the construction of pipelines, power lines, roads, objects of production and communal infrastructure, an increase in the population of the area, development of towns and settlements. On the one hand, all these tendencies contribute to the improvement of social welfare not only for the residents of the area, but also for the whole country. On the other hand, the region under development, including the Urengoy oil and gas production area, is subject to a substantial technogenic burden. This results in degradation of vegetation and soil covers, soil and ground contamination, pollution of surface and ground waters.

With the intensive development of the region's industry and its significance for the national economy, the task of the quantitative and qualitative residential and industrial water supply is of vital importance.

Efficient use and conservation of natural resources and primarily of natural water supplies becomes at present one of the crucial issues.

The main factors for the formation of the chemical composition of natural waters.

The factors determining modern conditions of the formation of the chemical composition of natural waters fall into two main groups [2–3]:

1) Indirect factors determine conditions of water/substance interaction. These factors are climate, vegetation, landscape, water regime, hydrogeological and hydrodynamic conditions, etc.

2) Direct factors influence the water enriching it with soluble compounds or, on the contrary, causing precipitate formation that consists of the components suspended in water. These factors include lithology of surrounding formations, soils, living organisms and human activity.

In the natural environment of the Urengoy oil and gas production area water exchange rate is a major factor. It determines the interaction time in the water-rock-gas-organic matter system [4]. The influence of technogenic factors on the formation of the chemical composition of natural waters is specified by a long list of pollutant sources and requires a separate analysis.

Surface waters. A distinctive feature of surface waters is fluctuation of their composition depending on the season. The formation process of water composition in surface water bodies is influenced by a number of factors. The most important ones are atmospheric precipitation getting into the water and soil cover, biological processes in the water body involving aquatic organisms, and human activity (river regulation, irrigation, shipping, discharge of wastewater, etc.) [5]. As a result of the influence of the factors listed above on the surface water composition, chemicals in different forms (suspended, colloid, dissolved) get into surface water bodies.

Indirect factors (climate, landscape, vegetation and water regime) differentiate the entry of chemicals into surface waters both in space (climatic and geographic zonation) and in time (hydrochemical regime).

Surface waters on the territory of the Urengoy field belong to the hydrocarbonate type with a low salt content (up to 200 mg/L); over a half of all known chemical elements have been found in them. The change in total salt content over a year is insignificant; the salt content reaches its maximum level by the end of winter runoff low. During all the seasons the basic ions are HCO_3^- , Ca^{2+} and Mg^{2+} (Table 1). The rivers of the region are nourished by overland runoff and partially by underground water runoff.

Concentration of normalized heavy metals in surface water—Pb, Ni, Mo, Cd, Sr, Cr, Co, Cu, Zn—does not exceed MAC (maximum allowable concentration). The only microelement that is found in all waters of the area and whose concentration

level exceeds MAC by 6.5 times is manganese (Mn), which is typical for the Urengoy oil and gas production area. The quantity of methanol found in a number of samples sometimes exceeds or is equal to MAC.

Table 1

**The chemical composition and salt content of surface waters
in large rivers of the region**

Sampling points	Average concentration values, mg/dm ³ , percentage						Sum of ions, mg/dm ³
	HCO ₃ ⁻	SO ₄ ²⁻	Cl ⁻	Ca ²⁺	Mg ²⁺	Na ⁺	
Pur River–Samburg settlement	<u>15.2</u>	<u>8.2</u>	<u>3.4</u>	<u>4.2</u>	<u>1.8</u>	<u>4.0</u>	36.8
	24.0	16.4	9.6	20.2	14.4	15.4	
Taz River–Sidorovsk settlement	<u>60.4</u>	<u>1.6</u>	<u>2.8</u>	<u>13.2</u>	<u>4.9</u>	<u>1.0</u>	83.9
	45	1.4	3.6	30.0	18.2	1.8	
Pur River–Samburg settlement	<u>42.5</u>	<u>1.2</u>	<u>2.5</u>	<u>9.4</u>	<u>3.6</u>	<u>0.2</u>	59.0
	44.2	1.3	4.5	30.1	19.2	0.7	

At the initial stage of the Urengoy oil and gas condensate field development, surface water bodies and watercourses were characterized by chloride and sodium-calcium waters (lakes) and sodium-magnesium waters (rivers). Their salt content was between 350 and 1540 mg/L, and the chlorine content was 192–873 mg/L [6–7]. Such chemical composition and salt content can be explained the uncontrolled large-scale discharge of wastewater onto local terrain at the first stage of the field development.

Ground waters. Long-term permafrost strata on the examined territory excluded a significant part of ground waters from the water exchange process and influenced the formation and existence of ground waters that overlay permafrost or are found below or in the permafrost mass. The conditions of formation, abundance, dynamics of ground water and other properties of an active water exchange zone are almost completely preconditioned by permafrost. Seasonal melt waters, suprapermafrost waters, interpermafrost waters, subpermafrost waters and waters in continuous permafrost are formed in these conditions [2]. Each type of these ground waters plays an important role in the environment of the Urengoy oil and gas production area.

Taking the geological history of the regional groundwater formation and development into account, it can be argued that the main reason for its low salt content (from fresh water to sweet water) is a high water exchange rate and cryogenic metamorphization of ground water as a result of multiple freezing and thawing of Eocene-Oligocene-Quaternary aquifer [8].

The processes of concentrating and dispersal of substances play an important role in the formation of ground water composition. Modern factors that influence ground water formation are climatic ones, mainly atmospheric precipitation.

It is acknowledged that the formation of natural waters composition starts in the atmosphere and continues in soils and rocks until the water gets into a water discharge area and leaves the rock formation. Thus atmospheric water is the first stage of formation.

Atmospheric waters are under-explored in terms of their chemistry, and their composition is highly variable in time and space. In view of this fact, to analyse the content of a certain component in precipitation, average annual values are traditionally used and the extreme values are specified.

As a rule, the salt content of atmospheric waters is lower than that of surface and ground waters and is about 10–20 mg/dm³.

There is another key distinction of atmospheric waters from surface and ground waters, namely, characteristics of dominant ions and organic matter content. Atmospheric precipitation is enriched with ions of SO₄²⁻ and it is slightly cleaner than other types of water. Atmospheric precipitation contains a large proportion of biogenic substances, NH₄⁻ and NO₃⁻, whose concentration is up to 20–25% from the total number of components.

Table 2 presents the results from the analyses of atmospheric water samples collected by the authors of the research on the territory of the Urengoy field.

Table 2

Chemical composition of atmospheric precipitation

Precipitation form		Rainwater	Snow	Average by Yamal–Nenets Autonomous Area
Average concentration values, mg/L	HCO ₃ ⁻	6.1	5.3	12.2
	SO ₄ ²⁻	not found	2.7	1.7
	Cl ⁻	8.0	1.1	1.8
	NO ₃ ⁻	not identified	0.9	2.0
	Ca ²⁺	0.5	1.2	3.7
	Mg ²⁺	0.3	0.6	0.4
	Na ⁺	8.7	0.2	1.0
	K ⁺		0.3	0.3
	NH ₄ ⁺	not identified	0.6	0.1
	M, g/L	20.9	11.2	17.8
pH		5.8	5.3	5.7

Suprapermafrost waters are a buffer horizon between surface and ground interpermafrost waters; they have a large-scale distribution and often determine the formation of the chemical composition of waters in an active water exchange zone. According to their chemical composition, suprapermafrost waters of seasonal melt water layer and discontinuous permafrost are hydrocarbonate-calcium waters, magnesium waters, and hydrocarbonate-sodium waters with a salt content of 0.06-0.12 g/L. The chemical composition of suprapermafrost waters is formed as a result of mixing atmospheric precipitation with melted subterranean ice, pore fluids and their cryogenic metamorphization [9–10].

Cryogenesis has a direct impact on the chemical composition and salt content of suprapermafrost waters: translocation of salts between permafrost soils, containing water and ice takes place (when saturation point is reached, calcium carbonate, magnesium carbonate precipitate from the solution, and calcium sulphate, sodium sulphate precipitate from salt waters). When the water melts again, the salt content becomes lower in comparison with the content before freezing as not all soluble and labile compounds are transferred back to the solution.

Freezing of interpermafrost salt waters, which are found in some areas of the northern part of the field, results in the creation of supercooled waters—cryopegs.

When suprapermafrost waters melt, the runoff takes place down the surface slopes. The regime and dynamics are mostly defined by the landscape and atmospheric precipitation.

Interpermafrost waters. The main water supply source in the Urengoy oil and gas production area is interpermafrost waters which connect with suprapermafrost waters through “talik windows”, and the existence of interpermafrost aquifer is mostly determined by permafrost conditions.

The main factors determining ion-salt and gas composition of ground interpermafrost waters are plant decomposition, biological processes of microorganisms and, to a lesser degree, leaching of rock [8].

The aquifer nourishment is provided by means of infiltration of atmospheric precipitation in talik zones without the first layer of long-term permafrost, water infiltration from unfrozen rivers, and also by means of underlake and underflow taliks. The aquifer discharges to a river network. The main water discharge area is the valley of the Pur River and its large tributaries: the Yevo-Yakha, Pyakupur, Tabyakha, Khadutte rivers.

In the study of the chemical composition of ground waters in the interpermafrost aquifer, the results of water analyses conducted during the initial water well tests were used, as well as the analyses of water sampled in the process of water intakes operation in different years (see Tables 3, 4).

Table 3

**The chemical composition of ground water in interpermafrost aquifers of the Urengoy oil
and gas condensate field during the initial water well tests**

CGTP area	Dates of sampling, years	Indicator values, from-to/average (number of samples)						
		Content, mg/dm ³						
		Cl ⁻	SO ₄ ⁻²	HCO ₃ ⁻	K ⁺	Na ⁺	Mg ⁻	Ca ⁻
1AC	1983–1984	<u>1.4–7</u> 3.4(4)	-	<u>23–71</u> 44(3)	<u>1.2–2.0</u> 1.5(3)	<u>3.0–10.0</u> 5.2(3)	<u>1.0–5.2</u> 3.1	<u>2.2–6.0</u> 4.1(3)
1	1976–1977	<u>2.0–9.0</u> 3.9(11)	-	<u>9.0–49.0</u> 25(10)	<u>0.1–1.2</u> 0.7(8)	<u>1.0–13.0</u> 3(8)	<u>1.0–4.0</u> 2.3(12)	<u>1.0–6.0</u> 3.7(12)
2	1977–1978	<u>2.0–14.0</u> 5.5	-	<u>13.0–98</u> 44(6)	<u>0.6–1.5</u> 0.9(3)	<u>1.0–16.0</u> 5.5(5)	<u>1.0–9.0</u> 4.4(5)	<u>6.0–14.0</u> 7.1(5)
2B	1982–1986	<u>0.7–3</u> 2.0(7)	<u>up to 6</u> 1(6)	<u>12–170.9</u> 47(7)	<u>up to 1.1</u> 0.47(7)	<u>1.0–8.7</u> 3.8(7)	<u>1.0–4.9</u> 2.8(7)	<u>2.0–5.4</u> 3.7(7)
3	1978	<u>2.0–3.0</u> 2.9(7)	<u>19–51</u> 17(5)	<u>12.0–61.0</u> 24(7)	<u>0.5–0.7</u> 0.6(3)	-	<u>1.0–5.0</u> 2.5(6)	<u>2.0–34.0</u> 9.7(6)
3	1984	2	-	24	0.8	1	4	2
4	1979–1981	<u>2.0–3.0</u> 2.3(11)	<u>3.0–17.0</u> 4.9(9)	<u>12.0–49.0</u> 27(11)	<u>0.5–0.8</u> 0.7(7)	<u>1.0–3.0</u> 1.6(11)	<u>1.0–24</u> 4.6(11)	<u>1.0–10.0</u> 45(11)
5	1979–1981	<u>2.0–7.0</u> 3.3(12)	<u>3.0–6.0</u> 0.92(8)	<u>12.0–37.0</u> 33(12)	<u>0.5–0.1</u> 0.8(9)	<u>1.0–9.0</u> 2.2(12)	<u>1.0–5.0</u> 2.7(12)	<u>2.0–6.0</u> 5(12)
6	1980–1981	<u>1.0–4.0</u> 2.6(10)	<u>3.0–17</u> 4.6(9)	<u>12.0–17.0</u> 19.9(10)	<u>0.5–1.2</u> 0.7(10)	<u>1.0–2.0</u> 1.2(10)	<u>1.0–4.0</u> 1.5(10)	<u>2.0–4.0</u> 3.0(10)
7	1981–1982	<u>1.0–8.0</u> 3.3(16)	<u>3.0–16</u> 5.9(16)	<u>6.0–61.0</u> 23(16)	<u>0.4–1.1</u> 0.9(15)	<u>0.5–6.0</u> 2.5(16)	<u>1.0–4.0</u> 1.7(17)	<u>1.0–8.0</u> 3.7(17)
8	1981–1983	<u>2.0–8.0</u> 3.9(13)	<u>3.0–20</u> 4.8(10)	<u>6.0–122</u> 47(13)	<u>0.3–1.0</u> 1.04(9)	<u>1.0–19.0</u> 5.18(13)	<u>1.0–7.0</u> 3.4(14)	<u>2.0–8.0</u> 4.4(13)
9	1982–1983	<u>2.0–8.0</u> 41(14)	<u>8.6–19</u> 2.3(13)	<u>12.0–366</u> 106(13)	<u>2.0–3.0</u> 2.2(8)	<u>2.0–47.0</u> 22.4	<u>0.6–23.0</u> 5.4(14)	<u>20–68</u> 8.9(14)
10	1983–1984	<u>2.2–6.0</u> 7.9(9)	<u>6.6–16.0</u> 4.2(9)	<u>3.0–122</u> 67(9)	<u>2.0–4.0</u> 3.1(7)	<u>9.0–39</u> 14.0(8)	<u>1.0–10.0</u> 5.4(9)	<u>2.8–12.0</u> 7.6(9)

CGTP area	Dates of sampling, years	pH	Salt content, mg/dm ³	Indicator values, from-to/average (number of samples)				Oxygen demand mg O ₂ /L
				Content, mg/dm ³				
				Total Fe	NH ₄ ⁺	NO ₃ ⁻	NO ₂ ⁻	
1AC	1983–1984	<u>6.4–7.4</u> 6.8(4)	<u>36–97</u> 61(4)	<u>0.7–1.0</u> 0.8(3)	not identified	not identified	not identified	<u>2.1–3.5</u> 2.8(2)
1	1976–1977	<u>5.8–7.5</u> 6.9(9)	<u>21–80</u> 43(5)	<u>1.9–7.9</u> 4.9(2)	<u>0.2–0.4</u> 0.1(8)	-	-	<u>2.6–2.9</u> 2.8(2)
2	1977–1978	<u>6.4–7.9</u> 6.9(6)	<u>56–149</u> 78(5)	<u>1.6–3.6</u> 2.6(2)	<u>0.5–0.7</u> 0.6(3)	<u>up to 0.02</u> 0.05(4)	<u>up to 0.02</u> 0.5(4)	<u>2.0–8.2</u> 4.4(5)
2B	1982–1986	<u>3.9–7.0</u> 5.8(7)	<u>26–77</u> 55(6)	<u>0.25–8.8</u> 3.6(6)	not identified	not identified	not identified	0.75
3	1978	<u>5.3–6.7</u> 6.0(6)	<u>25–121</u> 52(5)	not identified	-	-	<u>up to 0.01</u> 0.003	1.2
3	1984	6.15	34	0.74	-	-	-	1.36
4	1979–1981	<u>4.8–7.1</u> 6.3(11)	<u>20–71</u> 49(6)	<u>0.4–6.1</u> 4.0(3)	<u>up to 1.0</u> 0.5(4)	<u>up to 11</u> 1.8(6)	-	<u>1.2–3.2</u> 2.2(8)
5	1979–1981	<u>5.3–7.4</u> 6.5(12)	<u>18.5–59</u> 43(5)	<u>0.6–6.4</u> 3.3(3)	<u>0.2–0.4</u> 0.08(5)	-	<u>up to 1.0</u> 0.16(6)	<u>1.4–3.4</u> 2.8(9)
6	1980–1981	<u>5.4–6.3</u> 5.9(10)	<u>19.5–54</u> 33(7)	1.7	<u>0.7</u> 0.5(3)	-	-	<u>2.2–3.6</u> 2.7(3)
7	1981–1982	<u>4.0–7.6</u> 6.4(17)	<u>21–85</u> 41(15)	<u>0.15–2.4</u> 1.0(8)	<u>0.2–4.7</u> 0.7(8)	-	-	<u>0.9–3.5</u> 2.2(11)
8	1981–1983	<u>4.0–7.7</u> 6.5(11)	<u>19–134</u> 65(10)	<u>0.2–1.6</u> 0.6(7)	<u>up to 0.7</u> 0.4(6)	-	-	<u>0.9–5.3</u> 2.7(8)
9	1982–1983	<u>5.9–7.6</u> 7(14)	<u>30–224</u> 149(12)	<u>0.4–7.3</u> 2.4(11)	<u>0.4–1.4</u> 0.51(11)	<u>up to 0.3</u> 0.04(7)	<u>0.003–14</u> 0.5(8)	<u>3.3–16.0</u> 7.6(11)
10	1983–1984	<u>5.1–7.6</u> 6.7(9)	<u>88–230</u> 143(7)	<u>0.3–0.9</u> 0.4(7)	<u>0.5–1.0</u> 0.5(7)	<u>up to 10.0</u> 2.5(4)	<u>up to 0.03</u> 0.01(3)	<u>3.2–6.9</u> 5.4(6)

Note: CO₃²⁻ —not found.

Table 4

The chemical composition of ground water in interpermafrost aquifers of the Urengoy field (2001–2005)

Sampling point	pH	Salt content, mg/dm ³	Principal components content: mg/dm ³									
			Cl	SO ₄	HCO ₃	CO ₃	NO ₂	K	Na	Mg	Ca	NH ₄
CGTP-1	7.16	25.11	2.13	not found	5.49	not found	not found	0.60	0.80	1.09	1.00	not found
CGTP-1	6.00	21.56	1.77	not found	6.10	not found	not found	0.60	0.80	1.09	1.20	not found
CGTP-1	6.70	111.30	1.42	not found	36.00	not found	not found	1.00	4.50	2.07	5.41	0.40
CGTP-2	6.90	86.35	1.42	not found	19.53	not found	not found	0.70	3.50	2.19	3.81	0.40
CGTP-2	6.60	101.19	1.42	not found	33.56	not found	not found	0.90	3.90	2.80	5.21	0.40
CGTP-2	7.03	64.82	1.77	not found	27.46	not found	not found	0.60	2.90	2.68	4.41	not found
CGTP-3	6.35	30.18	1.42	not found	6.71	not found	not found	0.40	1.40	1.95	1.20	not found
CGTP-3	5.80	27.21	1.42	not found	4.88	not found	not found	0.40	1.40	2.31	1.00	not found
CGTP-3	6.03	28.05	1.77	not found	5.49	not found	not identified	0.30	1.10	1.09	2.20	not found
CGTP-4	6.15	41.83	1.42	not found	9.76	not found	not found	0.40	1.40	0.24	3.01	not found
CGTP-4	6.53	59.40	1.42	not found	18.31	not found	not found	0.65	1.90	1.22	2.00	0.20
CGTP-5	6.25	39.52	1.42	not found	7.93	not found	not found	0.50	1.40	2.07	1.00	not found
CGTP-6	6.90	60.72	1.77	not found	19.53	not found	not found	0.95	4.05	2.31	2.81	0.40
CGTP-6	7.15	61.65	1.77	not found	20.75	not found	not found	0.95	3.80	2.07	3.01	0.50
CGTP-7	6.31	41.94	1.42	not found	4.25	not found	not found	0.65	2.90	1.82	2.20	0.40
CGTP-7	5.10	43.37	1.42	not found	6.10	not found	not found	0.50	1.90	1.58	1.80	0.30
CGTP-7	6.74	49.70	1.77	not found	12.81	not found	not found	0.50	2.90	2.31	3.41	not found
CGTP-8	7.72	161.87	1.42	not found	89.70	not found	not found	2.40	18.25	6.08	9.42	1.50
CGTP-8	7.35	106.00	1.42	not found	51.87	not found	not found	1.50	5.60	5.59	10.02	not found
CGTP-9	6.72	16.02	2.13	not found	3.05	not found	not found	0.25	1.15	1.34	0.80	not found
CGTP-9	6.25	17.82	1.42	not found	4.88	not found	not found	с.л. ???	0.70	0.12	1.40	not found

Subpermafrost waters include ground waters of upper tibeysale subformation which were analysed on the examined territory by means of one water well test.

The open Upper Paleocene water-bearing horizon of sand deposits in the tibeysale formation was tested within the range 338–351 m. The water is sodium chloride with a salt content of 3.05 g/L. The well yields are very low, about 1m³/hr, with the drawdown to 172 m.

Conclusions. In the formation process of the chemical composition of fresh natural waters, the following series of changes is clearly observed: from atmospheric precipitation to surface waters and ground waters.

Due to the latest glaciation, there have been observed the formation of long-term permafrost, the processes of cryogenic freezing and cryogenic metamorphization, which allowed forming sweet water aquifers.

Nowadays the development of regional water intake field conditions takes into account the influence of permafrost–hydrogeological and paleogeographic factors on the formation and location of fresh groundwater in the cryolithic zone. In addition, industrial metamorphism plays an important role in the process of fresh groundwater formation.

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