Assessment of hydromineral resources of the southern part of the Pre-Ural Foredeep on the example of spring waters for household use and balneotherapy

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Abstract. The results of the research devoted to the geochemistry of natural sources of springs on the territory of the Pre-Ural Artesian Basin are relevant, since the springs are understudied and are not classified according to their chemical composition and purpose. The southern area of the Pre-Ural Artesian Basin with salt-gypsum tectonics was studied. There are many springs with various chemical compositions there. The prevailing salinity level of spring waters varies from 197 to 941 mg/l, with total hardness of 1.33-5.5 mg-eq/l, and with good quality drinking water. The goal was achieved. The hydrogeological conditions and hydrogeochemical characteristics of the source waters were studied. Analogues of mineral waters of the group without "specific" components and properties of the Krainsky and Varninsky types with the salinity level from 1.2-3.36 g/dm³ are found by comparative analysis: sulfate, bicarbonate-sulfate, sulfate-bicarbonate calcium, magnesium-calcium waters. Springs with high salinity sodium chloride leaching waters with 124 g/dm³ for balneotherapy are associated with salt dome structures. A certificate on the exact possible therapeutic properties of spring mineral waters can be issued by the Institutes of Health Research Study after research.

1. Introduction
The study area is located in the zone of the Pre-Ural Foredeep at the junction of the Volga-Ural Anteclise with the Hercynian Ural fold system and the Caspian Depression [1]. In the Pre-Ural Foredeep, drilling of deep wells gives a general idea of the structure of the Kungurian layer, the sediment of which undergo abrupt changes in the composition and thickness. This is related both to the conditions of sedimentation in different parts of the basin and the intensive plastic relocations of salts and manifestations of gypsum tectonics. In terms of tectonics, the southern part of the Pre-Ural Foredeep is represented from the south by the Ural-Ilek Anticline passing into the Caspian Depression and the Mrakovo Depression with the manifestation of salt-gypsum tectonics [2].

The Western structural-geological zone belongs to the Pre-Ural Foredeep itself. The southern part of the Pre-Ural Foredeep is distinguished by the development of "salt-gypsum tectonics", which can be conditionally related to the intermediate type folding. The development of various morphological and genetic types of folding within the specified zones enables to divide them into smaller structural units. Disjunctive faults are common within the area under consideration, and they are the most frequent in the Pre-Ural Foredeep. Most of them are related to salt tectonics.
2. Materials and methods
The following methods were used to study the underground water for household use and balneotherapy in the southern part of the Pre-Ural Foredeep:

- Analysis of fund and literary sources.
- Sampling with further laboratory study to assess the chemical composition of underground waters. The selection of quality indicators was based on the requirements of SanPin (Sanitary rules and norms) 2.1.4.1074-01 and GN (Hygienic normatives) 2.1.5.1315-03.
- Comparative analysis of analogies to identify mineral waters.

3. Results and Discussion
The territory of the Pre-Ural Foredeep is a part of the Pre-Ural Artesian Basin. In this area, aquifers and sedimentary sheath complexes from alluvial to Upper Permian deposits of the pre-salt layer prevail.

The zone of active water exchange, where fresh underground waters prevail and where the strata are pressurized and non-pressurized, is the most studied throughout the territory [4]. It is a source of household waters. Springs and all the explored underground drinking water deposits are related to this part of the section.

The zone of active water exchange with fresh water in pressurized and non-pressurized strata is the most studied on the territory of the Pre-Ural Artesian Basin foothills [2].

Slow water exchange zone is less studied. In this part, the strata are mostly stagnant, and the underground waters cannot be used for water supply due to the hydrochemical situation. This zone contains mineralized fluids and mineral water analogues. Water is brackish and its composition varies. Sulphate and chloride ions prevail; bicarbonate ions are less frequent.

The relatively water-bearing Ufa stratum (P2u) is not widespread. It is known in the north of the Pre-Ural Foredeep and in the southeastern part of the front folds of the Western Urals. The penetrated thickness does not exceed 500 m. Underground waters are related to siltstone, sandstone, and mudstone beds interfingered with heavy clay lenses and beds. Flow rates do not exceed 3.1 l/s in case of reduction up to 1.0 m. The strata are pressurized with a pressure height of up to 24 m. The main inflow is obtained to a depth of 120 m. The stratum rocks are highly gypsified. A group of descending springs with sulfate-bicarbonate sodium water and salinity level of up to 1 g/dm³ is related to surface deposits.

The hydrogeology of the Pre-Ural Foredeep is understudied due to the insignificant sampling of water-bearing sedimentary rocks. In general, the sedimentary section of the inter-dome trough of the Sagarchin salt ridge in the Akobinsk area contains three hydrogeological strata with a locally water-resistant sequence of the Kungurian layer.

In the Akobinsk area, the power of above-salt water-bearing complexes up to the Kungurian hydrochemical sediments reaches 3,400 m with the absolute elevation of 3184 m at well 173.

Water-bearing Tatar complex (P3) is limited by the southern Pre-Ural Foothill basin and meridian strip along the Ural Fold Mountains. The composition of spring underground waters varies. There are fresh and brackish waters; in the first case, bicarbonate ions prevail, in the second case – sulphate and chloride ions.

This hydrogeological characteristic enables to make the following conclusions. Water-bearing rocks of Cretaceous, Jurassic and Triassic complexes are represented by large basin surface outcrops. They are drained by springs.
Figure 1. Fragment of the structural-tectonic map of the Pre-Ural Foredip of the Ural-Ilek Anticline.

One of them, Jurassic water-bearing complex, consists of grey marls and sandstones with various grains, with interlayers of marl, mudstone, limestone. As for salinity level, waters are both fresh and slightly brackish. If Jurassic sediments become deeper, the salinity level increases. Water flow rates vary from 0.4 to 4.2 m/sec. The thickness of the Cretaceous water-bearing strata with fresh waters is from 2 m to 5 m. The flow rates of springs coming from the Turon-Konyaksky aquifer (K₃t-k) vary from 0.01 to 0.07 l/sec.

Visean-Bashkir water-bearing complex, one of post-salt complexes, was studied in wells No. 172 and 173 of the Akobinsk deposit, where the Bashkir carbonate items were tested in the production casing. These are chloride calcium-sodium and sodium brines with salinity level of 102-247 g/dm³.

Let us consider the most interesting sources – fresh water springs. These are fresh spring waters with salinity level of 156-941 mg/l, with total hardness of 1.33-5.5 mg-eq/l from soft to moderately hard. Water from these sources can be used for drinking, without harmful impact on health.

In the Tyulgansky District, there are springs with good quality fresh water drained by Triassic sandstones (T₃). In chemical composition, the water in spring No. 8 is bicarbonate magnesium-calcium, neutral (pH 7.0), moderately hard. The total hardness is 5.5 mg-eq/l:
The spring water is of high quality, the salinity level is 440 mg/l. The salt composition is as follows (\%): Ca (HCO\(_3\))\(_2\)-65, Mg (HCO\(_3\))\(_2\)-29, MgSO\(_4\)-2, NaCl-4. Type II a-magnesial (CaHCO\(_3\)). According to the genesis, waters are infiltration waters.

In the northern side, there are outflows of mineral hydrogen sulfide waters in the Tyulgansky, Belyaevsky, Akbulaksky, Saraktashsky Districts of the Orenburg Oblast. They are related to gypsum fields and salt domes. Hydrogen sulfide underground waters are one of the most valuable groups of mineral waters.

The salty area Tuzlukkol is located between the Ilek river and the Ural river. In the bottom of the small river Tuzlukkol, there are outflows of springs with salt water on the right side. In chemical composition, spring waters are sulphate calcium and calcium-magnesium (SO\(_4\)-Ca, Mg Na) with salinity level of 2.16 to 3.137 g/dm\(^3\). They are close analogues of the Krainsky, (SO\(_4\)C –Na) and Varnitsky types \([4]\). They can be used as therapeutic table waters and for balneotherapy.

Table 1 shows the ion-salt composition of natural water sources in the Pre-Ural Basin. Spring Rudnyi the second is located in the Tyulgan district, at absolute elevation of 300.0 m, to the east of village Rudnoye. It is drained by the Kungurian gypsum (P\(_1\)kg). By chemical composition, this is calcium sulfate water with salinity level of 2.26 g/dm\(^3\), alkaline:

\[
M \frac{HCO_3^{94}Cl^{14}SO_4^{2-}}{Ca^{65}Mg^{31}Na^{4}} \text{ pH 7.0}
\]  

(1)

The salinity level of spring water is 2260 mg/l. The salt composition is as follows (\%): Ca SO\(_4\)-76 Ca (HCO\(_3\))\(_2\)-14, Mg SO\(_4\)-7, Na\(_2\)SO\(_4\)-2, NaCl-1. Type II b-gypsum (Ca>HCO\(_3\)>). According to the genesis, waters are infiltration waters. It is a close analogue of the Krainsky waters.

Waters of all natural geochemical types are found in the springs of the Pre-Ural Foredeep. Such a variety is associated with salt-gypsum tectonics. A certificate on the exact possible therapeutic properties of spring mineral waters can be issued by the Institutes of Health Research Study after research.

Table 1 Ion-salt composition of natural water sources in the Pre-Ural Basin \([6-11]\).

4. Conclusion

The southern part of the Pre-Ural Foredeep, especially the Ural-Ilek Anticline that connects the Caspian Depression and the Mrakovo Depression, contains various groups of healing mineral and fresh hydromineral resources of shallow aquifers, which are drained by springs.

In the Orenburg Oblast, the interest in clean drinking water has increased. The article presents a comparison of the qualitative characteristics and systematization of fresh and mineral water sources. In the active and slow water exchange zone, there are spring waters with various chemical compositions:

- There are fresh waters with salinity level of 156-941 mg/l of good quality for household use in the springs of Saraktashsky, Tyulgansky, Belyaevsky, Akbulaksky Districts.
- Sources from the group without "specific" components and properties with a salinity level of 1.15-3.36 g/dm\(^3\) were found, which are the analogues of Varnitsky and Krainsky types of mineral medicinal table waters.
- There are sources of sodium water with salinity level of 124.7 g/dm\(^3\) for balneotherapy, which are the analogues of the Usolsky and Vologodsky types.
## Table 1. Ion-salt composition of natural water sources in the Pre-Ural Basin

| No | Name of water sources | Mineralization, mg / dm³ | Cations and anions, mg/dm³ / mg * EQ |
|----|-----------------------|--------------------------|-------------------------------------|
|    |                       | 1 | 2 | 3  | 4  | 5  | 6  | 7  | 8  | 9  |
| 1  | Spring 198, Akbulaksky District, absolute elevation 239.0 m, left side of the balka (gully), village Kharkovka Pre-Ural Foredeep | 197.5 | 19.3 | 79.0 | 44.1 | 9.9 | 18.5 | 5 | 40.7 |
| 2  | Spring 232 Karagachsky, Akbulaksky District, absolute elevation 225.0 m, 1.7 to the southeast from the village Rodniki, right side of the balka (gully), upper reach. Flow rate 0.33 l/sec Pre-Ural Foredeep | 156.4 | 97.6 | 8.2 | 5.3 | 38.7 | 5.5 | 1.1 |
| 3  | Spring 8 Tyulgansky District, absolute elevation 150.0 m, in the center of the village Rodniki Pre-Ural Foredeep | 941.8 | 244 | 62.55 | 347 | 40.64 | 22.81 | 347.5 |
| 4  | Spring 242 (Rodnikovsky) Saraktashsky District, absolute elevation 150.0 m, in the center of the village Rodniki Pre-Ural Foredeep | 440 | 327 | 8.4 | 0.27 | 74.3 | 21.4 | 4.37 |
| 5  | Spring 8 Tyulgansky District, absolute elevation 360.0 m Pre-Ural Foredeep | 2260 | 274 | 1320 | 6.5 | 582.0 | 25.6 | 23.0 |
| 6  | Spring Rudny the second Tyulgansky District, absolute elevation 300.0 m, to the east of the village Rudnoye Pre-Ural Foredeep | 2116 | 159 | 1350 | 7.10 | 565.0 | 19.50 | 29.20 |
| 7  | Spring 164 Tyulgansky District Pre-Ural Foredeep | 1115.2 | 451.4 | 212.3 | 11.0 | 32.9 | 27.4 | 280.8 |
| 8  | Spring 223 (Voznesensky) Akbulaksky District, absolute elevation 237.0 m, right side of the balka (gully) of the Tuzlukkol stream village Solenity Pre-Ural Foredeep (on the border with Kazakhstan) | 124700 | 120.8 | 4802 | 9.4 | 33.7 | 519.2 | 117.6 |
| 9  | Spring 238 (Petrovsky) Saraktashsky District, absolute elevation 160.0 m, right side of the balka (gully) of the Tuzlukkol stream village Solenity Pre-Ural Foredeep in the floodplain of the river Assel on the right bank | 3363 | 713.7 | 1667 | 80 | 569.4 | 164.0 | 169.7 |
| 10 | Spring 83 Tyulgansky District, absolute elevation 300.0 m, to the west of the village Rudnoye Pre-Ural Foredeep | 2258 | 274 | 1320 | 6.5 | 582.0 | 25.6 | 23.0 |
Table 1 continued.

| No. | Name of water sources                                                                 | pH unit weight | Total hardness mg/ dm³ | Carbonate hardness g/ dm³ | Chemical composition formula | Water by O. A. Alekin GOST R 54316-2011 |
|-----|--------------------------------------------------------------------------------------|----------------|------------------------|---------------------------|-------------------------------|----------------------------------------|
| 1   | Spring 198, Akbulaksky District, absolute elevation 239,0 m, left side of the balka (gully), village Kharkovka | 7.4  1.0       | 1.33                   | 1.9                       | HCO₃CaSO₄30 Cl₁₉ (Na+K) 58 Ca29 Mg13 | CaNa SC I Fresh drinking water          |
| 2   | Spring 232 Karagachsky, Akbulaksky District, absolute elevation 225.0 m, 1.7 to the southeast from the village Rodniki, right side of the balka (gully), upper reach. Flow rate 0.33 l/sec Pre-Ural Foredeep Spring 242 (Rodnikovsky) Saraktashsky District, absolute elevation 150.0 m, in the center of the village Rodniki, Pre-Ural Foredeep | 7.4  1.0       | 4.03                   | 2.38                      | HCO₃CaSO₄30 Cl₁₉ Ca80 Mg19 (Na+K) 1 | Ca C IIIa Fresh drinking water          |
| 3   | Spring 8 Tyulganl District, absolute elevation 360.0 m Pre-Ural Foredeep              | 7.3  1.0       | 5.4                    | 4.0                       | Cl₆5 HCO₃26 SO₄9 (Na+K) 64 Ca23 Mg13 | C³ Ca Na Fresh drinking water           |
| 4   | Spring Rudny the second Tyulganl District, absolute elevation 300.0 m, to the east of the village Rudnoy Pre-Ural Foredeep | 7.5  1.0       | 5.53                   | 5.36                      | HCO₃CaSO₄30 Cl₁₉ Ca65Mg31(Na+K)4 | Ca² Na Fresh drinking water            |
| 5   | Spring 164 Tyulganl District Pre-Ural Foredeep                                       | 7.4  1.0       | 31.13                  | 2.6                       | SO₄85 HCO₃14 Cl₁₁ Ca90 Mg7 (Na+K) 3 | S Ca Krainsky type                     |
| 6   | Spring 223(Voznesensky) Akbulaksky District, absolute elevation 237.0 m, right side of the balka (gully) Sargachinskaya, village Yuryevka Pre-Ural Foredeep (on the border with Kazakhstan) Spring 225 (Soleniy) Belyaevsky District, absolute elevation 167.0 m, right side of the Tuzlukkol stream balka (gully) village Soleniy Pre-Ural Foredeep Spring 238 (Petrovsky) Saraktashsky District, absolute elevation 160.0 m, right side of the balka (gully) of the Tuzlukkol stream village Soleniy Pre-Ural Foredeep in the floodplain of the river Assel on the right bank | 7.2  1.0       | 26.78                  | 2.8                       | SO₄91 HCO₃9 Cl₁₁ Ca91 Mg5 (Na+K) 4 | S Ca Krainsky type                     |
| 7   | Spring 83 Tyulganl District, absolute elevation 300.0 m, to the west of the village Rudnoy Pre-Ural Foredeep | 7.2  1.0       | 26.78                  | 2.8                       | Cl₉5 SO₄5 (Na+K) 99.5 Ca0. 5 | Na SO₄ SC I For drinking Varnitsky type |
| 8   | Spring 238 Karagachsky, Akbulaksky District, absolute elevation 225.0 m, 1.7 to the southeast from the village Rodniki, right side of the balka (gully), upper reach. Flow rate 0.33 l/sec Pre-Ural Foredeep Spring 242 (Rodnikovsky) Saraktashsky District, absolute elevation 150.0 m, in the center of the village Rodniki, Pre-Ural Foredeep | 7.2  1.0       | 41.96                  | 11.7                      | SO₄70 HCO₃27 Cl₁₃ Ca58 Mg27 (Na+K) 15 | CS MgCa Krainsky type                  |
| 9   | Spring 83 Tyulganl District, absolute elevation 300.0 m, to the west of the village Rudnoy Pre-Ural Foredeep | 7.3  1.0       | 31.19                  | 4.49                      | SO₄85.5HCO₃14Cl₁₀.5 Ca90 Mg9 (Na+K) 3 | S Ca Krainsky type                     |
Every significant spring deserves to be equipped and to have a poster-passport with the chemical composition data and the purpose of use.

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