Hydrogeological aspects of the hydrocarbon deposit formation within the northern framing of the Caspian Lowland

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Abstract. The formation of oil and gas deposits in the near-port zones of the Caspian Basin is associated with the generation of hydrocarbons in deep-submerged zones and its subsequent migration to the near-port zones. The migration of oil and gas occurs together with reservoir waters. Under these conditions, the identified gas-hydrochemical anomalies in the instrument zones of the depression are important in determining the routes of hydrocarbon migration and oil and gas accumulation zones. The article analyzes the hydrogeological situation in the subsalt Paleozoic sediments in the junction zone of the Volga-Ural anteclise and the Caspian basin, describes the salt composition of reservoir waters, and the composition of water-dissolved gases. The waters of anomalous composition are identified, which indicate the predominant migration of reservoir waters towards the Volga-Ural anteclise. In the Devonian sediments of the region, anomalies are distinguished by the appearance of reservoir waters of a reduced degree of metamorphization, or their reduced mineralization (desalinated water). The identified anomalies allow us to identify zones favorable for the migration of reservoir waters and hydrocarbons, zones of oil and gas accumulation. These studies can be used to interpret the results of geological exploration for oil and gas in the port zones of the Caspian Basin.

1. Introduction

Administratively, the district in question is located within the Orenburg Region. A large volume of hydrogeological studies of subsalt Lower Permian, Carboniferous and Devonian sediments was carried out in the Orenburg region. A systematic study of the ion-salt composition of reservoir waters, the composition of water-dissolved gases, and water-dissolved organic matter was carried out. According to these indicators, the hydrogeological conditions of the formation and destruction of oil and gas deposits were studied, and gas-hydrochemical criteria for the oil and gas content of local structures were developed. For the Orenburg region, this is the work of V. I. Malinovskaya [1], which provides a breakdown of the section into hydrogeological complexes, their hydrochemical characteristics are given. In the work of Sevostyanov O. M. [2], ideas about the formation of reservoir waters of the Devonian sediments of the Pribortovye region of the Caspian basin are presented, Kuznetsov V. I. [3] explains the nature of hydrochemical anomalies in this region. The works of V. N. Korzenstein [4] and other researchers are devoted to the study of the hydrogeological conditions of the Orenburg oil and gas condensate field. A lot of factual material has been accumulated. The study and generalization of this material in the light of modern concepts of the formation of oil and gas deposits (Tyurin A.M. [5]) allows us to assess the hydrogeological conditions for the formation of oil and gas deposits in the north-eastern frame of the Caspian Basin.
2. Materials and methods
Deposit waters of the pre-salt sediments of the south-east of Volga-Ural anteclise are of the calcium-chloride type with the mineralization of mainly 250 – 260 g/l. The degree of metamorphization of the deposit waters of the Low Permian and Carboniferous sediments (ratio r(Na+K)/rCl) decreases with the increase in the age of sediments and makes up 0.86 – 0.62. In the Devonian sediments, the degree of metamorphization is 0.57 - 0.42. Typical representatives of such waters are the deposit waters of Kolganskaya, Olkhovskaya, Zaykinskaya, Miroshkinskaya, Garshinskaya, Davydovskaya areas (Table 1).

Within the Volga-Ural anteclise, we currently see two types of water exchange: fading elysional and infiltrational [1]. By the definition by E.A. Bars, such water exchange should be called reinfiltrational.

Table 1. Results of the analysis of representative samples of deposit waters.

| No. of hole | Perforation interval | Age of rock | Mineralization (g/l) | Bromine (mg/l) | Na/Cl |
|------------|----------------------|-------------|----------------------|----------------|-------|
| 8 Kolganskaya | 3534-3541 | D2 | 264.0 | 1971 | 0.48 |
| 401 Olkhovskaya | 3367-3374 | D3 | 263.6 | 1295 | 0.59 |
| 561 Zaykinskaya | 4458-4600 | D2af | 204.5 | 1148 | 0.57 |
| 562 Zaykinskaya | 4449-4460 | D2yr | 243.0 | 1881 | 0.45 |
| 565 Zaykinskaya | 4165-4192 | D3p | 241.0 | 1598 | 0.58 |
| 571 Zaykinskaya | 4540-4551 | D2af | 207.4 | 1069 | 0.52 |
| 556 Miroshkinskaya | 4568-4673 | D2 | 213.8 | 1609 | 0.43 |
| 2 Davydovskaya | 4643-4650 | D2 | 256.0 | 1651 | 0.46 |
| 287 Garshinskaya | 4387-4391 | D2 | 246.6 | 1433 | 0.42 |
| 85 Kopanskaya | 3686-3708 | D2 | 110.0 | 213 | 0.77 |
| 1 Shuvalovskaya | 3764-3772 | D2 | 258.9 | 697.0 | 0.78 |
| 101 Dolinnaya | 5196-5220 | D2 | 226.8 | 319.0 | 0.97 |
| 113 Koshinskaya | 4936-4990 | D1 | 141.9 | 344 | 0.52 |
| 20 Peschanaya | 4195-4222 | C2m-C1sr | 229.2 | 685.5 | 0.88 |
| 3 Nagumanovskaya | 4948-5000 | C | 210.5 | - | 0.78 |
| 1 Nagumanovskaya | 5566-5631 | D1fm | 233.9 | 298.6 | 0.85 |
| 501 Vershinovskaya | 6420-6432 | D1fr-fm | 247.5 | 211.8 | 0.89 |
| 2 Kainsayskaya | 6427-6477 | D2ef | 187.6 | - | 0.67 |

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3. Results and Discussion
Within the Volga-Ural anteclise, we currently see two types of water exchange: fading elysional and infiltrational. By the definition by E.A. Bars, such water exchange should be called reinfiltrational.

In the adjacent areas of the Caspian Lowland, the mineralization of the deposit waters of Devonian sediments does not exceed 200 g/l [6], and, in some areas, it reduces to 100 g/l. A similar pattern is observed in the above-lying salt deposits. The mineralization of deposit water here increases to 290 g/l, at the same time, in some regions with an increase in the depths of occurrence, we see its decline to 60 – 70 g/l, there is a hydrochemical inversion of the section.

Distinctive features of the pre-salt deposits of the Caspian Lowland compared to the south-eastern slope of the Volga-Ural anteclise is:
- lack of deposit water with a high degree of metamorphization (Na/Cl < 0.6), which are a feature of the Devonian sediments of the Volga-Ural anteclise;
- inversion of the hydrochemical section;
- the widespread development of desalination processes of deposit waters due to the emergence of regenerated, condensategenous, organogenic waters.

In the near-edge zones of the Caspian Lowland compared to the south-eastern slope of the Volga-
Ural antecline, we see a significant change in the degree of mineralization and the composition of deposit waters. Within the Dolinnaya, Peschanaya, East Peschanaya, Nagumanovskaya, and Kainsayskaya areas (Figure 1), the degree of metamorphization of Na/Cl is 0.66 – 0.89, the bromine content (298.6 – 685.5 mg/l) significantly reduces. To the south, there is also a decrease in the mineralization of deposit waters in some holes: in hole 101 of the Dolinnaya area – to 226.7, in hole 2 of the Kainsayskaya area – to 187.6, in hole 113 of the Kosinskaya area – to 141.9, in hole 85 of the Kopanskaya area – to 110 g/l. In the Karachaganak field, the mineralization of deposit water (underlying waters) reduces to 101.7 – 169.0 g/l. According to A.S. Zinger [7] and N.V. Klychev [8], desalinated waters are found all over the perimeter of the Caspian Lowland. Their formation, in A.S. Zinger’s opinion, is associated with the emergence of “regenerated waters” that appear due to the rearrangement of the structure of clay minerals in conditions of high temperatures and pressure.

These anomalies allow marking out the zones favorable for the migration of deposit waters and hydrocarbons and the zones of oil and gas storage.

Dissolved gases are an effective indicator of the conditions for the formation and preservation of oil and gas deposits. On the south-eastern slope of the Volga-Ural antecline, there is a clear dependence of the gas saturation and the composition of dissolved gases on the distance from the oil fields. The gas saturation within the scattering halos varies from 600 to 240 cm³/l.

The deposit waters of the Orenburg field are saturated with gas at most, reaching 1000 - 2000 cm³/l in the gas factor near the field, the composition of gases is predominantly hydrocarbon.

30 km to the northwest from the Orenburg field, on the Zemlyansky field, the background value of the gas saturation of deposit waters of Carboniferous beds is 300 cm³/l. In the sediments of the upper Devon of the Shuvalov field (15 km to the north from the Orenburg field), the gas saturation is 334 cm³/l. It is difficult to ideate the size of the scattering halos but it is obvious – to the north from the Orenburg field, there is observed a decrease in the gas saturation of deposit waters, which indicates a gas-chemical situation with violated phase balance between beds and deposit waters, which usually characterizes the destruction of hydrocarbons. To the south from the Orenburg field, deposit waters are saturated with gas at most, the gas saturation of deposit waters exceeds 1000 cm³/l, this is the situation with phase equilibrium between beds and deposit waters – such situation usually characterizes the formation of hydrocarbon deposits.

Within the Caspian Lowland, four fields of dissolved gases are marked out: the hydrocarbon field, the nitrogen one, the hydrogen sulfide-containing one, and the carbon dioxide one (classification by Ilchenko V.P.). In the northern part of the Lowland, the most common fields are those containing hydrogen sulfide and hydrocarbon gases. Hydrogen sulfide gases account for 20 to 55%, carbon dioxide-15 to 84%, and methane - to 54%.

The gas content of water underlying the oil fields is 5 to 15 m³/m³. The field of hydrocarbon gases is the most extensive in the territory of the Caspian Lowland. Hydrocarbons make up to 70 – 95%, the amount of heavy hydrocarbons – 5 – 10%, the nitrogen content does not exceed 5%, carbon dioxide – 3%, hydrogen sulfide is absent. Background values of the gas content do not exceed 1.5 - 2.0 m³/m³.

To the south from the Orenburg field, deposit waters are saturated with gas at most. In hole 85 Kopanskaya, the gas saturation of deposit water is 1704 cm³/l, the content of hydrocarbon components – 89% [6]. At the Berdyan field (hole78, deposits of lower Permian) the gas saturation of deposit waters is 890 cm³/l, the composition of the gas is hydrocarbon.

The values of the gas saturation of deposit water do not reduce lower than 1020 cm³/l to the west from the Orenburg embankment in the Koshinskaya area within the Zaykinskaya-Rostashinskaya group of deposits.

The concentrations and the composition of dissolved gases reflect the geochemical situation of individual regions. Within the Sol-Iletsky vault, there are beds of gas, gas and oil, and light oils. To the north from the Orenburg field, oil beds lie within the East Orenburg Structural Protrusion.

The most common hypotheses of oil and gas deposit formation in the near-edge zones of the Caspian Lowland are associated with the migration of hydrocarbons from the submerged areas of the Caspian
Sea region [8]. All conditions for the implementation of the phases of oil and gas formation, the generation of hydrocarbons from the scattered organic matter have been created here.

Confirmation of the intensity of these processes is the discovery of giant deposits: Astrakhan, Karachaganak, Tengiz, and others. The formation of the Orenburg oil and gas condensate field, oil and gas fields in the southern Volga-Ural oil and gas province is also connected with these processes.

It is assumed that the formation of the Orenburg field took two stages. Initially, the field was filled with oil, after the onset of the main phase of gas formation in the petroleogenetic rocks, oil was replaced by gas and the bulk of it migrated in the north direction.

Migration processes were controlled by the thickness of the kungur-age salts, which explains the absence of oil and gas deposits in the post-salt thickness in the areas of its distribution and their presence in areas of pinch-out of salt thickness.

The main provisions of the formation of oil and gas deposits in the near-edge zones of the Caspian syncline are confirmed from the point of view of hydrogeology.

According to A.S. Zinger, the pre-salt deposits of the Caspian syncline are characterized by the elysion nature of deposit waters. In the course of geological time, their movement came from the most submerged parts of the syncline to the near-edge zones. These processes determine the composition of deposit waters of the near-edge zones of the syncline. There is an introduction of deposit waters from the side of the syncline into the platform part, which is confirmed by the anomalous composition of the waters in holes 1 Shuvalovskaya, 113 Koshinskaya, 101 Dolinnaya, 85 Kopanskaya. In these holes, we see a low degree of metamorphization of deposit waters, which is not typical of Devonian sediments, and their low mineralization (desalinated water).

The processes of the oil and gas deposit formation are also reflected in the composition of dissolved gases. Almost to the south from the latitude of the Orenburg OGCF, in the development zone of gas condensate and gas-oil deposits, the gas saturation of deposit water is 1.0 – 2.0 l/l, methane is predominant in the composition of gases. To the north, in the area of the distribution of oil fields, the background values of the gas saturation reduce to 0.2 l/l, the composition of the gas significantly varies from hydrocarbon to nitrogen depending on the distance to the oil deposits.

4. Conclusion

There is an observed introduction of deposit waters from the Caspian syncline to the areas of Volga-Ural anteclise, which is reflected in the appearance of deposit waters of a reduced metamorphization degree in Devonian sediments, or their reduced mineralization (desalinated waters).

Modern gas-hydrochemical conditions of the Orenburg OGCF are complicated. In the southern part of the field, there are conditions favorable for the formation of oil and gas deposits while in the northern part – conditions favorable for their destruction.

Discovered gas-hydrochemical anomalies allow one to mark out the zones favourable for the migration of deposit water and hydrocarbons, the zones of oil and gas storage.

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