Geological and hydrogeological features of the lower Permian carbonate locally bituminous complex of the Tatarstan

R L Ibrahimov¹, E A Korolev¹, A A Eskin¹, I S Nuriyev¹, E R Barieva²

¹Institute of geology and petroleum technologies, Kazan Federal University, Kazan, Russia
²Kazan State Power-engineering University, Kazan, Russia

E-mail: ibragimovrl@yandex.ru

Abstract. The Lower Permian bituminous complex is characterized by complex hydrogeological conditions. The predominant type of reservoir is mixed porous-fractured-cavernous. Water layers lateral prevalence is directly related to the degree of fracturing and cavernous of dolomites and limestones. Regional hydrogeological studies have shown that at the dividing ranges the Lower Perm sedimentary stratum is anhydrous, and in the river valleys it is water-rich. The center parts of such areas are erosive incisions of river valleys. From the periphery to karst regions center, a consistent increase in well flow rates and a decrease in piezometric groundwater levels from the slopes of dividing ranges to the river valleys are observed. In the domed sections of the South Tatar Arch in the Asselian-Sakmarian sediments, calcium-sulphate waters with a total salinity of 1.5 to 3.5-4.0 g/dm³ are prevalent. Sodium sulfate waters appear within the western slope of the arch. Within the eastern part of the Melekess Depression, the Asselian-Sakmarian stage groundwater deposits are already completely sulphate-sodium. The predominance of sodium components over calcium in groundwater is observed during total salinity of 4.5-5.5 g/dm³. In the areas of the Melekess Depression, where the Lower Permian sediments are drowning, groundwater acquires to sodium-chloride composition.

1. Introduction

The Tatarstan Republic is one of the Russia industrial regions, where large reserves of shallow lying natural bitumen are concentrated. To date, 450 heavy hydrocarbon deposits with proven reserves of 1.4 billion tons have been identified here [1]. Until recently, bitumen was not considered as hydrocarbons due to the lack of cost-effective technologies for their extraction. However, in recent years the situation has changed. The emergence of new approaches and technologies [2, 3, 4, 5, 6, 7, 8, 9, 10] the development of such resources has again sparked interest in bitumen deposits. Experimental work at the Ashchalchinskoye and Mordovo-Karmalinskoye fields showed the possibility of heavy hydrocarbons industrial extraction using SAGD method [11, 12]. The problems identified during the development of these bitumen deposits [13, 14] stimulated oil companies to take a more thorough approach to studying potentially promising deposits of high-viscosity hydrocarbons. As a result of such geological exploration, the geological and hydrogeological structure features of the Lower Permian carbonate bituminous complex in the Tatarstan were established.
The conducted geological and geophysical studies of the areas of bituminous deposits occurrence made it possible to distinguish four bituminous complexes in the Permian deposits. From bottom to top among the section, successively occur: the Lower Permian carbonate locally bituminous complex; the Ufimian terrigenous zonal bituminous complex; the Lower Kazanian carbonate terrigenous zonal bituminous complex; the Upper Kazanian carbonate terrigenous zonal bituminous complex. In tectonic terms fields are located on eastern side of the Melekess Depression and conjugated western side of the South Tatar Arch. According to bedding conditions they are layer-uplifted and massive bitumen deposits, which controlled by small anticlinal uplifts. The thickness of productive formations varies from 0.5 to 34 m. The depth of occurrence from the surface is 70-400 m. The main layers are associated with carbonate deposits of the Asselian, Sakmarian, Artinskian and Kungurian stages of the Lower Permian system. The reservoir rocks are fractured, porous and cavernous dolomites and limestones. The predominant type of reservoir is mixed porous-fractured-cavernous.

1.1. Asselian stage

Asselian stage is composed by gypsum dolomites with layers of anhydrite, gypsum and limestone. Two types of sections are distinguished: carbonate and carbonate-sulfate. Carbonate sections are composed of dolomites with limestone interlayers, spatially confined to upstanding areas. Carbonate-sulfate sections are composed of dolomites with anhydrites layers, as a rule, confined to large negative structures. Small accumulations of bitumen are found both on the western slope of the South Tatar Arch and on the eastern side of the Melekess Depression. cavernous and fractured dolomites are reservoir rock of stage upper part. According to drilling data, tuff-like dolomites and perforated relict-fusulinid dolomites lie here. The effective porosity of bituminous rocks is on average 16%, cross bedding permeability is 0.22 μm². Bitumen is predominantly layer-uplifted and rarely massive deposit, controlled by local uplifts of small sizes. Due to bitumen deposits small size and low mobility of hydrocarbons located in them, they do not have industrial and commercial significance. Small oil influxes were obtained only at the Nikolashkinskoye bitumen deposit.

1.2. Sakmarian stage

Sakmarian stage is composed of calcareous dense dolomites with interlayers of clastic and oolitic dolomites, which, conformable bed on the Asselian stage underlying rocks. The Sakmarian stage roof is eroded, composed of breccia dolomites, which the highest reservoirs are connected. The thickness of the Sakmarian stage deposits increases from west to east from the Melekess Depression to the South Tatar Arch from 50 m to 140 m. The reservoir rocks are represented by fractured clastic and cavernous oolitic dolomites with porosity from 0.8 to 30% and permeability from thousandths to 1.4 μm². The reservoirs type are sheet and massive, controlled by local brachy-anticline structures, often hydrodynamically associated with reservoirs of the Artinskian stage overlying dolomites, but only if absence of impermeable anhydrite layer between them. The bitumen concentration in this layer is much higher than in the Asselian stage rocks. The average bitumen-saturated thickness of deposits varies from 1.2 to 34.0 m.

1.3. Artinskian stage

Artinskian stage is represented by anhydrites, gypsums, dolomites, to a lesser extent limestones, marls and clays, which transgressively lie on eroded surface of the Sakmarian stage rocks. In all thickness of section interlayers of breccia like and fractured dolomites and limestones are noted. In these rocks distribution there is certain zonality. In the western direction, the thickness of dolomite rocks decreases, and anhydrites with interlayers of limestone predominate. The reservoir rocks are mainly represented by fractured, breccia like dolomites, with porosity of which varies from 11 to 20%, and permeability -
from tenths to 0.42 μm. Thicknesses of bitumen-saturated rocks vary from 0.5 to 6.0 m. Deposits are layer-uplifted and massive, controlled by low-amplitude uplifts.

1.4. Kungurian stage

Kungurian stage is composed of lagoon-marine facies of a shallow, become salty basin. In the sole, on the eroded surface of Sakmarian and Artinskian stage deposits, there are lie very fine-grained, slightly clayed and gypsified dolomites, sometimes with oolitic structure. Above them lie dense light gray anhydrites interstratified with pelitomorphic light gray dolomite layers. The upper part of stage is a halogen stratum composed mainly of anhydrites, to a lesser extent - gypsum and dolomites. In the western direction, towards the Melekess Depression, the thickness of sulfate deposits is reduced, clay and sandy layers appear. The thickness of the Kungurian stage increases from west to east, reaching 140 m. The reservoir rocks are developed limited mainly within the South Tatar Arch. Bitumen occurrences associated with pore-cavernous dolomites, which are overlapped by gypsum-anhydrite formations from above. Deposits are layer-uplifted and lithological shielded type.

2. Hydrogeological characteristics of different age’s bitumen reservoirs

Within the Lower Permian sediments, water-saturated rocks are not bituminous. As a rule, they are associated with depressions between the anticlinal structures and wings of uplifts. Water inflow occurrences were recorded by flushing fluid intensive absorption and flowing of wells. Some wells drilled in the river valleys gave spouting up to 5-15 thousand m$^3$/day.

In the Asselian stage rocks, the aquifer is characterized by lateral discontinuity and local distribution. Groundwater is coinciding with rotted, fractured, cavernous dolomites and limestones. The highest piezometric levels are associated with river valleys watersheds (abs. Marks +120 m). The water production volume of wells, which uncovered aquifers, vary from 0.5 to 17.5 l/sec. Chemical composition waters are sodium-sulfate with a total salinity of 3.7-5.3 g/dm$^3$, with a small content of hydrogen sulfide.

In the Sakmarian Stage rocks, the most widespread area aquifer is the brecciated fractured dolomites, which lie in erosed roof of this stage. Gypsum-anhydrite rocks, lying below the stage, perform the function as regional waterproof rocks. Underground waters by bedding conditions and chemical composition are close to the Asselian aquifer waters. Piezometric levels on the watersheds are higher than the Asselian aquifers (+126 m), but in the river valleys it is lower (up to +103 m). The water production rates of self-flowing wells vary from 0.5 to 10.0 l/sec. According chemical composition the waters are sulfate-calcium-sodium, with a total salinity of 3.2-4.9 g/dm$^3$. The hydrogen sulfide content ranges from traces to 5-10 mg/dm$^3$.

Regional hydrogeological studies have shown that in most cases the Lower Permian sedimentary stratum is waterless on watersheds and very water-rich at river valleys [15]. This is due to the presence here a thick mass sequence (up to 160 m) of well-permeable, fractured-karst carbonate rocks that form karst
areas. The karst areas centers are erosive incisions of downcutting of river valleys. The karst regions wells flow rates from periphery to center vary from 20-40 m³/day to 1-2 thousand m³/day. Piezometric levels also decrease from watershed slopes to river valleys, from 120-140 m to 50-60 m. River valleys play the role of hydrogeological windows through which the underlying aquifers are fed or, conversely, discharge of deep pressure water.

The chemical composition of waters also shows certain zonality. In the South Tatar Arch domed areas in the Asselian-Sakmarian stages sediments, calcium-sulfate waters with a total salinity of 1.5 to 3.5-4.0 g/dm³ are prevalent. Sodium-sulfate waters appear within the western slope of the Arch. However, the main area of their distribution is confined to the eastern side of the Melekess Depression. The predominance of sodium over calcium in groundwater is usually observed with a mineralization of 4.5-5.5 g/dm³. Water of this composition is usually found at depths of 300-400 m. Their appearance at a depth of only 100-200 m and above is associated with discharge of underground waters of deeper horizons. In areas of significant subsidence of the Lower Permian deposits, groundwater acquires a sodium-chloride composition. Within the study area, this is the Melekess Depression, the eastern and southeastern slopes of the South Tatar Arch (valley of the Ik River).

In a some wells drilled on the eastern side of the Melekess Depression, from roofing of the Sakmarian stage sediments were obtained sodium-chloride waters with a total salinity of 17-31 g/dm³ (Nurlat city) to 77.4 g/dm³ (Gorskoye field). Water of similar chemical composition with a total salinity of 22.8 to 82 g/dm³ was obtained by testing wells drilled in the Ik River valley (Muratovskaya Square). Waters of mixed sulfate-sodium-chloride compositions with a total salinity of up to 6-11 g/dm³ were obtained from wells drilled in the Kzyl-Yarovo village area. Sodium-chloride waters were encounter by separate wells in lower part of the Sheshma River, near the Omary village. The waters total salinity varies between 13.9-126 g/dm³.

Most researchers attribute the local manifestations of chloride waters to groundwater discharge from deeper horizons. These sites gravitate towards tectonically fractured zones. It should be noted that groundwater of complex under consideration is characterized by a high content of organic matter dissolved in water. This is explained by the Lower Permian rocks regional bitumenosity, through which groundwater with high dissolving ability is migrated.

3. Conclusions

Thus, characterizing overall geological and hydrogeological conditions of studied complex, we can draw the following conclusions:

1. Lower Permian bitumen-saturated and water-saturated reservoirs are composed mainly of fractured, cavernous and karst dolomites and limestones. The predominant type of reservoir is mixed porous-fractured-cavernous.

2. The prevalence of aquifers is directly related to the degree of their destruction, fractured and karst.

3. The presence of common auriferous complexes of Asselian-Kungurian and Asselian-Sakmarian stages is explained by associated with zones of karst formation on the one side. On the other side, when can distinguished separate water-saturated layers, by presence in section of water-resistant rocks composed of fine-grained carbonate rocks with gypsum and anhydrite intercalations, sometimes completely represented by sulfate rocks.

4. In chemical composition of the waters there is certain zonality. In domed and watershed areas of the South Tatar Arch and its southeastern slopes in Asselian-Sakmarian stages sediments, calcium-sulfate
waters are prevalent. Sodium-sulfate waters are less common. The main area of sodium-sulfate waters distribution is the eastern side of the Melekess Depression. In areas of significant subsidence of the Lower Permian deposits, groundwater acquires a sodium-chloride composition.

Acknowledgments

This study was performed in the context of the Russian Government Program of Competitive Growth of Kazan Federal University.

References

[1] Polovnyak V, Habibrahmanov A 2012 Nauchno-tekhnicaskiy vestnik Povolzh'ya 5 12-15
[2] Aleksandrov E, Kuznetsov N, Kozlov S, Serkin Yu 2016 Georesources 18(3.1) 154-159
[3] Altunina L, Kuvshinov V 2008 Oil & Gas Science and Technology 63(1) 37-48
[4] Butler R, Stephens D 1981 J. Can. Pet. Tech. 20(2) 90-96
[5] Kayukova G, Feoktistov D, Vakhin A, Kosachev I 2017 Neft. Khoz. - Oil Industry 4 100-102
[6] Kayukova G, Foss L, Feoktistov D, Romanov G 2017 Petroleum Chemistry 57(8) 657-665
[7] Novikova S, Nurgaliyev D, Sudakov V, Delev A 2017 Georesources 19(4.1) 331-340
[8] Reis J 1992 J. Can. Pet. Tech. 31(10) 14-20
[9] Wenlong Q, Zengli X 2013 Advanced Materials Research 608 1428-1432
[10] Khasanov R, Mullakaev A, Dusmanov E 2017 Uchenye Zapiski Kazanskogo Universiteta. Seriya Estestvennye Nauki 159(1) 164-173
[11] Ibatullin R, Amerkhanov M, Ibragimov N 2007 Neft. Khoz. - Oil Industry 7 40-43
[12] Khisamov R, Morozov P, Khairullin M 2015 Nefti. Khoz. - Oil Industry 2 62-64
[13] Korolev E, Usmanov S, Nikolaev D, Gabdelvaliyeva R 2017 IOP Conf. Ser.: Earth and Environmental Science 2017 155(1) 012019
[14] Korolev E, Khramchenkov M, Khramchenkov E 2018 Neft. Khoz. - Oil Industry 1 55-57
[15] Anisimov B 1984 Prirodnyye bitumy – dopoln. ist. uglevod. syr'ya 136-142