

The structure of the pore space of Tournaisian reservoir rocks in the southeast of Tatarstan Republic

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Abstract. The article shows the main types of structures of the porosity of the Tournaisian reservoirs from the southeast of Tatarstan. The main type of pore space is intergrain porosity, while the fractures have a subordinate significance. They are analyzed in detail main factors of the origin of the pore space of the Tournaisian reservoir rock. There are include depositional, diagenetic, structural and tectonically factors. The depositional factor is the selectivity of rock types as reservoirs, only two lithological types of limestone have industrially significant reservoir properties and represented by peloidal and crinoid-peloidal packstones. The diagenetic factor realizes via secondary leaching of carbonate rocks during burial diagenesis of rocks. Leaching processes provide the main increase in rock porosity. On the one hand, the structural and tectonic factor provides the possibility of oil charge in the structure, on the other hand, it shows the heterogeneity of the distribution of porosity depending on the position of the reservoir rocks on the structure. The highest porosity values are characteristic for the crest part, lower for the flanks and minimal for the deflections of the oil-bearing structures.

1 Introduction

Tournaisian carbonate rocks are located in the south-east of the Tatarstan, east part of the Russian Platform. They are regionally oil-bearing and are considered important objects for today's, and especially future oil production in the region [1]. Tournaisian reservoir rocks have particular importance, since they are developed almost everywhere and in most of the east of the Russian Platform and they have industrially significant oil-bearing capacity (Figure 1). The Tournaisian deposits are represented by limestones, dolostones are rare in studied sections. As part of the Tournaisian unit there are 4 main horizons: Malevkian, Upiian, Cherepetian and Kizelian. They are well recognizable both from core data and using well-logging data.

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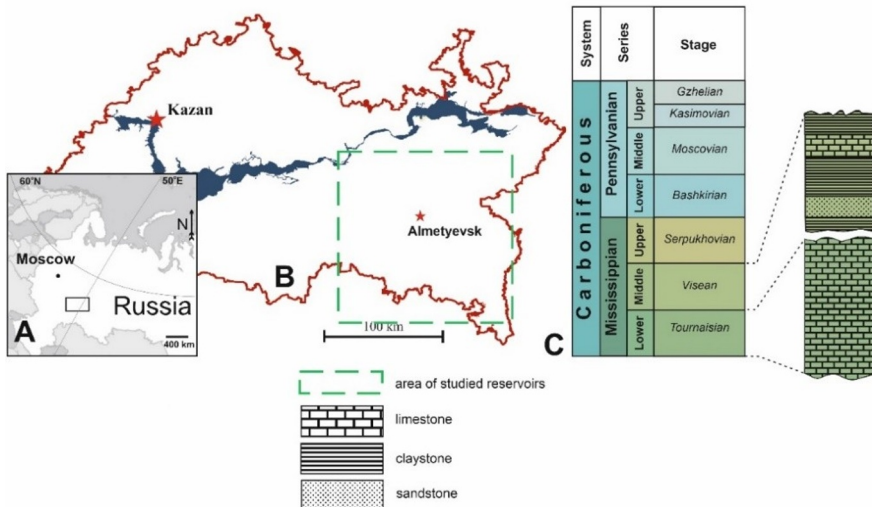


Fig. 1. Regional overview and Carboniferous stratigraphy. (A) European part of Russia, inset shows Volga-Ural basin region. (B) Map of the Tatarstan Republic and location of oil fields discussed in this paper (red dots). (C) Stratigraphy and general lithology of Tournaisian and Viséan stages in the southeast of the Tatarstan Republic.

The relevance of studying of the Tournaisian deposits is dictated by their still insufficient knowledge. One of the most pressing problems is the origin of the effective pore space of rocks. Some researchers associate the formation of porosity with karst processes that occurred during the Viséan continental stage of the territory's. In this time large areas of Tournaisian limestone were brought to the surface and were subjected to surface karst leaching processes [2]. Other scientists believe that the main mechanism for the formation of porosity is the process of secondary deep leaching of carbonate rocks under the influence of aggressive fluids migrating through the rocks [3-4]. Probably, both mechanisms created the pore space of Tournaisian successions, however their contribution may be significantly different. In addition, the question remains about the degree of involvement of fractures in the effective porosity which found in sections not everywhere. Fractures in Tournaisian reservoir have are secondary nature, like most share of pore space, and their origin and time of formation also require explanation.

Here we examine the main factors in the formation of the pore space of the Tournaisian rocks. The applied systematic approach to the study of sediments will allow us to answer several questions: 1) What is the structure of the porosity of the Tournaisian reservoirs? 2) What is the contribution of each identified types of porosity to ensuring the reservoir properties? 3) What is the origin of the main types of pore space in the Tournaisian carbonate rocks in the southeast of Tatarstan and what are the main factors that influenced the possibility of the formation of industrially significant reservoir properties in the rocks?

2 Materials and methods

The objects of study were Tournaisian carbonate rocks from various oil deposits in the south-eastern part of Tatarstan, selected during contract studies commissioned by small and big oil companies in region. Generalization and analysis of the accumulated material was carried out on more than 7000 m of studied core from more than 30 oil fields. In addition, the authors analyzed a significant amount of geophysical material, which made it possible to significantly detail the correlation of sections and increase the reliability of data in areas poorly characterized by core data.

Work with core material included several successive stages. At the first stage, It was done a detailed layer-by-layer description of the core material in a number of regional core storage, including the own core storage of Kazan University, which included:

- Identification of the sequence of sediment bedding.
- Determination of the lithological composition of rocks and the relationship of the identified lithotypes.
- Determination of the structure and texture of rocks.
- Determination of the degree and nature of oil saturation.
- Determination of the porosity structure, etc.

Samples were selected in order to maximally and most fully characterize the intervals identified during the macro-description of the core. After, the samples were transferred for special analytical studies. The main method was an optical microscopy. The description of the thin sections was using an AxioImagerA2 polarizing microscope and a Leica DM 2700P microscope. The analysis of thin sections included determining the mineral composition of rocks, identifying the microtexture and structure of rocks, fossils analysis and determining of facies settings of carbonate sediments.

During the analysis, it was analyzed the position of grains and their quantity, the nature of the relationship between grains and cement, the degree of material sorting, the type and composition of cement, secondary mineral transformations, type and distribution of porosity. Dunham's structural classification was chosen as a classification of carbonate rocks [5]. This classification has long and successfully proven itself for sequence stratigraphic constructions and facies analysis of carbonates and is the most universal among geologists involved in the study of carbonate strata. The structural classification is based on the structural and textural characteristics of limestones. This classification is often called "hydrodynamic", since it reflects the depositional conditions of carbonates depending on the position of sea level, the distance of the coastline and the wave base and storm base.

3 Results

All identified types of Tournaisian limestones were formed in the settings of a normal marine shallow-water basin [6]. Two main lithological types of limestones is observed, in all studied sections. It is packstones and wackestones. At the same time, within each of the lithotypes can be distinguished varieties. Thus, in the studied sections were identified the following limestones: peloidal packstones, crinoid-peloidal packstones, peloid-foram packstones, crinoidal wackestones, crinoid-algal wackestones (Figure 2). Often the listed varieties of limestone form transitional types. Sometimes, it is complicated to assign them to one type or another. In such cases, limestones transitional between packstones and wackestones are defined as packstone-wackestones or wackestone-packstones, depending on the predominance of one or another lithological type.

The formation of Tournaisian oil reservoirs is the result of the combination of several favorable factors: deposition settings, diagenetic alterations, structural and tectonically factors. As a rule, the absence any of the listed factors does not lead to the formation of hydrocarbon reservoirs. It is also true for other sedimentary oil-bearing basins.

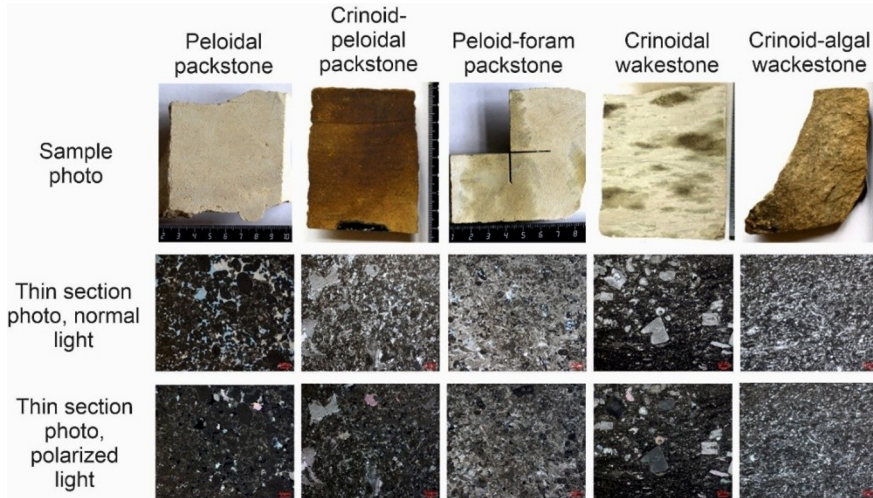


Fig. 2. Main lithological types of the Tournaisian limestones.

The role of the depositional factor is the specific of carbonate sedimentation in different facial zones. Only peloidal and crinoid-peloidal packstones have a reservoir property, among the identified lithotypes (Figure 2). They are distributed mostly in the Kizelian horizon of the Upper Tournaisian unit and Malevkian-Upian horizons of the Lower Tournaisian unit. The porosity of the Kizelian horizon usually varies from 9% to 12%, while porosity of the Malevkian-Upian horizon varies from 10% to 18% (Figure 3). The porosity of both types of limestone is formed by burial leaching processes in them. Other types of limestone identified in the sections are wackestones, widely developed in the Cherepetian horizon and should not be considered as reservoir rocks. The pores in wackestones are usually single, subpapillary in size and not interconnected, and the total porosity of the rocks does not exceed 6-7%.

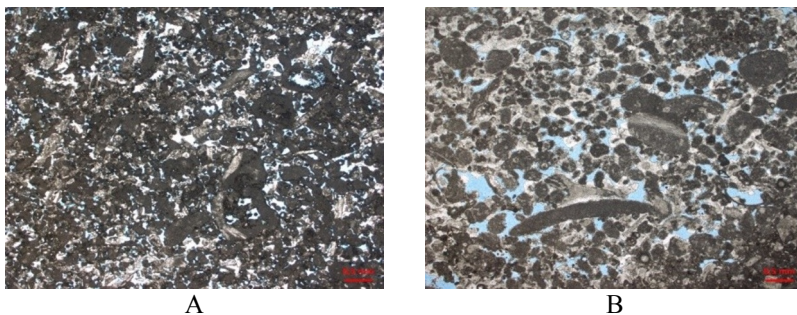


Fig. 3. Photos of thin sections: A – packstone of the Kizelian horizon; B – packstone of the Upian horizon.

Leaching is the most pronounced secondary diagenetic alteration in the Tournaisian reservoirs. First of all, the primary intergrain micritic calcite of packstones has been leached. The possibility of micrite dissolution is due to its chemical composition, which is close to the chemical formula of “pure” calcite. Opposite, grains are presented by organic and mineral components and more resistant for leaching. Other diagenetic processes rather have a negative effect on the reservoir properties of rocks, such as secondary calcite, sulfate and silica cementation, since they usually lead to the filling pore space.

Karst processes in the Tournaisian rocks have very low intensity and lead only to a local increase in reservoir properties and do not cover large volumes of rocks. Analysis of a significant amount of core data showed that karst processes are weakly developed. The authors know of only a few examples of karst type of porosity in the Tournaisian rocks, which are clearly associated with areas of the Visean erosional incisions.

The fracture type of porosity in the Tournaisian rocks is extremely rare. It should be noted that among the fractures there are at least two genetic types: tectonic fractures and leaching fractures (Figure 4).



Tectonic fracture



Leaching fracture

Fig. 4. Types of fractures of the Tournaisian reservoirs.

Tectonic fractures are usually localized in packstones of the Malevkian-Upian and Kizelian horizons. Leaching fractures are rare and they usually have a tortuous shape and are often filled by secondary minerals (usually calcite and anhydrite). In general, fractures do not have any significant effect on the reservoir properties and have a subordinate role in ensuring the reservoir properties of Tournaisian oil deposits. In exceptional cases, tectonic fractures can be quite extensive, but they do not extend beyond the stratigraphical horizons, that is, they develop in the upper part and lower part of reservoir. Fractures of the Malevkian-Upian horizon are located in the aquifer zone, which defines them as a negative phenomenon. It can lead to an additional water flooding effect due to the penetration of bottom waters into the oil reservoir.

Another, most important factor of the formation of oil reservoirs is the structural and tectonic factor. Most part of Tournaisian reservoirs are clearly confined to anticlinal structures of various orders (mainly third and fourth). In the post-Permian time, the territory of the Volga-Ural region had significant structural and tectonic transformations, and the Alpine tectonic cycle played an important role in the formation of the structural plan and the formation of local structural forms [7]. Modern structural plan of the Tournaisian unit is combination of block tectonic movements and sedimentary structures covering Devonian bioherms. This combination played an important role in the distribution of oil reservoirs in

the southeast of Tatarstan. On the one hand, the tectonic factor led to the uplifting of the western, southwestern and central parts of the South-Tatar anticline; on the other hand, the structures of smaller orders superimposed on the general structural plan and formed independent oil-bearing structures.

Porosity is distributed unevenly on structure and has a decreasing trend towards to flanks and troughs of structural uplifts. It seems, that the main migration channel of fluids was through of the crest part of structures. Analysis of a large number of structures shows highest reservoir properties in the crest part of oil-bearing structures. Sometimes such areas are called “lithological windows” [8]. Fluids saturated with CO₂ prepare the pore space by dissolving the calcite cement of limestone, during migration through “lithological windows”. This is confirmed by data from studies of the overlying Bashkirian strata [9], where at least two-time stages of intense corrosion of calcite cement were established.

Some of the dissolved material could be transferred along the section, and some could “flow down” to the flanks of the structures and to oil-water zones. The first is confirmed by large volumes of secondary calcite cement in the overlying the Bobrikian sandstones [10], the second by a larger proportion of secondary calcite cement on the flanks of structures, compared to the crest parts of oil-bearing structures, as well as zones of secondary calcite cementation of oil-water zones [11]. On the other hand, on flanks are significantly lower intensity of the leaching process compared to their crest parts (Table 1). It is confirmed by data from E.A. Kozina [12].

Table 1. Reservoir properties of Tournaisian limestones on different elements of structures in the southeast of Tatarstan [12].

Reservoir properties (average values)	Part of structure		
	Crest	Flank	Deflection
Porosity %	10.2	10	7.1
Permeability $n \cdot 10^{-3} \text{ mkm}^2$	4.3	4.2	0.18

There are also other works indicating differences of the reservoir properties of rocks in the crest and flanks of structures [13]. In particular, S. Morad and co-authors shows contrasting differences in the reservoir properties of rocks in different parts of the structures [14].

Studies of Tournaisian sections from the southeast of the Tatarstan confirm the hypothesis of variability of reservoir properties in different parts of the structures. An example, here is an own model of an oil-bearing structure (Figure 5). The figure shows photo of thin sections and position of rocks on structure.

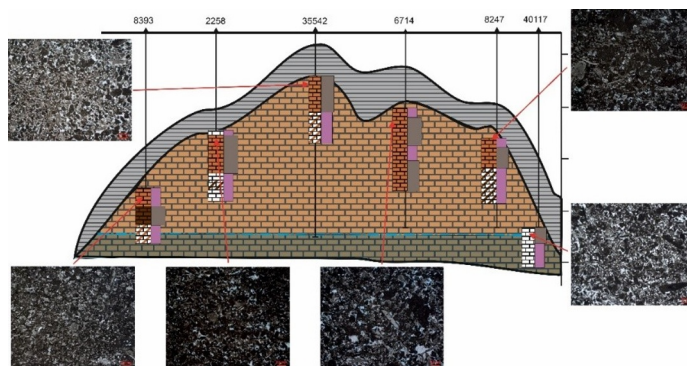


Fig. 5. Model of limestone distribution with thin section photo on different part of oil-bearing structure.

4 Conclusions

- The analysis of various types of porosity showed that the most important type of pore space in the Tournaisian reservoir are intergrain pores. Pores have a relative uniform distribution in the volume of the rock and form the matrix type of porosity. Fracture type of pore space has a low importance in ensuring the reservoir properties.
- The main mechanism for the formation of the pore space of rocks is the process of secondary leaching of limestones under conditions of burial diagenesis of rocks. Leaching increase porosity in initially rather dense limestones. At the same time, only certain types of limestone are leaching. It is peloidal and crinoid-peloidal packstone.
- On the one hand, the structural and tectonic factor, provides the possibility of oil-charging in structural traps, on the other hand, it predetermines the uneven distribution of reservoir properties in different parts of oil-bearing structures. The highest porosity values are typical for the crest parts of the structures, lower for the flanks and minimal for the deflections.

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