DEFINITION OF MECHANICAL FACIES FOR DOMANIK SHALE FORMATION (UNCONVENTIONAL OIL SOURCE)

Assoc. Prof. Dr. Ilmir Nugmanov[1]

Assist. of Prof. Alexander Starovoytov[1]

Senior Lecturer Dr. Ekaterina Nugmanova[1]

Assist. of Prof. Alexey Delev[1]

[1] Kazan Federal University, **Russia**

ABSTRACT

The Volga–Ural petroliferous basin is the oldest oil producing region of Russia. Therefore, most of the major oil and gas fields of traditional types here are already at the final stage of production. This provides for the increasing interest to develop unconventional resources of hydrocarbons associated with potential resources of the Upper Devonian–Lower Carboniferous (Tournaisian) Domanik-type sedimentary formations. This study focused on the geomechanical and petrophysical evaluation of the Domanik Formation and Domanikoids (younger rocks overlying the Domanik Formation) rocks. These are low-permeable cherty limestone or organic-rich mudstone rocks. We have investigated core samples from 6 wells from several oil-bearing areas. Laboratory studies of intact rock core specimens were carried out to determine rock failure parameters, cohesion and angle of internal friction under representative reservoir loading/stress conditions; and to estimate static and dynamic elastic modulus (Young's modulus and Poisson's ratio) under representative reservoir loading/stress conditions. Samples porosity, permeability and volumetric bitumen content were obtained by routine core analysis (RCA) technics. End faces of the specimens were used for mineralogical thin section optical analysis, X-ray diffractometry and X-ray fluorescence spectroscopy. Inferred from the results, we have distinguished three mechanical facies of the Domanik Formation and Domanikoids rocks substantially different in terms of chemical, mineralogical composition and petrophysical properties. Outcomes may assist to optimize the development of multistage hydraulic-fracturing technology in horizontal wells.

Keywords: geomechanics, unconventional oil, carbonates, lithological facies, laboratory core analysis.

INTRODUCTION

The ratio of hard-to-recover (HTR) reserves, which include shale hydrocarbons, is significant in Russia and Tatarstan and is estimated at 65% of the total volume of hydrocarbon reserves [1]. In the context of growing deterioration of the structure of reserves, the search for the new sources of hydrocarbons associated with domanic carbonate-siliceous deposits is very relevant in Tatarstan. The development of such deposits is only possible by underground methods, which requires increased attention to their lithological-petrophysical-geomechanical study since the production of hydrocarbons from them cannot be based on conventional technologies. The most promising methods of development of such reserves include drilling horizontal wells and multistage hydraulic fracturing.

OBJECT OF STUDY

The object of the study was the domanic deposits represented by carbonate-siliceous and carbonate rocks. The former are substantially enriched with organic matter and are considered as potential sources of hydrocarbons. The location of the so-called shale formation is the Kama-Kinel Throughs System (KKTS), stretching to the North-West and passing through the territory of Tatarstan (Fig. 1.1).

Domanic sediments accumulated in a vast epicontinental basin with a weakly dissected relief in the domanic time itself with the transition to conditions of less dissected bottom relief in the subsequent era of Late Devonian and Early Carboniferous. Relatively deep-water, stable on the vast territory depositional environment typical for the domanic time, continue to exist in a later epochs in the depression zones of the emerging Kama-Kinel system of uncompensated depressions of the East of the Russian platform [2]. The formation of domanic deposits is dated to the stages of tectonic activity, endogenous fluidization contributing to the development of basins of non-compensated type. It is assumed that the strata formation depths were up to 300-400 m.

The high silica content in the strata was one of the important factors of accumulation of high organic matter contents in the domanikites. Volcanism in the Devonian period probably influenced the formation of domanic facies.

This effect was expressed in a significant input into the sedimentation area, both of hydrothermal silica and a complex of trace elements, possibly necessary for the intensification of development of planktonic and benthic flora and fauna, providing the input of large volumes of organic matter into the sediments. The influence of volcanism and geodynamic processes is confirmed by the results of microelement analysis of rocks.

The main purpose of the work was to assess the domanic rocks as alternative sources of hydrocarbons in the territory of the Republic of Tatarstan [3].

In order to achieve the goal, a rational set of research methods, including lithological-petrographic and geomechanical methods, was chosen. The study of core material included its preliminary macroscopic description, representative sampling, as well as their processing associated with sample preparation and analytical laboratory work itself.

This paper presents core analysis from the boreholes of Mamadysh, Upper-Garey, Chishminsk, Bondyuzhsk areas located within the Kama-Kinel Throughs System (KKTS), as well as Bavly's area in the South-East of the South-Tatar arch (STA) of the Republic of Tatarstan. Domanic-type rocks are represented within the territory of KKTS by the deposits of Rechitsa and Semiluk horizons of Upper Devonian Fransian stage. Within the STA they are presented by the deposits of Dankova-Lebedyansky horizon of Upper Devonian Fransian stage.

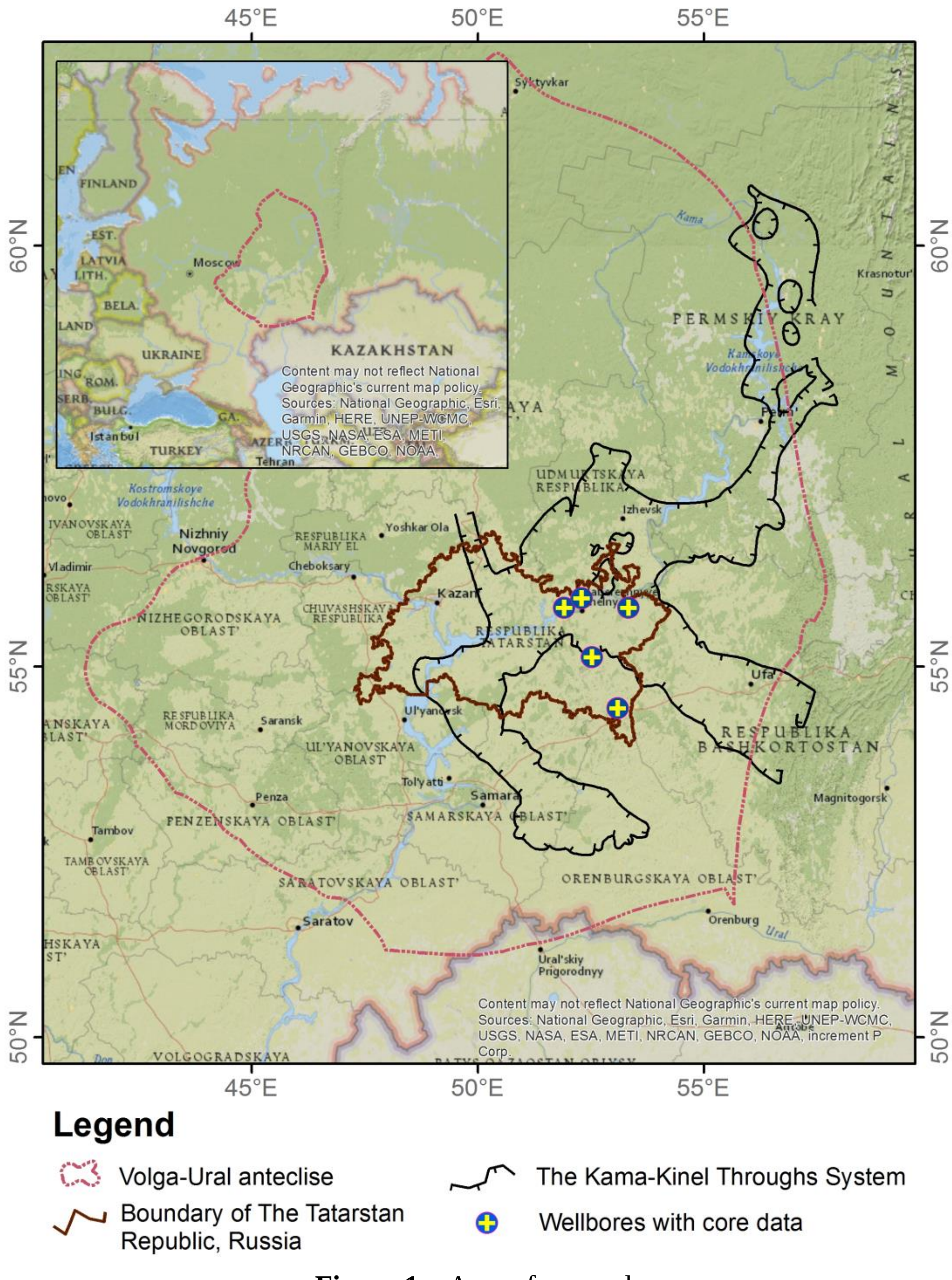

Figure 1 – Area of research

RESEARCH TECHNIQUES

Determination of lithofacies characteristics of samples is based on the results of macroscopic examination of core, optical mineralogical studies of thin sections, X-ray diffractometry [4] and X-ray fluorescence spectroscopy (chemical composition) analysis in powders.

The laboratory geomechanical tests and petrophysical studies of core samples were accomplished on the apparatus of PIC-UZ-UP (JSC "Geologica", Novosibirsk, Russia) and GTAN.441179.050 ("SPE "GEOTEK", Penza, Russia). Tests to determine the dynamic and static Young's modulus and Poisson's ratio were performed at a temperature of 35 °C and an effective pressure of 25 MPa. The uniaxial compression, uniaxial tensile splitting and single-stage triaxial compression tests were conducted to obtain the strength properties of samples.

RESULTS AND DISCUSSION

The research indicates that by macroscopic observations the studied samples of core can be divided into four groups. Below are their generalized characteristics.

1) Carbonate rocks. Differ by light color. React with hydrochloric acid. No signs of oil saturation were detected. The structure is hidden-grained (cryptocrystalline). The texture is massive. The thickness of the carbonate layers varies in wide range: from 1 cm up to 20-40 cm. They're quite common.

2) Carbonate rocks, oil-saturated. Have light brown to brown color. There are obvious signs of oil saturation. Porosity is not visually detected. Reaction with hydrochloric acid is from violent to weak. Presumably contain dolomite. The structure is hidden-grained (cryptocrystalline). The texture is massive. The thickness of oil-saturated carbonate layers is small and does not exceed 10 cm. They're a quite rare.

3) Carbonate breccia. The fragments are composed of hidden-grained (cryptocrystalline) limestone, as indicated by their violent reaction with hydrochloric acid. The color is light gray. The size of the fragments does not exceed 5-7 cm. The shape of the fragments is isometric from angular to smooth. The fragments are cemented with carbonate-siliceous material with a high content of organic matter. This material has a hidden-grained (cryptocrystalline) structure and dark gray to black color. There are obvious signs of oil saturation. Can be found among the layers of carbonate-siliceous rocks and do not occur among carbonate. Rarely encountered in the sections of the studied wells, though in some wells their ratio is quite large.

4) Carbonate-siliceous rocks saturated with organic matter. Have a gray, dark gray to black color. There are obvious signs of oil saturation. Porosity is not visually detected. Reaction with hydrochloric acid is violent, indicating the presence of calcite. The structure is hidden-grained (cryptocrystalline). The texture is massive. The layer thickness changes from 5-10 cm to 30-40 cm, rarely more. The carbonate-siliceous rocks frequently contain carbonate concretions with a non-isometric shape. Their size in laterals often exceeds the diameter of the core, i.e. 10 cm, and their vertical length, as a rule, does not exceed the first centimeters.

The results of the optical microscopic analysis of the thin sections confirm the results of macroscopic observations. Below are the generalized characteristics of the most common rocks.

Carbonate rocks. According to the data of optical microscopy studies, the structure of the rock is fine-grained with grain size less than 0.1 mm, conformal. The texture is homogeneous (massive). The mineral composition is represented by calcite. Its grains are isometric, xenomorphic. Sometimes there are spotted areas, composed of a coarser calcite with grain size up to 0.1-0.25 mm, indicating partial recrystallization with increase in a grain size. Banded appearance is due to uneven layer-by-layer distribution of carbon material. Organic remains represented by the ostracod valves are detected in limestones extremely rare. Porosity under a microscope is not detected.

Carbonate-siliceous rocks. According to the data of optical microscopy studies, the structure of the rock is fine-grained, the texture is homogeneous (massive), but very often it is banded due to the uneven layer-by-layer distribution of organic material. Among rock-forming minerals, calcite, which has a xenomorphic form, grain size 0,08-0,25 mm is reliably diagnosed. Grains of chalcedony, usually, found with difficulty, because they have a smaller size compared with grains of calcite, and are hardly recognized among the dark-brown organic matter. They have a size of 0.01-0.1 mm (usually 0,05-0,1 mm) and are isometric and xenomorphic. The quantitative ratio between calcite and chalcedony is variable. The content of calcite varies from 25% to 80-90%. The porosity visible under the optical microscope is not found in the rock matrix. The horizontal micro cracks in such rocks are quite rare, its irregular, but sometimes the length of cracks exceeds the size of a standard thin section. Crack opening is hundredths of a millimeter (usually 0.05 mm).

X-ray diffractometry results provide additional information. The main types of rocks in the studied sections are carbonate and carbonate-siliceous rocks.

The main rock-forming mineral in carbonate rocks is calcite, quartz, dolomite, sporadic pyrite are present as an impurities.

The main rock-forming minerals in carbonate-siliceous rocks are quartz and calcite, the orthoclase and mica are often present in significant quantities, the dolomite, pyrite, albite, apatite serves as a non-permanent impurities.

Inferred from the results, we have distinguished three mechanical facies (also called here as group) of the Domanik Formation and Domanikoids rocks substantially different in terms of chemical, mineralogical composition and petrophysical properties. They are:

group A – carbonate rocks; group B – carbonate-siliceous rocks; group C – siliceous-carbonate rocks. The border between the latter two is rather conventional, since for a number of samples within the groups the ratios between silica/quartz (chemical compound/mineral) and calcium carbonate/calcite are comparable.

It should be noted that with community of lithological composition the heterogeneous remains within the "large" groups. The descriptive statistics presented in Table 1 reflect this.

Group A – carbonate rocks are significantly different from the rocks of group B and C in considerable density, almost reaching the mineralogical density of pure calcite (sample 8 of well 1877 Bondyuzhsk, ρ=2.692 g/cm3 ≈ 2.7 g/cm3 for pure calcite). The rocks of this group are characterized by high values of dynamic elastic moduli – Young’s modulus and Poisson's ratio, which, however, do not correlate well with static elastic moduli. Tests with the application of deviatoric stress (triaxial compressive strength) are characterized by the greatest variability, regardless of the lateral pressure value. The reason for significant differences within the group is structurally textural features and the nature of secondary (epigenetic) changes. So the following differences in the factors of influence can be identified within the group A:

1) samples 1 and 2 of well 1877 Bondyuzhsk – the presence of secondary dolomitization determines the decrease in density, low values of static modulus of elasticity;

2) samples 1A and 10 of well 6818 vil. Chishminsk - preservation of the biomorphic structure determines the geomechanical parameters most typical for dense limestones; after destruction of rocks the weak oil staining are observed on the face of the shear cracks.

Table 1 – Porosity values provided by different methods.

Descriptive statistics	**Density, g/cm^3**	**Elastic moduli measured by sonic methods**		**Elastic moduli measured under stress**		**Splitting Tensile Strength, MPa**	**Triaxial failure tests, MPa**
		Yong's modulus, GPa	Poisson's ratio	Yong's modulus, GPa	Poisson's ratio		
Group A – carbonate rocks							
Minimum	2.51	31.55	0.28	19.14	0.12	4.90	92.88
Maximum	2.69	73.96	0.34	33.75	0.32	8.83	306.07
Mean value	2.61	62.57	0.31	25.98	0.22	6.85	177.98
St. Deviation	0.06	13.71	0.02	5.48	0.06	1.60	75.54
Group B – carbonate-siliceous rocks							
Minimum	2.29	33.86	0.26	15.97	0.23	3.87	116.77
Maximum	2.35	58.97	0.32	18.37	0.27	10.40	192.61
Mean value	2.29	45.77	0.29	17.09	0.25	6.96	165.22
St. Deviation	0.09	12.61	0.03	1.21	0.02	3.28	42.08
Group C – siliceous-carbonate rocks							
Minimum	1.84	15.39	0.30	8.04	0.13	3.57	49.39
Maximum	2.56	68.92	0.40	25.50	0.24	19.14	348.32
Mean value	2.23	39.43	0.33	15.49	0.19	11.22	180.56
St. Deviation	0.38	25.95	0.05	8.26	0.06	7.45	152.62

It was found that with community of lithological composition there is a significant heterogeneity of petrophysical and geomechanical properties within the "large" groups. The sources of the revealed heterogeneity are also different. So the rocks of group A-carbonate rocks-are divided according to the influence on them of background lithogenesis and secondary changes: dolomitization, recrystallization, calcification, desalinisation. For the rocks of group B and C, the differences in most cases are due to the ratio between mineral matrix and kerogen.

3) sample 3 of well 6818d Chishminsk, sample 6 and 8 of well 1877 Bondyuzhsk, sample 14 of well 298 Upper-Garey – the intensive uneven secondary recrystallization/calcitization defines extremely high levels of compressive strength and bulk density values.

The values of tensile strength (Brazilian test results) differ little from the reference data typical for dense carbonate rocks.

As it was stated earlier, despite the differences in the name of rocks by the predominance of silica/quartz and calcite/calcium the carbonate rocks of group B and C should be considered as a single sample of a lithological-facies conditions. At the same time, samples 4 and 5 of well 1877 Bondyuzhsk represent the most "weak" rocks (group B – siliceous-carbonate rocks), rocks of group C – carbonate-silicon (samples 3 and 4 of well 6818d Chishminsk, sample 1 of well 277r Mamadysh exploration area) are the rocks of "medium" strength. The use of contingent ranking is explained by the fact that these samples are similar in macroscopic scale rocks, which are comparable to the formation of combustible shales in physical and mechanical properties. Differences in the volume density of the rock are due to the ratio between mineral matrix and kerogen. The schistosity of rocks as a characteristic feature is manifested by the results of geomechanical triaxial compression tests –when the rock is destroyed, the angle of the shear plane reaches 80-85°, the rock splits into many prismatic fragments.

The samples 8 and 11 of well 298 of the Upper-Garey behave otherwise. This is siliceous carbonate rocks of group B with a high and very high strength. They are characterized by extreme values of tensile strength (Brazilian test) and triaxial compressive strength; low values of static Poisson ratio comparable to pure quartz. In well 298 of the Upper-Garey at the depth interval of 1721-1728 m in the rocks of comparable macroscopic appearance both healed shear fractures and opening mode fractures are observed. The rocks behave as brittle under atmospheric conditions resulting in destruction of samples during drilling and their shearing under even a little pressure of a diamond head.

The commonality of rocks of group B and C confirms the results of the correlation and regression analysis of geomechanical properties.

CONCLUSION

Laboratory studies of intact rock core specimens from 6 wells from several oil-bearing areas were carried out to determine petrophysical, geomechanical and lithological features of domanic deposits represented by carbonate-siliceous and carbonate rocks.

Inferred from the results, we have distinguished three mechanical facies of the Domanik Formation and Domanikoids rocks substantially different in terms of chemical, mineralogical composition and petrophysical properties.

The patterns of distribution of facies and main accumulations of hydrocarbons in domanikites indicate a strong influence of the Ural deep-water basin and the rifting activization processes of the East European platform, accompanied by volcanism and periodic input of deep fluid systems into the sedimentation basin on the biogenic sedimentation.

The results of lithochemical studies have provided data on trace element composition of domanikits which is important for environmental risk assessment in the development of shale formations. High nickel and uranium contents, which are significantly higher than clarks, represent a potential environmental hazard in the production of shale hydrocarbons.

We assumed that outcomes can be used to optimize the development of multistage hydraulic-fracturing technology in horizontal wells.

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