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Identification of technological indicators' correlation dependences of projects for field development with low-permeability reservoirs

Abstract. This paper presents the analysis result of available data on shale oil deposits in various basins of North America, comparing them with the available data from projects for the development of the Domanik deposits in the Samara region, followed by the identification of a number of correlations.

The paper notes that in terms of geological and physical characteristics the US shale oil fields of the Eagle Ford basin are closest to the Domanik deposits of the Samara region, which allows us to accept these objects as analogues.

The data analysis revealed correlations between the values of the average cumulative oil production for the first year of the well operation and the average proppant mass per hydraulic

fracturing stage. There is a high correlation between the noted parameters, for the US shale oil fields, which allows us to assume a significant influence of the mass of injected proppant and the volume of hydraulic fracturing fluid per stage on the cumulative production from the well for the first year work on these sites.

The high value of the correlation coefficient makes it possible to predict the cumulative oil production in the fields of the Eagle Ford basin and its analogues in the form of the Domanik deposits in the Samara region.

Keywords: low-permeability reservoir; hard-to-recover reserves; enhanced oil recovery; hydraulic fracturing; geological structure; mineralogical composition; data sets; data analysis; correlations; production forecasting

Currently, the world's oil and gas reserves are replenished largely due to the initiation of the development of already known objects, rather than the discovery of completely new fields, since large vertically integrated oil companies tend to work in the already developed old oil and gas provinces. This is facilitated by the revision of previous reserves estimate, taking into account the development of modern technologies for enhanced oil recovery, drilling of deeper horizons, inclusion of previously unprofitable reserves of small fields, as well as hard-to-recover reserves (HRR) into the balance sheet. According to the project for Development Strategy of Russia's mineral resource base up to 2030, developed in 2019 by the Institute of Petroleum Geology and Geophysics (IPGG) of the Siberian Branch of the Russian Academy of Sciences, unconventional hydrocarbon reserves will become the main source of reserves growth in Russia.

According to information provided by the U.S. Energy Information Administration, the world's recoverable shale oil reserves are more than 57 billion tons of oil. The leading positions in this rating are: the USA (10.6 billion tons), Russia (10.1 billion tons), China (4.4 billion tons)¹.

This paper presents an analysis of the available data on shale oil deposits in various basins of North America, followed by the identification of a number of correlations, generalization of statistical data and their comparison with the available data from projects for the development of the Domanik deposits in the Samara region.

The considered objects and some of their geological and physical characteristics are shown in table 1.

From the characteristics of a number of objects listed in Table 1, it seems possible to take the Eagle Ford Basin (USA) as an object analogous to the Domanik deposits of the Samara region in the framework of this work.

According to table 1, low values of porosity and permeability of reservoir rocks are noted, which is a feature of the structure of the considered objects. As a rule, shale oil, HRR is oil deposited in tight rocks with very low permeability [2–6].

One of the main ways to produce such oil is hydraulic fracturing (HF). The method makes it possible to "get out" oil or gas from isolated microscopic pores in dense rock, to ensure the presence of highly permeable filtration channels [2–8].

¹ World Shale Resource Assessments. // U.S. Energy Information Administration: офиц. интернет-ресурс. — 2020. — URL: www.eia.gov/analysis/studies/worldshalegas/ (дата обращения: 11 August 2020).

Table 1
**Geological and physical characteristics of shale oil objects,
 North American basins in comparison with the Domanik deposits of the Samara region**

Object	Number of considered wells, units	Mineralogy	Depth, m	Permeability, mD	Porosity, %	Total organic carbon, %
Domanik deposits, Samara region	-	Clay = 5 % Silicon = 20 % Carbonates = 75 %	2685	0,0001	6,6	4,76
Bakken	14639	Clay = 30 % Silicon = 61 % Carbonates = 9 %	2150	0	6	12
Eagle Ford	24650	Clay = 14 % Silicon = 23 % Carbonates = 63 %	1859	0,01	8,5	4
Permian Bone Spring	16461	Clay = 15 % Silicon = 53 % Carbonates = 26 %	2690	0,08	11	4
Powder River Cretaceous	2003	Clay = 1 % Silicon = 90 % Carbonates = 8 %	600	34	15	4,5
Uinta Green River	767	Clay = 11 % Silicon = 38 % Carbonates = 51 %	3950	2	10	6
Woodbine	1759	Clay = 17 % Silicon = 80 % Carbonates = 3 %	2667	10,05	12,5	8

The hydraulic fracturing technology consists in the initial drilling of the target formation with a well with a horizontal ending. In this case, the length of the horizontal section of the wellbore varies from several hundred meters to 2–5 kilometers, which are more common for basins in the United States [2–8].

At the end of the drilling and cementing of the well, the process of formation of the well completion is initiated. Then hydraulic fracturing is carried out. A mixture of water, proppant and auxiliary reagents is injected into the formation. At a certain point, the injection pressure exceeds the tensile strength of the reservoir rock, resulting in the formation of extended fractures around the horizontal part of the wellbore. As a result, the produced cracks connect oil-saturated voids isolated from each other, which further allows oil and gas to be extracted. The proppant contained in the hydraulic fracturing fluid (quartz sand is also used to reduce the cost of the process) [7; 8] prevents cracks from closing under rock pressure. At the same time, the number of hydraulic fracturing operations on one well is limited only technologically. When performing multi-stage hydraulic fracturing (MSHF), several hydraulic fracturing operations are sequentially performed, starting from the far part of the wellbore [2–8].

During the analysis of the available statistical data set for shale oil fields in the US basins, it is possible to identify a number of correlations between the cumulative oil production per well for the first year and the mass of injected proppant per hydraulic fracturing stage, as well as the volume of hydraulic fracturing fluid per stage (fig. 1–2).

Figures 1.1 and 1.2 shows the correlation coefficients R^2 between the values of the average cumulative oil production for the first year of well operation and the average proppant weight per hydraulic fracturing stage. Thus, a high correlation is noted for the Bakken, Eagle Ford, Powder River Cretaceous, Permian Bone Spring basins, which suggests a significant effect of the mass of injected proppant per stage on the cumulative production from the well for the first year of operation at these objects.

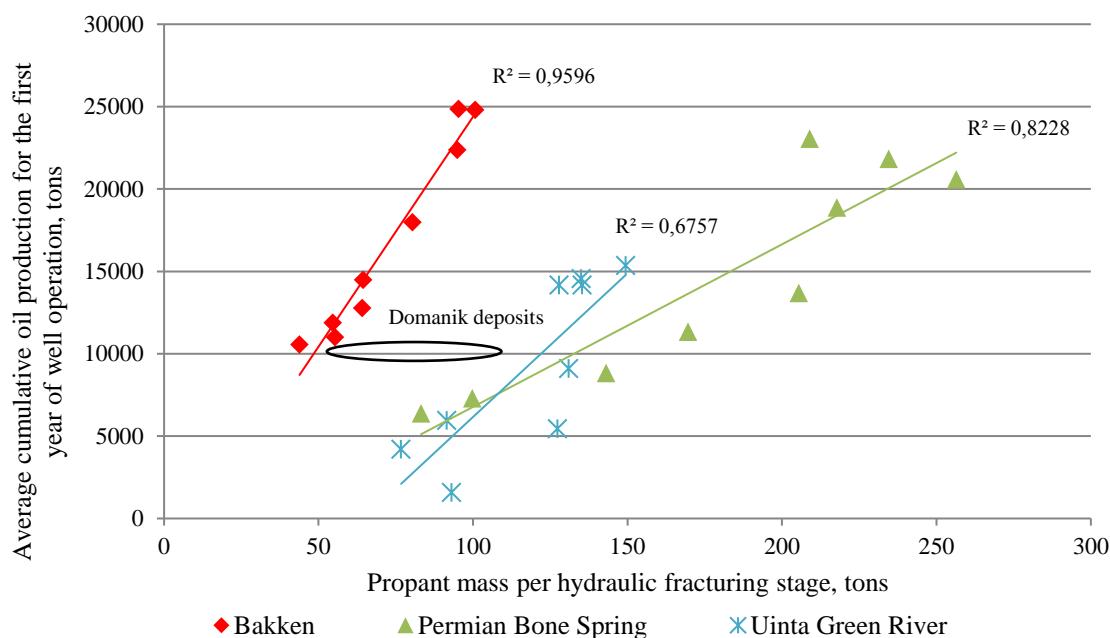


Figure 1.1. Dependence of the average cumulative oil production for the first year of well operation on the average proppant weight per hydraulic fracturing stage

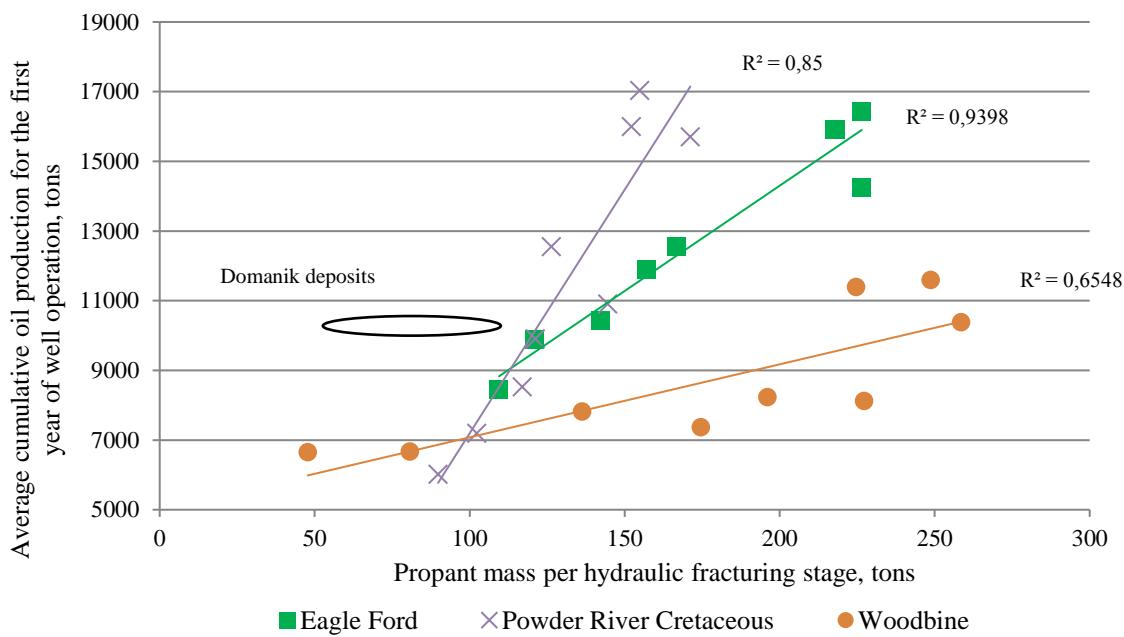


Figure 1.2. Dependence of the average cumulative oil production for the first year of well operation on the mass of proppant per one stage of hydraulic fracturing

A similar situation can be traced from the data in figures 2.1 and 2.2, which also suggests a significant effect of the volume of injected hydraulic fracturing fluid per stage on the cumulative production from the well for the first year of operation at the Bakken, Eagle Ford, Powder River Cretaceous, Permian Bone Spring sites.

Also, based on the data in figure 1–2, it is worth noting that the value of the average cumulative oil production for the first year of well operation on the Domanik deposits is quite high in comparison, taking into account the relatively small mass of injected proppant and the volume of hydraulic fracturing fluid per stage.

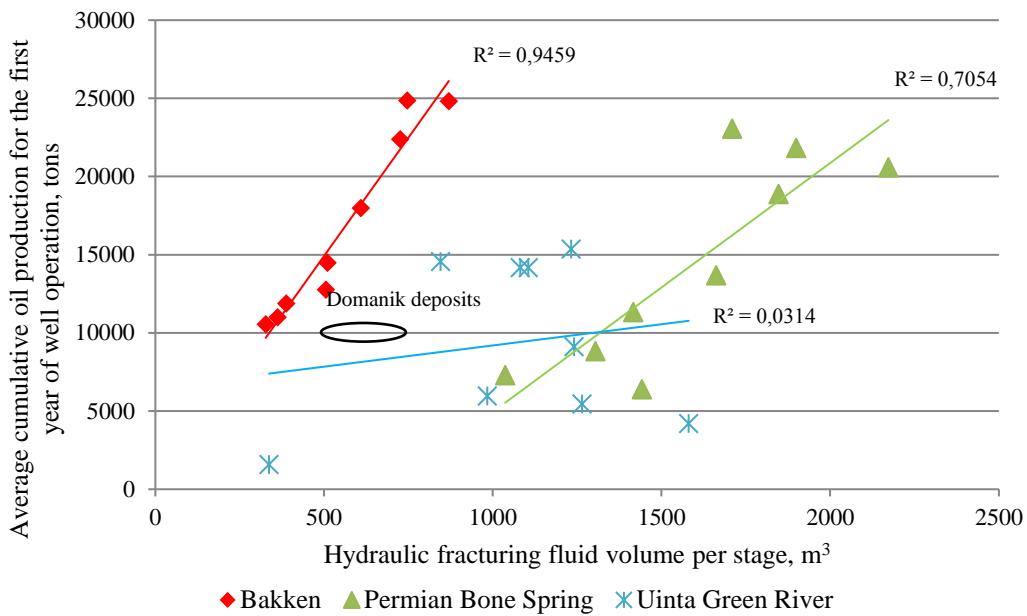


Figure 2.1. Dependence of the average cumulative oil production for the first year of well operation on the volume of fluid per hydraulic fracturing stage

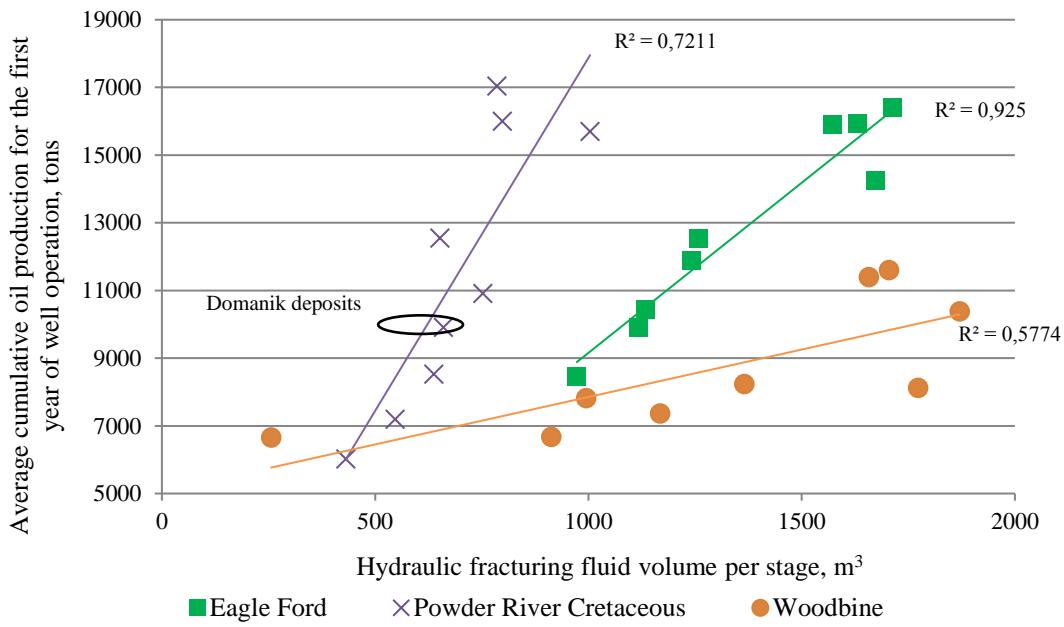


Figure 2.2. Dependence of the average cumulative oil production for the first year of well operation on the volume of fluid per hydraulic fracturing stage

Ultimately, a high correlation coefficient ($R^2 > 0.9$) according to the given parameters makes it possible to predict the cumulative oil production in fields with low-permeability reservoirs in such basins as the Eagle Ford, as well as in analogues in the form of objects belonging to the Domanik deposits of the Samara region (fig. 3, 4). Presented in figure 3, 4, the range and its intermediate values were obtained during the analysis of data on the fields of the Eagle Ford basin for the period from 2011 to 2020.

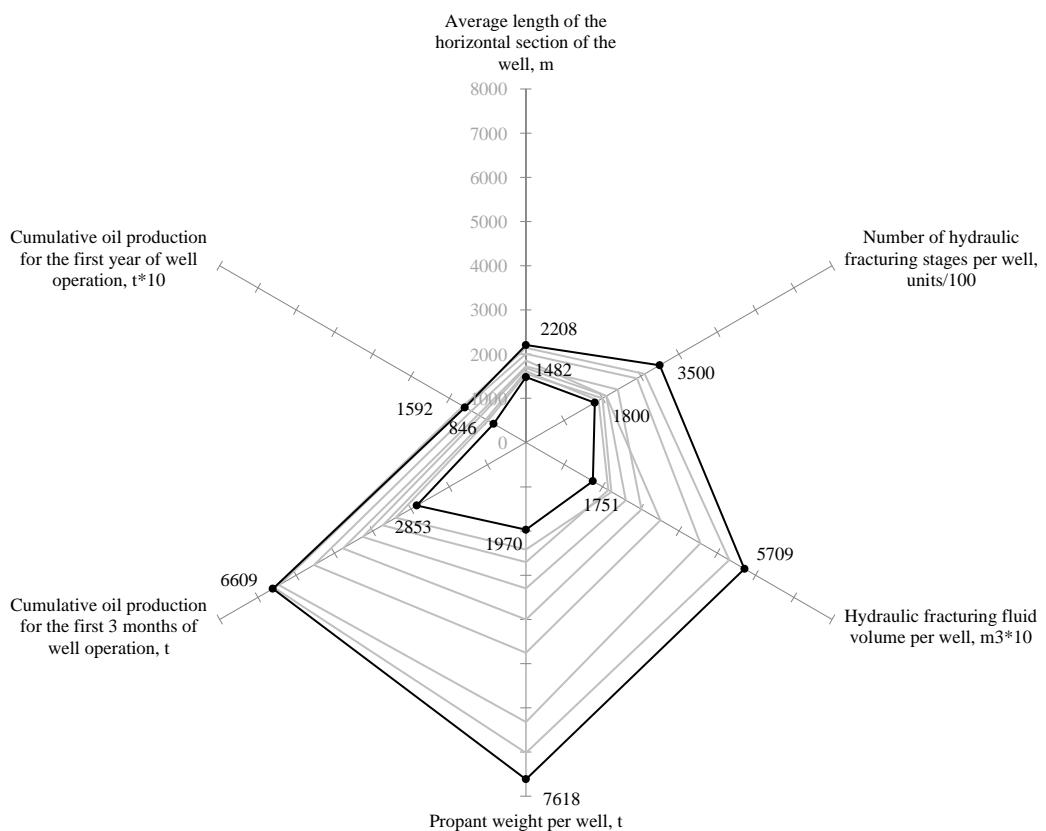


Figure 3. Oil production forecast diagram (Eagle Ford, Domanik deposits)

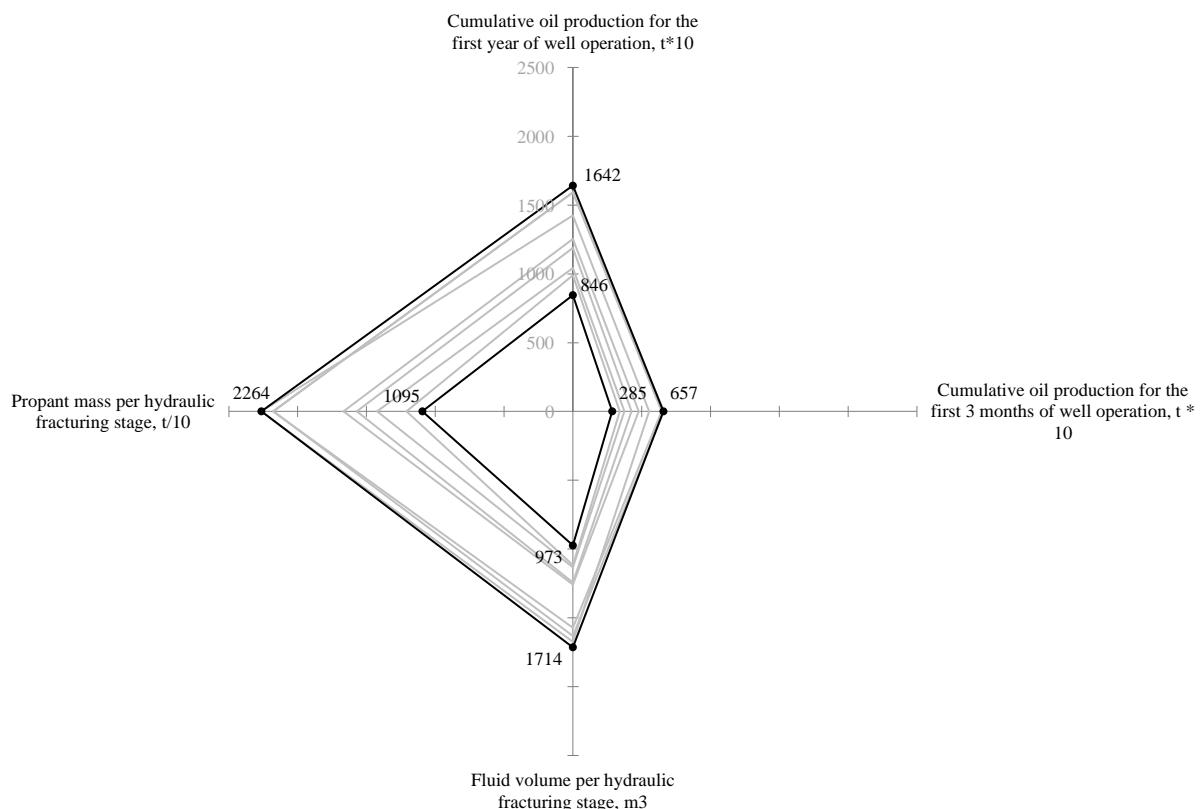


Figure 4. Oil production forecast diagram (Eagle Ford, Domanik deposits)

The areas marked in figures 3 and 4 between the minimum and maximum values of the given parameters can be used to forecast the cumulative production per well for the first year (or the first 3 months) of work at the fields of the Eagle Ford basin and their analogues, such as objects belonging to the Domanik deposits of the Samara region.

Based on figure 4, with a volume of hydraulic fracturing fluid per stage of 973 m³ and a proppant weight of 109.5 tons, the cumulative production from the well for the first 3 months will be 6570 tons, for the first year 16420 tons.

As a result of analysis and comparison of available data, it is possible to summarize the following:

1. The most comparable object to the Domanik deposits of the Samara region in terms of a number of given parameters are the US shale oil fields of the Eagle Ford basin, which allows us to accept these objects as analogues.
2. Technological indicators for the Domanik deposits of the Samara region reflect the initial development stage of the US shale projects, but at the same time, there are already good results in a number of parameters. For example, there are relatively high rates of cumulative oil production for the first year with a relatively small mass of injected proppant, which allows us to assert high technological and economic prospects for the Domanik deposits in the Samara region.
3. The given correlations (fig. 3–4) and the high value of the correlation coefficient for them make it possible to forecast the cumulative oil production in the fields of such basins as the Eagle Ford and their analogues in the form of the Domanik deposits in the Samara region.

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Выявление корреляционных зависимостей технологических показателей проектов по разработке месторождений с низкопроницаемыми коллекторами

Аннотация. В данной работе представлен результат анализа имеющихся данных по месторождениям сланцевой нефти различных бассейнов Северной Америки, сравнением их с имеющимися данными проектов по разработке доманиковых отложений Самарской области с последующим выделением ряда корреляций.

В 2019 г. Институтом нефтегазовой геологии и геофизики (ИНГГ) СО РАН разработан проект Стратегии развития минерально-сырьевой базы России до 2030 г., исходя из которого основным источником прироста запасов в России станут нетрадиционные запасы углеводородов.

В работе отмечается, что наиболее близкими к доманиковым отложениям Самарской области по геолого-физическим характеристикам являются месторождения сланцевой нефти США, бассейна Eagle Ford, что позволяет принять данные объекты в качестве аналогов.

В ходе анализа данных обнаружены корреляционные зависимости между значениями средней накопленной добычи нефти за первый год работы скважины и средней массой пропанта на стадию ГРП. Так, по месторождениям сланцевой нефти США бассейнов Bakken, Eagle Ford, Powder River Cretaceous, Permian Bone Spring отмечается высокая корреляция между

отмеченными параметрами, что позволяет предположить о значительном влиянии массы закачиваемого пропанта и объёма жидкости ГРП на стадию на накопленную добычу по скважине за первый год работы на данных объектах.

Высокое значение коэффициента корреляции позволяет спрогнозировать накопленной добычу нефти по месторождениям бассейна Eagle Ford и его аналогам в виде объектов доманиковых отложений Самарской области.

Ключевые слова: низкопроницаемый коллектор; трудноизвлекаемые запасы; увеличение нефтеотдачи; гидравлический разрыв пласта; геологическое строение; минералогический состав; массивы данных; анализ данных; корреляционные зависимости; прогнозирование добычи

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