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GEODYNAMIC AND HYDRODYNAMIC CONDITIONS OF THE URNA AND UST-TEGUS OIL FIELDS

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Abstract: This paper discusses the productive beds of the Urna and Ust-Tegus oil fields (West Siberia, Russian) and permeability and capacity properties that are influenced by geodynamic processes. Strong tectonic processes, accompanied by periodic magma intrusions, produced numerous fractures and faults in the Jurassic sediments, which act as conduits for groundwater flows, and thus led to the hydrothermal alteration of rocks and changes in the pore space. The data presented in the paper testify to the manifestation of these processes in the modern hydrogeochemical and geothermal conditions of the Jurassic-Cretaceous sediments within the two oil fields and their vicinity. The petrophysical studies of the core samples and the hydrodynamic studies in the wells confirm that the reservoir properties of the productive strata are considerably heterogeneous. Despite the significant effect of the geodynamic factors, the analysis of the tracer data has not revealed any apparent spatial consistency of the presence (or absence) of a hydrodynamic connection between the wells and the locations of fractured and dynamically stressed zones. In our study, we have proposed and tested a method based on the analysis of morphotectonic features detectable in the depth maps of reference surfaces. This method is a useful additional tool for discovering and analyzing the relationships between the tectonic and hydrodynamic conditions of oil and gas fields.

Key words: geodynamics; magmatism; Paleozoic basement; Jurassic reservoir; reservoir properties; heterogeneity; Urna and Ust-Tegus oil fields

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Геодинамические и гидродинамические условия Урненского и Усть-Тегусского нефтяных месторождений

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Аннотация: В работе рассматриваются особенности строения и фильтрационно-емкостных свойств продуктивных отложений Урненского и Усть-Тегусского месторождений Западной Сибири, обусловленные воздействием геодинамических процессов. Эти процессы привели к формированию многочисленных трещиноватых зон в осадочных отложениях юрского комплекса, по которым происходило активное движение подземных вод и сопутствующее гидротермальное преобразование порового пространства осадочных отложений. Представленные в работе данные свидетельствуют о проявлении этих процессов в современных гидрогеохимических и геотермических условиях юрско-меловых отложений рассматриваемых месторождений и прилегающих районов. Следствием комплексного воздействия отмеченных процессов является существенная неоднородность коллекторских свойств продуктивных отложений рассматриваемых месторождений, что подтверждается петрофизическими исследованиями керна и результатами гидродинамических исследований в скважинах. Анализ проведенных трассерных исследований свидетельствует о том, что, несмотря на существенное влияние геодинамического фактора, не прослеживается явной пространственной согласованности в наличии или отсутствии гидродинамической связи между скважинами с расположением зон трещиноватости и динамически напряженных зон. В работе предложен и апробирован метод, основанный на анализе морфоструктурных показателей строения опорных горизонтов, который может служить дополнительным инструментом для анализа связи тектонических и гидродинамических условий на месторождениях.

Ключевые слова: геодинамические условия; юрский комплекс; палеозойский фундамент; интрузия; фильтрационно-емкостные свойства; неоднородность; Урненское и Усть-Тегусское месторождения

1. Introduction

Geodynamic processes are among the most important natural processes influencing the structure and properties of sedimentary strata. Recently, the attention to the analysis of these factors in the problems of hydrocarbon deposits exploration and development has increased markedly [*Afonin, 2008*; *Bagdasarova, 2001*; *Vakhromeev et al., 2017*; *Volobuev et al., 2003*; *Shein, 2007*; *Schuster, 2010*]. This is mainly due to the development of high-precision remote seismic 3D methods that allow studying a deposit structure in detail, as well as improving the quality, diversity and amount of information obtained by well research at the stages of geological exploration and development of the oil fields.

The scale and nature of the impact of geodynamic processes determine the block structure of the sedimentary cover and can cause a significant heterogeneity of hydrodynamic properties of the productive strata of oil fields. In order to ensure successful exploration and development of oil deposits with such features, specialized research approaches are required to predict and clarify the structure and properties of productive horizons in detail.

In West Siberia, the Urna and Ust-Tegus oil fields are typical cases showing the significant influence of geodynamic factors on the structure and properties of productive sediments, as well as the problems experienced during the field exploration and development, and the problem solving approaches. The exploitation of these oil deposits and the effectiveness of enhanced oil recovery (EOR) techniques are considerably influenced by faults and fractures detected by geological and geophysical studies [*Vashchenko et al., 2005*; *Kurchikov et al., 2013; Prokhorov et al., 2012*; *Khasanov et al., 2004*]. Based on the analyzed characteristic features of the terrestrial surface, dynamically stressed zones of mainly NW and NE orientations were identified. These zones are traced in the crystalline basement and the Jurassic and Neocomian strata and form the block system of the productive sediment structure [*Kurchikov et al., 2013*; *Prokhorov et al., 2012*].

Substantially heterogeneous properties of the Urna and Ust-Tegus oil fields are described in [*Kurchikov et al., 2012*]. According to [*Vashchenko et al., 2005*], the

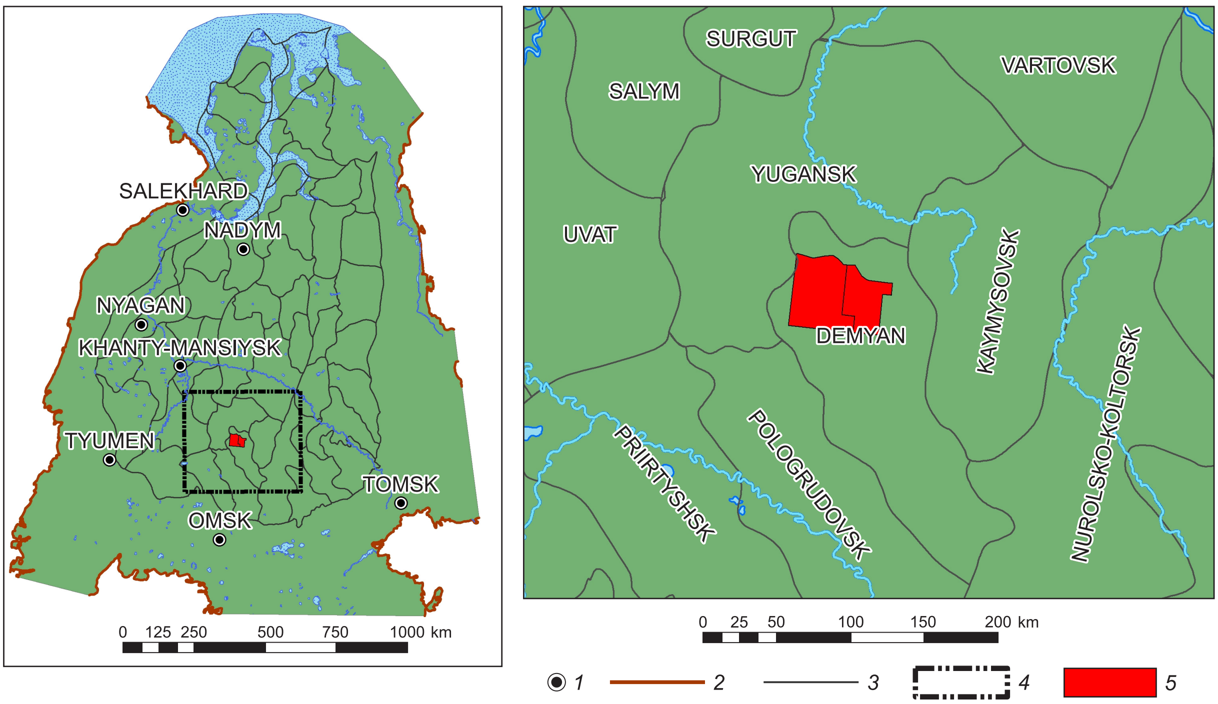

Fig. 1. Overview map of the study area.

1 – cities; *2* – border of West Siberian megabasin; *3* – borders of oil and gas regions; *4* – area of research; *5* – borders of Urna and Ust'-Tegus license areas.

Рис. 1. Обзорная карта района исследования.

1 – города; *2* – граница Западно-Сибирского мегабассейна; *3* – границы нефтегазоносных районов; *4* – область исследования; *5* – границы Урненского и Усть-Тегусского лицензионных участков.

deposit at the Urna field is associated with a basal stratum that is a product of weathering, destruction and hydrothermal processing of Palaeozoic rocks. Hydrodynamic connection is possible between the Jurassic sediments and the fracture system of the pre-Jurassic basement [*Kurchikov et al., 2012; Kurchikov et al., 2013*], since the heterogeneity of the deposits properties is largely determined by magma intrusion and effusion. The analysis of hydrogeochemical and geothermal features confirms the above assumption and complements the understanding of the manifestation and significance of the processes caused by the influence of tectonic factors in the Urna and Ust-Tegus oil fields [*Kurchikov et al., 2013*].

Although extensive research has been carried out on these oil fields, a number of research problems remains as the nature of the influence of geodynamic processes on the structure and properties of productive rocks is ambiguous. A challenging task is to analyze and predict the spatial patterns of changes in hydrodynamic properties of the productive sediments, which is of importance for both theoretical modeling of the relationships between geodynamic and hydrodynamic conditions and technologies aimed at the efficient development of the oil and gas fields in West Siberia.

2. General characteristics of the Urna and Ust-Tegus oil deposits

The Urna and Ust-Tegus oil deposits are located in the Uvat area of the Tyumen region and confined to the NW part of the Demyanka hydrocarbon-bearing area (Fig. 1). The distance between these deposits is about 20 km. In the Urna field, Jurassic sediments are represented only by the upper strata (Vasyugan, Georgievsk and Bazhenov Formations), and oil deposits are confined to bed J_1. In the Ust-Tegus field, beds J_2 and J_4 (Tyumen Formation) are productive, and bed J_3 is oil-bearing, but not productive and therefore not involved in the development.

Despite the proximity in location, the oil deposits are significantly different in structure, primarily due to differences in the formation of the pre-Jurassic basement. In the Urna field, due to strong intrusive and effusive processes, the basement is by 200–300 m higher than in the Ust-Tegus field.

Corresponding differences are manifested in the compositions of the basement rocks. According to the core data, the pre-Jurassic stratum of the Urna field is represented by metamorphosed igneous rocks, mainly andesite-basalt, dacitic, and diabase porphyrites. The

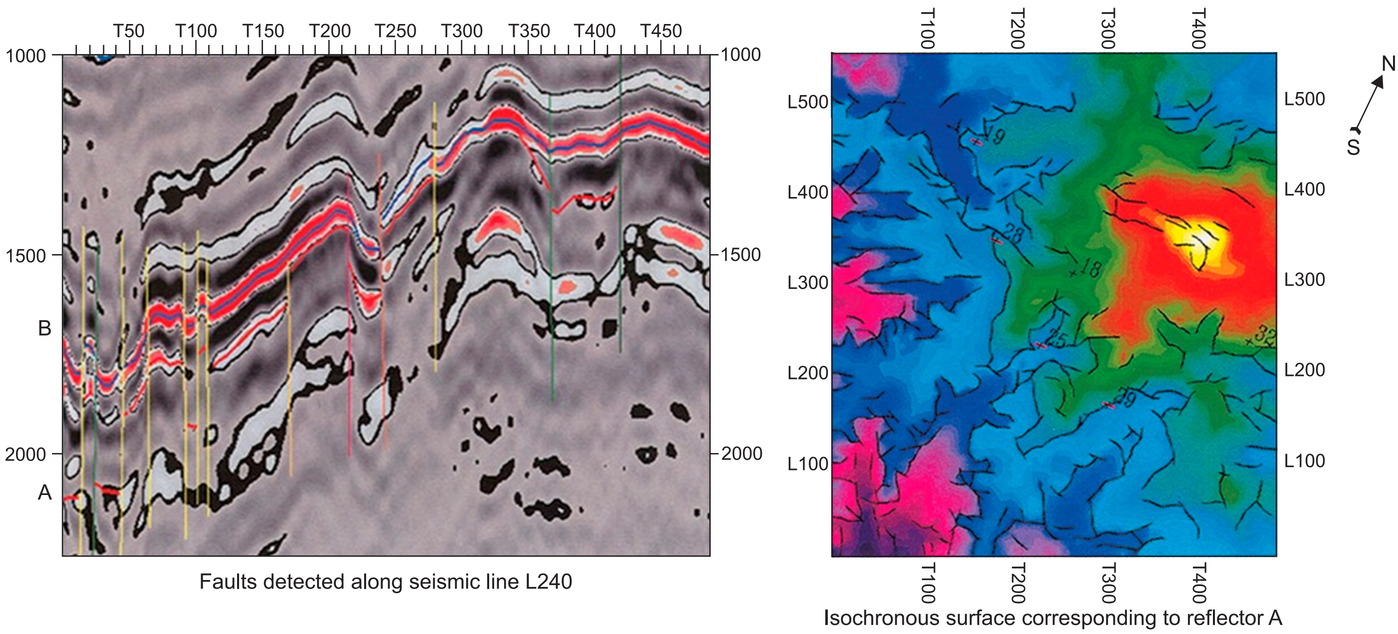

Fig. 2. Detected faults in the Urna field [*Khasanov et al., 2004*]. Faults detected along seismic line L240 isochronous surface corresponding to reflector A.

Рис. 2 Выделение разрывных нарушений на Урненском месторождении [*Khasanov et al., 2004*]. Разломы установлены вдоль сейсмического профиля L240. Изохронная поверхность соответствует отражающему горизонту A.

composition of the pre-Jurassic formations of the Ust-Tegus field is more diverse and, in addition to effusive rocks, includes marbled limestone and shale. The weathering profiles of the Urna field show the products of granite erosion, effusive rocks and tuffs. Tuff breccias are present in the Ust-Tegus field as well.

The characteristic features of the intrusive and effusive magmatic processes are their periodicity and occurrence with a varying intensity over a long period of time. At the same time, new intrusions penetrated into previously unaffected zones, which predetermined the formation of complex local features of the studied fields, including small domes on the respective surfaces of the Ust-Tegus field. Magma cooling and crystallization was accompanied by the emergence of low-density fractured zones at the boundaries of the intrusive objects.

This idea is supported by the presence of faults on the limbs of local uplifts in the Urna field, which are detectable in the interpreted 3D seismic images (Fig. 2) [*Khasanov et al., 2004*]. More detailed depth maps of the basement beneath the oil fields show a complex structural framework (Tyumen Science Centre [*Baburin, Zervando, 2009*]). See, for instance, a depth map of the pre-Jurassic basement surface (Fig. 3), where tectonic faults are shown as thick red lines.

As a consequence of tectonic processes, groundwater moved actively along faults and low-density zones, and this process was accompanied by the hydrothermal alteration of the pore space of the sedimentary deposits (also traced in other nearby fields [*Nedolivko et al., 2005*]). As a result, the pore space of the reservoir rocks became substantially heterogeneous with the presence of highly permeable rocks. This fact accounts for the high daily yields of the production wells (400–500 tonnes and more).

3. Manifestation of tectonic factors in groundwater chemistry and formation temperatures

The hydrothermal processes that cause significant changes to the pore space of reservoir rocks are reflected in the alterations of groundwater chemistry in the Jurassic sediments of the Urna and Ust-Tegus oil fields (Table 1).

The groundwaters of the two fields are similar in pH, water salinity and concentrations of Na^{2+} and Cl^{-}. The groundwater of the Urna field has higher Ca^{2+} and SO_4^{2-}, but lower HCO_3^{-} than the groundwater of the Ust-Tegus field. The groundwater of the Urna field is of Ca-Cl type, according to the classification of V. Sulin [*Sulin, 1948*], while the groundwater of the Ust-Tegus field rarely shows Ca-Cl (2 samples) and Mg-Cl compositions, but contains much more Na^{2+} and HCO_3^{-}, with moderate variations (Table 1).

A characteristic feature is traced in the groundwater chemical composition change with depth in the Ust-Tegus oil field. In the samples from well 116, the

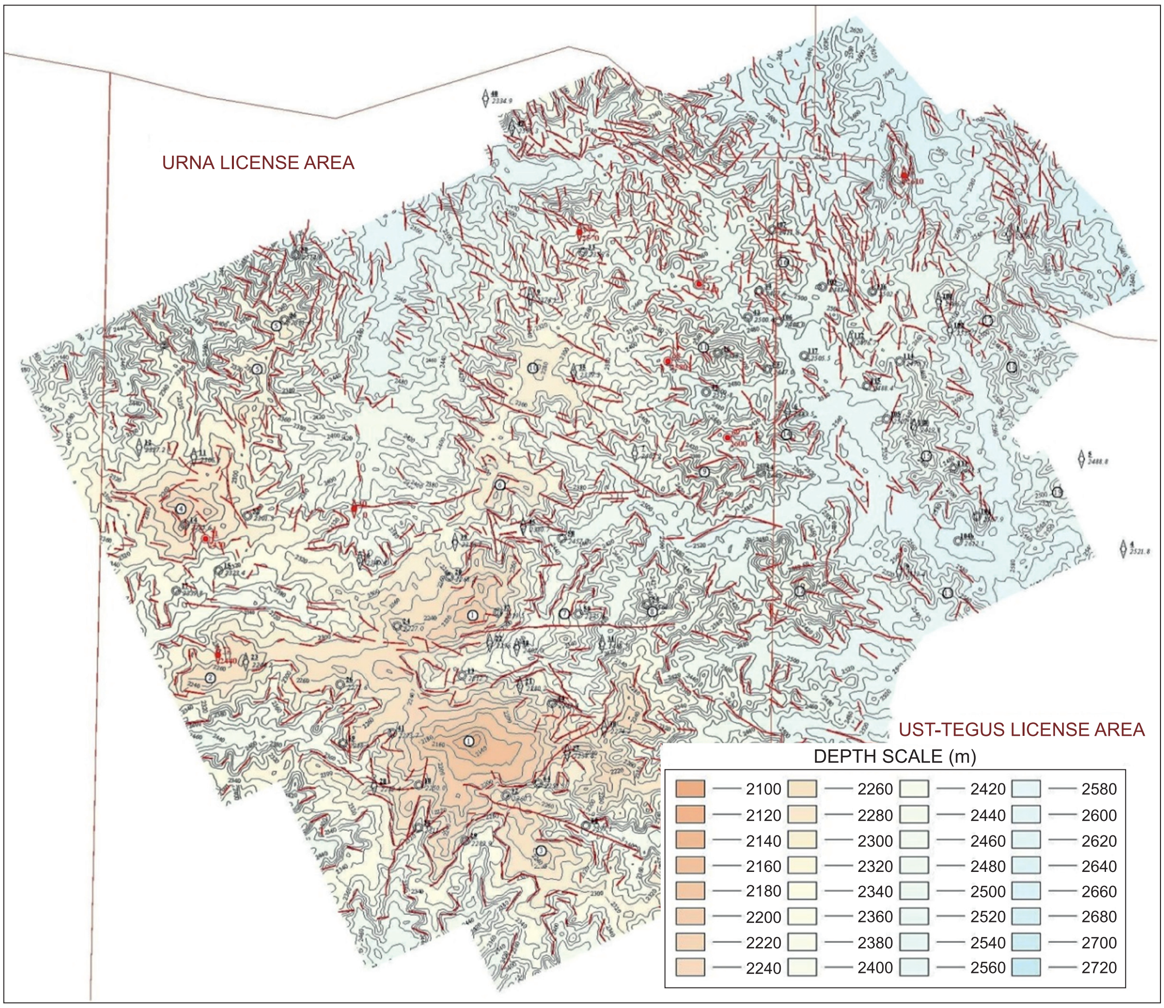

Fig. 3. Depth map of pre-Jurassic basement surface, reflector A [*Baburin, Zervando, 2009*]. Thin red lines are boundaries of license areas; heavy red lines are faults.

Рис. 3. Структурная карта доюрской кровли фундамента по отражающему горизонту А [*Baburin, Zervando, 2009*]. Тонкие красные линии – границы лицензионных участков; жирные красные линии – разломы.

Table 1. **Average content of the main chemical components in the groundwaters of the Urna and Ust-Tegus fields**

Таблица 1. **Средние значения химического состава подземных вод**

Parameter/Component	Urna		Ust-Tegus	
	N	Average	N	Average
pH	7	6.62	19	6.94
M	9	23.81	19	22.51
Na^+	9	7589.89	19	8070.72
Ca^{2+}	9	1398.56	19	320.46
Mg^{2+}	9	99.29	19	112.67
SO_4^{2-}	9	79.11	19	13.85
Cl^-	9	14067.56	19	12314.37
HCO_3^-	9	611.33	19	1688.47
I^-	4	33.35	1	4.80
Br^-	4	61.78	1	44.90
B^-	1	18.77	0	
CO_3^{2-}	4	3.00	2	12.00

Note. *N* – number of analyses; *M* – total salinity (g/L). Concentrations of the main chemical components in mg/L.

Примечание. *N* – количество анализов; *M* – общая минерализация (г/л). Концентрации основных химических компонентов в мг/л.

Table 2. **Major-ion chemistry of the groundwater sampled from well 116 in the Ust-Tegus field**

Таблица 2. **Химический состав проб подземных вод из скв. 116 Усть-Тегусского месторождения**

Sampling interval, m	pH	*M*	Na^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	Cl^-	HCO_3^-	Type
		g/L	mg/L						
2458-2460	6.65	24.60	8680	460	175	16	14000	1490	Ca-Cl
2485-2529	6.9	23.00	8000	520	120	12	12700	1540	Ca-Cl
2485-2529	6.9	23.00	8000	520	130	12	12700	1540	Mg-Cl
2485-2529	7.15	22.40	7800	510	130	15	12400	1510	Mg-Cl
2485-2529	6.6	23.00	8000	510	130	15	12700	1540	Mg-Cl
2553-2563	6.95	21.10	7660	215	73	13	11000	1800	$Na\text{-}HCO_3$
2553-2563	7	20.80	7540	224	73	16	11000	1800	$Na\text{-}HCO_3$

Note. *N* – number of analyses; *M* – total salinity (g/L). Concentrations of the main chemical components in mg/L.

Примечание. *N* – количество анализов; *M* – общая минерализация (г/л). Концентрации основных химических компонентов в мг/л.

major-ion chemistry of the groundwater varies with depth from Ca-Cl to Mg-Cl and then to $Na\text{-}HCO_3$ (Table 2).

The presence of sodic-bicarbonate waters in the Ust-Tegus Jurassic sediments indicates a strong impact of the groundwater movements,most likely, as a result of the penetration of carbonated water from the pre-Jurassic basement. This idea is consistent with the lithological difference of the pre-Jurassic rocks in the Urna and Ust-Tegus fields – abundant basaltic volcanics in the former, and carbonates in the latter.

Generally, the observed hydrogeochemical features may occur due to the influence of other factors, such as the expulsion of pore waters from mudrocks during sediment compaction or dehydration. However, this effect appears unlikely in the Urna and Ust-Tegus fields, judging by the continuity of the overlying Bazhenov Formation and supra-Achimov shales and the environments of deposition and subsequent metamorphism.

The penetration of bicarbonate waters from the overlying Cretaceous sediments, as another likely factor, was investigated by analyzing the chemical compositions of the groundwaters sampled from the two fields and their vicinity, including most of the Yugan, Kaimys, and Demyanka areas and partly the Pologrudov and Priirtysh areas (in total, ~55000 km²).

In total, 176 analyses were performed using the samples from 97 wells (Lower Cretaceous, Aptian-Albian-Cenomanian and Neocomian and Jurassic) aquifers). The average major-ion concentrations in the groundwaters from Cenomanian, Neocomian (without Achimov shale), Achimov, and Jurassic strata are given in Table 3. The Achimov shale is considered separately because it differs in structure and deposition environment, as well as in the presence of continuous and thick mudrock layers above it.

Generally, the analyses of groundwaters from the Aptian-Cenomanian and Neocomian strata (without the

Table 3. **Major-ion chemistry of the groundwaters sampled from the Jurassic and Cretaceous aquifers**

Таблица 3. **Химический состав подземных вод водоносных комплексов**

Component	Cenomanian		Neocomian		Berriasian-Valanginian		Jurassic	
	N	Average	N	Average	N	Average	N	Average
M	29	18.9	52	18	14	17.5	81	23.6
Na^+	29	6659.1	48	5691.4	14	6067.2	80	8156.8
K^+	18	63.7	14	58	6	195.5	16	128.3
Ca^{2+}	29	520.1	48	1032.7	14	513.7	80	716.5
Mg^{2+}	29	96.1	47	51.5	14	33.6	80	90.5
$SO4^{2-}$	28	3.7	45	16.4	14	70.1	76	20.9
Cl^-	29	11385.7	48	10569.7	14	9792.1	80	13420.6
HCO_3^-	29	213.9	48	289.8	13	1013.5	80	1162.2
I^-	24	13.1	45	12	11	12.6	55	10.6
Br^-	24	50.1	46	49.7	11	44.9	55	63.3
B^-	8	10.3	42	12.5	10	14.4	47	16.3

Note. *N* – number of analyses; *M* – total salinity (g/L). Concentrations of the main chemical components in mg/L.

Примечание. *N* – количество анализов; *M* – общая минерализация (г/л). Концентрации основных химических компонентов в мг/л.

Achimov shale) show the same Ca-Cl type (according to the classification of V. Sulin). Their salinity is slightly lower than that of the Jurassic aquifers in the Urna and Ust-Tegus fields: ~18 g/L against 23 g/L. Compared to these waters, those from the Achimov shale contain much more HCO_3^- (1,952 mg/L) than the Cenomanian and Neocomian waters (329.4 and 994.3 mg/L, respectively). The HCO_3^- contents in the Berriasian-Valanginian and Jurassic aquifers are nearly similar (1013.5 and 1162.2 mg/L, respectively).

The similarity/dissimilarity of HCO_3^- concentrations in the groundwaters from the Jurassic, Achimov, and Neocomian strata is hard to trace within individual structures because the available groundwater analysis results are quite few and sampling for investigating the major-ion chemistry is incomplete. However, it should be noted that the groundwaters in the Tailak license area are rich in HCO_3^- in both Jurassic and Berriasian-Valanginian sediments (1830 and 1293 mg/L in the samples from wells 171 and 1732, respectively; and 841 mg/L in well 150). The groundwater HCO_3^- contents are also high (810–830 mg/L) in the Achimov shale of the Ust-Tegus field, but are lower in both Jurassic and Achimov strata (366 mg/L and 293 mg/L, respectively) of the Gustorechensk field (well 3P).

The groundwater HCO_3^-concentrations, that are locally high in the Jurassic and Achimov sediments while decreasing up the section, give evidence suggesting vertical ascending water flows that occurred, most likely, along the deformed zones.

Comparison of morphotectonic indicators with groundwater major-ion compositions. The validity of the above assumption was analyzed by comparing the morphotectonic features of the depth maps of the top surfaces of the basement, Bazhenov Formation, and Neocomian sequence, the groundwater salinity values, and the major-ion contents. It should be noted that the experience of studying the tectonic structure of the earth's crust on the basis of remote sensing data on the ground surface and, in particular, the details of relief heights (in digital elevation models) indicates the complexity and ambiguity of this problem, which requires an integrated research approach.In [*Florinsky, 2016*; *Jordán et al., 2005*], the curvatures of the bed surface function are used as one of the reservoir morphotectonic formalized parameters for lineament tracing, which depend on the second-order directional derivatives. In our study, the value of the second derivative of the profile along the gradient direction is used as follows:

$$C_r = \frac{\partial^2 S}{\partial e^2}, e = \frac{\nabla S}{|\nabla S|}, \tag{1}$$

where $\nabla S = \left(\frac{\partial S}{\partial x}, \frac{\partial S}{\partial y}\right)$ is the gradient of a depth surface defined by the function of coordinates $S(x,y)$. It should be noted that possible locations of tectonic zones correspond to the zero value of parameter C_r.

Using the second derivative of the profile, we compared the pattern of the anomalies in the groundwater major-ion concentrations to the distribution of surface features in the depth maps of the surfaces corresponding to reflectors B (Bazhenov Formation) and A (basement), as well as in the map of the Neocomian surface. The *GST* software [*Sidorov et al., 2005*] was used for calculations.

For the groundwater sampling sites, the values of parameter Cr were calculated for the depth surfaces of the Neocomian and basement top surfaces, and compared to the groundwater salinity values and HCO_3^- concentrations (Figs. 4 and 5). Parameter Cr is plotted along the abscissa; the salinity M (g/L) and HCO_3^- concentration values (mg/L) are given along the ordinate.

The maximum salinity and the HCO_3^- content of the groundwaters from the Neocomian, Achimov and Jurassic strata are circumscribed to the zone of zero Cr values calculated for the depth map of the Neocomian surface (see Fig. 4). Similar calculations based on the basement depth (see Fig. 4) and the Bazhenov Formation surfaces do not show such a pronounced correlation between the profile second derivative Cr and the groundwater composition. Obviously, this indicates that high hydrogeochemical indicators are traced at relatively younger and more active tectonic zones.

Thus, the above-described data analysis shows that the groundwaters from the Urna and Ust-Tegus fields and their vicinity are chemically similar and change monotonously from the Aptian-Cenomanian to Jurassic strata. The aquifers are reliably isolated by rather thick clay layers that obstruct downward migration of water, whereas tectonic processes facilitate ascending water flows along the zones of faults and fractures.

The studies of geothermal conditions in exploration wells of the Urna and Ust-Tegus fields also revealed a number of specific features of the rocks. The temperature logging of the pre-Jurassic rocks show variations from 75 °C to 90 °C. However, the temperature of these rocks does not gradually increase with depth towards the basement (Fig. 6). The observed temperature pattern may result from the hydraulic connectivity between the sedimentary reservoirs and fracture zones in the basement.

4. Reservoir properties

The heterogeneity of the reservoir properties of the Urna and Ust-Tegus productive beds is an indirect evidence of the impacts of several major processes on the hydrodynamic conditions of these fields. In particular, this is manifested by several local extremes in the frequency distribution (histograms) of the porosity values

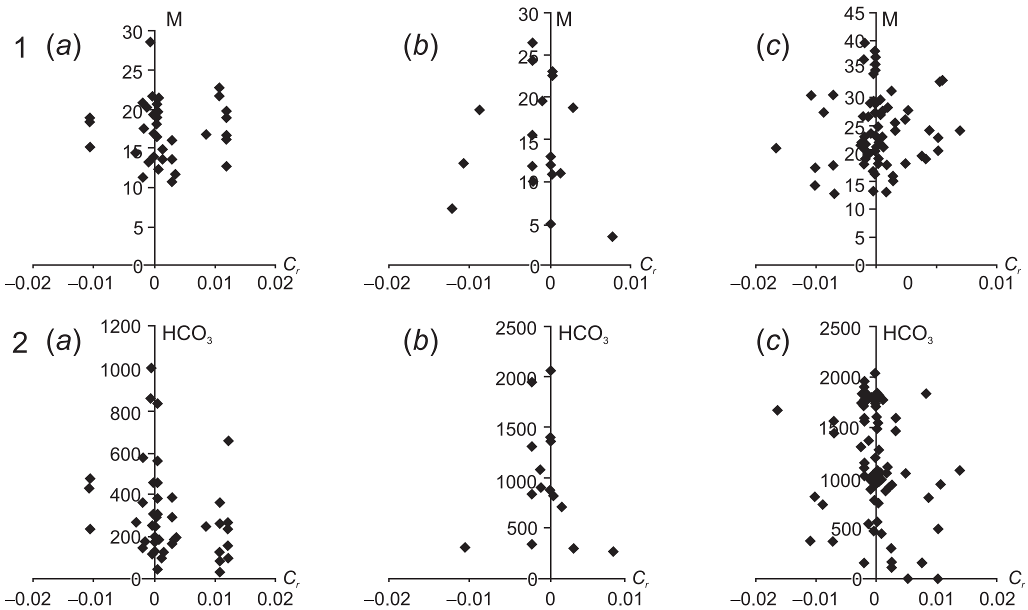

Fig. 4. Profile second derivative (C_r) of the Neocomian surface compared with salinity, g/L (1) and HCO_{3^-} concentration, mg/L (2) in groundwater from Neocomian (*a*), Achimov (*b*), and Jurassic (*c*) strata.

Рис. 4. Сопоставление показателя C_r кровли неокомских отложений с минерализацией (1) и содержанием гидрокарбонат-иона (2) в подземных водах неокомских (*a*), ачимовских (*b*) и юрских (*c*) отложений.

and permeability rates (Fig. 7). The data are presented separately for two lithological types of rocks, sandstones and gravelstones.

In the plots, the porosity values of core samples from reservoir J_1 in the Urna field show several frequency peaks: ~7 %, 10–12 %, 15–16 %, and 22 % (Fig. 7, *a*). The distribution of low porosity values (8 to 15 %) is similar for the two above-mentioned lithological types of rocks. The value of 15–16 % estimated for sandstones is almost twice higher than that for for

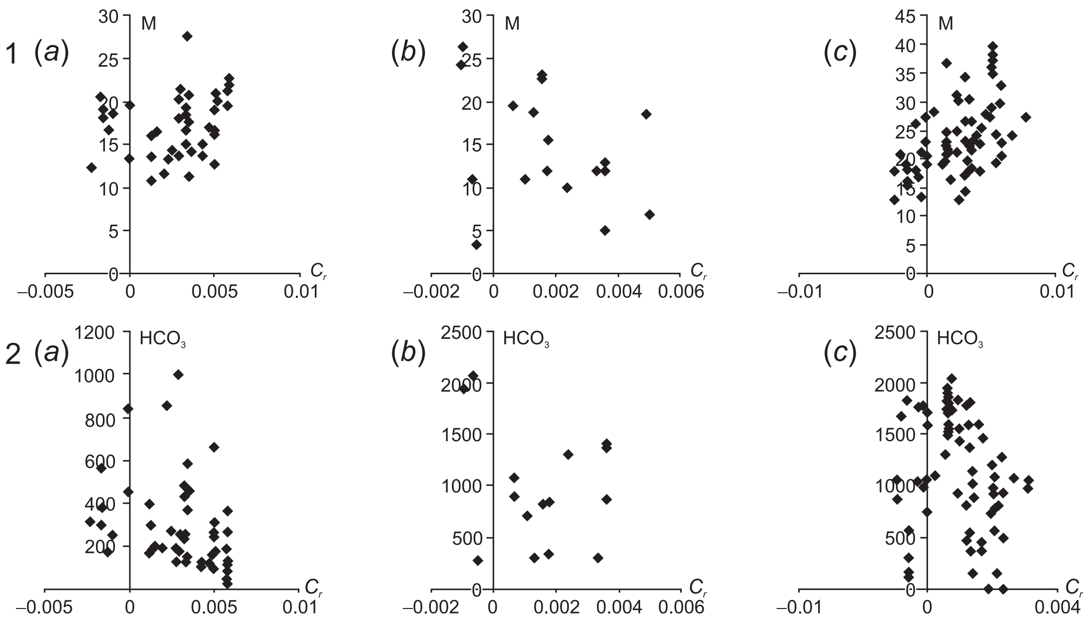

Fig. 5. Profile second derivative (C_r) of the basement surface compared with salinity, g/L (1) and HCO_{3^-} concentration, mg/L (2) in groundwater from Neocomian (*a*), Achimov (*b*), and Jurassic (*c*) strata.

Рис. 5. Сопоставление показателя C_r кровли фундамента с минерализацией (1) и содержанием гидрокарбонат-иона (2) в подземных водах неокомских (*a*), ачимовских (*b*) и юрских (*c*) отложений.

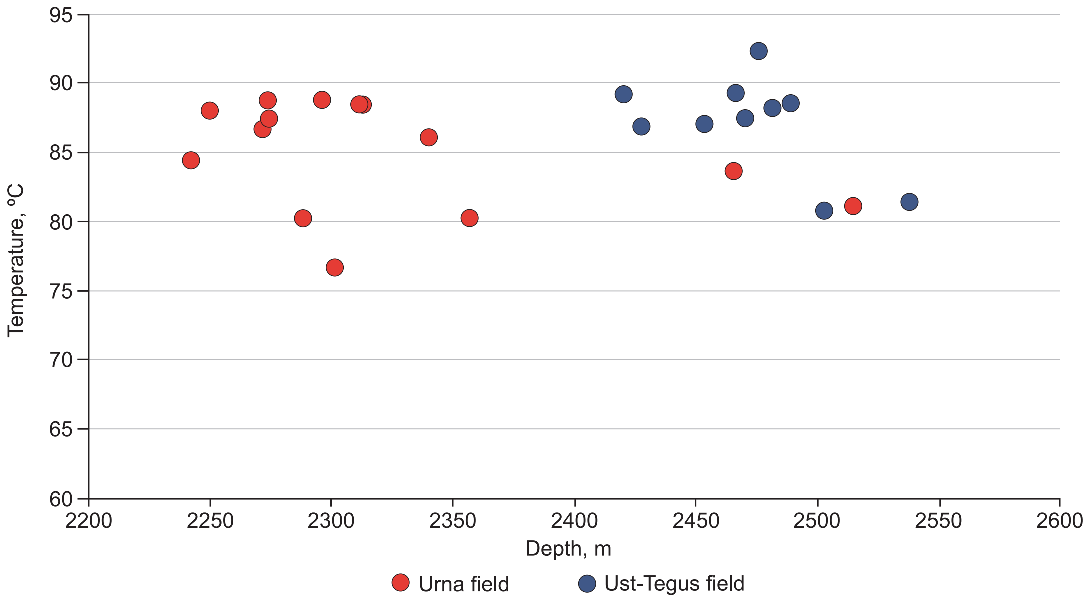

Fig. 6. Temperature variations with depth: pre-Jurassic basement surface (well data) in the Urna and Ust-Tegus fields.

Рис. 6. Сопоставление глубины и температуры по кровле доюрского фундамента (по исследованиям разведочных скважин) в пределах Урненского и Усть-Тегусского месторождений.

gravelstones. The porosity above 20 % is almost exclusively typical of sandstones.

The permeability rates of J_1 rocks vary widely, from 0.01 mD to 1000 mD and range from 500 to 1000 mD in most samples. There is a difference in the distribution of high permeability rates (above 50 mD) for sandstones and gravelstones,while the distribution patterns of low permeability rates (as well as in the porosity distribution) are similar.

In general, the above-described distributions of porosity values and permeability rates are indicative of the sharp heterogeneity of the reservoir properties, which can be schematically represented as a double-pore system, including one space characterized by an average porosity of 15–16 % and permeability of 5–10 mD, and another space with an average porosity of 21–22 % and permeability of 500–1000 md.

Unlike the reservoir properties of the Urna sandstone, the porosity values and permeability rates of core samples from reservoir J_2 in the Ust-Tegus field (Fig. 7, *b*) show distributions with a clearly single frequency peak (with both porosity and permeability increased to a maximum). Open porosity values vary from 13.5 % to 26.6 % and, in most samples, range from 19 % to 22 %, while permeability rates vary widely from 1.0 to 1398 mD and amount to 500–1000 mD in nearly 110 estimates (~50 % estimates).

The analysis of a few samples available to study the properties of reservoir J_3 shows lower porosity values and permeability rates (Fig. 7, *c*) than those of reservoir J_2. In most samples, porosity values and permeability rates range from 15 % to 19 % and 0.1 to 50 mD, respectively. Permeability rates are above 500 mD in a few samples.

In average, porosity (13–21 %) and permeability (5–10 mD) values of sandstone and siltstone in most samples from reservoir J_4 are almost similar to those in reservoir J_2. (Fig. 7, *d*) However, in many samples from reservoir J_4, permeability reaches or exceeds 500 mD.

The signatures of reservoir heterogeneity, which are unexpressed explicitly in the porosity and permeability histograms, are detected when the two parameters are juxtaposed (Figs. 8, 9).

The data from the Urna core samples are split into four subsets (see Fig. 8) with different correlated porosity-permeability patterns depending on the pore sizes of sediments and clay-cement mineralogy [*Shchetinina et al., 2012*]. The Ust-Tegus core samples show two data subsets with lower and higher porosity and permeability ranging, respectively, from 5 to 20 % (average about 15%) and 0.01 to 10 mD in one subset, and from 15 to 25 % and 10 to 1000 mD in the other (see Fig. 8).

In the Urna and Ust-Tegus oil fields, postdepositional processes, including hydrothermalism, are likely to control the features of the reservoir properties [*Bernabé et al., 2003*; *Morad et al., 2010*; *Taylor et al., 2010*]. This idea is supported by the presence of tuff in weathering profiles of the Urna field [*Khasanov et al., 2004*] and tuff breccias in the Ust-Tegus field. The Na-HCO_3 major-ion chemistry of groundwaters in the Jurassic reservoirs of the Ust-Tegus field correlates with the presence of metamorphic carbonates in the basement. This correlation is consistent with redistribution of reservoir properties in the active tectonic zones under

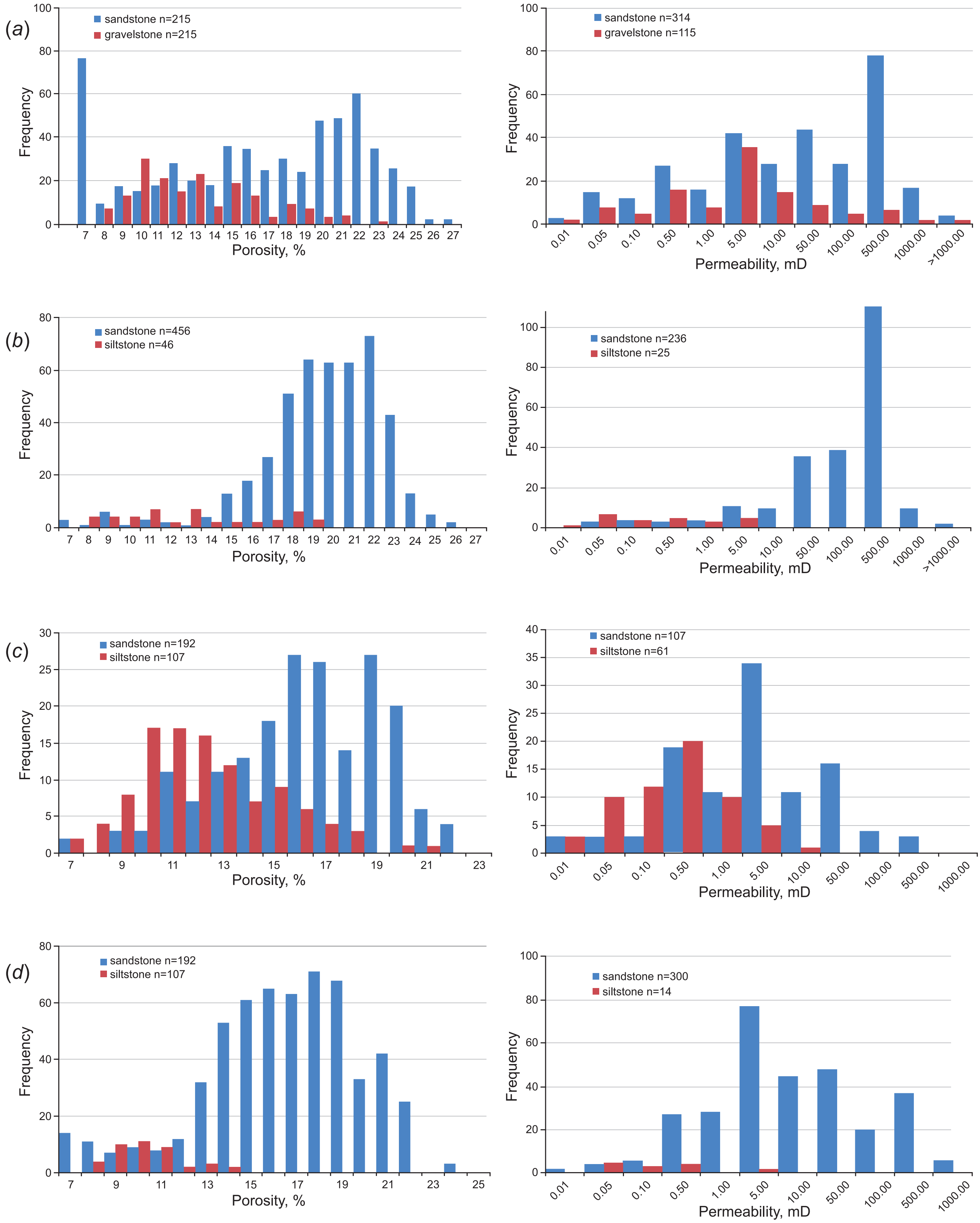

Fig. 7. Porosity and permeability of reservoir J_1 (*a*) in the Urna field and reservoirs J_2 (*b*), J_3 (*c*), and J_4 (*d*) in the Ust-Tegus field.

Рис. 7. Распределение коэффициентов пористости и проницаемости пласта J_1 (*a*) Урненского и пластов J_2 (*b*), J_3 (*c*), J_4 (*d*) Усть-Тегусского месторождения.

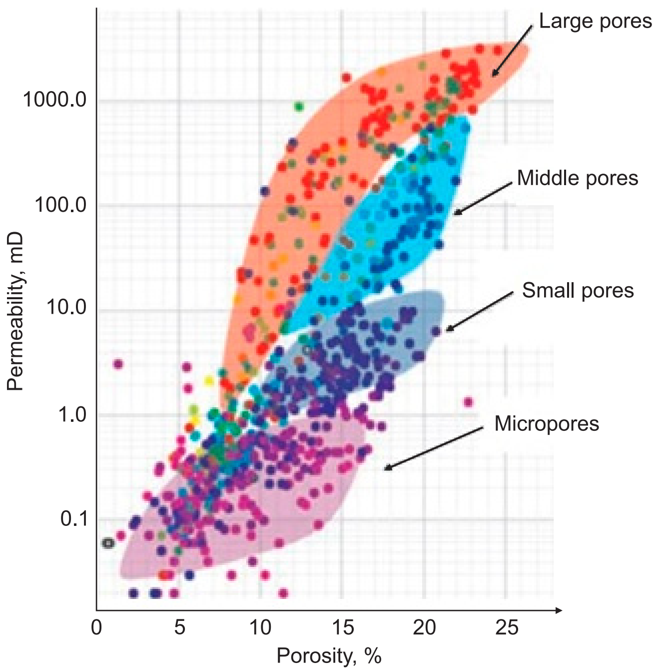

Fig. 8. Permeability vs. porosity variations at different apparent pore sizes (Urna field) [*Shchetinina et al., 2012*].

Рис. 8. Соотношение проницаемости и пористости в зависимости от кажущегося размера пор (Урненское месторождение) [*Shchetinina et al., 2012*].

the effect of CO_2 fluids that penetrate from below [*Aplonov et al., 2000*]. Similar postdepositional processes caused notable secondary changes (the permeability rates amount to 2370 mD in several core samples) to the pore space structure in the Vasyugan Formation of the Dvurechensk oil field [*Nedolivko et al., 2005*].

Thus, the core data show high heterogeneity of the reservoir rock properties of the two oil fields. However, it should be noted that the available highly porous and permeable samples were subject to destruction during drilling and coring and, for this reason, not quite fully represent the maxima reservoir properties associated with micro- and macro-cracks.

The permeability ranges, according to the well pressure transient tests, are 2.13–2818.9 mD (Urna field) and 2.19–672 mD (Ust-Tegus field) and exceed those from the laboratory core analysis. A significant difference between the laboratory and well-test permeability estimates provides additional evidence for the reservoir heterogeneity at both oil fields.

In the frequency histogram (Fig. 10), most of the permeability rates (17 estimates) determined by the well tests at the Urna field range from 1000 to 3000 mD; 13 values are between 500 and 1000 mD. The second local extremum in the distribution refers to permeability values of 10–50 mD. This distribution is generally consistent with that from the core analysis (see Fig. 5), but the peak values are shifted from the 100–500 mD range to that of 1000–3000 mD.

The permeability rates estimated from the well pressure transient tests data at the Ust-Tegus field are mostly between 10 and 50 mD (19 values). Statistically closer to the mean is the extremum in the range from 100 mD to 200 mD, followed by another frequency peak of permeability rates exceeding 500 mD. This comparison demonstrates the significant structural heterogeneity of the reservoir properties of the Urna and Ust-Tegus oil fields.

In general, for the Urna field, the core permeability rates are lower than those determined from the well pressure transient test data. Obviously, this may be due

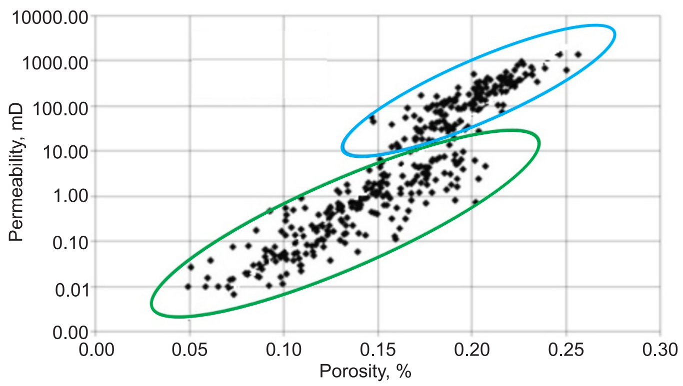

Fig. 9. Permeability vs. porosity variations in core samples from reservoirs J_{2-4}, Ust-Tegus field

Рис. 9. Соотношение проницаемости и пористости образцов керна пластов J_{2-4} Усть-Тегусского месторождения.

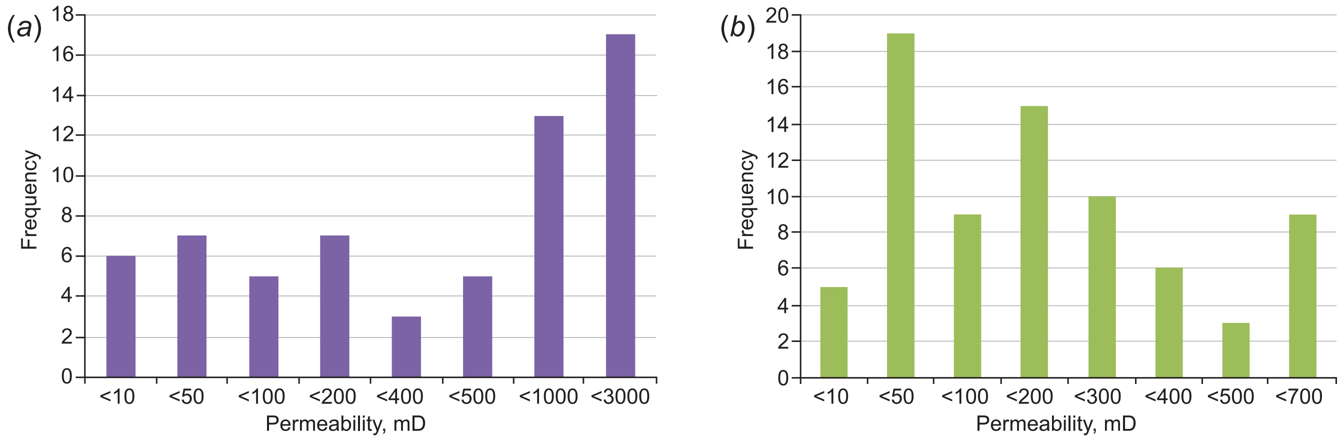

Fig. 10. Permeability histograms based on well test data from the Urna (*a*) and Ust'-Tegus (*b*) fields.

Рис. 10. Распределение значений проницаемости, определенных по результатам ГДИ для Урненского (*a*) и Усть-Тегусского (*b*) месторождений.

to the presence of highly permeable reservoirs of both fracture- and pore-types. For the Ust-Tegus productive rocks, the differences of such a scale in permeability rates determined from various types of data are rare.

5. Comparison of tectonic conditions and productive rock hydrodynamic properties

To assess the relationships between tectonic and hydrodynamic conditions, tracer methods of reservoir research are commonly used [*Huang et al., 2018*; *Wu et al., 2011*; *Yao et al., 2016*]. The results of tracer tests at the Urna field demonstrate that these relationships are ambiguous (Fig. 11). Similar results were obtained at the Ust-Tegus field.

Figure 11 shows the wells directly involved in the tests. Producers with high contents of the tracer fluid are shown by yellow circles (3). Yellow cross-circles show producers with low contents of the tracer fluid (4). Wells wherein the tracer fluid was absent are shown in purple (5). The blue diagram (10) illustrates the predominant directions and amounts of the tracer fluid input into the producer wells. The figure also shows stress zones revealed from elevation data (8) and fractured zones revealed from seismic data (9).

The zones of stress and fracturing are closely spaced, and many of them are located between the producer wells (Fig. 11). However, any specific correlation between their positions and the flow patterns between the wells has not been detected. For instance, fractured zones (green lines) between injector 1050 and most of the producers do not affect much the migration of the tracer fluid. It should be noted that all the wells (except well 103) involved in the above-described tests are located within a single block bordered by stress zones (red lines), wherein no tracer input was observed.

The tracer contents were high in producers 1221 and 1214, that are separated from the injector by a stress zone. The connectivity of injector 1222 was poor with producers 1227 and 1233 and zero with wells 1232 and 1229, even though there are no deformation zones between these wells.

Numerous tectonic fractures and stress zones have been detected in the two fields, but their tracing is

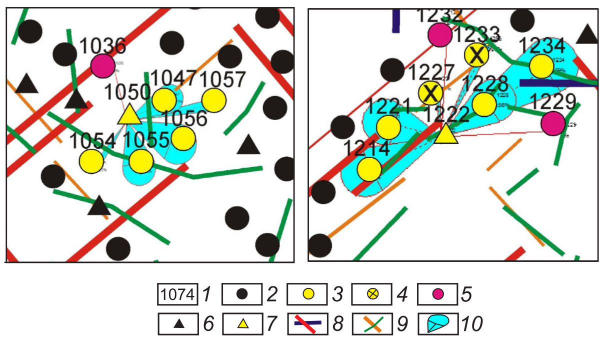

Fig. 11. Migration of the tracer fluid from injectors to producers: test results (Urna field).

1 – well number; *2–5* – producers; *6–7* – injectors; *8–9* –zones of stress and fracturing; *10* – injection directions and amounts of the injected tracer fluid. See text for explanation.

Рис. 11. Миграция трассирующей жидкости от нагнетательных к добывающим скважинам: результаты испытаний (Урненское месторождение).

1 – номер скважины; *2–5* – добывающие скважины; *6–7* – нагнетательные скважины; *8–9* – динамически напряженные зоны и зоны трещиноватости; *10* – направления и объемы фильтрации индикатора.

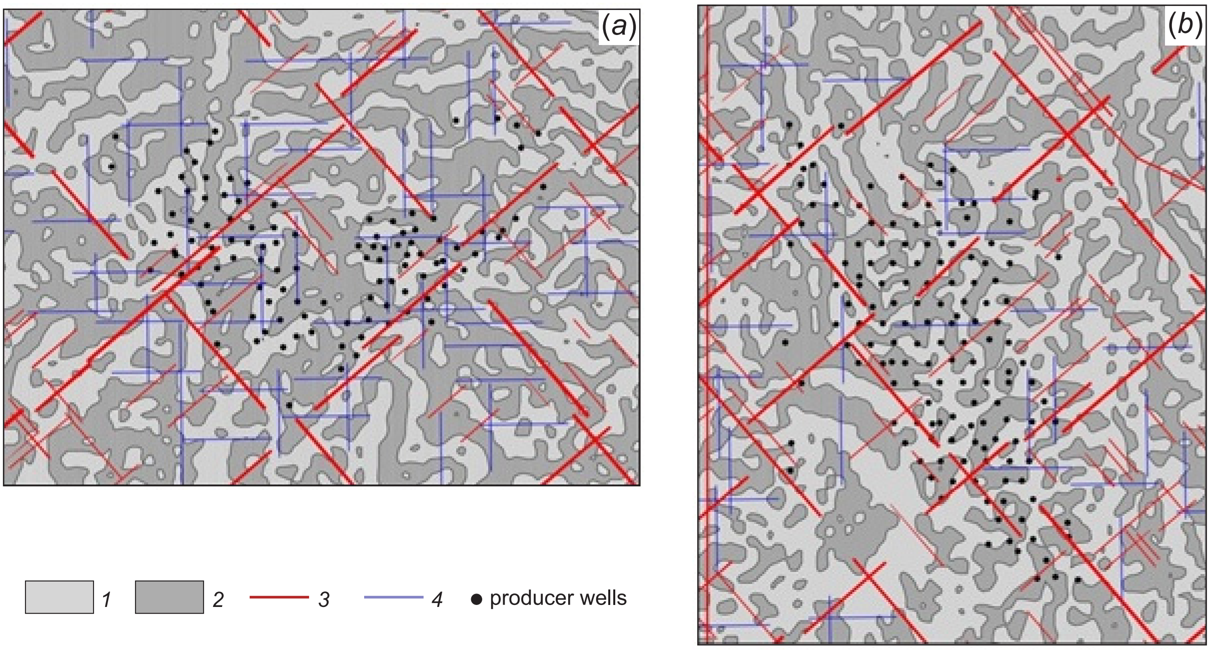

Fig. 12. Morphotectonic elements identified in the Urna (*a*) and Ust'-Tegus (*b*) fields.

1 – negative elements; *2* – positive elements; *3–4* – boundaries of regional and subregional stress zones.

Рис. 12. Выделение детализированных морфоструктурных элементов в пределах Урненского (*a*) и Усть-Тегусского (*b*) месторождений.

1 – отрицательные морфоструктурные элементы; *2* – положительные морфоструктурные элементы; *3–4* – границы региональных и субрегиональных зон напряжений.

challenging, which makes it difficult to analyze the spatial patterns of the reservoir properties. Thus, in order to study a correlation between tectonic conditions and reservoir properties, it is required to apply other approaches, in addition to the conventional methods.

This task can be addressed by the morphotectonic analysis of depth maps constructed on the basis of reflection surfaces, using the curvature of normal plane section in gradient direction (profile curvature C_r, see above). However, rather than searching for lineaments or other boundaries, the proposed approach is focused on dividing the territory into elements, that are shifted vertically relative to each other and comprise the continuous zones of positive and negative C_r values, and transitional zones ('slope breaks') that can be easily identified along their boundaries.

We have applied the above-described approach (Fig. 12) using the depth map of the pre-Jurassic basement surface (see Fig. 3). In our model, we analyzed the clay contents and permeability rates estimated from the well test data on more than 100 production wells located in different morphotectonic elements (Table 4).

Despite the fact that the yielded difference between the considered parameters is not very reliable statistically (in most estimates, the confidence level is below 95 %), the analysis results reveal some patterns. The most spectacular one is a stable change in the average permeability rates estimated from the well pressure transient tests: lowest for positive C_r, high for negative C_r, and the highest for slope breaks, in both oil fields (Table 4). The clay contents, on the contrary, are the lowest at the slope breaks and the highest at the positive slope convexity. Such a correlation between the permeability rates and clay contents appears quite reasonable and supports a correlation between the reservoir properties of the Jurassic sediments in the Urna and Ust-Tegus oil fields and the locations of positive and negative morphotectonic elements.

Certainly, having analyzed only one basement depth map, it is hard to expect obtaining fundamentally new results that could clarify an interplay between geodynamic factors and reservoir properties Nevertheless, our study demonstrates that the use of additional quantifiable parameters characterizing the structure of deep surfaces is a promising approach to studying oil and gas fields.

6. Conclusions

The effect of geodynamic factors on the structure and properties of reservoir rocks has been revealed in our study of the Urna and Ust-Tegus oil fields in West

Table 4. **Permeability rates and clay contents in the morphotectonic elements of the Urna and Ust-Tegus oil fields**

Таблица 4. **Статистические характеристики значений проницаемости и глинистости отложений**

Morphotectonic element	Oil field	Average	Minimum	Maximum	Standard deviation
		Permeability (well tests), mD			
+	Urna	643.8	2.13	2790	737.4
–		841.1	20.5	2818.9	791.5
B		923	4.89	1540	866.7
+	Ust-Tegus	148.2	2.93	615	149.8
–		241.4	2.19	643.5	206.3
B		472.1	284	657.8	186.9
		Clay content, u.f.			
+	Urna	0.1	0.02	0.49	0.086
–		0.08	0	0.27	0.061
B		0.06	0.01	0.11	0.046
+	Ust-Tegus	0.15	0	0.46	0.126
–		0.11	0	0.54	0.124
B		0.07	0	0.33	0.103

Note. Symbols + and – refer to the data on elements with positive and negative profile curvature C_r, respectively; B – data on slope breaks.

Примечание. Символы + и – указывают на данные об элементах с положительной и отрицательной кривизной профиля C_r, соответственно; B – данные об уклонах.

Siberia. This effect is evident yet ambiguous, which poses problems to its investigation and requires improvements to the analysis and interpretation of the available geological survey and exploration data.

Strong tectonic processes, accompanied by periodic magma intrusions, produced numerous fractures and faults in the Jurassic sediments, which act as conduits for groundwater flows, and thus led to the hydrothermal alteration of rocks and changes in the pore space. These processes are reflected in the modern hydrogeochemical and geothermal conditions of the Jurassic-Cretaceous reservoirs at the Urna and Ust-Tegus oil fields and their vicinity. This is evidenced by the regularities of changes in the chemical compositions of the groundwaters, the maximum values of mineralization and the contents of bicarbonate-ion in the areas with characteristic morphotectonic features of the aquifers, as well as by the lacking trend of an increase in the sediment temperature with depth.

The reservoir properties of the two fields are significantly heterogeneous due to the combined impacts of tectonic, magmatic, and hydrothermal processes, which is confirmed by the laboratory core analysis and the well pressure transient tests. Significant variations of the porosity values and permeability rates are characteristic of both fields. Furthermore, there are several extremes in the frequency distribution of these parameters, and differences in the ratios of theparameters for different groups of the core samples.

Moreover, based on the results of the well tests with the tracer fluid, no evident spatial correlation between the tectonic and hydrodynamic features has been identified, while the effect of the geodynamic factors on the heterogeneity of reservoir properties is considerable. Thus, new approaches are required to analyze the geodynamic conditions and their correlation with porosity and permeability of sediments in the oil and gas fields. In our study, we have tested a new approach based on using the morphotectonic features detectable in the depth maps of reference surfaces reconstructed from seismic reflection data. This promising tool is a useful addition to conventional methods used for discovering possible correlations between tectonic factors and fluid dynamics.

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