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NEW APPROACH TO RANKING OF JURASSIC SEDIMENTARY COMPLEXES OF THE NORTHERN PART OF THE WEST SIBERIAN PETROLEUM BASIN

I.A. Panarin
LUKOIL-Engineering LLC, Moscow, Russia
E-mail: niranap@mail.ru

Abstract. Recent events, such as the commencement of commercial development of the Novoportovskoye, Bovanenkovskoye fields in the Yamal Peninsula, the creation of infrastructure, pipeline and railway transport facilities, and the decision to build an liquified natural gas plant for the Tambey group of fields, – all of it builds a case for increasing the exploration of the resource base of the northern territories of West Siberian petroleum basin and the adjacent Kara Sea offshore. Jurassic hydrocarbon exploration leads/prospects have not been sufficiently studied and require additional exploration.

The resource potential of Jurassic and Cretaceous reservoirs of South Kara region are estimated by various authors from 18,5 to 41,2 billion tons of oil equivalent. The systematization of information was executed from different sources and in the presented work was proposed the methodology for ranking the Jurassic sedimentary complexes.

The ranking of selected fundamental characteristics were divided into three groups depending on their priority. This method allowed to determine the most prospective intervals of the Jurassic section for further study.

The priority targets for further exploration in the Jurassic section based on the ranking results are the Middle Jurassic reservoirs of the Lower Bajocian-Upper Bathonian and Upper Aalenian-Lower Bajocian sedimentary complexes and the Upper Jurassic Callovian-Tithonian reservoirs.

Key words: ranking, exploration leads/prospects, Jurassic reservoirs, Western Siberia

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Despite the high level of production that has been maintained in this region for over 50 years, the West Siberian petroleum basin (PB) has an enormous potential for discovering new fields. The prospects of exploring for large oil and gas fields in West Siberian PB are mainly associated with its northern poorly developed territories of the Yamal and Gydan Peninsulas, and the adjacent Kara Sea offshore with deep sedimentary cover and unconventional structural-lithological hydrocarbon traps.

The low exploration maturity of the Jurassic reservoirs of the Yamal and Gydan petroleum areas (PA) and the adjacent Kara Sea offshore hinders forecasting the conditions for the formation of possible large and unique accumulations of oil and gas. Studies focusing on the architecture of main reservoirs, promising from the point of view of further hydrocarbon (HC) exploration, also remain insufficient. The relevance of research in this area is also supported by the fact that the majority of the fields are a rather complex object of research, and the details of their geological setting are not fully taken into account during exploration planning.

The resource base of the region under study is colossal and, naturally, many oil and gas producing companies strive to increase it through exploration in this region. An example of this is the discovery by Rosneft in 2014 of the Pobeda oil- gas-condensate field on Universitetskaya structure in Kara Sea offshore in Cretaceous and Jurassic deposits. According to preliminary estimates, the in-place volumes of the discovered field are 338 billion cubic meters of gas and more than 100 million tons of oil (www.rosneft.ru).

The gas potential of the entire Yamal region can reach 61-62 trillion m^3, and in addition, there are 13.8 trillion m^3 of in-place resources in the "marginal" and tight reservoirs (with gas recovery factors of no more than 0.25), including onshore Yamal – 22.5 trillion m^3/4.5 trillion m^3 (in-place/reserves), offshore – 39.1/9.3 trillion m^3 (Skorobogatov, 2013). The resource potential of the Jurassic and Cretaceous complexes of the South Kara PA is estimated at 18.5 to 41.2 billion tons of oil equivalent. The minimum and maximum estimates differ by more than 100%, which confirms the low exploration maturity of the region (Kazanenkov et al., 2014). N.Ya. Kunin estimated the resources of the Jurassic-Cretaceous deposits of the Gydan Peninsula at 40 billion tons of oil equivalent, mainly oil. According to A.R. Kurchikov and others (2012), the initial total hydrocarbon resources (ITR) of the Gydan

PA are more modest and amount to 9772.1 million tons of oil equivalent, including oil – 938.1 million tons, gas – 8181.1 billion m^3, and condensate – 652.8 million tons (Kazanenkov et al., 2014).

The share of hydrocarbon resources of the Jurassic complex is much less than that of the Cretaceous one and accounts for 10-20% of the total volume (Kurchikov et al., 2012). Thus, it is believed that the primary targets for exploration and further development of the discovered fields in this region are mainly associated with the Cretaceous productive horizons of Yamal, Gydan and the Kara Sea offshore, taking into account mainly their shallow depths and better reservoir properties vs. Jurassic prospects. This results in significantly lower exploration, development and commissioning costs. However, the emergence of new technologies that significantly accelerate drilling operations (including offshore) and allow cost savings, is expected to offset this difference in the near future. In addition, it is necessary to account for the rather rich Western (mainly US) experience of hydrocarbon production from rocks, which were traditionally considered non-reservoirs (shales, low permeability rocks).

Thus, it is time to evaluate and plan exploration programs taking into account the discovery potential in the Jurassic complex, which is regionally associated mainly with positive structures, such as swells and uplifts (Panarin, 2012).

In this paper, we propose to rank the Jurassic sedimentary complexes (SC) and identify the most promising of them. In total, according to the data of various researchers, six such complexes are identified: the Hettangian-Lower Pliensbachian, the Upper Pliensbachian, and the Toarcian-Lower Aalenian; the Upper Aalenian-Lower Bajocian; the Lower Bathonian-Upper Bathonian and the Callovian-Tithonian (Figure 1).

Ranking methodology

To perform the ranking of the Jurassic sedimentary complexes, some basic characteristics were selected, which were then divided into three groups depending on the degree of priority (first, second and third order characteristics – Table 1). The characteristics of the **first order** include five most significant conditions:

- Presence of a high-quality seal – preservation conditions;
- Generation potential of the SC oil source unit – generation conditions;
- Specific productivity of similar complexes in adjacent areas;
- Distribution of SC reservoir rocks (local or regional);
- Number of identified reservoirs in SC.

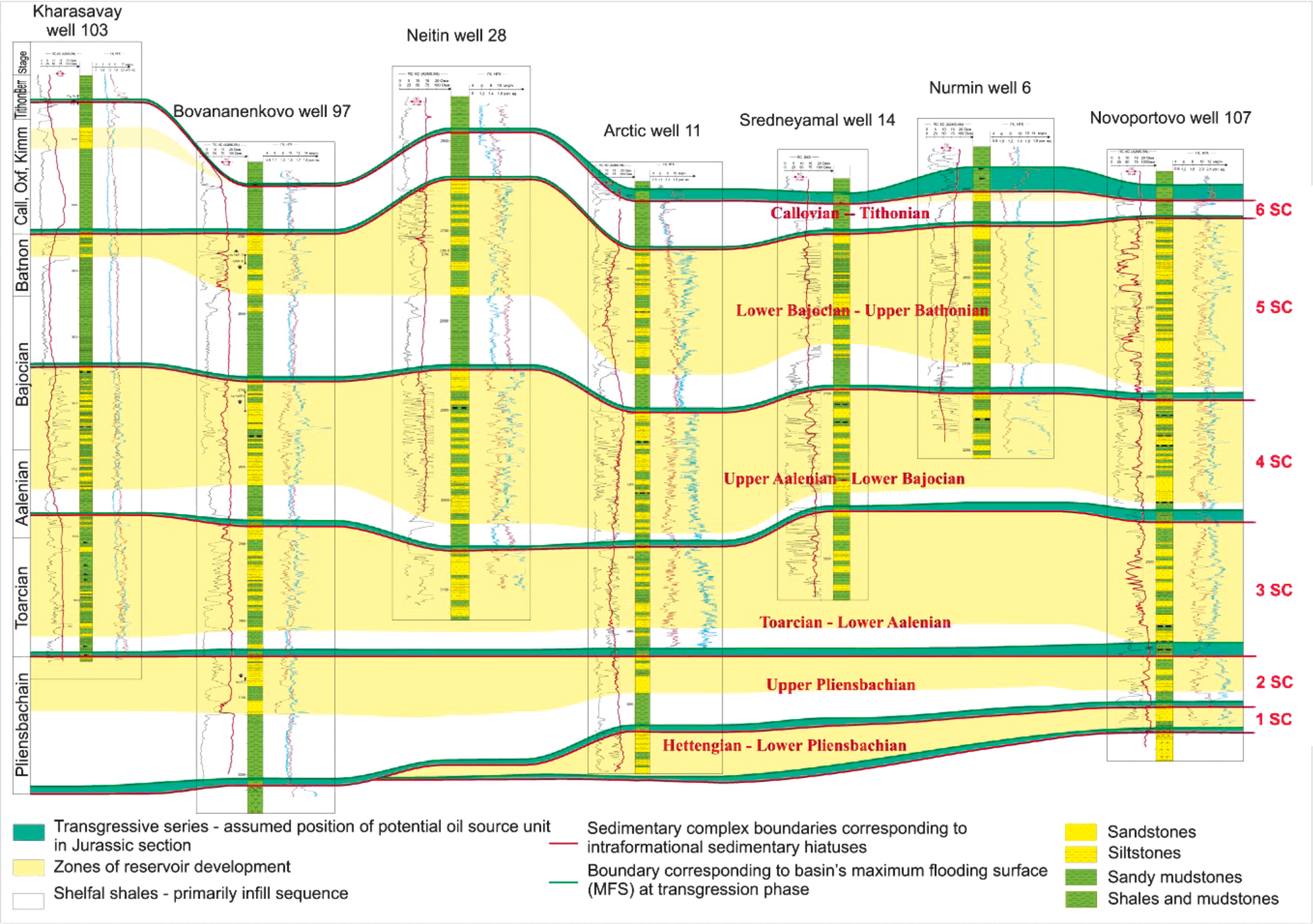

Figure 1. Jurassic sedimentary complexes of the Northern part of Western Siberia PB

Field	Type	Productive zone (reservoir)	Productive horizon	Choke diameter, min/max, mm	Oil rate, min/max, m^3/d	Gas rate, min/max, k m^3/d	Condensate rate, min/max, m^3/d
Bovanenkovo	G-C	Yu$_{12}$	Zimny	12	-	76,9	14,57
Novoportovskoye	G-C	Yu11	Sharapov	5/16	-	G+C 25.7/175.62	
Bovanenkovo	G-C	Yu10	Nadoyakha		-	111,01	41
West Tambei	G-C	Yu6-7	Vymsk	10	-	44,98	no data
Malygin	G-C	Yu6-7	Vymsk	10,5/20,3	-	28.7/544.5	6.8/34.9
Nurmin (non-commercial flow)	O	Yu8	Vymsk	no data	0,1	no data	-
Novoportovskoye	O	Yu2-3	Malyshev	no data	288	176	38
Tazov	G-C	Yu2-3	Malyshev	no data	-	519	no data
Kharasavay	G-C	Yu2-3	Malyshev	14/19	-	149/283	no data
Maloyamal	G-C	Yu2-3	Malyshev	5,4	-	14,3	no data
Maloyamal	G-C	Yu4	Malyshev	14,5	-	164,4	no data
Yubilei	O	Yu2	Malyshev	9	13,2	13,7	no data
Urngoi (Pestsov area)	G-C	Yu2	Malyshev	5	-	126	65
Geophysics field	G-C	Yu2	Malyshev	15	-	68	no data
Beregovoye	O	Yu2-3	Malyshev	5/8	9.6/15	-	-
North Tambei	G-C	Yu2	Malyshev	20	-	77	no data
Lenzit	O	Yu2	Malyshev	no data	0.225-5	-	-
Urengoi (S.Pestsov area)	G-C	Yu3	Malyshev	5	-	35	7
Russko-Rechensk	G-C	Yu1	Vasyugan	8/17	-	168/740	109/180
Mangazei	O	Yu1	Vasyugan	no data	5.4/14.2	-	-
Limbayakha	O	Yu1	Vasyugan	4	6.2/26.2	-	-
Yarovoye	O-G-C	Yu1	Vasyugan	8	14.1/64.4	52/170	18.1/19.5
Naumov	G-C	Yu1	Vasyugan	4/8	-	11/116	4/63

Table 1. Productivity of Jurassic targets (Skorobogatov et al., 2003)

Second-order characteristics:
- Total SC in-place volumes in the study region;
- Average reservoir rock porosity;
- Average reservoir rock permeability;
- Average SC net sand;
- Depth of occurence;
- Vertical zone heterogeneity (average NTG).

Third-order characteristics include:
- Environments of deposition (EODs);
- The predominant composition of the reservoir rock cement;
- Percentage of cement in inter-pore space.

The above characteristics did not include important properties complicating further development of reservoirs, for example, such fluid properties as viscosity, density, content of harmful components (hydrogen sulphide, carbon dioxide) or overpressure. This is due to the fact that oil or condensate of discovered reservoirs in Jurassic SCs have similar features – they are light or very light and have low viscosity, and also contain practically no harmful components. And almost all the reservoirs of the complexes have characteristic overpressure conditions. So in this particular case, these items were excluded from ranking.

To determine the priority level of each six SCs, the scoring system was used from 1 to 6. One point corresponds to the lowest priority, the six points to the highest priority.

Thus, all sedimentary complexes received their own score for each of the characteristics (Table 2). But for the final ranking, each score should be multiplied by a factor depending on the priority level of each characteristic – the first order parameters must be multiplied by the maximum coefficient of 3, the second order by the coefficient of 2 and the third order by the coefficient of 1 (Table 3). The sum of all points, with the weighting factor and the ranking results, is presented in Table 4.

First-order characteristics

Presence of quality seal

The maximum score (6) is assigned to the Malyshev Horizon, since the quality of the overlying Bazhenov and Abalak seals is probably beyond doubt. The second highest score (5) is Vymsky Horizon, considering the thick predominantly shale unit (up to 200 meters) of the Lower Bajocian-Upper Bathonian SC. Four (4) points were awarded to the Vasyugan Horizon, since the lower part of the Cretaceous complex contain shales of the Akhsky

INTERNATIONAL SCALE				Regional scale		Gydan PA (Petroleum Area)						Yamal PA									Nadym-Pur PA							Pur-Tazov PA								South Kara PA
						Messov PD (Petroleum District)					Napalkov PD	Nurmin PD			Malygin PD	Tambei PD			South Yamal PD		Urengoi PD					Nadym PD		Tazov PD								
						North Parusov	Minkhov	East Messoyakha	East Minkhov	Semakov	Geophysics field	Bovanenkovo	Neitin	Kharasavay	Malygin	North Tambei	West Tambei	South Tambei	Maloyamal	Novoportovo	Medvezhie	Samburg	Urengoi	North Urengoi	Lenzit	Yamburg	Yurkhar	Russko-Rechensk	Mangazei	Limbayakha	Yarovoye	Naumov	Zapolyarnoye	Ust-Yamsovey	Tazov	Pobeda
Era	System	Subsystem	Stage	Suite		F I E L D S																														
Mesozoic (Mz)	Jurassic (J)	Upper (J3)	Volgian (J3v)	Bazhenov (K1-J3bg)	Danilov (J2-3dn)																															
			Kimmeridgean(J3rm) Oxfordian (J3o) Callovian (J2k)	Abalakov (J2-3ab)			(?) Yu1	🟧 Yu1	(?) Yu1	(?) Yu1			🟩 Yu1									(?) Yu1		🟧 Yu1				🔴 Yu1	🟢 Yu1	🟢 Yu1	🟡 Yu1	🔴 Yu1			🟦 Yu1	
		Middle (J2)	Bathonian(J2bt)	Malyshev (J2ml)	Tyumen (J2tm)	🔴 Yu2					🔴 Yu2	🔴 Yu2-3		🔴 Yu2-3	🔴 Yu2-3	🔴 Yu2		🔴 Yu2,Yu3, Yu4	🔴 Yu2-3 Yu4	🟡 Yu2-6	🟢 Yu2		🟡 Yu2 Yu3 Yu4		🟢 Yu2	🔴 Yu2	🔴 Yu2						🔴 Yu2	🟩 Yu2 🟧 Yu4	🔴 Yu2-3	🟡 Yu2-6
			Bajocian (J2b)	Leontiev (J2ln)								🔴 Yu6			🔴 Yu6		🔴 Yu6																	🟧 Yu5		
				Vymsk (J2vm)								🔴 Yu7			🔴 Yu7		🔴 Yu7	🔴 Yu7,Yu8																		
			Aalenian (J2a)	Laidin (J1-J2ld)																																
		Lower (J1)	Toarcian (J1t)	Jangod (J1dg)								🔴 Yu10																								🟡 Yu10-11
			Pliensbachian(J1p)	Levin (J1lv)																🔴 Yu11																
			Sinemurian-Hettangian (J1s-g)	Zimny (J1zm)								🔴 Yu12																								

Reservoir (zone) indexation:
Vasyugan SC - Yu1;
Malyshev SC - Yu2, Yu3, Yu4;
Yuymsk SC - Yu5, Yu6, Yu7, Yu8, Yu9;
Nadoyakha SC - Yu10;
Sharapov SC - Yu11;
Zimny SC - Yu12.

Productive reservoirs	Potentially productive reservoirs
🟢 Oil	🟩 Oil
🔴 Gas-condensate	🟦 Oil-gas
🟡 Oil-gas-condensate	🟧 Gas
	(?) Assumed productivity

Table 2. Hydrocarbon systems of Jurassic SCs in the North of Western Siberia

Upper Jurassic (Callovian-Tithonian)				
		C1	C2	C1+C2
OOIP	k tons	12561	44938	57499
OGIP	M m^3	12988	8794	21782
OCIP	k tons	3088	1366	4454
OHCIP	k tons OE	28637	55098	**83735**
Middle Jurassic 1 (Lower Bajocian-Upper Bathonian)				
		C1	C2	C1+C2
OOIP	k tons	326082	212688	538770
OGIP	M m^3	247417	668526	915943
OCIP	k tons	48559	128587	177146
OHCIP	k tons OE	622058	1009801	**1631859**
Middle Jurassic 2 (Upper Aalenian-Lower Bajocian)				
		C1	C2	C1+C2
OOIP	k tons	0	0	0
OGIP	M m^3	97409	245033	342442
OCIP	k tons	18490	32915	51405
OHCIP	k tons OE	115899	277948	**393847**
Lower Jurassic 1 (Toarcian-Lower Aalenian)				
		C1	C2	C1+C2
OOIP	k tons	0	0	0
OGIP	M m^3	3007	60531	63538
OCIP	k tons	467	9385	9852
OHCIP	k tons OE	3474	69916	**73390**
Lower Jurassic 2 (Upper Pliensbachian)				
		C1	C2	C1+C2
OOIP	k tons	0	0	0
OGIP	M m^3	5959	1152	7111
OCIP	k tons	362	70	432
OHCIP	k tons OE	6321	1222	**7543**
Lower Jurassic 3 (Toarcian-Lower Aalenian)				
		C1	C2	C1+C2
OOIP	k tons	0	0	0
OGIP	M m^3	12637	31758	44395
OCIP	k tons	1960	5220	7180
OHCIP	k tons OE	14597	36978	**51575**

Table 3. Initial HCIP of Jurassic sedimentary complexes

Suite (up to 100 meters thick), which are widespread, and predicted reservoirs will be mainly confined to lithological (non-structural) traps and will be sealed, including shales of the same SC (Abalak and Bazhenov shales). Three (3) points were awarded to the Zimny Horizon, as its preservation is provided by a thick Levin unit. Two (2) points are assigned to Sharapov Horizon, considering its insignificant average seal thickness (62.5 m).

1 point is given to the Nadoyakh Horizon with the minimum shale thickness (about 30 meters on average).

Oil source rock generation potential

The ranking was perfomed according to the average Corg content, so the targets were ranked in the following order: Nadoyakh (3.13%), Vymsky (1.52%), Malyshev (0.94%), Vasyugan (0.79%), Zimny (0.83%), Sharapov (0.75%).

Specific productivity of similar complexes in adjacent areas

The best indicators of productivity by the analog field are reservoirs of the Callovian-Tithonian SC. However, the productivity of the Lower Bajocian-Upper Bathonian reservoirs based on the production test results has been proven at least 12 zones (Table 1) of the sedimentary complex; in addition, the Yu$_{2-3}$ zone at the Novoportovskoye field is already in commercial production. Therefore, the highest score for this characteristic was assigned to the Malyshev reservoirs (6 points). The productivity of Vasyugan reservoirs (score of 5) in the study region is proved at 5 fields, the maximum gas productivity is recorded at the Russnekschenskoye field (up to 34,400 m^3 of gas/m). Commercial gas and condensate flows from the Vymsky reservoirs were obtained in the West Tambey and Malygin fields, so they were given a third degree of priority. The maximum productivity for the Lower Jurassic zones is related to the Sharapov reservoir (4,500 m^3 of gas / m) of the Novoportovskoye field (3 points), the minimum specific productivity indicator corresponds to the Yu$_{10}$ (Nadoyakhsky reservoir) of the Bovanenkovskoye field (1 point).

Distribution of SC reservoir rocks

Malyshev, Vymsk, Nadoyakh and Sharapov reservoirs were discovered in all wells of the study region, and taking into account their regional distribution, a maximum score of 6 was assigned to this characteristic. For locally distributed Zimny (SC deposits mainly fill the slopes of positive structures and deep depressions) and Vasyugan reservoirs (shaled out in many wells in the region) was awarded a score of 3.

Number of fields with reservoirs identified in SC

The largest number of fields with discovered hydrocarbon reservoirs in the Malyshev zones (17 fields plus 1 field with oil and gas shows). The Vasyugan sandstones are productive in 5 fields (Table 2) of the study region (plus oil and gas shows during drilling in 8 fields), the Vymsky complex is productive in 4 fields (in addition, gas shows were recorded at the Ust-Yamsoveiskoye field). The productivity of the Zimny reservoir was proven only in one reservoir of the Bovanenkovskoye field (1 point), Sharapov – in the Novoportovskoye and the Pobeda fields, the Nadoyakh – in the Bovanenkovskoye and Pobeda fields. The ranking of the Lower Jurassic Sharapov and Nadoyakh reservoirs was made accounting for the number of discovered reservoirs: Sharapov – 3 points (8 reservoirs), Nadoyakh – 2 points (3 reservoirs).

Second-order characteristics

Total resources of the SC in the study region

The estimate of the resource base in Jurassic complexes used data from 2014 State Reserves Balance.

Name of sedimentary complex (reservoir name)	SC №	First-order characteristics					Second-order characteristics						Third-order characteristics		
		Presence of quality seal	Oil source generation potential	Specific productivity in adjacent areas	Distribution of sedimentary complex reservoir rocks	Number of fields w/reservoirs identified in SC / with oil/gas shows	Total SC HC voulmes in study region	Average porosity	Average permeability	Average net sands of sedimentary complex	SC depth of occurrence	Reservoir vertical heterogeneity (NTG)	Enviroments of deposition	Cement composition and content in reservoir rocks	
		Thickness, m	Corg/DOM content, %	gas k m^3 / m or oil m$^{3/}$ d/m	Regional / Local	Unit	M tons OE	%	mD	m	m	fraction		Dominant composition	Content, %
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Callovian-Tithonian (Vasyugan)	**1**	7-90	1.44 / 0.35-1.21	gas 34.4 k m^3 / m (Russko-Rechensk) oil 3.0 m^3 /d / m (Yarovoye)	Local	5 / 8	84	8-28, average 12-18	0.01-1690, average 0.01-100	21,5	2450-3150 *top tvdss	0,23	Shallow-marine	clay-carbonate, carbonate-clay	3-10
Lower Bajocian-Upper Bathonian (Malyshev)	**2**	first tens to 200 m average 80-150, property degradation towards basin periphery	2.14 / 0.53-1.33	gas 7.7 k m^3 / m (Tazov); oil 4.3 m^3-/d / m (Novoportovo)	Regional	17 / 1	1632	8-27, average 13-17	0.01-214, average 0.01-10	67,0	2520-3570 *top tvdss	0,32	Continental, shallow-marine	Carbonate-clay	5-15
Upper Aalenian-Lower Bajocian (Vymsk)	**3**	60-150, w/sandstone, siltstone interlayers	2.17 / 0.64-2.38	gas 7.1 k m^3 / m (Malygin);	Regional	4 / 1	394	8-23, average 11-16	0.01-98, average 0.01-1	76,5	2550-3700 *top tvdss	0,45	Continental, shallow-marine	Clay, carbonate-clay	5-15
Toarcian-Lower Aalenian (Nadoyakha)	**4**	first tens to 60, increase of sand to the south	2.03 / 0.96-5.2	gas 1.8 k m^3 / m (Bovanenkovo)	Regional	2 (3 reservoirs) / 0	73	8-24, average 10-15	0.01-81, average 0.01-1	61,7	2770-3911 *top tvdss	0,41	Continental, shallow-marine	Carbonate-clay, clay-carbonate	5-15
Upper Pliensbachian (Sharapov)	**5**	40-85	1.44 / 0.2-1.2	gas 4.5 k m^3 /m (Novoportovo);	Regional	2 (8 reservoirs) / 0	8	8-21, average 9-15	0.01-73, average 0.01-1	39,0	2950-4200 *top tvdss	0,37	Continental, shallow-marine	Carbonate-clay	3-10
Hettangian-Lower Pliensbachian (Zimny)	**6**	0-207	average - 0.83; max - 3.0	gas 2.5 k m^3 + cond 0.5 m^3 /d/ m (Bovanenkovo);	Local	1 (1 reservoir) / 0	52	8-18, average 8-11	0.01-62, average 0.01-0.1	31,3	3000-6900 *top tvdss	0,59	Mostly continental	Clay	1-5

Table 4. Characteristics of sedimentary complexes

The volumes are presented in Table 3. The ranking based on this characteristic was performed in accordance with the total hydrocarbon volumes of the explored and preliminary estimated categories (ABC1 + C2) in tons of oil equivalent. The summation of HC resources was based on the following assumption 1 ton of OE here corresponds to 1000 m^3 of gas.

Average porosity of reservoirs

Average values of porosity from G.G. Shemin study for the reservoirs of sedimentary complexes are: Vasyugan (15%), Malyshev (15%, but with a lower cutoff value), Vymsk (13.5%), Nadoyakh (12.5%), Sharapov (12%), Zimny (9.5%). Targets are ranked in the appropriate order (the "youngest" complexes have the best reservoir properties and vice versa).

Average permeability of reservoirs

A similar trend is observed for permeability. Permeability of reservoir rocks decreases with the subsidence depth. The average permeability cutoff values: Vasyugan (0.01-100 mD), Malyshev (0.01-10 mD). The average ranges for permeability variation of the SC four lower reservoirs coincide, however, the maximum recorded values of the Vymsk, Nadoyakh, Sharapov and Zimny ones decrease with depth and are 98 mD, 81 mD, 73 mD, 62 mD, respectively.

Average net sands

The average thickness of the reservoirs in the Jurassic sedimentary complexes was determined from a sample of wells in the Yamal fields – Kharasavey, Bovanenkovo, Neytin, Arctic, Sredniamalsk, Nurmin, Novoportovo. The results of the SC net sand averaging in Yamal wells: Vasyugan (21.5 m), Malyshev (67 m), Vymsk (76.5 m), Nadoyakh (61.7 m), Sharapov (39 m), Zimny (31.3 m).

SC depth of occurrence

For the further exploratory well planning and determination of capital costs for drilling, it is extremely important to rank the prospective complexes by the depths of occurrence. With increasing depths of productive deposits, with all other things being equal, the likelihood of field development and subsequent commercial hydrocarbon production from deep-seated reservoirs can be significantly reduced. In this case, the oldest Jurassic sedimentary complexes have correspondingly higher depths of occurrence.

Zone vertical heterogeneity

An important indicator of the vertical heterogeneity of the formation in terrigenous rocks is the net-to-gross ratio (NTG). For the ranked sedimentary complexes, this factor was determined for the wells of Kharasavei, Bovanenkovo, Neytin, Arctic, Sredniamalsk, Nurmin, Novoportovo fields. The final order of the Jurassic complexes according to this characteristic in the order of decreasing NTG is represented as follows: Zimny (0.59), Vymsk (0.45), Nadoyakh (0.41), Sharapov (0.37), Malyshev (0.32) and Vasyugan (0.23).

Third-order characteristics

The ranking of this group of characteristics was based on the studies of G.G. Shemin, A.Yu. Nekhaev, A.L. Beisel published in 2011 (Shemin et al., 2011).

EODs

The prioritizing of this characteristic assumed that rocks of shallow-marine genesis have the best reservoir properties, usually with better sorted sand material, and prediction of the presence and distribution of sand bodies of shallow-marine origin is somewhat simpler than predicting, for example, the position of river channels. The complexes under study are characterized by three depositional environments – shallow-marine, mixed (shallow-marine and continental) and exclusively continental. Thus, the Jurassic complexes formed in shallow-water environments were assigned a maximum score of 6, mixed conditions – 4 and continental – 2 points.

Dominating composition of sedimentary rock cement

The greatest negative impact on the further development of reservoirs is the content of clay cement in the inter-pore space. This is especially evident if the composition of the clay admixture is not uniform, the various forms of clay minerals create serious obstacles to the fluid movement. In addition, clay minerals can react differently to injection of water into the reservoir in order to maintain reservoir pressure (RPM). For example, mixed-layer minerals (montmorillonite) can increase in volume several times, plugging the vug-pore space, and chlorite is less susceptible to this, or not at all. For the carbonate cement the development solution is standard – hydrochloric acid treatment of the reservoir (RAT). Thus, the ranking by this characteristic relied on the clay component content in reservoir rocks. The result of the Jurassic target ranking is as follows: 6 points – Vasyugan (cement is mainly clay-carbonate, less often carbonate-clay), 5 points – Nadiyakh (carbonate-clay, in some cases clay-carbonate), 4 points – Sharapov (carbonate-clay, but with a lower percentage of cement content), 3 points are Malyshev (carbonate-clay), 2 points are Vymsk (mostly clay, less often carbonate-clay), 1 point is Zimny (exclusively clay cement).

Cement content in reservoir rocks

By the cement percentage in the six Jurassic complexes, 3 intervals of values are allocated. The maximum priority corresponds to the minimum cement content and vice versa. Six (6) points were assigned to the Zimny target (1-5%), 4 points to Vasyugan and

SC name	№	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Callovian-Tithonian (Vasyugan)	1	4	3	5	3	5	4	6	6	1	6	1	6	6	4
Lower Bajocian-Upper Bathonian (Malyshev)	2	6	4	6	6	6	6	5	5	5	5	2	4	3	2
Upper Aalenian-Lower Bajocian (Vymsk)	3	5	5	4	6	4	5	4	4	6	4	5	4	2	2
Toarcian-Lower Aalenian (Nadoyakha)	4	1	6	1	6	2	3	3	3	4	3	4	4	5	2
Upper Pliensbachian (Sharapov)	5	2	1	3	6	3	1	2	2	3	2	3	4	4	4
Hettangian-Lower Pliensbachian (Zimny)	6	3	2	2	3	1	2	1	1	2	1	6	2	1	6

Table 5. Ranking of sedimentary complexes

SC name	№	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Callovian-Tithonian (Vasyugan)	1	12	9	15	9	15	8	12	12	2	12	2	6	6	4
Lower Bajocian-Upper Bathonian (Malyshev)	2	18	12	18	18	18	12	10	10	10	10	4	4	3	2
Upper Aalenian-Lower Bajocian (Vymsk)	3	15	15	12	18	12	10	8	8	12	8	10	4	2	2
Toarcian-Lower Aalenian (Nadoyakha)	4	3	18	3	18	6	6	6	6	8	6	8	4	5	2
Upper Pliensbachian (Sharapov)	5	6	3	9	18	9	2	4	4	6	4	6	4	4	4
Hettangian-Lower Pliensbachian (Zimny)	6	9	6	6	9	3	4	2	2	4	2	12	2	1	6

Table 6. Total score using characteristics of 1st, 2nd, 3d order

SC name	№	Total score	Rank
Callovian-Tithonian (Vasyugan)	1	124	3
Lower Bajocian-Upper Bathonian (Malyshev)	2	149	1
Upper Aalenian-Lower Bajocian (Vymsk)	3	136	2
Toarcian-Lower Aalenian (Nadoyakha)	4	99	4
Upper Pliensbachian (Sharapov)	5	83	5
Hettangian-Lower Pliensbachian (Zimny)	6	68	6

Table 7. Results of Jurassic sedimentary complexes ranking

Sharapov (3-10%), 2 points to Malyshev, Vymsk and Nadoyakh. All Jurassic sedimentary complexes were ranked for each of the 14 characteristics (Table 4). For the final ranking, each obtained score must be multiplied by a factor depending on the degree of priority of each characteristic – the first order must be multiplied by the maximum factor of 3, the second order by the factor of 2 and the third order by factor of 1 (Table 5). The sum of all the scores with the weighting factor is presented in Table 6, the ranking result is in Table 7.

Conclusions

Thus, the primary targets of further exploration in the Jurassic section based on the ranking are the Middle Jurassic reservoirs of the Lower Bajocian-Upper Bathonian and Upper Aalenian-Lower Bajocian sedimentary complexes, and the third priority exploration targets are the Upper Jurassic Callovian-Tithonian reservoirs. The most promising Lower Jurassic SC is certainly the Toarcian-Lower Aalenian, primarily due to the enormous generation potential of the Toarcian shales, and it is still premature to speak about the potential of underlying complexes.

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About the Author

Ivan A. Panarin – Head of Geological Exploration Department
LUKOIL-Engineering LLC
3 Pokrovsky boul., build. 1, Moscow, 109028, Russia

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UNDERGROUND HYDROSPHERE OF THE SEDIMENTARY BASINS AS NAPHTIDES-GENERATING SYSTEM (ON THE EXAMPLE OF THE SOUTH CASPIAN BASIN)

A.A. Feyzullayev
Institute of Geology and Geophysics of Azerbaijan National Academy of Sciences, Baku, Azerbaijan
E-mail: fakper@gmail.com

Abstract. The analysis of organic matter (OM) content dissolved in the formation waters and waters of mud volcanoes (water dissolved organic matter – DOM) of the oil and gas bearing South Caspian Basin and its distribution in stratigraphic and hypsometrical depth is given in the article. The stratigraphic interval of research covers the period from the Lower Pliocene to the Jurassic, and the depth interval: from 73 to 6043 m. In these intervals, the values of the DOM in reservoir waters vary from 4.1 mg/l to 271.2 mg/l, averaging (by 219 analyzes) 48.9 mg/l. A good correlation of the values of DOM and OM in rocks has been established. In both cases, Paleogene and Jurassic rocks have the highest values. In the change of the DOM with depth, an increase in its values from a depth of about 3.3 km is noted, which is possibly due to the onset of catagenetic transformation of OM into hydrocarbons in the rock-water system. The dependence of the DOM content on the mineralization of water has been established: its highest values are characteristic for waters with mineralization not higher than 50 g/l. The waters of mud volcanoes are characterized by low levels of DOM and low mineralization, which is most likely due to their condensation nature.

The conducted studies confirm the idea of the DOM participation, along with the OM of rocks, in the processes of oil and gas generation. The process of OM transformation into oil and gas in aqueous solution should be taken into account in basin modeling and in estimating the predicted resources of hydrocarbons in the sedimentary basin.

Keywords: sedimentary basin; formation water; water of mud volcanoes; organic matter; oil and gas
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Introduction

Sedimentary rocks are widespread on our planet. Together with the modern sediments lining the bottom of the World Ocean and the water basins of the land, they form the sedimentary cover of the Earth. The thickness of the sedimentary cover of the Earth varies in a wide range: from 0 to 20-30 km. The total volume of sedimentary cover rocks is estimated at $1.1x10^9$ million km^3, which is about 11% of the Earth's Crust (Ronov, 1980).

According to existing concepts, all the voids of sedimentary rocks (except for hydrocarbon deposits) are filled with water below the groundwater level, in connection with which the mass of the waters contained in these rocks is quite large. According to available estimates (Zverev, 2001), only $3.0*10^{23}$ g of water is contained in the sedimentary cover of the Earth's Crust. In particular, in the South Caspian Basin, the volume of these waters is about $5.3*10^{20}$ g (Zverev et al., 1998). Groundwater is represented both in free and bound (adsorbed) form.

V.I. Vernadsky has pointed out in his works on the huge role of water in geological processes in this works. He believed that the composition of water is a function of the long evolution of the system water-rock-gas-organic matter system (Vernadsky, 2003).

The fundamental property of this system is its equilibrium-nonequilibrium state (Vernadsky, 2003; Shvartsev, 1997, 2008; Bullen, Wang, 2007). Water in the porous-fractured space is in continuous interaction with the mineral skeleton of rocks, which is maximal in finely dispersed (clayey) rocks, which account for about 70% of the total volume of sedimentary rocks. Water at all stages of interaction with rocks continuously concentrates some elements and dissipates others, which is manifested by a regular change in the composition of the aqueous solution. The evacuation of mobile mineral and organic matters (OM) from the rock is accompanied by a gradual increase in their contents in the porous waters.

OM of water is only a part of the organic component of the water-rock system of sedimentary basins. There are autochthonous OM, formed in the water body as a result of the vital activity of aquatic organisms, and allochthonous OM, entering it from outside (Lozovik, 2012). The main source of OM in the reservoir is phytoplankton (Vinberg, 1960; Vinogradov, 2004). However, the water-soluble OM can be inherited not only from the waters of the sedimentary basin, but also include OM, which has passed into the groundwater from rocks (highly soluble organic acids in water, mobile products of the dispersed OM transformation, etc.) during lithogenesis.

M.E. Altovsky and others (1962) showed that the mutual transitions of OM in the water-rock system are determined by the ratio of their concentrations and the sorption capacity of the rocks. At the same time, the enrichment of rocks with dispersed OM renders significant influence on the value of the water dissolved organic matter (DOM) content in underground waters (Shvets, 1982; Bars et al., 1990).

The total amount of OM in groundwater is commensurate with the amount of OM in many natural objects and second only to its content in sedimentary rocks (Zverev, 2001).

The theoretical and experimental studies carried out by a number of scientists (Altovsky et al., 1962; Zinger, Dolgova, 1982; Zinger, 1995; etc.) made it possible to establish an identical distribution of OM in the formation water-water-bearing rock system. This served as the basis for the first time to put forward the concept of the possible participation in the oil and gas generation not only OM of rocks, but also DOM (Altovsky et al., 1962; Kudryakov, 1982; etc.).

The background content of DOM, like the OM of rocks, is controlled mainly by such factors as: the evolution of the sedimentation basin, the intensity of the OM inflow from the surrounding land by water flows, the sedimentation environment, lithogenesis processes, etc.

The enrichment of the rocks with dispersed OM influence significantly on the amount of the DOM content in underground waters (Shvets, 1982) (Table 1).

E.A. Bars with co-authors (Bars E.A., Aleksandrova et al., 1967) have established the apparent positive dependence of the OM background concentrations in groundwater on its concentration in the water-bearing rocks, based on the analysis of more than 1500 analyses of different parameters of the OM composition in waters and about 3000 analyses of the OM composition in the rocks for the eastern part of the Azov-Kuban and western parts of the Middle Caspian oil and gas basins (Figure 1).

The South Caspian Basin is one of the oldest and well studied oil and gas basins. However, specific studies on the analysis of regional regularities of the OM distribution in groundwater, their connection with OM of rocks, the role of the DOM in oil and gas generation have not yet been carried out.

In this regard, the purpose of this article is to generalize and analyze the data accumulated to date on the content of OM in the formation waters of various stratigraphic complexes, as well as mud volcanoes, and its correlation with the content of OM in the sedimentary rocks of the South Caspian Basin.

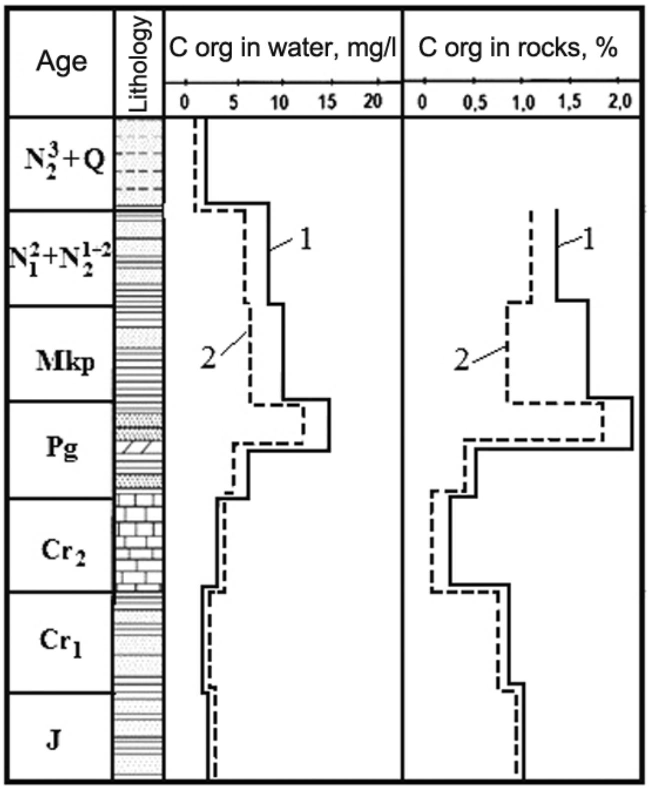

Figure 1. The content of OM in the waters and rocks of Ciscaucasia: 1 – Azov-Kuban basin; 2 – Middle-Caspian basin (Bars et al., 1967)

Age of rocks	**C$_{org}$ of rocks,%**	**C$_{org}$ of underground waters, mg/l**
Neogene	0,9	14,4
Paleogene	0,9	8,3
Cretaceous	0,5	4,2
Palaeozoic	0,3	2,6

Table 1. Dependence of the DOM content on the enrichment of rocks with organic matter

Actual material

The research results presented in this article are based on about 300 analyzes of formation waters and waters of mud volcanoes, as well as more than 400 data on the content of OM in rocks of the South Caspian Basin. The stratigraphic interval of research covers the period from the Lower Pliocene to the Jurassic, and the deep interval – from 73 to 6043 m.

Results and Discussion

The South Caspian Basin (SCB) occupies a vast area of deflection of the Earth's Crust, which includes the southern part of the Kura intermountain trough, the West Turkmen depression and the deep-sea basin of the Southern Caspian located between them. In the hydrogeological sense, the SCB is a classical connate basin (Kostikova, 2002).

The content of OM in the rocks of the sedimentary complex of the SCB has been previously studied primarily on natural outcrops of different stratigraphic ages, the results of which are reflected in the works (Bailey et al., 1996; Guliyev et al., 1997; Feyzullayev et al., 2001). According to these studies, the rocks of the Miocene-Oligocene deposits, which are referred to as oil source rocks (Guliyev, Feyzullayev, 1996; Katz et al., 2000; Feyzullayev et al., 2001; Gurgey, 2003; et al.), differ in the highest values of total organic carbon (TOC).

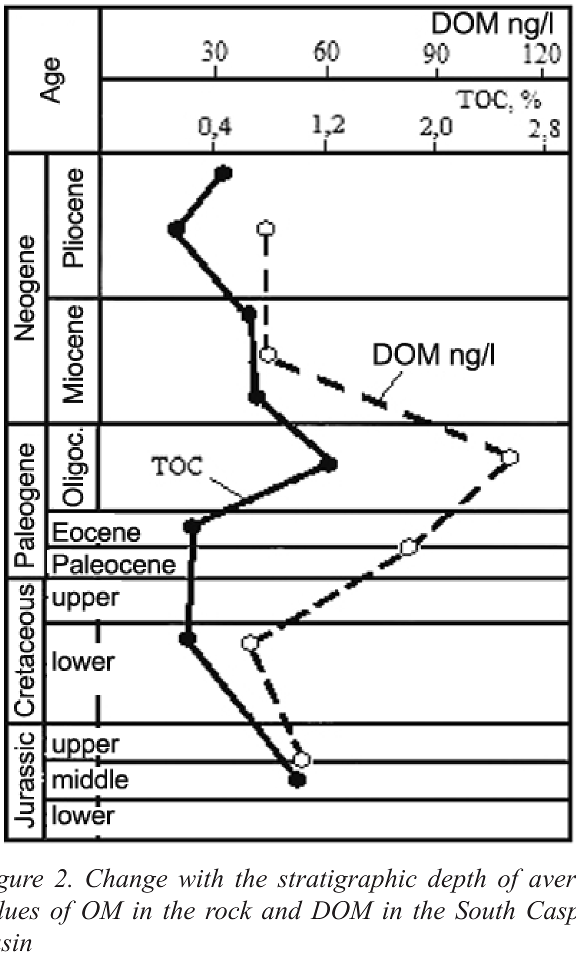

Figure 2. Change with the stratigraphic depth of average values of OM in the rock and DOM in the South Caspian Basin

An analysis of the variation in the section of the values of this parameter averaged over individual stratigraphic complexes showed its uneven distribution (Aliev et al., 2005). As already noted, the maximum OM contents were distinctive for Maikop (Oligocene-Lower Miocene) sediments; The Jurassic rocks are also distinguished by elevated values (Figure 2).

In order to compare the nature of the change of OM in the section of rocks, the mean values of the DOM in the formation waters of various stratigraphic complexes of the SCB were also calculated in this work based on the created database: from the Lower Pliocene (Productive series – PS) to the Jurassic. In the considered stratigraphic interval, the DOM was changed in the range from 4.1 mg/l (PS) to 271.2 mg/l (PS). The average value for 219 analyzes was 48.9 mg/l, which agrees well with previous estimates for other basins, according to which the background values of dissolved OM in underground aquifers of oil and gas basins do not exceed 50 mg/l (Kiryukhin et al., 1973; Shakhnovsky, 2003).

As can be seen from Figure 2, the nature of the change in the section of the average values of the DOM is in good agreement with the nature of the change in the OM content in rocks. A certain deviation towards higher values of OM in the waters in comparison with the rocks is noted only for the Eocene-Paleocene interval of the section.

The content of OM in the formation waters of the various stratigraphic complexes of the SCB is more clearly demonstrated by the distribution histograms of its values shown in Figure 3. According to these histograms, in water, as well as in rocks, the highest values are characteristic to oil-source rocks of Paleogene-Miocene and Jurassic deposits.

The waters of mud volcanoes are characterized by the lowest concentrations of OM.

The revealed correlation between the OM content in the waters and their enclosing rocks allows us to conclude that a dynamic equilibrium is established between the rock and water that are constituent parts of a single rock-fluid system and which are in continuous interaction during a long geological time.

Moreover, as shown by the results of A. Schimmelmann, M. Mastaler (2001), the dynamic equilibrium is also manifested in the relationship between the isotope composition of hydrogen (the ratio D / H) of oils (its various fractions) and contacting with them formation waters (Figure 4).

As is known, physical (temperature and pressure), chemical (composition of formation water), lithofacies (the density of rocks and their reservoir properties) and other conditions and associated processes (oil and gas formation, clay dehydration, etc.) change with depth. In this connection, it is of some interest to analyze the

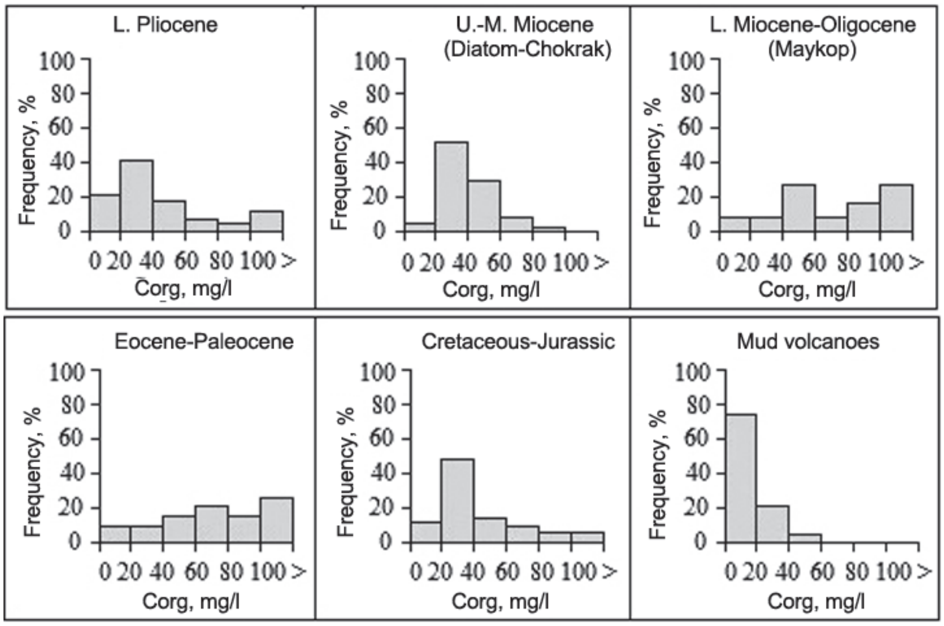

Figure 3. Distribution histograms of values of OM content in formation waters of various stratigraphic complexes of SCB

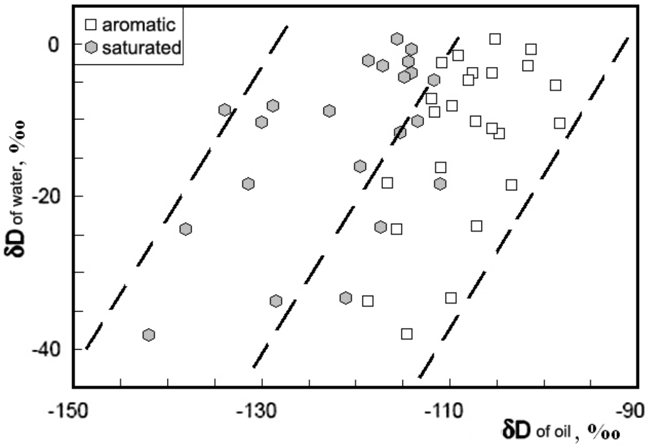

Figure 4. The dependence between the isotopic composition of hydrogen in formation water and various fractions of oil (Schimmelmann, Mastaler, 2001)

regularities of the change in the content of the DOM with hypsometric depth.

As can be seen from the graph presented in Figure 5A, a pronounced feature of the change of the DOM values is common for various stratigraphic complexes. This feature is expressed in the presence of a sharp jump in the direction of increasing the values of the DOM, recorded from a depth of approximately 3.3 km. A similar character is noted in the change with the depth of naphthenic acids (Figure 4B), which have a direct dependence on the amount of hydrocarbons (Smirnova, 2009).

Most likely, this is due to the transition of the rock-water system from the diagenesis stage (where relatively low temperatures are not yet sufficient for thermal decomposition of OM) into the catagenesis stage, where favorable temperature conditions exist for the transformation of OM into hydrocarbons.

Given the relatively higher migration potential of oil and gas in comparison with their ancestor – OM, in the

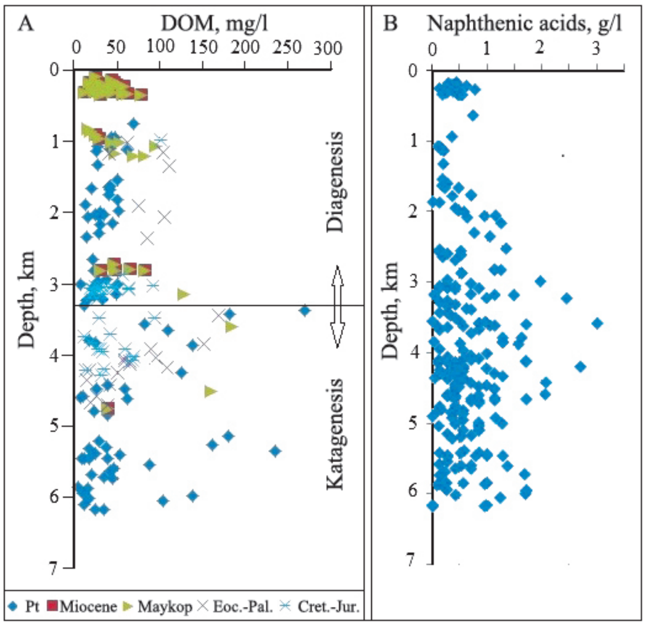

Figure 5. The change with the depth of OM content dissolved in the formation waters of various stratigraphic complexes of South Caspian Basin (A) and the content of naphthenic acids in the waters (B)

zone of catagenesis, their infiltration from rocks into water begins accompanied by an increase in water of the organic component and bitumen.

The type of the relationship between the DOM and the carbon content of bitumoids (C_{bit}) confirms this conclusion. According to Figure 6, high contents of C_{org}, which are observed from a depth of more than 3 km (Figure 5), are characterized by high values of C_{bit}, which is a derivative of the thermal transformation of C_{org}.

Kartsev and others (Kartsev, Vagin, Baskov, 1969) also considers that sedimentogene waters dissolve hydrocarbons formed as a result of catagenesis and move with them to reservoir rocks. When moving through

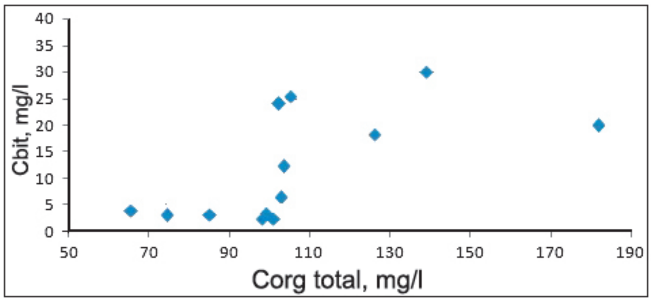

Figure 6. Relationship between C_{org} *and* C_{bit} *content in water*

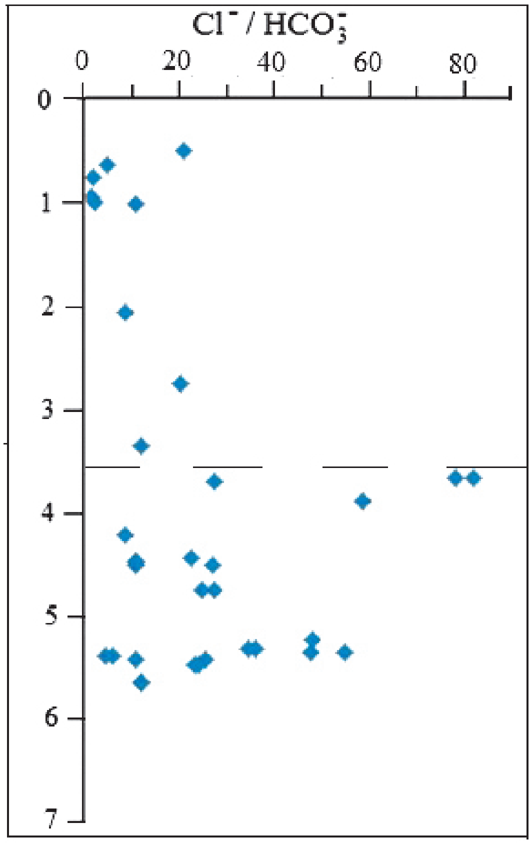

Figure 7. Ratio of chlorine ion to hydrocarbonate ion changing with depth

reservoirs, groundwater can additionally dissolve a certain amount of hydrocarbons and other organic compounds in reservoir rocks.

Studies conducted by V.M. Shvets (1973) have found that the content of DOM depends on the chemical composition of the waters. However, according to other studies (Metody i napravleniya issledovanii organicheskikh veshchestv ..., 1975), mineralization and chemical composition of waters have an ambiguous effect on the content of OM in them.

To study the relationship between these parameters in the formation waters of the SCB, data on the well-studied productive strata were involved.

As can be seen from Figure 7, a pattern similar to the change with the depth of the DOM is observed in the ratio of chlorine ion to the hydrocarbonate ion changing with depth (Figure 4A). In this case, too, approximately from the same depth (3.5 km), a jump in the values of the considered parameter in the direction of its increase is observed. This fact gives grounds to assert the existence of a certain relationship between the chemical composition of water and the OM contained in it.

From the world experience, the dependence of the OM content in waters on its salinity is also known. Thus, the investigation of the DOM in wells of the fields of the Michigan basin (USA), producing gas and water, has established the dependence of the OM content in the formation waters on its salinity (Huang, 2004). According to the results of other studies (Yan Chen et al., 2013), there is a negative relationship between the content of DOM and the salinity of the water.

To study the nature of the dependence of these two parameters, in relation to the geological conditions of the SCB, a corresponding graph was constructed, which is shown in Figure 8. According to Figure 8, the formation waters of SCB containing high concentrations of DOM (more than 70 mg/l) are characterized by a relatively

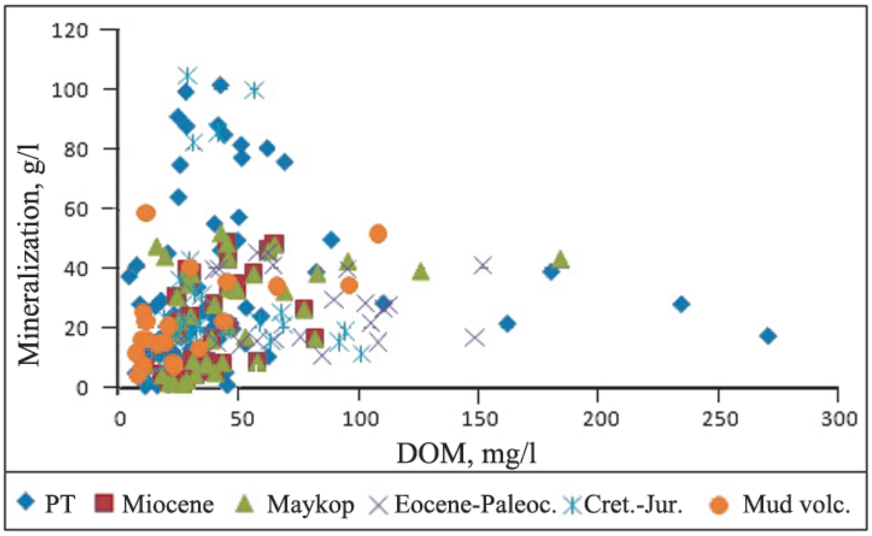

Figure 8. Relationship between the content of DOM of formation waters of various stratigraphic complexes and waters of mud volcanoes and the mineralization of these waters in the South Caspian Basin

low mineralization (less than 50 g/l). In waters with a salinity of more than 60 g/l, the content of DOM is low and varies within the limits of 25-70 mg/l.

At the same time, formation waters with low DOM values (less than 20 mg/l) and low salinity are also encountered. It is important to note that the same fact is established in the Michigan basin of the USA (Huang, 2004). Such waters are also characteristic for mud volcanoes. According to data from 24 analyzes, DOM in waters of mud volcanoes in the SCB varies from 7.9 mg/l to 108.5 mg/l (average 28.6 mg /l), while water salinity ranges from 4.1 mg/l to 58.7 mg/l (24.2 mg/l). The same feature was previously revealed in the study of the mud volcano waters in the Taman Peninsula (Alexandrova, Bars, 1967).

Low mineralization and low content of OM in some formation waters and waters of mud volcanoes are most likely due to their condensational genesis. To some extent, this is confirmed by the low mineralization of formation waters, which are directly connected to oil in comparison with the waters behind the oil-bearing contour established on the example of Neftechala and Khilly fields of the SCB (Figure 9). Taking into account that the oil in the PS is of a epigenetic nature, this phenomenon can be associated with phase transitions caused by changes in the thermobaric conditions during the subvertical migration of fluids.

It should be noted that T.S. Smirnova (2009) also found that the waters of gas-condensate and oil-bearing deposits are characterized by very high concentrations of hydrocarbonates.

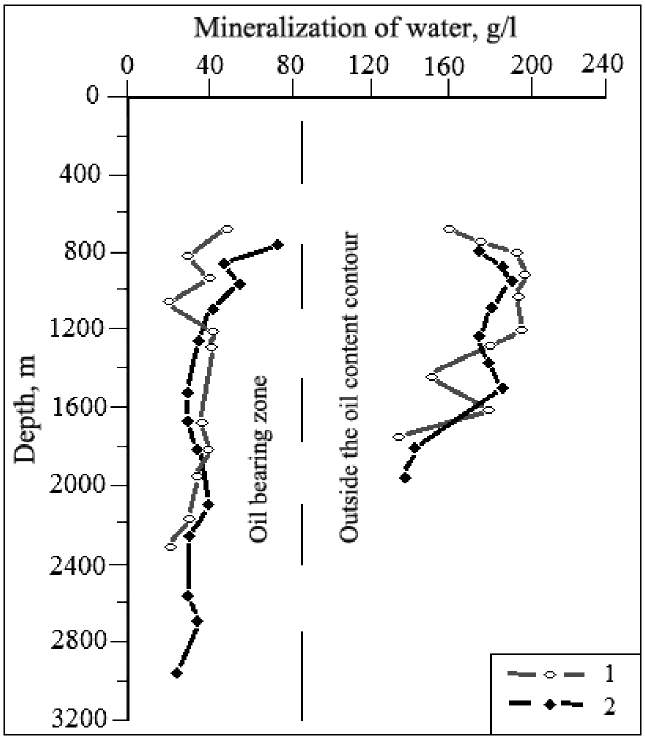

Figure 9. Change in mineralization of formation waters with depth within the oil deposit and behind the contour of oil bearing areas of Khilly (1) and Neftechala (2) of the South Caspian Basin (Feyzullaev, 2010)

Conclusion

An analysis of the world experience in the study of OM in the underground hydrosphere, as well as the results of the present studies on the example of the SCB, makes it possible to conclude the following.

Underground hydrosphere of sedimentary basins (including its organic component) is part of a single water-rock system, between the component parts of which there is a continuous interaction and interchange of substances, the intensity of which depends on a complex of geological factors. The consequence of interaction processes between water and its host rock is the establishment of dynamic equilibrium in this system during its geological evolution. This explains the good convergence of the distribution of OM in rocks and formation waters of the sedimentary section of SCB, the relationship between the content of OM in waters and their chemical composition and mineralization, and the nature of changes of these parameters with depth.

Based on the results of the research carried out for DOM in the South Caspian Basin, the following conclusions can be making.

- The average statistical value of the DOM content in the formation waters of SCB as a whole is about 50 mg/l, which agrees well with the results for other basins.

- The distribution of DOM on the section is uneven and correlates well with the content of OM in the rocks: its highest content, as in rocks, is noted in the Paleogene-Miocene and Jurassic sediments. This relationship is due to the primary enrichment of rocks with OM, the degree of lithification of rocks, the features of hydrodynamic regime of confined water complexes and continuous processes of interaction between water and its host rock.

- The features of the change in the content of DOM in formation waters with hypsometric depth are revealed, which are characterized by an increase in its values from a depth of approximately 3.3 km. It is believed that this is due to the onset of catagenetic transformations of OM into hydrocarbons.

- A characteristic relationship between the content of OM in the reservoir waters of the SCB and its mineralization was found. It has been established that the highest values of DOM are characteristic of waters with mineralization not exceeding 50 g/l. There are also reservoir waters with low values of both DOM and water salinity. These waters include waters of mud volcanoes. In all likelihood, these waters are of a condensation nature.

The performed studies confirm the idea that the underground hydrosphere, which is an inseparable part of the unified rock-water system of the basin, can play the role of an additional source of hydrocarbons. In this connection, the process of transformation of OM into oil and gas in aqueous solution should be taken into account in basin modeling and in estimating the forecast resources of hydrocarbons of the sedimentary basin.

However, it should be recognized that if an express method of pyrolysis of rocks is widely and successfully used to quantify the hydrocarbon potential of rocks (Espitalie et al., 1977), an express method has not yet been developed to quantify the scale of hydrocarbon generation in an aqueous medium.

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About the Author

Akper A. Feyzullayev – DSc (Geology and Mineralogy), Professor, Academician of the Azerbaijan National Academy of Sciences (ANAS), Head of «Geochemistry and Fluid Dynamics of Sedimentary Basins» Department

Institute of Geology and Geophysics of Azerbaijan National Academy of Sciences

119 H. David avenue, Baku, AZ1143, Azerbaijan

Tel: +994 12 510 11 63, e-mail: fakper@gmail.com

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INFLUENCE OF GEODYNAMIC PROCESSES ON RESERVOIR PROPERTIES OF GEOLOGICAL ENVIRONMENT (ON THE EXAMPLE OF THE ROMASHKINO FIELD)

A.A. Dragunov, R.S. Mukhamadiev, S.V. Chernov*
TNG-Kazangeophysica LLC, Kazan, Russia

Abstract. A significant contribution to the structure of the hydrocarbon deposits can be made by fracturing, which is in the active state under the external stresses relative to the Earth (the lunar-solar gravitational action, the total rotational field of the Earth's stresses, etc.). On the example of comparing the results of system-geodynamic interpretation with reservoir properties of the Bobrikovian, Timanian and Pashian horizons of the Romashkino field using mathematical-statistical analysis, it has been shown that geodynamic activity significantly affects the reservoir properties. Improvement of reservoir productivity is noted in the areas of mutual overlap of geodynamically active zones of dislocations of various orders and strike, which is recommended to be taken into account both in exploration and development of hydrocarbon fields. Consideration of the geodynamic situation, carried out using the results of system-geodynamic interpretation, will allow the most rational use of various methods of oil extraction at operation sites.

The results of system-geodynamic zoning should be used in solving a wide range of oil and gas exploration and operational problems, where the development of fractured zones is important. They can be used both for the search and exploitation of hydrocarbon deposits in conventional carbonate and terrigenous reservoirs, and in non-conventional reservoirs, where the main reservoir properties are determined by fractures.

Keywords: geodynamic activity, reservoir properties, system-geodynamic interpretation, fractures
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Introduction

The geodynamic factor in the study of oil and gas fields is still practically ignored. A significant contribution to the structure of the hydrocarbon deposits can be made by fracturing, which is in the active state under the external stresses relative to the Earth (the lunar-solar gravitational action, the total rotational field of the Earth's stresses, etc.). All structures of this kind form a multi-rank, regularly developed system of geodynamically active zones of dislocations (DAZD) (Dragunov, 2011).

The activation of the DAZD system is connected, first of all, with the discharge of internal stresses caused by the uneven rotation of the Earth. Within the DAZD of various ranks, all existing tectonic dislocations are involved in constant movements. In this paper, it is shown that geodynamic activity affects the processes of oil formation and oil accumulation at the regional scale, while on the local scale it has a complicating effect on hydrocarbon traps. Proceeding from this, the question of the degree of DAZD influence of different ranks and strike on the porosity, oil saturation, phase and relative permeability of productive horizons within hydrocarbon deposits can be considered.

Initially, remote system-geodynamic studies were carried out at the Russian State University of the oil and gas named after I.M. Gubkin (Gridin, Gak, 1994) and have been further developed in the works of A.A. Dragunov, R.S. Shaikhutdinov and others (Dragunov, 2011; Dragunov et al., 2003; Dragunov, 2008).

Results of the research

Mapping of DAZD within the North Romashkino range was performed within the framework of remote system-geodynamic studies of the South Tatar arch. Reconstruction of the DAZD frame was performed using scaled-up space scanner images based on the following geo-indicators: input and output loop of rivers, active meandering, sharp turns of channel flows, and development of sandy beaches downstream of intersections with DAZD rivers (Dragunov, 2011) (Figure 1).

On the example of the North Romashkino range, a comparison was made between the reservoir properties

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[*] *Corresponding author: Andrey A. Dragunov*
E-mail: asgr@tng-kazan.ru

of productive horizons within the DAZD and within the blocks with relatively stable geodynamic characteristics. The values of the porosity and oil saturation coefficients, as well as the phase and relative permeabilities, determined from the core of 3260 wells, were compared: 1523 wells along the Bobrikovian horizon, 1393 wells along the Timanian horizon, 1450 wells along the Pashian horizon. For comparison, samples were used for wells located within the DAZD of different rank and strike, and also in wells outside the DAZD (so-called control group). The comparison was performed using the variance analysis (Figure 2; Table 1).

The main results of the work are as follows (Figure 3).

- Within the DAZD, not complicated by the overlapping of several DAZDs of different ranks and strikes, the relative permeability is higher, and porosity, oil saturation and phase permeability are lower than in the control group.

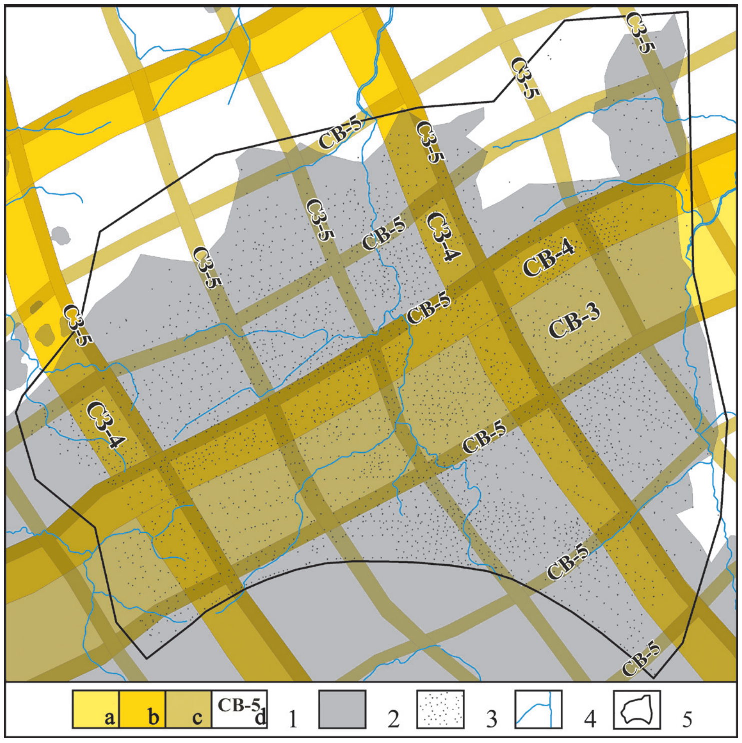
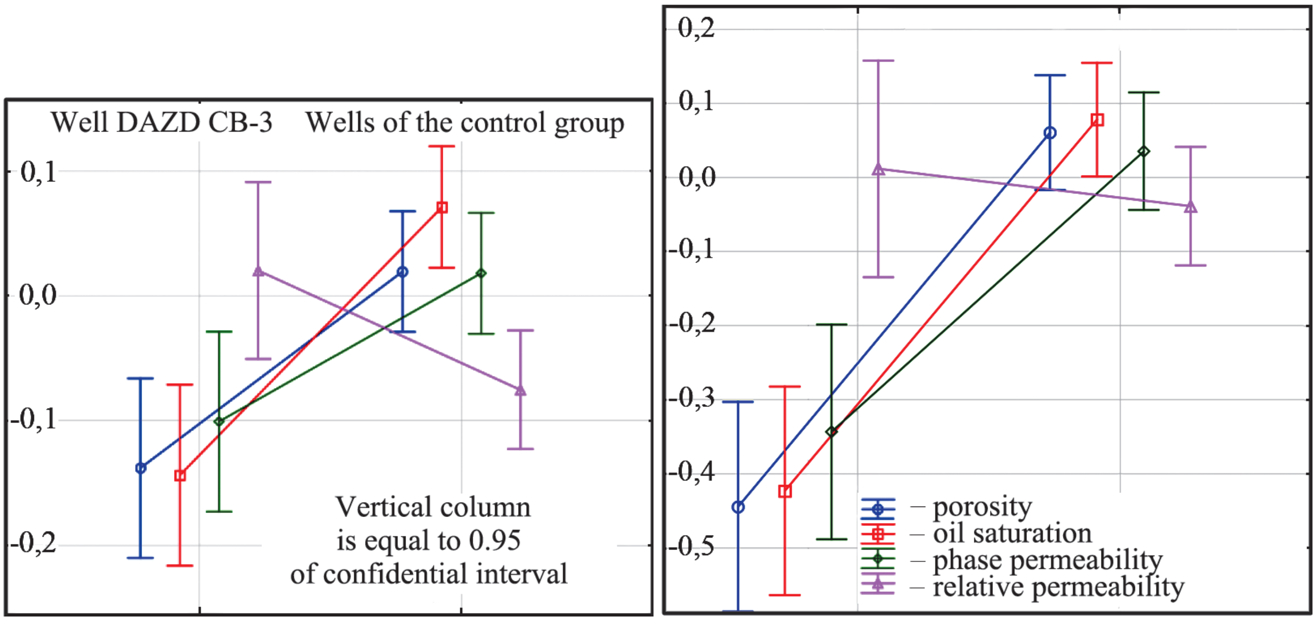


Figure 1. Results Map system-geodynamic interpretation of the North Romashkino range. Scale 1: 350,000. 1 – geodynamically active zone: a – of the 3d rank, b – of the 4th rank, c – of the 5th rank, d – its name; 2 – oil field; 3 – wells; 4 – river bed; 5 – border of the North Romashkino range



A

B

Figure 2. Diagrams of reservoir properties within the DAZD of 3d rank and North-East strike: A – 3 horizons, B – Bobrikovian horizon

A

	3-CB			
Dependent variable	SS Model	SS residual	df residual	p
POR	12,50569	2319,734	2351	0,000378
NNAS	23,30947	2357,346	2351	0,000002
PRONFAZ	7,13744	2326,915	2351	0,007295
PRONOTN	4,60700	2247,008	2351	0,028225

B

	031PL 3-CB			
Dependent variable	SS Model	SS residual	df residual	p
POR	36,87082	794,0621	814	0,000000
NNAS	36,31501	784,8007	814	0,000000
PRONFAZ	20,72185	834,0544	814	0,000008
PRONOTN	0,36554	848,0715	814	0,553792

Table 1. Confidence by DAZD of 3d rank and North-East strike: A – 3 horizons, B – Bobrikovian horizon

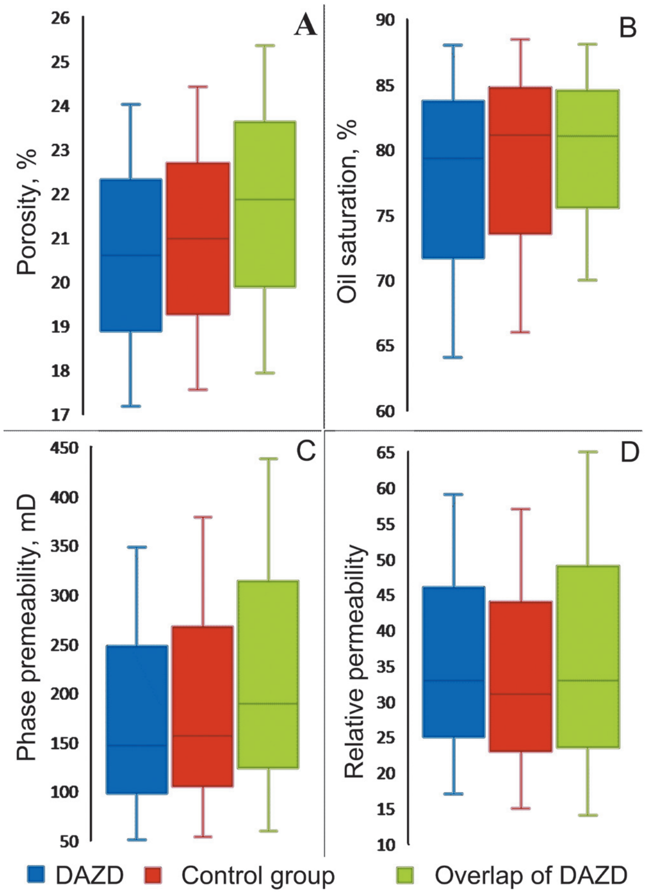


Figure 3. Percentages of the reservoir properties distributions over the 3 horizons: A – porosity, B – oil saturation, C – phase permeability, D – relative permeability.

- Within the zones of mutual overlapping of DAZD, porosity, oil saturation, the phase and relative permeability is higher than in the control group.

Based on the results of the dispersion analysis, the following conclusions can be drawn.

- The increased relative permeability noted within the DAZD facilitates the flow of anhydrous oil to the production wells and, ultimately, facilitates its more efficient extraction.
- The relatively less porosity within the DAZD, not complicated by the mutual imposition of several DAZDs of different ranks and strike, associated with the processes of gravitational compaction of rocks, causes a lower phase permeability, which increases the probability of formation of oil deposits within the DAZD and contributes to their better safety.
- The marginal parts of the DAZD and, mainly, the zones of mutual overlapping of DAZDs of different ranks and strike, are distinguished by improved reservoir properties.

Conclusion

Based on the results of the dispersion analysis of the reservoir properties conducted at the North Romashkino range, with a confidence greater than 95%, it is established that geodynamically active zones of dislocations have an impact on the reservoir properties.

Consideration of the geodynamic situation, carried out using the results of system-geodynamic interpretation, will allow the most rational use of various methods of oil extraction at operation sites.

The results of system-geodynamic zoning should be used in solving a wide range of oil and gas exploration and operational problems, where the development of fractured zones is important. They can be used both for the search and exploitation of hydrocarbon deposits in conventional carbonate and terrigenous reservoirs, and in non-conventional reservoirs, where the main reservoir properties are determined by fractures – in clay, siliceous, volcanogenic, metamorphic, magmatic and intrusive rocks, including the rocks of the crystalline basement.

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About the Authors

Andrey A. Dragunov – Head of the Interpretation Department, TNG-Kazangeophysica LLC
27 Tetsovskaya St., Kazan, 420080, Russia
E-mail: asgr@tng-kazan.ru

Rafail S. Mukhamadiev – Managing Director
TNG-Kazangeophysica LLC
27 Tetsovskaya St., Kazan, 420080, Russia
E-mail: muhamadiev@tng-kazan.ru

Sergey V. Chernov – Leading Geophysicist
TNG-Kazan-geophysica LLC
27 Tetsovskaya St., Kazan, 420080, Russia
E-mail: asgr@tng-kazan.ru

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LOCAL REFINEMENT OF THE SUPER ELEMENT MODEL OF OIL RESERVOIR

A.B. Mazo, K.A. Potashev[*]
Kazan (Volga region) Federal University, Kazan, Russia

Abstract. In this paper, we propose a two-stage method for petroleum reservoir simulation. The method uses two models with different degrees of detailing to describe hydrodynamic processes of different space-time scales. At the first stage, the global dynamics of the energy state of the deposit and reserves is modeled (characteristic scale of such changes is km/year). The two-phase flow equations in the model of global dynamics operate with smooth averaged pressure and saturation fields, and they are solved numerically on a large computational grid of super elements with a characteristic cell size of 200-500 m. The tensor coefficients of the super element model are calculated using special procedures of upscaling of absolute and relative phase permeabilities. At the second stage, a local refinement of the super element model is constructed for calculating small-scale processes (with a scale of m/day), which take place, for example, during various geological and technical measures aimed at increasing the oil recovery of a reservoir. Then we solve the two-phase flow problem in the selected area of the measure exposure on a detailed three-dimensional grid, which resolves the geological structure of the reservoir, and with a time step sufficient for describing fast-flowing processes. The initial and boundary conditions of the local problem are formulated on the basis of the super element solution. This approach allows us to reduce the computational costs in order to solve the problems of designing and monitoring the oil reservoir.

To demonstrate the proposed approach, we give an example of the two-stage modeling of the development of a layered reservoir with a local refinement of the model during the isolation of a water-saturated high-permeability interlayer. We show a good compliance between the locally refined solution of the super element model in the area of measure exposure and the results of numerical modeling of the whole history of reservoir development on a detailed grid.

Keywords: super elements method, numerical simulation, petroleum reservoir, local refinement, reservoir treatments simulation, two phase flow, downscaling

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The development of geological and technical measures of exposure on oil reservoirs and an increase in the overall share of hard-to-recover reserves raise the requirements for numerical modeling of flooding of oil deposits. The arising problems require both the detailedness of the solutions obtained and the increase in the computational speed when carrying out adaptation or optimization calculations. At the same time, the dimensionality of the grids detailing the fine geological structure of the entire reservoir is so great that their application for mass flow calculations leads to excessive computational costs.

To reduce the dimension of the calculated grids, averaging techniques are usually used (rescaling, upscaling) (Durlofsky, 1998; Panfilov, Panfilova, 1996; Belyaev, 2004; Mazo, Potashev, 2017 (a); Mazo, Potashev, 2017 (b)). At the same time, the possibility of describing small-scale flow processes characteristic for complex geological and technical measures is lost. An alternative option for accelerating computation is to use detailed grids not simultaneously for the entire deposit, but in local subareas. Examples of this approach are the family of multiscale methods (Aarnes et al., 2004, Arbogast, 2000; Efendiev et al., 2006; Gautier et al., 1999; Jenny et al., 2006; Pergament et al., 2010), which come to the construction of a detailed velocity field based on the solution of the pressure equation on a coarse grid and the subsequent solution of the saturation transfer equation on a fine grid. In this case, a significant part of the computational work for calculating the saturation is unnecessary for modeling the global dynamics of water flooding.

This paper demonstrates the feasibility of applying a two-stage super element modeling, using detail models of varying degrees for describing different-scale processes. Such an approach, in our opinion, allows us not only to reduce computational costs in order to solve the problems of oil reservoir design, but also to improve the accuracy of calculations in comparison with many conventional methods.

The choice of the method for local refinement of the super element model depends on the exposure method during the geological and technical measures. When

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[*] *Corresponding author: Konstantin A. Potashev*
E-mail: kpotashev@mail.ru

modeling area measures, such as polymer flooding, the effect of which is occurred in the extended areas of interaction between injection and production wells, the method of fixed stream tubes (Mazo et al., 2017) can be used. This approach allows us to use high-resolution computational grids due to the decomposition of the three-dimensional problem into a series of two-dimensional ones. In this paper, we consider a method for local refinement of the model by isolating a small section of the geological and technical measures and constructing a small three-dimensional grid on it for a detailed calculation of the short-term consequences of isolating the watered perforation interval of a single production well.

To calculate the global development dynamics, a super element model is being built (Mazo, Bulygin, 2011; Mazo et al., 2013; Bulygin et al., 2013; Mazo et al., 2015) on large (200-500 m horizontally and 10-100 m vertically) unstructured computational grids with a number of cells comparable to the number of wells in the field. This makes it possible to reduce the computation time by hundreds of times in comparison with the calculations traditionally using grids with a pitch of 30-50 m. Satisfactory accuracy of calculations is achieved by formulating problems for smooth averaged fields of pressure and saturation, as well as performing upscaling of reservoir properties (Mazo, Potashev, 2017 (a); Mazo, Potashev, 2016) and the modified functions of the relative phase permeabilities (Mazo, Potashev, 2017 (b); Potashev, Abdrashitova, 2017). The super element approach allows us to carry out calculation of design parameters of oil reservoir development and predict the dynamics of the energy state of the deposit. At the same time, the super element method does not allow the modeling of relatively fast small-scale processes, for example, accompanying geological and technical measures to enhance oil recovery.

To describe such processes, a solution built on a super element grid must be locally refined in the area of the geological and technical measures. On the selected section of the reservoir, the two-phase flow problem is solved on a detailed spatial grid that resolves the geological structure of the reservoir, and with a time pitch sufficient to describe fast processes. The principal question of modeling the development of a single section is the formulation of the initial and boundary conditions on the basis of the super element solution. These conditions define a one-way connection between the global and local refined solutions.

To demonstrate the proposed approach, an example of a two-stage super element modeling of the development of a small oil deposit of a layered structure, penetrated by a series system of vertical perfect wells, is given (Figures 1, 2). The presence of a highly permeable interlayer leads to water breakthrough to production wells. To isolate the water inflow, a partial pouring of the perforation interval on a separate well is performed. This leads to a sharp change in the filtrational flows in the vicinity of the conducted geological and technical measures. Simulation of the consequences of this measure is carried out with the help of local refinement of the super element solution.

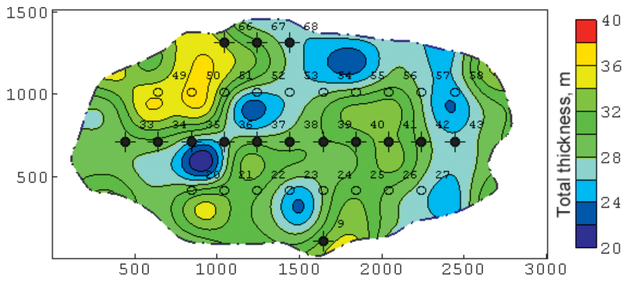

Figure 1. Projection to the horizontal plane of a model oil reservoir with cutoff along the outer contour of the oil content [1]

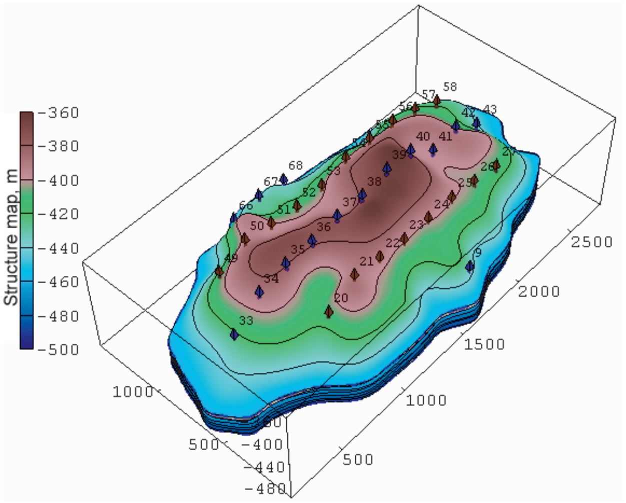

Figure 2. Three-dimensional representation of a model oil reservoir with a cut-off along the outer contour of the oil content

1. Local refinement method of a numerical solution

Let us describe the general sequence of actions for two-stage super element modeling.

1. The whole region of the reservoir D is covered by a super element grid. Absolute permeability and relative phase permeabilities are upscaled. Numerical modeling of the global dynamics of reservoir development is performed on the time interval $0 \le t \le T$. Averaged grid pressure functions $P(\mathbf{x}, t)$ and water saturation $S(\mathbf{x}, t)$ are sought in $\mathbf{x} = (x, y, z) \in D,\ t \in [0, T]$.

2. The site $\Omega \subset D$ is given, which is composed of a small number of super elements; a short time interval $t \in [t_0, t_0 + \tau],\ \tau << T$ is given, at which it is required to perform a local refinement of the super element solution.

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[1] To visualize the geological and flow models, special software was used (Mazo et al., 2012; Mardanov, Bulygin, 2012; Bulygin, Mardanov, 2017)

The boundary $\partial\Omega$ of the section Ω consists of the outer Γ and the inner γ parts. The outer part Γ is a continuous surface, which is the union of all the outer faces of the constituent parts of super elements. The inner part γ is represented by the set of surfaces γ_i of all wells located inside the section Ω.

3. The area of the section Ω is covered by a detailed computational grid for solving the two-phase flow equations for small-scale pressure p and saturation s in neglect of fluid compressibility, as well as capillary and gravitational forces (Barenblatt, 1984):

$$\beta\frac{\partial p}{\partial t}+\nabla\cdot\mathbf{u}=0,\quad \frac{\partial m\,s}{\partial t}+\nabla\cdot\left(f\,\mathbf{u}\right)=0,\quad \mathbf{u}=-\sigma\nabla p,$$

$$\sigma=\frac{k}{\mu}=\frac{k}{\mu_w}\varphi(s),\quad \varphi(s)=k_w(s)+\mathrm{K}_\mu k_o(s),\ \mathrm{K}_\mu=\frac{\mu_w}{\mu_o},$$

$$f(s)=k_w(s)/\varphi(s),\ k_w(s)=s^n,\quad k_o(s)=(1-s)^n,$$

$$n=1\div 4. \tag{1}$$

Here β – compressibility of the reservoir; $\mathbf{u}$ – total flow rate; f – water fraction in the total flow; σ – hydraulic conductivity; φ – mobility of the mixture; μ – dynamic viscosity of a two-phase fluid, μ_w, μ_o – viscosity of the water and oil phases.

4. To solve the task (1), the initial

$$t=t_0,\ \mathbf{x}\in\Omega:\quad p=p^0(\mathbf{x}),\ s=s^0(\mathbf{x}) \tag{2}$$

and boundary conditions are given. On the outer boundary Γ a third-kind condition is set (Potashev et al., 2016)

$$\mathbf{x}\in\Gamma:\ \sigma\frac{\partial p}{\partial n}=-\alpha\left(p-P_e\right),\ \alpha=\frac{\sigma}{h} \tag{3}$$

where P_e – is a superelement solution at a distance h from the boundary Γ in the direction of the outer normal $\mathbf{n}$ at time t_0. In the "input" areas Γ^{in}: $\mathbf{u}\cdot\mathbf{n}<0$ saturation s_Γ is additionally given, which is built on the large-scale saturation S. On the inner boundary of γ – surfaces of γ_i wells – nonlocal boundary conditions are set: the flow rates at constant pressure in the well are given

$$\mathbf{x}\in\gamma_i:\ -\int_{\gamma_i}\sigma\frac{\partial p}{\partial n}d\gamma=q_i(t),\ p=p_i=\text{const} \tag{4}$$

On the surfaces of the injection wells, the condition $s = 1$ is additionally specified.

The initial distribution of saturation s^0 in (2) is constructed on a detailed grid by means of the procedure of de-scaling (downscaling) of the mean field S in super elements at time $t = t_0$. The function p^0 in the initial condition (2) is given as the solution of the stationary problem for the pressure p. Since $\tau << T$, functions P_e and s_Γ in the boundary conditions can be assumed to be time-independent.

5. The task (1) with conditions (2)-(4) of local refinement of the model on a detailed grid is solved. The grid functions $p(\mathbf{x}, t)$, $s(\mathbf{x}, t)$; $\mathbf{x}\in\Omega,\ t\in\left[t_0, t_0+\tau\right]$. are constructed.

6. The found pressure p and saturation s functions are used to calculate the technological performance of the wells at the section of geological and technical measures.

The second stage of super element modeling is the local refinement of the model (actions 2-6) – can be performed for an arbitrary number of sections of the reservoir and at arbitrary instants of time. At the same time, the first stage – the modeling of global development dynamics on the super element grid (action 1) – is performed only once and does not involve the use of small-scale fields p, s for some refinement of the functions P, S.

2. An example of two-stage modeling

Let us consider an example of local refinement of the super element water flooding model. The geological characteristics of the reservoir, location of wells, and their operating modes were generated specifically to illustrate the proposed methodology. The geological model of the deposit is formed by three interlayers and two weakly permeable bridges. The permeability of the second interlayer was set much higher than the permeability of the first and third (Table 1). The average length of the deposit in two orthogonal directions was 2.5 km and 1.5 km (Figures 1, 2). The map of the total thickness of the reservoir is shown in Figure 1; parameters of the geological model are shown in Tables 1, 2. Absolute permeability of interlayers was calculated through porosity according to the Kozeny equation (Kozeny, 1927; Daigle, Dugan, 2009; Yang, Aplin, 2007).

Characteristic \ Interlayer	1	Bridge	2	Bridge	3
Average porosity, un. fr.	0.16	0.05	0.35	0.05	0.22
Average permeability, 10^{-15}m^2	6	0.15	120	0.15	20

Table 1. Average characteristics of interlayers

Characteristic	Minimum value	Average value	Maximum value	Standard deviation	Variability, m
Total thickness, m	20	30	40	4	300
Thickness of interlayer, m	0	7.5	15	8	300
Relative porosity within the interlayer, un. fr.	0.8	1	1.2	0.3	100

Table 2. Statistical parameters of the characteristics distribution of the geological model

At the beginning of development (01.2000), the reservoir is completely saturated with oil. The viscosities of water and oil were set equal to $\mu_w = 0.001$ Pa s, $\mu_o = 0.002$ Pa s. The functions of the relative phase permeability (1) were specified in the form of quadratic dependences (n = 2).

The reservoir is developed by a series system of 33 wells (Figure 1), 15 of which are injection wells with a constant injectivity of 150 m^3/day, and 18 – production wells with a constant flow rate of 100 m^3/day. The average well grid spacing is 200 m. All wells are vertical and initially perfect in the degree of reservoir penetration. On the production well 52 at the time 01.01.2004 the perforation interval is poured in the area of highly permeable interlayer in order to isolate the water inflow (Figure 3). This geological and technical measure is selected as the reason for the local refinement of the super element model.

On the super element grid, the whole reservoir development was modeled since 01.2000. The grid contained 90 super elements with an average diameter of 225 m (Figure 4). The height of the super elements coincided with the full height of the reservoir, that is, each super element contained all the interlayers and bridges.

For local refinement, a section around well 52 consisting of 18 super elements and containing 8 surrounding wells was determined (Figure 4). This section was covered with a detailed computational grid with an average cell diameter of 15 m, vertically the reservoir was divided into 5 finite volumes according to the structural surfaces of the interlayers and bridges. The constructed detailed computational grid contained 17900 finite volumes. The solution of tasks (1)-(4) on the detailed grid was built on a time interval covering the moment of the geological and technical measure under consideration – from 07.2003 to 01.2006. To specify the initial and boundary conditions of the local model, a super element solution – the pressure P and the saturation S – was used at the time 07.2003.

In constructing the initial saturation distribution s^0, a generalization to the three-dimensional case of the simplest technique was used as the procedure of downscaling (Stiles, 1949; Dykstra, Parsons, 1950; Bulygin, 1974). Two assumptions are used in it: (1) more penetrable interlayers are flooded in the first place; 2) the displacement of oil by water is of a piston type, therefore part of the interlayers is completely watered, and the other part is saturated with oil. The distribution of a given volume of water within the reservoir reduces to finding such an absolute permeability value k* that layers with a permeability $k < k^*$ are saturated with oil, and layers with $k > k^*$ are saturated with water. With reference to the considered three-dimensional task, the generalization of this technique was realized as follows:

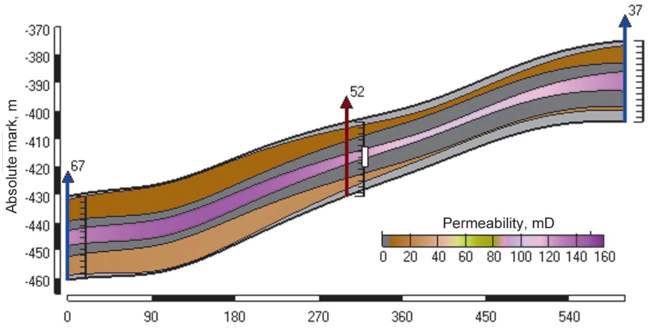

Figure 3. Arrangement of perforation intervals (solid lines) and pouring (white color)

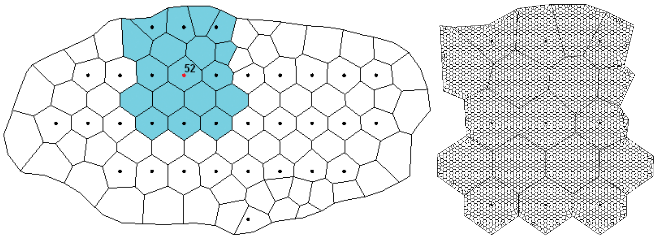

Figure 4. Covering the area of the deposit with a super element grid, the region of local refinement of the model (on the left) and its coverage with a detailed grid (on the right)

1) for each super element $V \subset \Omega$ with average porosity M and average saturation S known at the moment of downscaling, the elements V_i of the detailed grid located inside it were determined;

2) the found V_i elements were ordered in descending order of absolute permeability k_i;

3) in each V_i of the ordered set, the singular water saturation $s_i = 1$ was sequentially set before the condition $\sum_{i=1}^{N} m_i |V_i| \geq M|V|S$ was satisfied.

As an "accurate" solution for accuracy estimation, a solution based on a detailed grid in the entire deposit area was used, starting from the beginning of the reservoir development of 01.2000. The dimensions of the grid blocks were set in a manner similar to the detailed grid of the local refinement section – an average diameter of 15 m and with a breakdown of reservoir thickness for five final volumes according to the geometry of interlayers and bridges. The detailed grid of the entire deposit contained 92100 finite volumes. Simulation of the development of the entire deposit on a super element grid and on detailed grids was carried out until 01.2006.

The summary information on the used computational grids and computer time costs is given in Table 3. We note that in this paper we considered a model of a small oil deposit containing only 33 wells and a short period of its development (6 years). Therefore, the time expended on constructing a local refinement of the super element model in the section with 9 wells was only a few times shorter than the simulation time on the detailed grid of the deposit as a whole. Obviously, when considering large fields that number hundreds and thousands of wells and are being developed over several decades, the computational costs of building local and global models on detailed grids will differ by several orders of magnitude. For example, a grid with a lateral step of 15 m and a vertical step of 1 m covering an oil deposit of an average length of 5 km and an average thickness of 50 m will have a dimensionality of the order $5{\cdot}10^6$. In this case, the number of unknowns in solving the problem (1) on a small grid throughout the deposit area will increase by approximately 60 times. According to estimates of the dependence of the counting time on the dimension of the grid, we can conclude that the time required for constructing one option of the numerical solution in the entire area of such a deposit will increase approximately 100 times in comparison with the example considered, that is, about 15 days. But the dimension of the super element grid will increase only 5 times, and the duration of super element modeling will not exceed 2 minutes. The cost of the time for a performed only once upscaling will be about 10 hours. It should be noted that for large oil fields, the use of detailed computational grids may not be technically feasible at all or may require unacceptable costs of computational resources.

The time required for constructing a model on a super element grid is composed of three components – the performance of absolute permeability upscaling, relative phase permeability upscaling and modeling of water flooding directly (Table 3). The cost of modeling is less than 1%, since the upscaling procedures require solving a large number of auxiliary problems on detailed grids. On the other hand, upscaling is performed only once in the construction of the super element grid, so the use of super element model has significant advantages in carrying out multivariate design calculations in large oil fields. The greatest computational costs (more than 80%) fall on the procedure of relative phase permeability upscaling, which requires the solution of non-stationary two-phase flow problems for each super element. As shown in the work (Potashev, 2017), it is possible to accelerate the solution of this problem in principle by using an apparatus of artificial neural networks that use the statistical parameters of the local distribution of reservoir properties as input data.

3. Results of local refinement of the solution

Figure 5 shows the saturation distributions in the vertical section, plotted according to the detailed and super element model of the entire deposit at the time of the local refinement onset of super element model 07.2003. It can be seen that the super element grid allows us to describe the behavior of the average saturation, but does not give a detailed picture of the saturation distribution across the interlayers. The results of downscaling (transfer of the saturation field from super element to a detailed grid) are shown on the lower profile of Figure 5. It is possible to observe a completely satisfactory coincidence of the descaled field and the corresponding saturation distribution calculated on a detailed grid. The descaled saturation field was specified as the initial condition (2) for the local refinement task of the super element model.

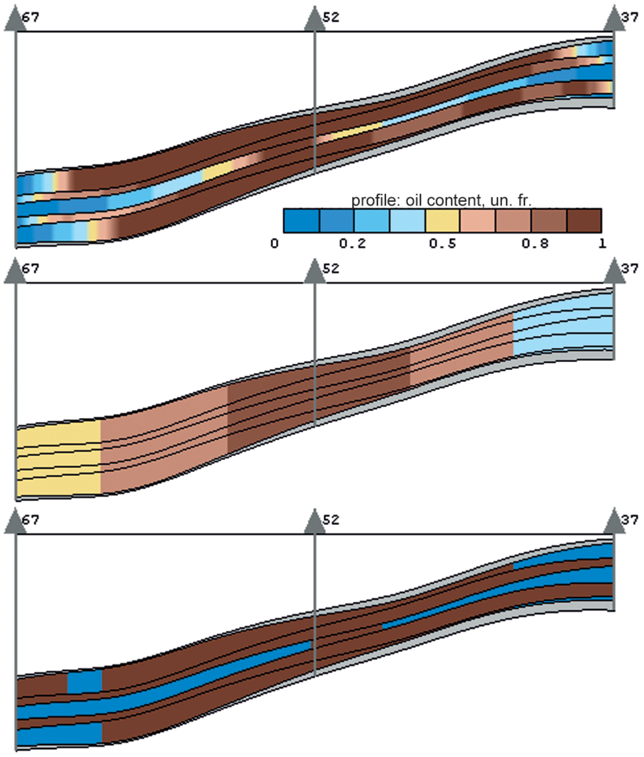

Figure 5. Distribution of saturation in the reservoir section as on 07.2003 for the detailed model of the whole deposit (above), for the super element model on a coarse grid (in the middle) and according to the descaling from the super element grid (bottom)

Computational grid	Lateral step, m	Number of layers vertically, un.	Dimensionality of grid, un.	Period of simulation, min	Computational time, min	
Super element on the entire deposit	225	1	90	01.00-01.06 гг.	upscaling (AP)	16
					upscaling (RPP)	87
					calculation	0.25
Detailed on the section	15	5	17 900	07.03-01.06 гг.	35	
Detailed on the entire deposit	15	5	92 100	01.00-01.06 гг.	216	

Table 3. Computational grid parameters and calculation duration

Calculations showed that over time, the agreement between the saturation fields calculated by the model of local refinement and the detailed model of the entire deposit is preserved to a certain extent (Figure 6).

Figure 7 shows the change in the pressure fields and the flow rate near the well 52, constructed on a detailed computational grid before and after the moment of filling the perforation interval.

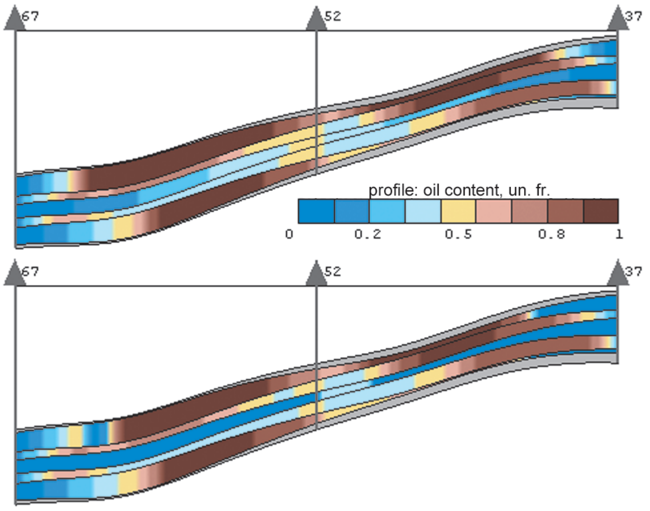

Figure 6. Distribution of saturation in the reservoir section as on 01.2006 for the detailed model of the whole deposit (above), for the super element model local refinement (bottom)

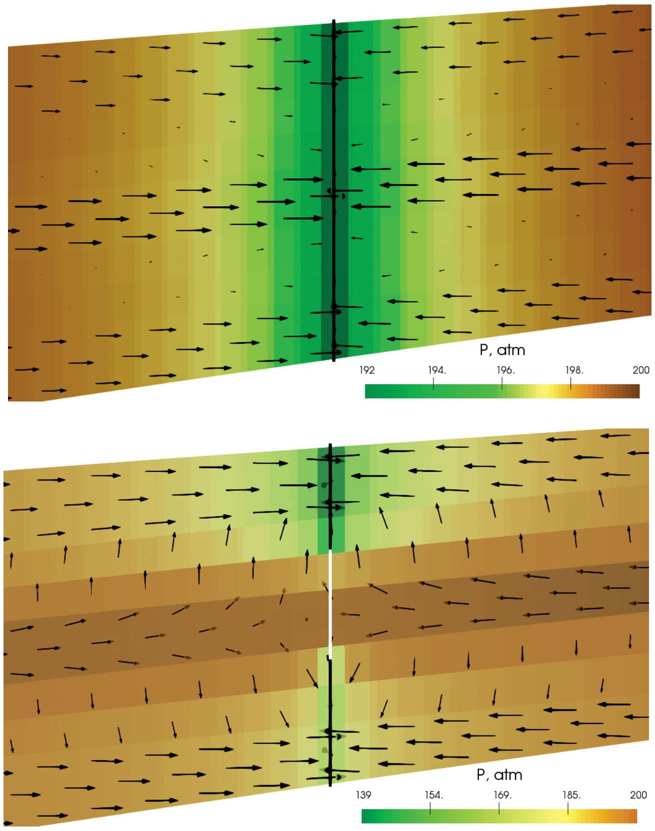

Figure 7. Distribution of reservoir pressure and filtrational rates in the vicinity of well 52: before (left) and after (right) isolating the middle section of the perforation interval

It is expected that the hydrodynamic consequences of the isolation of the highly permeable and the most watered interlayer will be as follows. Some time after pouring, the water cut in well 52 will be reduced due to the inflow of oil from the upper and lower less permeable layers to it. Then water will begin to flow into these layers from the isolated interlayer, which will lead to an increase in watering of the liquid taken out by the well. This behavior of oil selection was confirmed by calculations both from the detailed model of the entire reservoir and from the local refinement of the super element model (Figure 8). The curve obtained within the first stage of the super element model on a coarse grid describes only the average behavior of the true dynamics of the watering. But after a certain time of the effect of this geological and technical measure, the performance of the well, calculated on a coarse super element grid and on detailed grids, will converge.

As mentioned above, the local refinement of the super element grid also makes it possible to distribute the inflow to the well by individual intervals (interlayers). Figure 9 shows the flow rate of oil and water in well 52 for each of the three permeable

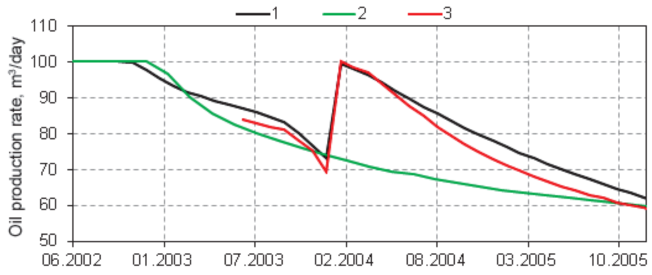

Figure 8. Estimated dynamics of oil production rate in well 52. 1 – by detailed model of the whole deposit, 2 – by super element model, 3 – by super element model with local refinement

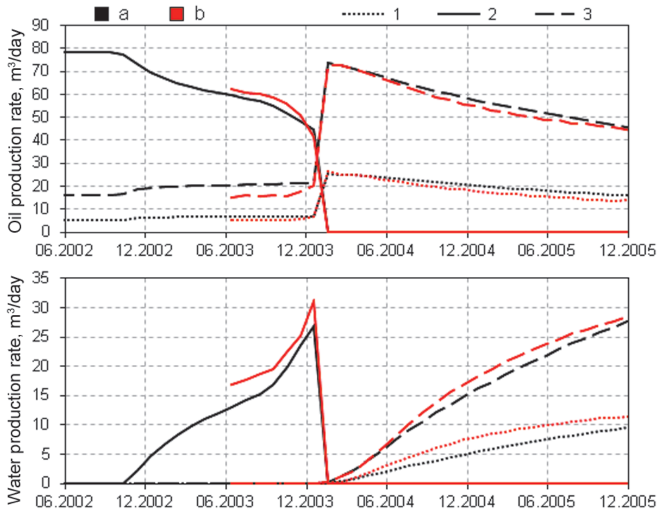

Figure 9. The calculated separation of the oil and water production rate from the first (1), the second (2) and the third (3) interlayers according to the detailed model of the whole reservoir (a) and the super element model with local refinement (b)

interlayers. Since the permeability of both bridges is lower by orders of magnitude, the fractions of the liquid inflow through them to the well are insignificant and not shown. It can be seen that the distribution of the inflow from the detailed model of the entire reservoir and the local refinement of the super element model are consistent with each other.

Conclusion

The presented method of two-stage super element modeling of an oil reservoir with local refinement of the solution is suitable for multivariate calculations in the design and evaluation of the efficiency of geological and technical measures in some parts of the oil field.

The advantage of this approach in comparison with the usual refinement of the computational grid in the entire flow area is clearly manifested when carrying out multivariate design calculations in large oil fields. Computational costs are determined by the preliminary stage of building a super element model and are weakly dependent on the number of sections selected to refine the solution and assess the consequences of geological and technical measures on the performance of wells. Moreover, the method of local refinement of the solution is applicable not only to modeling the redistribution of filtration flows by isolating individual intervals, but with minimal correction to other methods of oil recovery enhancement, for example, cyclic injection of the injected agent, acid treatment of the bottom-hole zone, sidetracking and other geological and technical measures on separate wells.

The accuracy of the results of the local refinement for the super element oil reservoir model is largely determined by the downscaling quality of the water saturation – the transfer of function S calculated on the coarse grid of super elements to the detailed grid constructed on the selected section of the reservoir. The simplest method of de-scaling S, adopted in the article, in determining the initial distribution of saturation s^0 needs to be improved. Considerable attention is expected to be given to this problem in the planning of prospective works.

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About the Authors

Aleksandr B. Mazo – DSc (Physics and Mathematics), Professor, Department of Aerohydromechanics, Kazan (Volga region) Federal University

35 Kremlevskaya St., Kazan, 420008, Russia

Konstantin A. Potashev – PhD (Physics and Mathematics), Associate Professor, Department of Aerohydromechanics, Kazan (Volga region) Federal University

35 Kremlevskaya St., Kazan, 420008, Russia

E-mail: KPotashev@mail.ru

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THE MAIN FEATURES OF THE GEOLOGICAL MODELING PROCESS OF A SHALLOW DEPOSIT OF SUPER-VISCOUS OIL IN ASPECT OF DEVELOPMENT STRATEGY PLANNING WITH THE USE OF STEAM-ASSISTED GRAVITY DRAINAGE METHOD

S.P. Novikova[1], D.K. Nurgaliev[1], V.A. Sudakov[1], A.N. Delev[1], N.G. Nurgalieva[1], M.R. Lyabipov[2], R.R. Akhmadullin[2]*
[1]Kazan (Volga region) Federal University, Kazan, Russia
[2]Tatneft PJSC, Almetyevsk, Russia

Abstract. Deficiency of fossil minerals, limited reserves of conventional hydrocarbon raw materials indicates the need to involve in the fuel and energy complex of other sources of hydrocarbons. Fields of super-viscous oil are one of the sources.

This article is devoted to the study of sediments of the Permian sedimentary complex containing super-viscous oil deposits. The geological structure of the Lower Kazanian and Ufimian deposits is considered. A characteristic of the Sheshmian sandstone pack is given. The analysis of the set of geophysical studies is presented. Modeling of a shallow super-viscous oil deposit based on the lithologic-technological types of the productive formation was carried out, based on the results of drilling, core material and logging. The features of constructing the structural framework of a three-dimensional grid, and a lithological-technological model are highlighted. The distribution of porosity, permeability and oil saturation is described.

Keywords: Permian sedimentary complex, super-viscous oil, geological modeling, Sheshmian horizon
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The reduction of prospected oil reserves, reduction of its production and the complexity of hydrocarbon extraction at the present stage of development, requires an assessment of developing unconventional hydrocarbon raw materials, such as super-viscous oil. There is a need to find the most optimal ways of extracting and processing super-viscous oil. Today, the development and production of super-viscous oil is an urgent task in the oil industry, solved using innovative technologies of Tatneft PJSC.

The Lower Karmalsky uplift, which controls the deposit of super-viscous oil of the Cheremshansky oil field is territorially confined to the western Zakamye. In tectonic terms, it is located on the western slope of the South Tatar arch, which is a sloping monocline, step-wise submerging in the direction of the Melekess depression.

Geological-tectonic development is associated with the late formation period of the Paleozoic sedimentary strata. In accordance with the allocated lithologic-stratigraphic complexes of rocks, the Permian system of this period is subdivided into three series – Priuralian, Biarmian and Tatarian (bottom-up) and 8 stages (Table 1 (Cohen et al., 2013)).

Permian deposits on the territory of the Republic of Tatarstan include four petroleum bituminous complexes: locally petroleum bituminous Lower Permian carbonate, zonally petroleum bituminous Ufimian terrigenous, Lower Kazanian terrigenous-carbonate and Upper Kazanian carbonate-terrigenous (Muslimov et al., 2012).

The article focuses on the Lower Kazanian and Ufimian deposits.

The relief of the South Tatar arch in the structural plan of the Kungurian time was weakly expressed, this created conditions for the generation of the Ufimian formation. With distance from the Urals and moving westward, this formation underwent certain lithologic-facies changes, which manifested in changes of the main rock complexes. These lithologic-facies changes are associated with the change of the boundaries to the east of the desalinated basin during the Sheshmian period under the influence of smooth oscillations arising under the influence of early tectonogenesis of the Urals. As a result, the Sheshmian sedimentation basin gradually regressed to the east. However, there

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[*] *Corresponding author: Svetlana P. Novikova*
E-mail: Novikovaspn@gmail.com

Age	System	Series	Stage	Substage	Horizon
Paleozoic	Permian	Tatarian (P_3)	Vyatskian		
			Severodvinskian		
		Biarmian (P_2)	Urzhumskian		
			Kazanian	Upper	
				Lower	Barbashinskian
					Kamyshlinskian
					Baytuganskian
		Priuralian (P_1)	Ufimian		Sheshmian
					Solikamskian
			Kungurian		Irenkinskian
					Fillipovskian
			Artinskian		
			Sacmarian		Sterlitamakskian
					Tastubskian
			Asselian		

Table 1. General stratigraphic chart as of 2016

was no complete regression of the Sheshmian basin on the territory of the Zakamye of Tatarstan. During regression, it was preserved in the most submerged part of the Sheshminsky paleo depression – in the basin of the river Sheshma. In near-shore conditions, bottom currents within the basin have developed the shoestring bodies of sandstones in the upper pack of the Ufimian tier (Petrov, 2000).

The unconcordant bedding of a sandy pack of the Sheshmian horizon on bedding rocks indicates that the formation of accumulative bodies rising above the bottom of the basin was proceeding (Uspensky, Valeeva, 2008).

The Ufimian stage (P_1u) belongs to the Priuralian series of the Permian system. Within the Lower Karmalsky deposit of the Cheremshansky field, the stage is represented by the Sheshmian horizon (P1u-ss, Figure 1), consisting of a lower sandy-clay pack and an upper sandstone pack (Akishev, Shalin, 1977; Nurgalieva et al., 2016).

The Sheshmian sandstone pack of the Ufimian stage is the main stratum containing hydrocarbons. The pack is composed of sands and sandstones with different degree of cementation with small interlayers of siltstones. The thickness of the pack varies from 3 to 10 meters on the slopes and up to 45 meters in the arch of the structure (Figure 2).

In the Permian sediments, shielding seals of regional, zonal and local distribution are distinguished. On the territory under consideration, the zonal impermeable layer is the clay rocks of the Baytuganskian horizon of the Kazanian stage (P2kz1), which is divided into two packs (Geologiya Tatarstana..., 2003).

The lower pack, lying on the deposits of Sheshmian sandstone pack of the Ufimian stage, is composed of clays, dark gray, with a bluish tinge and is a reliable impermeable layer (reference horizon – “lingula clays”). The thickness of the lower pack of the Baytuganskian horizon varies from 6 to 8 meters in the arched parts of the sand formations of the Ufimian stage. On the slopes of sand formations the thickness is up to 26 meters.

The upper pack, lying over the “lingula clays”, is composed of limestones, bluish-gray, dark gray, steel-gray, porous, cavernous, fractured, with a mass of brachiopod and spirifer residues, in the bottom with frequent remains of bryozoans with inclusions of pyrite (reference horizon – “Medium-spirifer limestone”). Its thickness is from 2 to 4 meters.

The thickness of the Baytuganskian horizon varies from 8 to 30 meters.

Like all deposits of super-viscous oil, Nizhne-Karmalsky deposit is located on the western slope of the South Tatar arch. It is confined to the Ufimian bituminous complex, to a sand pack of the Sheshmian horizon of the Permian system. It is controlled by the Upper Permian uplifts of the third order of sedimentary genesis allocated along the top of the Ufimian stage. The studied uplift is part of the group of uplifts of the Yamashino-Cheremshansky structural zone of the second order, its south-eastern part.

The Lower Karmalsky positive structural form is an integral part in the ridge of elongated sand bodies of the northwest strike. Sand bodies are paleobars; they have the form of local sedimentary domes of the brachiantical type. The chains of the uplifts are separated from each other by sections of reduced thickness of the sand pack. The sand pack is covered with “lingula clays” of the Baytuganskian horizon.

The arching part of the uplift is complicated by six domes with the maximum thickness of the Ufimian sandstone pack from 34 to 46 m. The amplitude of the domes varies from 25 to 40 meters.

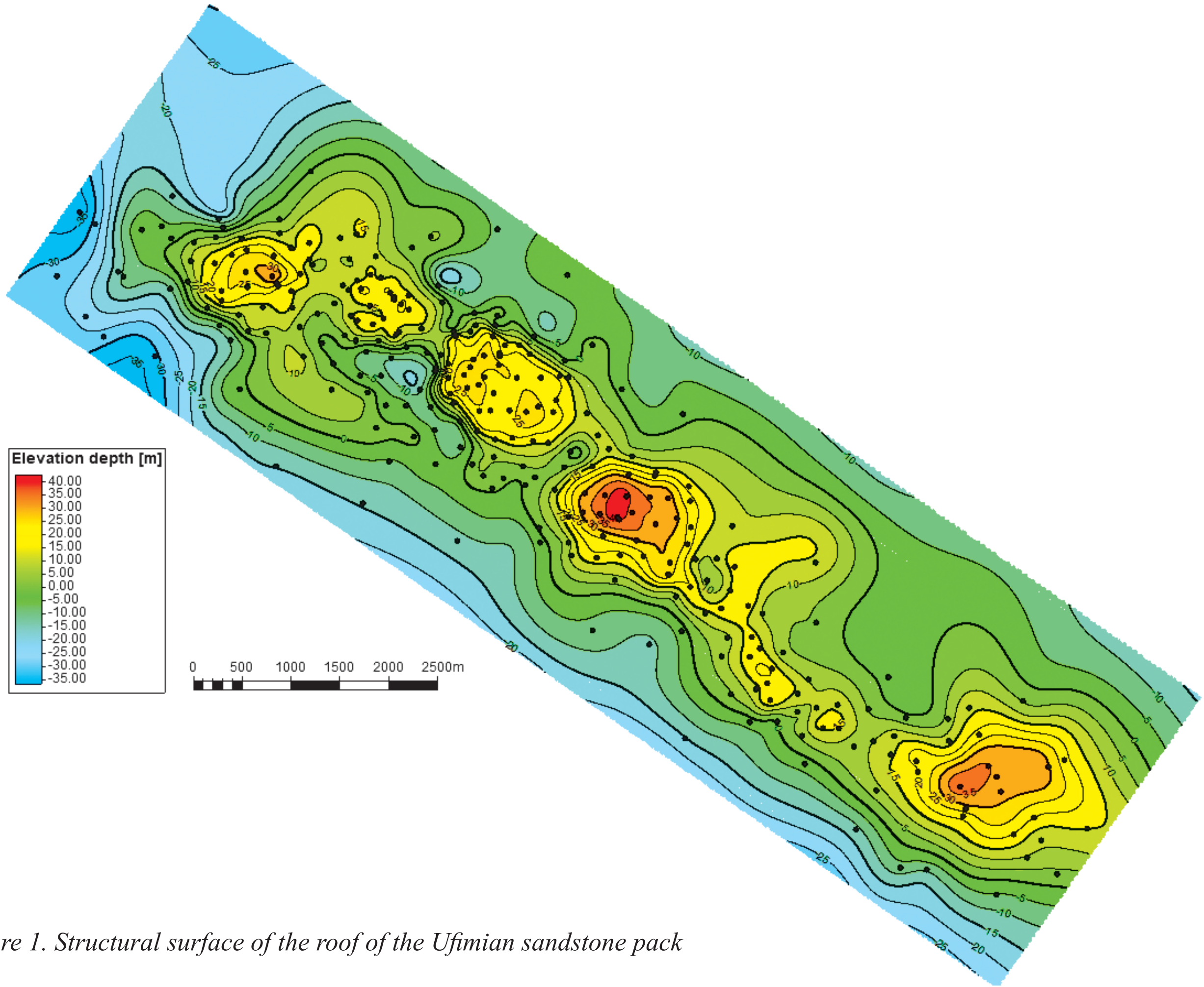


Figure 1. Structural surface of the roof of the Ufimian sandstone pack

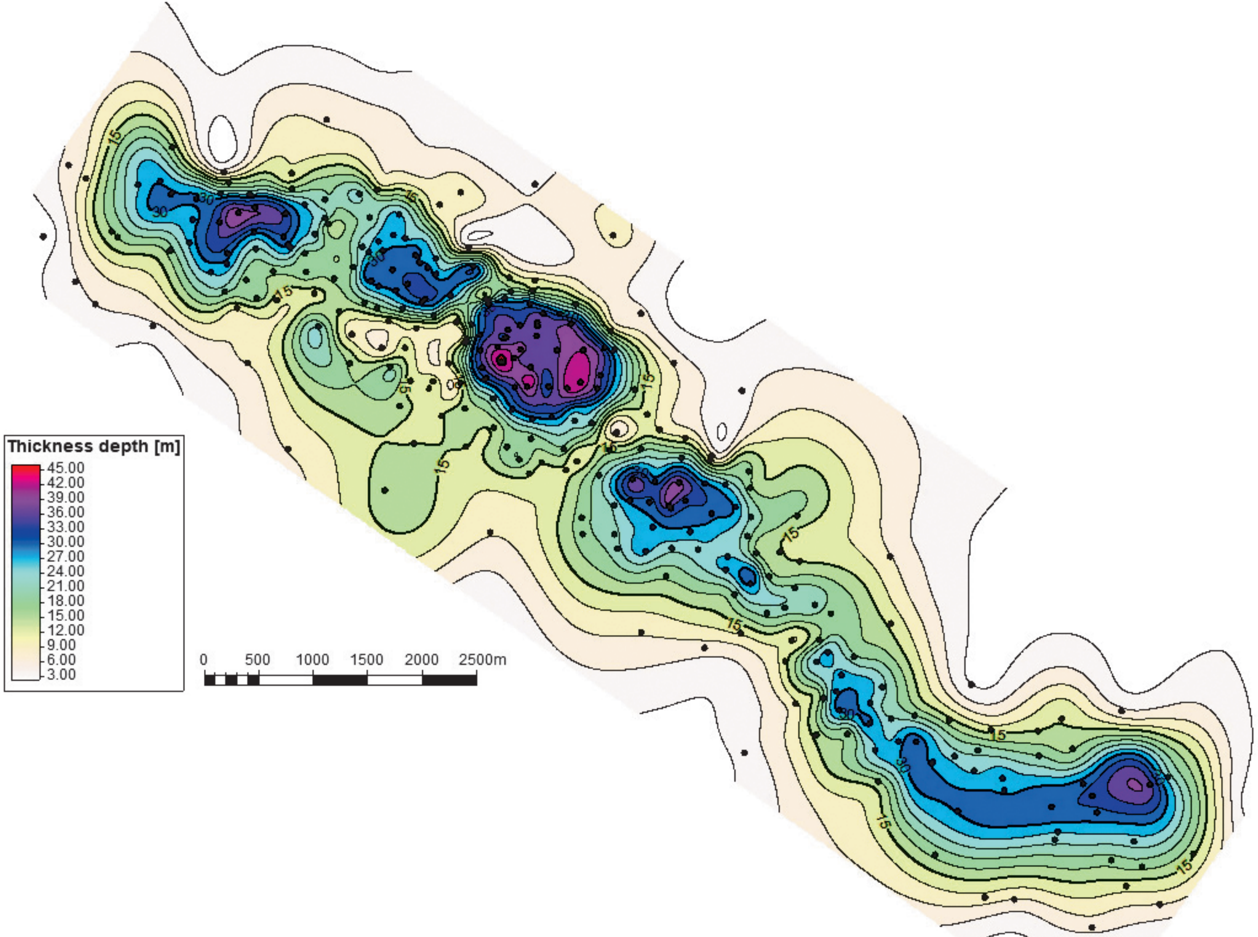


Figure 2. Map of the total thickness of the Sheshmian sandstone pack

The uplift is controlled by a closed isohypsum with absolute elevations of 0 meters. The thickness of the sandstone pack in the troughs decreases to 8 meters. The dimensions of the Lower Karmalsky uplift are 12.3 x 2.4 km.

The sections with the maximum thickness of the Sheshmian sandstones correspond to the minimum thickness of the "lingula clays" pack of the Lower Kazanian substage (Figure 3).

Structural plans for the Lower Kazanian and Upper Kazanian sediments basically repeat the structural plan for the top of the Ufimian deposits, but the slopes of the local uplifts in the Kazanian deposits are more gentle due to accumulation of "lingula clays" (Figure 4).

Taking into account the peculiarities of the studied section and the conditions for carrying out the well log survey, the developed **set of geophysical methods** now includes: self-potential logging, apparent resistivity logging, lateral logging sounding, lateral logging, inductive logging, electromagnetic propagation logging, neutron gamma-ray logging, gamma-ray logging, compensated neutron logging, cavernometry, resistivimetry. Correlation of deposits was carried out on 173 wells.

In exploratory wells drilled on Ufimian deposits, according to logging data, two main reference horizons are well distinguished: "medium-spirifer limestone" and "lingula clays". In the wells of structural drilling in addition to those named, tight limestones of the Sakmarian stage are applied (Syurin, 2017). But P1-ass layer was the main reference horizon in structural and deep drilling, including in wells of super-viscous oil deposit (Pavlov, Petrov, 1974).

Construction of a structural framework of three-dimensional grid

A peculiarity in structural constructions of a shallow deposit is the specificity of processing and interpretation of seismic data in the upper part of the section, which does not allow obtaining sufficiently accurate data about structures in the inter-well space. This is due to the low speed zone and, consequently, the poor resolving capacity of seismic exploration in the upper part of the section (~ 300 m). Exploration wells in the investigated deposit have been drilled with a close spacing, and therefore structural constructions based on well data are more accurate.

When constructing a grid model, a smaller grid should be defined than in traditional models in order to characterize the heterogeneity of a closely drilled reservoir and also to describe the process of steam-assisted gravity drainage (SAGD) in reservoir modeling, if the SAGD method is planned to be used during the deposit development. Rotation of the grid should be chosen from the calculation of its orientation, not only along the strike of the geological structures, but also in the cross of the main mass of the horizontal boreholes.

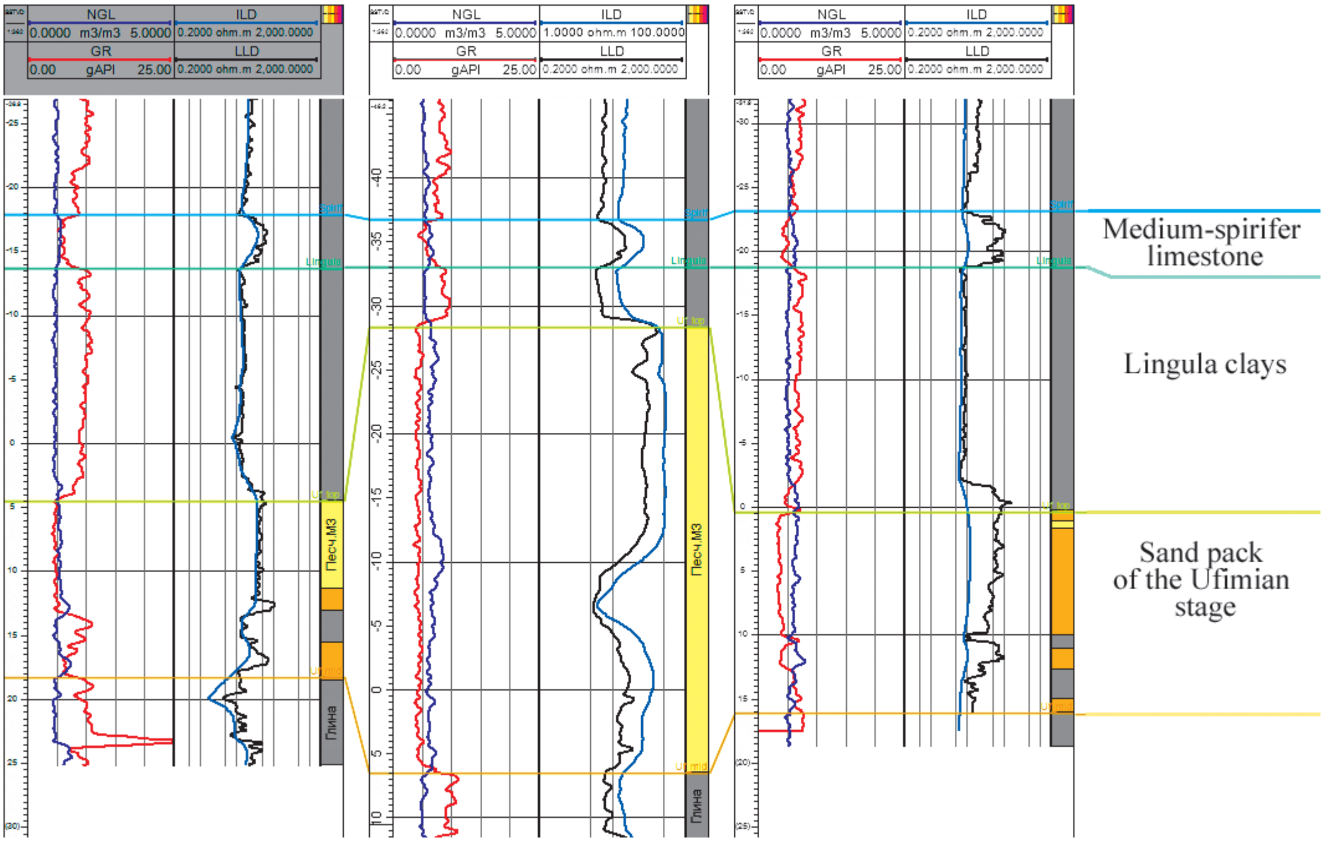
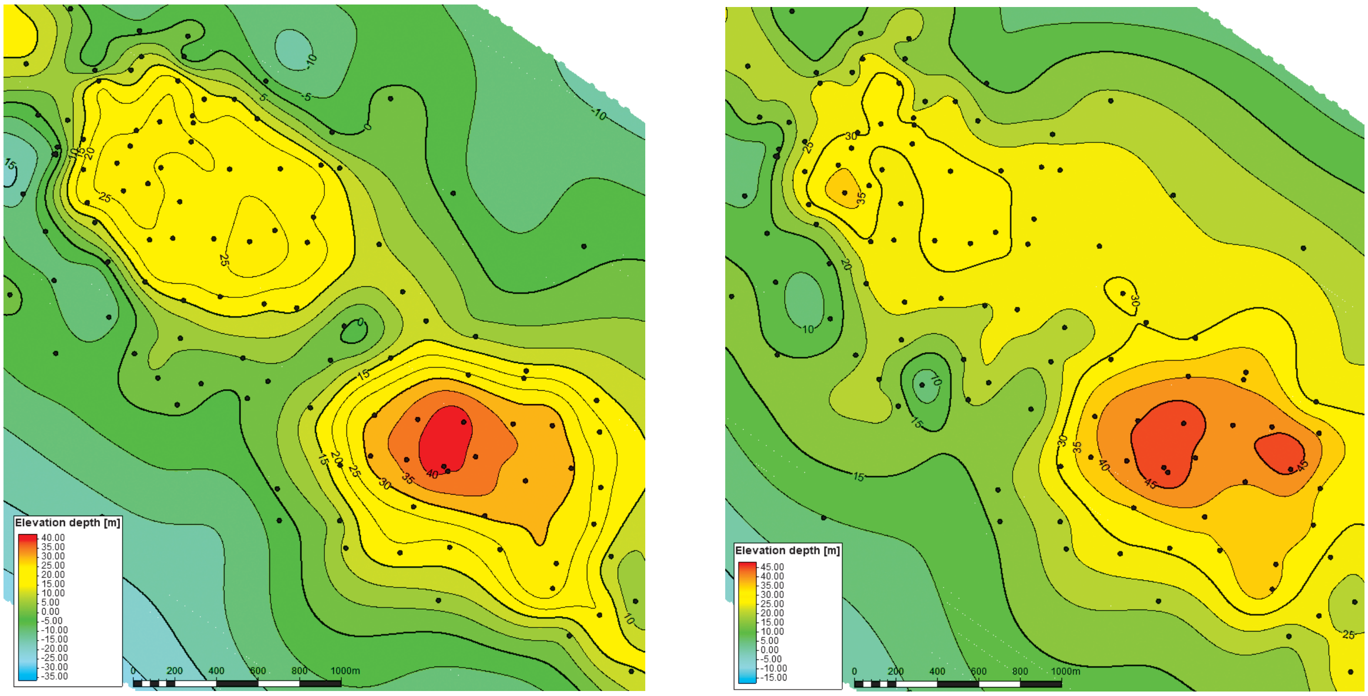


Figure 3. The correlation scheme



a b

Figure 4. Structural maps: a – for the roof of lingula clays; b – for the roof of the Ufimian stage

Construction of a lithologic-technological model

The difference from working with the traditional model is the presence of a large volume of core material from prospecting, exploration, structural wells. The use of core data as the main geological document in the macro description up to the definition of the reservoir properties makes it possible to expand the resolving capacity of logging methods and produce a more detailed breakdown of rocks into lithological differences (Figure 5).

Based on the concept of the bar structure of the studied deposit, the construction of the lithologic-technological model was carried out in two stages. At the first stage of the construction, the sand body was modeled with boundaries defined by the parametric wells. For this, the Truncated Gaussian with trends algorithm was used, which allows to set geometric trends in the constructions (Figure 6). At the second stage, 4 lithological-technological types of sandstones (fine-grained loose sandstone, fine-grained firm sandstone, medium-grained loose sandstone and medium-grained firm sandstone) were spread in the volume of the sand "body" obtained from the investigations carried out using the geostatistical methods and the Sequential indicator simulation algorithm.

When geostatistical methods are used, the distribution of lithological-technological types of rocks in the vertical section should be used as a trend. For this purpose, an analysis of the vertical proportion curve was performed on the set of wells (Figure 7). The upper part of the section, composed of clayey rocks (lingula clays), the middle part of the section, mainly composed of loose fine-grained sandstones (the top of the sand pack of the Ufimian stage) and the lower part of the section, represented by tight sandstones (the bottom of the sand pack of the Ufimian stage) are well traced along the vertical proportion curve.

Since the construction of the lithological-technological model was carried out by stochastic algorithms, the formation of unrelated volumes, "noise", is unavoidable. Quality control of the lithological-technological model was carried out by the method of connected volumes

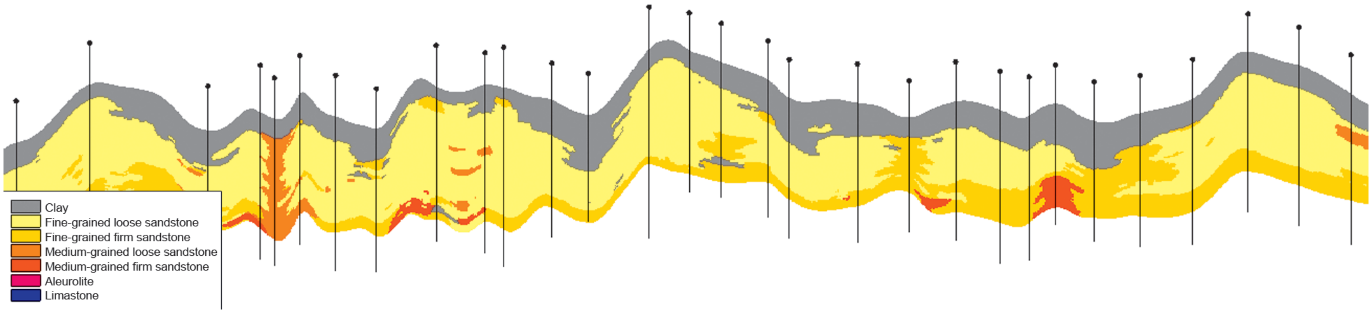


Figure 5. Profile. Lithological model

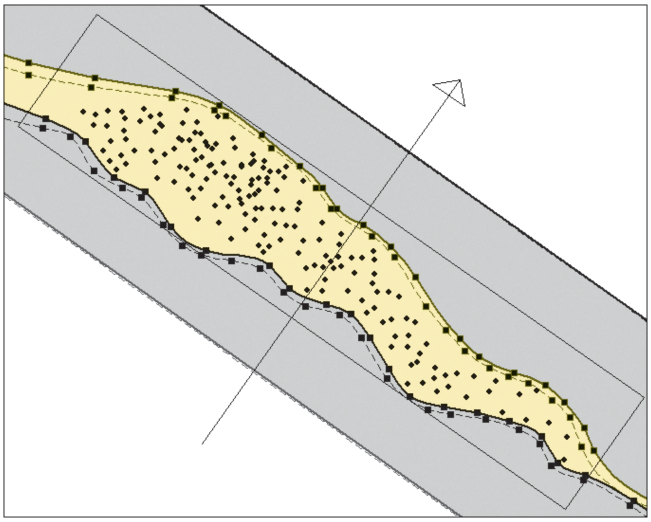


Figure 6. Boundary of the sand body

and analysis of distribution histograms of lithological-technological types of rocks (Zakrevsky, 2009). Further, the removal of clusters of cells not connected with the main body of the deposit and not justified by borehole data was carried out (Figure 8). This operation was carried out proceeding from the notion that the reservoir rocks within the bar body should be well connected in the consequence of sedimentation.

Distribution of porosity and permeability parameters

As a basis for the distribution of porosity, the model uses well log interpretation data that are correlated with the values obtained from core studies (reservoir properties). The porosity distribution methods do not differ from the work with the traditional model (Figures 9, 10). The distribution of porosity in the reservoirs was performed by Gaussian random function simulation method for each lithological-technological type of reservoir.

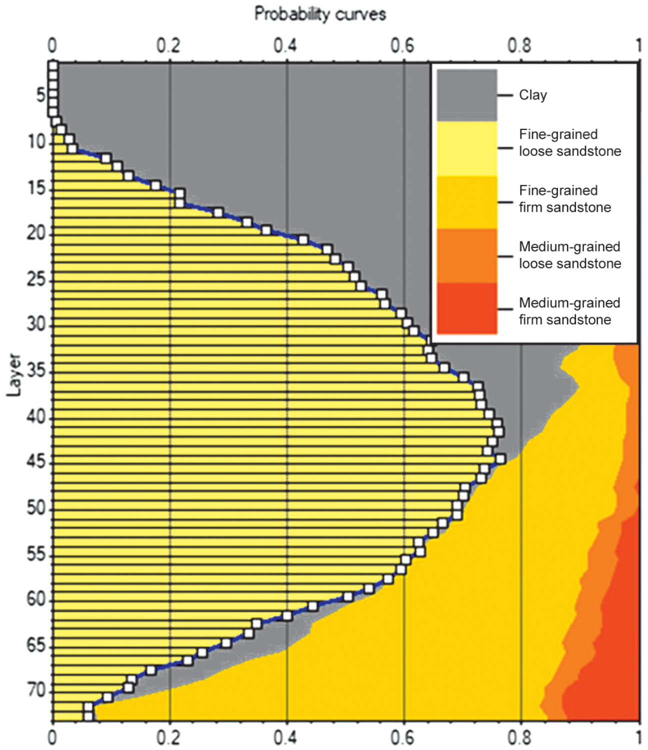


Figure 7. Vertical proportion curve

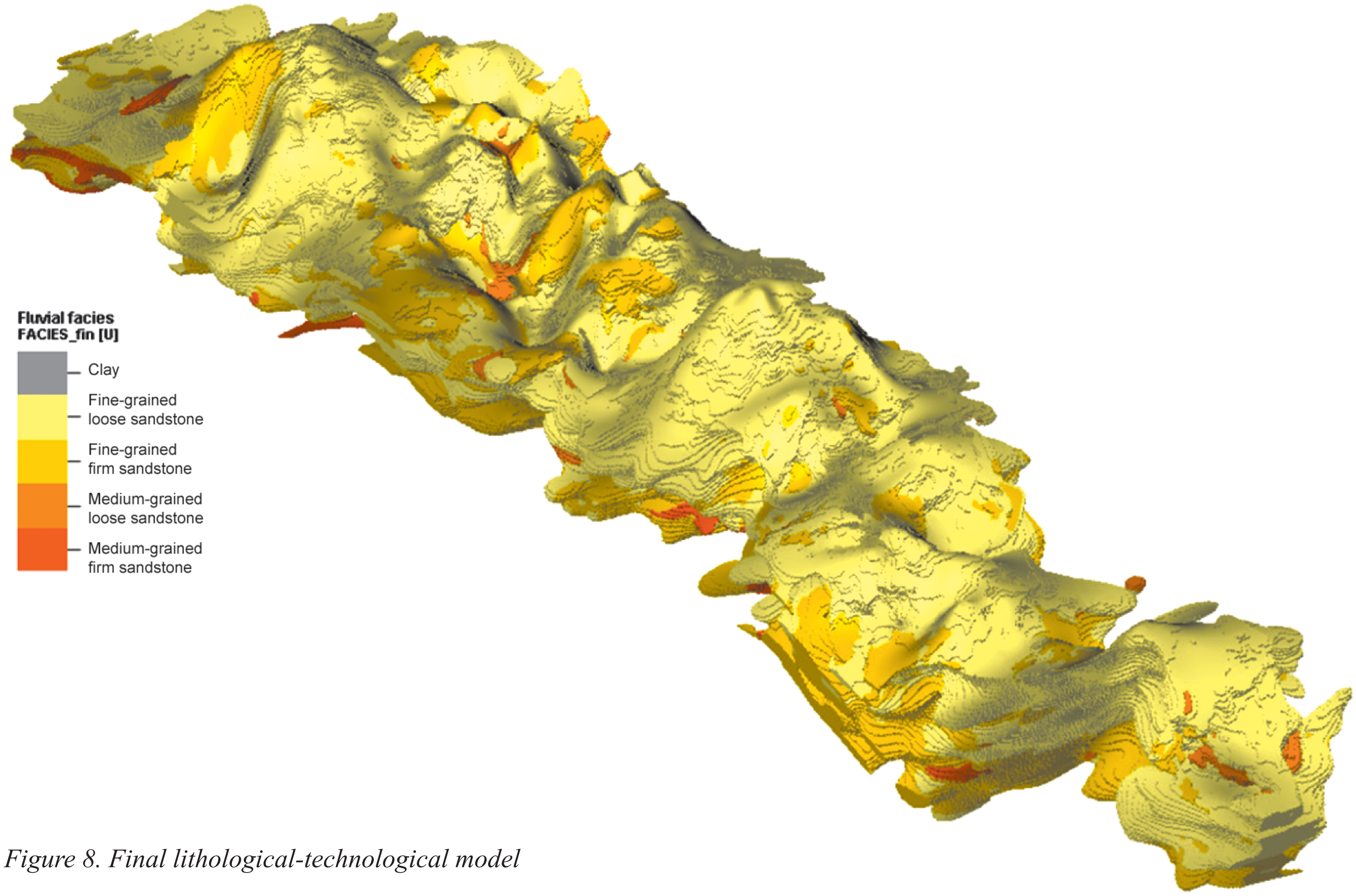


Figure 8. Final lithological-technological model

The permeability cube is calculated from the porosity-permeability dependences determined from the core data for each lithologic-technological type of rocks.

Distribution of saturation and justification of the bottom of the deposit

As a method for distributing oil saturation, we applied layered interpolation by means of Kriging method, using, as a trend, the dependence of saturation on depth (Figures 11, 12) (Zakrevsky, 2009).

Unlike conventional deposits, the investigated deposit from a top to a bottom of formation to some extent contains residual water in the bound volume of a layer, and sometimes also in the form of bypassed water.

The bottom of the oil-saturated zone was taken as the oil-water contact (the values of conditional limits were taken from the report on the reserves calculation), determined by the quantitative and qualitative characteristics of the laboratory studies of core and well logging survey (Figure 13). In the electric logging diagrams, this boundary is repulsed by the sharp drop in the apparent resistivity curve.

Often, the apparent resistivity curve shows a double decline. The latter characterizes the ancient oil-water contact (paleo oil-water contact).

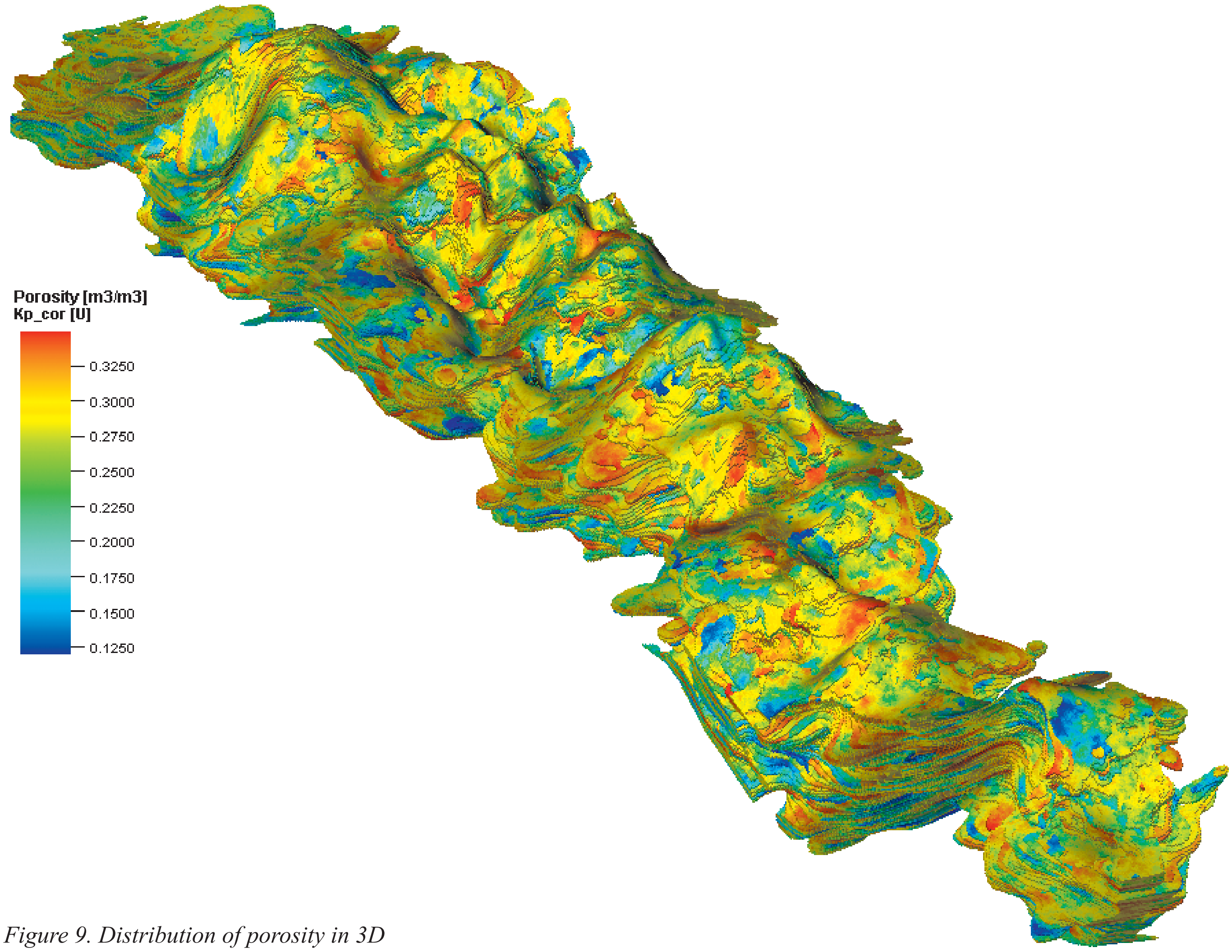


Figure 9. Distribution of porosity in 3D

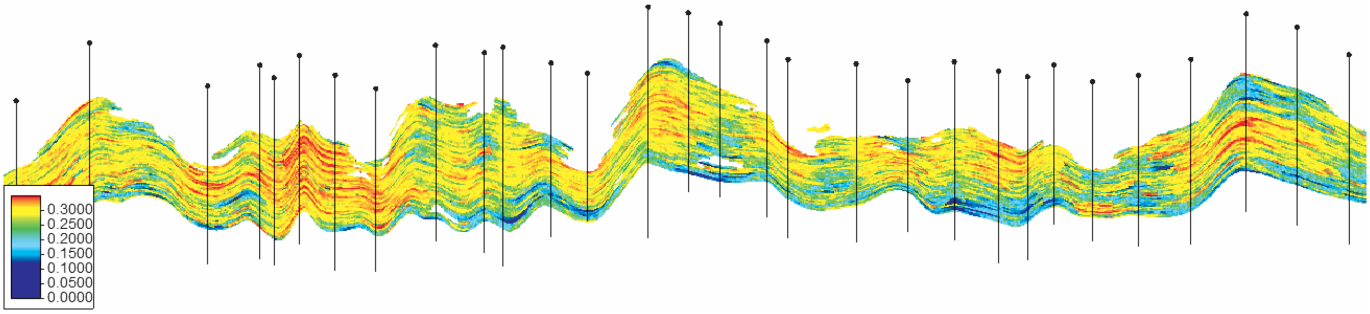


Figure 10. Distribution of porosity in the section

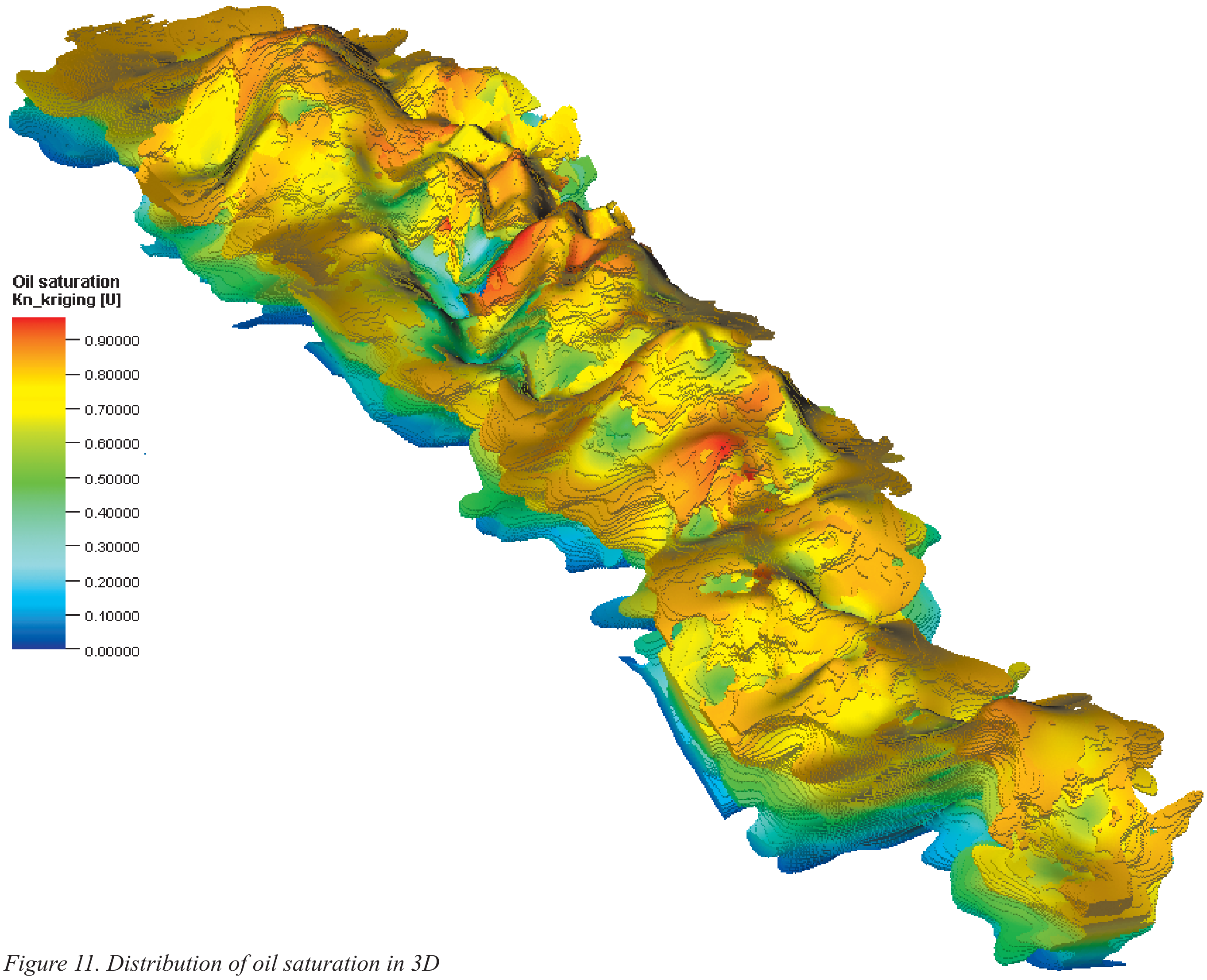


Figure 11. Distribution of oil saturation in 3D

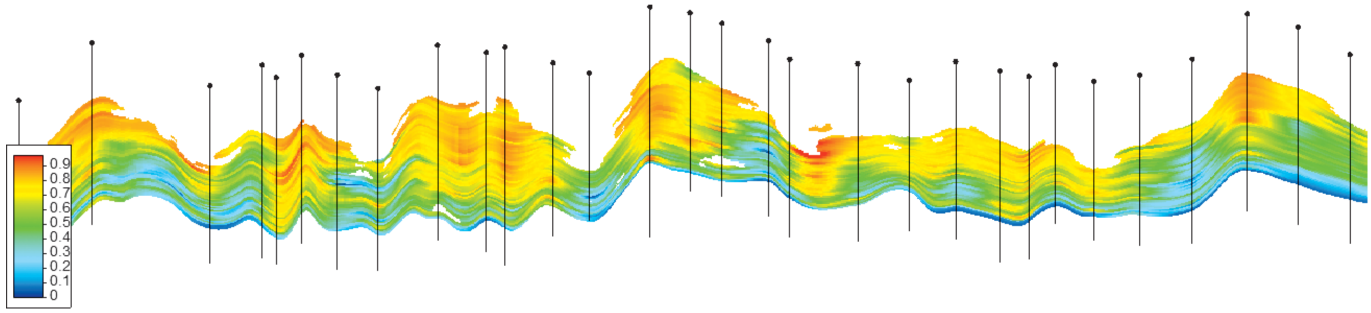
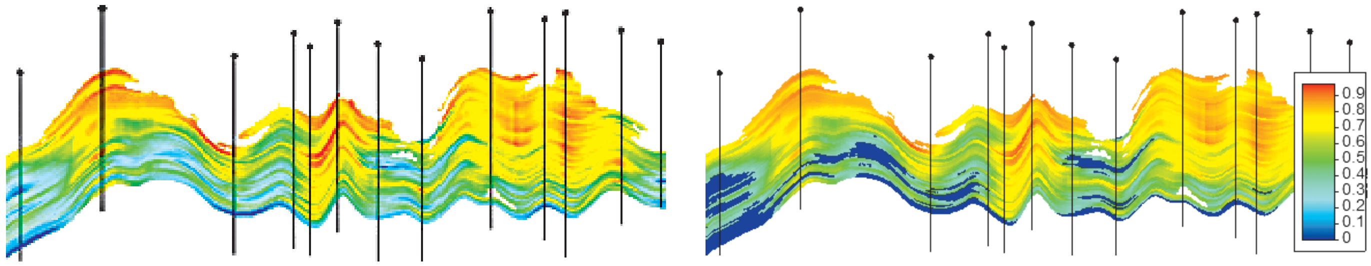


Figure 12. Distribution of oil saturation in the section



a

b

Figure 13. Oil saturation profile: a – the initial, b – the below-zero conditioning limit

To monitor the processes occurring in the formation, an original set of geophysical methods was used, including special electrical survey and seismic survey (Sudakov, 2016).

The main features of the geological model construction of shallow super-viscous oil deposit

In the process of analysis and preparation of the initial data and, subsequently, the geological model construction of the super-viscous oil deposit, the following features of the construction and the main differences from the conventional deposits were revealed.

1. The presence of a large volume of core material can serve as a source of data allowing to expand the resolution of logging methods and to produce a more detailed breakdown of rocks into lithological differences.

2. The complexity, and often the impossibility of processing and interpreting seismic data in the upper part of the section do not allow us to obtain sufficiently accurate data on structures in the inter-well space. In the case of close spacing of drilled wells, structural constructions for well data will be more accurate.

3. When constructing a grid model, a smaller grid should be made than in traditional models, in order to more accurately characterize the heterogeneity of a closely drilled reservoir, and also to describe the SAGD process. Rotation of the grid should be chosen from the calculation of its orientation not only along the strike of structures, but also in the cross of the main mass of horizontal well trunks.

4. The lower boundary of oil saturation is considered to be the bottom of the oil-saturated zone (the values of the conditional limits are taken from the report on the reserves calculation), determined by the quantitative and qualitative characteristics of laboratory studies of core and logging.

The spatial distribution of super-viscous oil deposits in the Permian system is controlled by the spread of lithofacies. Due to the variety of lithofacies, these deposits are characterized by incontinence and intermittent propagation. The detailed correlation of the section, the separation of reservoirs, the sealing layers and traps as a whole, as well as the considered features of the logging methods in combination with the core data and the completeness of this set, made it possible to construct a geological model of the field. The method of constructing geological model of a shallow deposit of super-viscous oil is presented; approaches and techniques in the arrangement of works for practical applications without considering periclinal zones are shown.

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About the Authors

Svetlana P. Novikova – Leading Engineer of REC Modern geophysical technologies, Institute of Geology and Petroleum Technologies
Kazan (Volga region) Federal University
4/5 Kremlevskaya St., Kazan, 420008, Russia
E-mail: Novikovaspn@gmail.com
Tel: +7 843 231 54 98

Danis K. Nurgaliev – Vice-Rector for Research, DSc (Geology and Mineralogy)
Kazan (Volga region) Federal University
4/5 Kremlevskaya St., Kazan, 420008, Russia

Vladislav A. Sudakov – Deputy Director for Innovation, Institute of Geology and Petroleum Technologies
Kazan (Volga region) Federal University
4/5 Kremlevskaya St., Kazan, 420008, Russia

Nuriya G. Nurgalieva – Professor, DSc (Geology and Mineralogy), Department of Oil and Gas Geology
Kazan (Volga region) Federal University
4/5 Kremlevskaya St., Kazan, 420008, Russia

Aleksey N. Delev – Engineer of REC Modern geophysical technologies, Institute of Geology and Petroleum Technologies
Kazan (Volga region) Federal University
4/5 Kremlevskaya St., Kazan, 420008, Russia

Marat R. Lyabipov – Assistant to the Head of Super-Viscous Oil Production Department
Tatneft PJSC
82 Mardzhani St., Almetyevsk, 423450, Russia

Robert R. Ahmadullin – Chief Engineer, Super-Viscous Oil Production Department, Tatneft PJSC
82 Mardzhani St., Almetyevsk, 423450, Russia

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SEVERAL METHODS TO INCREASE PRODUCTION FROM CARBONATE RESERVOIRS, DEVELOPED BY MEANS OF HORIZONTAL TECHNOLOGY

R.Kh. Akhmadullin
Oil and Gas Production Department Prikamneft Tatneft PJSC, Elabuga, Russia
E-mail: ahmadullinrh@tatneft.ru

Abstract. Market conditions during the economic crisis require the provision of high efficiency of capital investments at all stages of production in two main areas: increasing the flow rate of new wells, recovering production from highly-drained and inactive stock of wells, and reducing drilling and well site construction costs. The task is solved by improving the existing development systems, broadly implementing the already proven methods of increasing oil recovery, including the use of horizontal technology that provides more complete production of inter-well space and massive geological and technical measures to restore production from inactive and highly watered wells. Among the latter, there is little costly technology to restore oil production in open wells with a horizontal end, which operate carbonate reservoirs of the Lower and Middle Carboniferous deposits in the Republic of Tatarstan. The essence of the technology is to lower the suspension of the pump directly to the horizontal part of the well, if possible, to the lowest hypsometric mark of its trajectory in the oil-saturated part of the operational object. At the same time, the oil production rate increases, the watering of the well production decreases, its service life is extended, the design levels of production are maintained, the most complete production of oil reserves is achieved and the ultimate oil recovery factor is increased. Taking into account the positive results of the application of the technology, it is proposed to extend it to all fields of Tatarstan, where the carbonate reservoirs with wells with horizontal end are operated.

Keywords: geological structure, development object, pumping equipment, increase in production capabilities, well with horizontal end

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High efficiency of producing oil reserves from weak permeable carbonate reservoirs is carried out in two main directions: increasing the flow rate of new wells and recovering production from inactive and highly watered well stocks, reducing drilling and well development costs. In both cases, the development of oil reserves has proved to be effective through the introduction of modern technologies and methods for developing hydrocarbon fields using horizontal technology (HT). Moreover, the use of HT reduces the number of project vertical wells, while not decreasing, but increasing the coverage of produced oil reserves due to the spatial drainage of reservoirs, which means raising the oil recovery factor and saving on infrastructure. An important point is to increase the period of effective operation of wells with a horizontal end.

The Republic of Tatarstan, which has more than half a century of development of oil fields, plays a significant role in the total oil production of the country as a whole. All the fields of the republic are complex: multi-object and multi-deposit. By now, the share of oil production from low-productive carbonate reservoirs is steadily growing against the background of outstripping development of highly productive reservoirs. The problem of increasing reservoir recovery and maintaining a steady extraction rate at the fields of Oil and Gas Production Department Prikamneft of Tatneft PJSC is very relevant. The territory of the fields belongs to the Tatarstan oil-bearing region and is confined to the northern slope of the South Tatar arch and the southern slope of the North Tatar arch.

On the example of Kadyrovsky, Bastryksky and Kontuzlinsky fields, developed with the use of HT, the dependencies have been established of the production capabilities by wells with horizontal end and hypsometric position of the pumping equipment in the well: above the productive formation and directly in the interval of the productive formation. In the fields under consideration, deposits in the carbonate reservoirs of the Tournaisian and Bashkirian are being developed using wells with horizontal end. Moreover, it should be noted that the Tournaisian deposits at the Kadyrovsky and Bastryksky fields are damaged by erosion incisions, they have a predominantly massive type of structure (Figure 1).

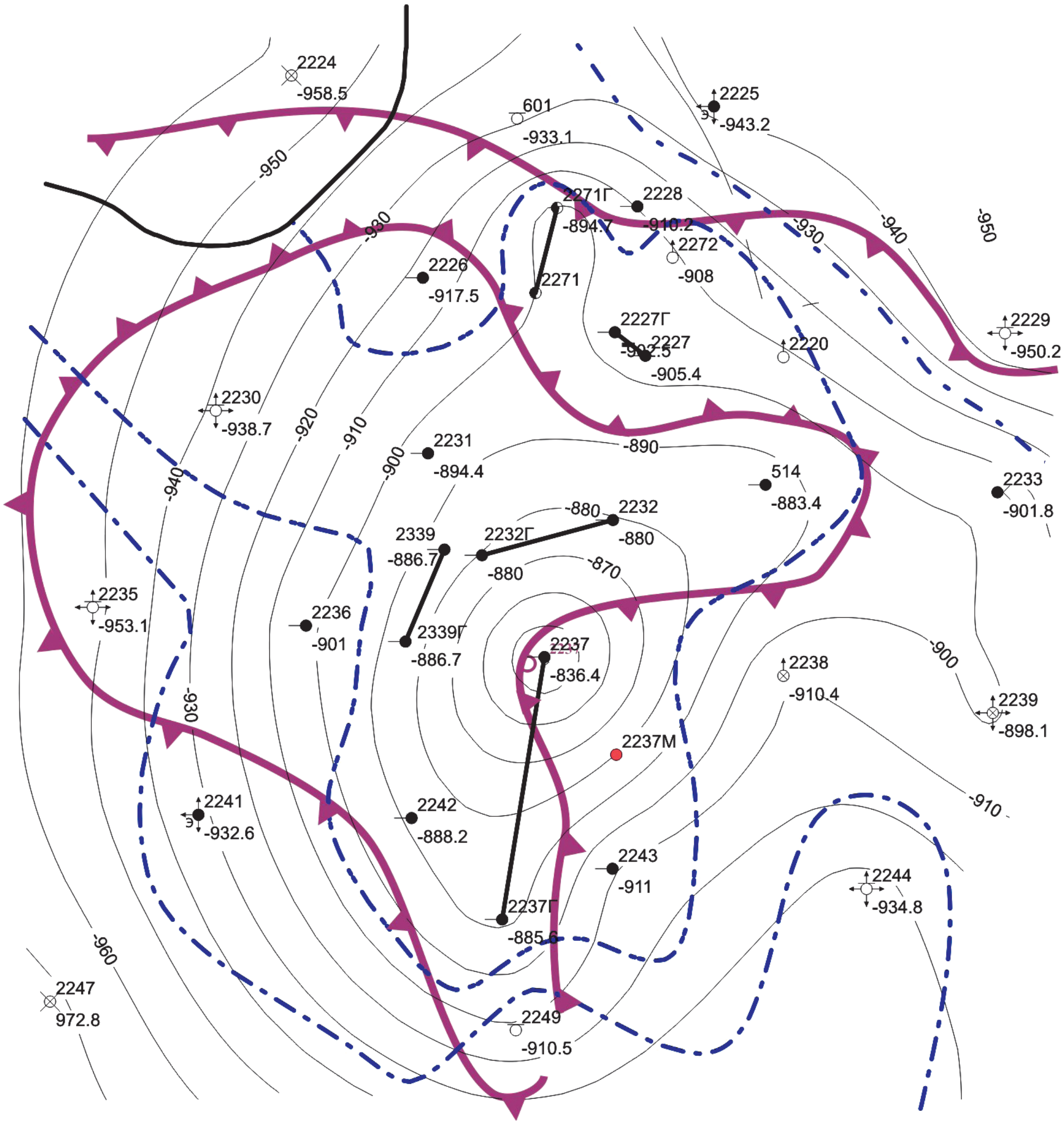

Figure 1. Fragment of the structural map along the top of the Tournaisian deposits at the Middle Bagryazhsky section of the Kadyrovsky field (area of wells Nos. 2271g, 2339g, 2227g)

Values of reservoir properties, determined by logging, on the Tournaisian deposits amounted to an average porosity of 10.2%, and a permeability of 4-157x10^{-3} µm^2. According to V.N. Dakhnov the reservoir refers to low-and medium-sized, weakly permeable reservoirs.

For a number of wells with horizontal end, for which oil production decreased by more than 60% from the initial, as well as for low-rate wells with horizontal end, an attempt was made to resuscitate and increase oil production by lowering pumping equipment into the conventional horizontal part of the well, into the interval of production formation.

The analysis results of technological indicators state about the significant advantage of producing reserves from carbonate reservoirs by means of open wellbores with a horizontal end, with the suspension of the pump placed in the conditional horizontal part of the well trajectory to the lowest hypsometric level (Figure 2).

As follows from the analysis (the graph of the technological indicators), the initial oil production for well No. 2271g was 10 tons per day with water cut 5.7%. The production rate fell according to the drop of the current reservoir pressure in the extraction zone. The section of sediments is highly inhomogeneous and the net to gross sand ration on the average on the Tournaisian deposits is 0.59 unit fractions, the ratio of permeable intervals is 4.7 units; on the Bashkirian carbonate sediments – the net to gross sand ration on the average is 0.344 unit fractions, and the ratio of permeable intervals is – 13.9 units. With such dismemberment, the reservoir pressure in the exctraction zone is practically not restored even if there is injection of a displacing agent. In the latter case, water breaks into production wells are observed along the fractures.

Due to the low production rate of the well, the geological service of the Oil and Gas Production Department decided to apply technology of moving the pump suspension in the conventionally horizontal part of the well to the maximum possible depth with logging – control of the position in the porous permeable interlayers, because the site is disturbed by the Early Visean erosion incision and has a high heterogeneity both in area, and the section (Figure 2).

On 05.2015 the suspension of the pump was lowered to the conventionally horizontal part of the well at a depth of 1172.1 m, which corresponds to an absolute mark of minus 905.1 meters, to the uppermost permeable pack of 8 meters thick (Figure 2). As a result of the measure conducted, the oil production rate doubled (Table 1, Figure 3).

Reservoir properties of the Bashkirian layer are slightly different from the characteristics of the Tournaisian rocks: they have a higher capacity (up

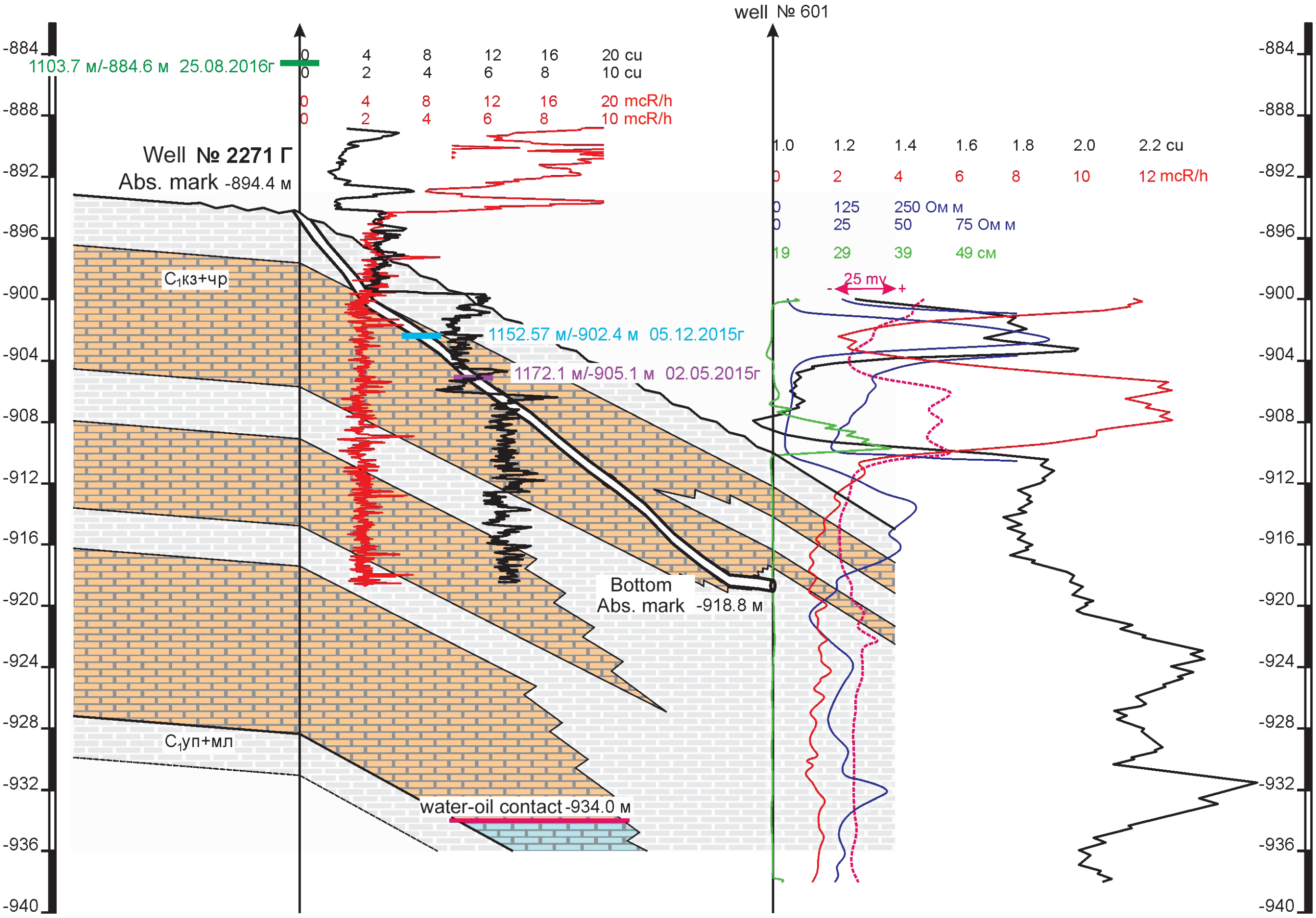

Figure 2. Fragment of the profile of the Tournaisian deposits in the Middle Bagryazhsky section of the Kadyrovsky field in the area of well with horizontal end No. 2271g

№ №	№№ well	Stage	Operating indicators of well depending on the position of pumping equipment in the well with horizontal end							
			initial		before lowering into the HW		after lowering into the HW		on 01.01.17 after pre-lift	
			Qo, t/day	%w	Qo, t/day	%w	Qo, t/day	%w	Qo, t/day	%w
1	1555	Tournaisian	9,6	76,5	5,8	36	13,25	8,3	8	19,5
2	1627Г	Tournaisian	7,8	13,1	6,32	12,3	6,86	2	3,2	6,8
3	1714Г	Bashkirian	3,2	12,5	1,81	4	6,37	3	2,484	2,32
4	1719Г	Bashkirian	1,1	5,4	1,3	3	5,18	10	2,708	3,37
5	1723Г	Bashkirian	2,6	4,8	3,89	4	5,22	3,3	3,148	3,36
6	2271Г	Tournaisian	10	5,3	2,7	11	5,35	9	1,527	7,12
7	2339Г	Tournaisian	3,6	3,3	2,09	5,3	3,41	4,2	5,475	4,02
8	2227Г	Tournaisian	2,6	25,3	0,57	11	2,85	6	1,036	4,6
9	2237Г	Tournaisian	7,6	3,9	3,9	7,2	7,2	4	3,078	25,7

Table 1. Dependence of oil production rate from the position of pumping equipment in the well with horizontal end

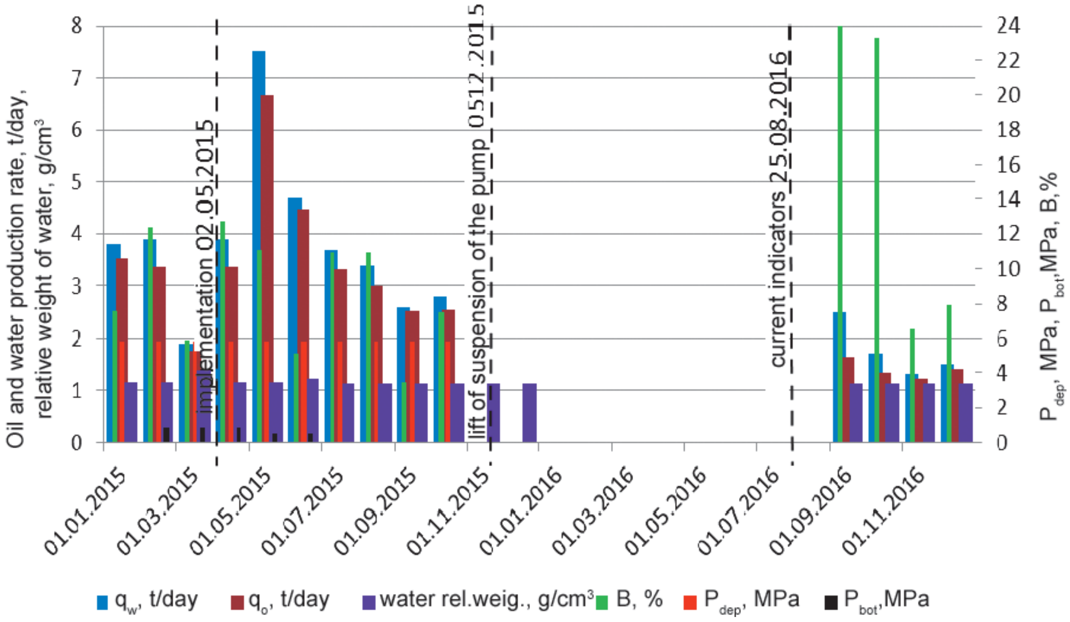

Figure 3. Technological performance of the well with horizontal end No. 2271g on the Tournaisian deposits of the Kadyrovsky field from the beginning of operation

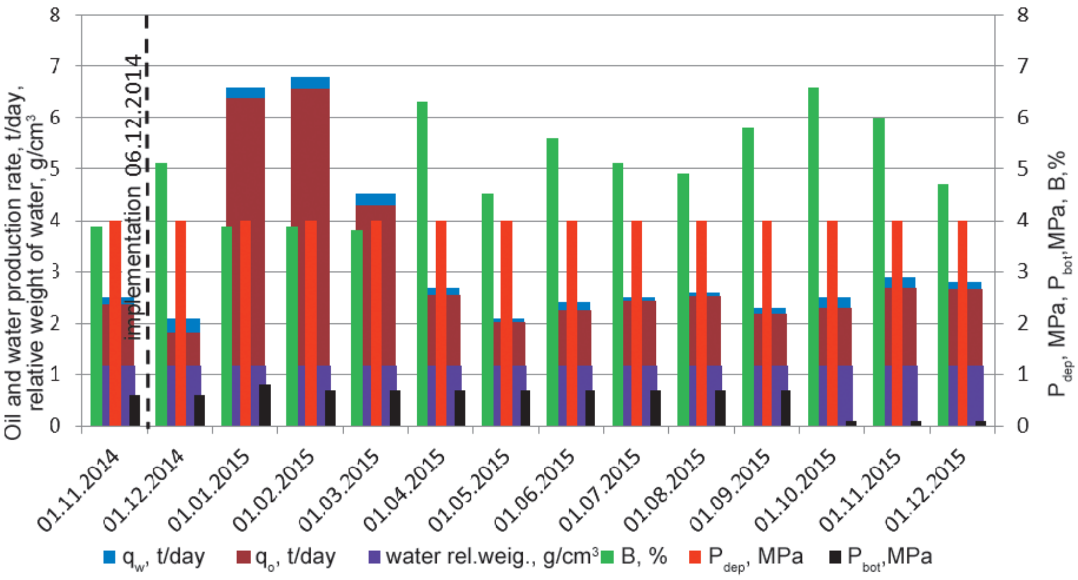

Figure 4. Technological performance of the well with horizontal end No. 1714g on the Bashkirian deposits of the Kontuzlinsky field from the beginning of operation

to 22%) and higher permeability (up to 300 μm^2 × 10 μm*) due to a more dense fracturing (up to 500 un./p.m) and cavernosity, which is increased down the section. But the dismemberment of the Bashkirian-Serpukhovian carbonate complex is higher.

The same picture is noted for all wells on which the technology was tested, including the wells with horizontal end, which operate the Bashkirian carbonate reservoir (Table 1, Figure 4).

Thus, for resuscitation of oil production in the wells with horizontal end and with open trunks that exploits carbonate reservoirs of the Lower and Middle Carboniferous in the territory of the Republic of Tatarstan, the author proposes new low-cost technology. The essence of the technology is to lower the suspension of the pump directly to the productive formation into the conventionally horizontal part of the well, where the zenith angle is 74-88°, to the lowest hypsometric mark of its trajectory in the oil-saturated part of the operational object. At such angles, the known brands of rod pumps are practically not working. Replacing them with upgraded 2SPNL-45/19 and 2SP45/24 makes it possible to operate pumping equipment in a horizontal trunk or in trunks with large zenith angles (over 60°), keep production levels, extend the life of the well with horizontal end, produce the most complete production of oil reserves and increase the final oil recovery factor.

The additional oil production from the geological and technical measures conducted for these wells as of 01.01.2017 amounted to 6507 tons of oil for the average life of the wells with the downhole pumping equipment in the horizontal part of the reservoir – 20 months.

About the Author

Rustam Kh. Ahmadullin – Head of the Technological Department for Oil and Gas Field Development, Oil and Gas Production Department Prikamneft Tatneft PJSC

32 Neftyanikov Ave, Elabuga, 423603, Russia

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In memory of the outstanding scientist S.S. Ellern - to the 95th anniversary of his birth

R.Kh. Muslimov, B.V. Uspensky, V.M. Smelkov
Kazan (Volga region) Federal University, Kazan, Russia

Semyon Samuilovich Ellern was born in June 29, 1922 in Kazan in the family of clerical worker. In 1939 he graduated from Kazan Secondary School No. 2 and entered the Faculty of Geology and Soil of the Kazan University. In April 1942, like many peers, S.S. Ellern was drafted to the Soviet Army and was trained until June 1942 in the 123rd training tank regiment in Kazan (as cadet). From November 1943 to February 1944, he served on the 1st Ukrainian Front with as radio-gunner of the tank-T-34 of the 233rd tank brigade of the 5th Mechanized Corps. In February 1944, he was wounded and, until June 1944, was treated in evacuation hospitals (Belaya Tserkov, Nezhin, Telavi). For military service he was awarded the medal “For victory over Germany”.

In September 1944, S.S. Ellern was restored to the 4th year of Kazan University, which he graduated with honors in 1946 and the same summer began his labor path in the expeditions of the Kazan branch of the Academy of Sciences. In August 1946 Semyon Samuilovich was invited to work at the Department of Geology in Kazan University as a senior laboratory assistant. On June 26, 1952 S.S. Ellern successfully defended his dissertation on “Zhivetsky deposits of southeastern Tataria”.

In the late fifties, the Department of Oil and Gas Geology concludes a number of large economic contracts with the “Tatneftegazrazvedka” trust, in which Semyon Samuilovich is a responsible performer as a well-known expert in petroleum geology. He begins to work on the most important topic “Studying regularities of oil and gas accumulation in the Aksubaevo-Melekess depression”. In the early sixties, the Department of Oil and Gas Geology was the initiator of the assessment prospects of oil content in the new, unexplored region at the time - the Melekess depression. This big and serious topic was entrusted to S.S. Ellern as a responsible performer. In December 1965, the Council of Kazan State University awarded the scientist a first-degree prize for the best scientific work in the university for 1964, including for his monograph “Geological structure and oil content in the Aksubaevo-Melekess depression”, written together with V.I. Troepolsky.

The rector of the University awarded him with the gratitude for the profound study of geological and geophysical materials as the basis for scientific forecasting of oil-bearing prospects and the development of rational methodology for conducting oil exploration.

In the sixties, the Middle Volzhsky Geological Administration began to work on the fundamental encyclopedic multivolume edition of “Geology of THE USSR”. Ellern was invited to participate in the compilation of the section “Devonian deposits” (vol. 11, Volga region) from the Department of Oil and Gas Geology of the Kazan State University.

In December 1978, S.S. Ellern was awarded the University Prize for the best scientific works published in 1977, in particular for the work “The Laws of placement and accumulation of oil and bitumen in the east of the Russian Platform”.

During more than thirty years of teaching work S.S. Ellern gave lectures and conducted practical classes in many, including leading, courses.

These are “Oil and gas bearing provinces” (later “Oil and gas bearing basins”), “Oil fields of the Second Baku”, “Fundamentals of oil and gas geology”, “Oilfield geology”, “Methods of prospecting and exploration of oil and gas fields”, “Geology of combustible minerals (for prospect generators)”. Semyon Samuilovich also developed and read a new course “Structural-facial (formational) analysis”.

Area of scientific interests of S.S. Ellern was characterized by a very wide variety. Along with active participation in general subjects such as the study of the Melekess basin or the study of the Kama-Kinel system of deflections, he was always interested in global issues of petroleum geology. In the 1970s he pays much attention to the study of the formation conditions of uncompensated deflections of platforms and their role in the distribution of oil and gas content. Studies on this topic were largely summarized by him in the monograph “Location of hydrocarbon deposits on platforms”. The result of these studies was the monograph “Uncompensated deflections of platforms and their oil and gas potential” (1976).

In subsequent years, the research interest of S.S. Ellern was focused on studying the formation conditions of natural bitumen accumulations . Semyon Samuilovich analyzed and summarized geological materials on the evaluation of prospecting for natural bitumen within Tatarstan; he is a scientific leader and a responsible executor of state budget and economic contracts: “Geology and bitumen content of Permian deposits in the east of the Russian plate”, “Bitumen” (1980), “Sheshma” (1982), “Basis” (1985), “BIN” (1985). In 1974 he took part in the preparation and editing of the departmental monograph on Permian bitumen of Tataria - the results of generalization of many years of research and applied subjects. In the summer of 1982, the scientist organized and conducted a scientific expedition to the Kaliningrad region to study the formation conditions of natural bitumen in the Baltic syneclise. S.S. Ellern leaded personally the staff of the department for bitumen expedition. He had participated in the commission of the research and production association Tatneft to study bitumen of Tatarstan.

Under the leadership of S.S. Ellern, the department successfully implemented the paleogeomorphological methods of mapping the non-anticlinal traps of natural bitumen in the Permian deposits of the Melekess depression and the slopes of the South Tatar arch.

In July 1982, he was awarded the badge “For Excellent Progress in Work” in the field of higher education of the USSR. For many years of fruitful activity S.S. Elern was repeatedly awarded with diplomas, as well as three commemorative medals. The scientist passed away on July 26, 1986.

MIGRATION ASPECT IN THE OIL-BEARING CAPACITY OF THE DOMANIC FORMATION IN TATARSTAN

I.N. Plotnikova[1*], *S.B. Ostroukhov*[2], *A.A. Laptev*[3], *I.G. Gazizov*[3], *V.V. Emelyanov*[3], *N.V. Pronin*[4], *F.F. Nosova*[4], *A.D. Salikhov*[3]
[1]*Academy of Sciences of the Republic of Tatarstan, Kazan, Russia*
[2]*VolgogradNIPImorneft Branch of LUKOIL-Engineering LLC, Volgograd, Russia*
[3]*Oil and Gas Production Department Prikamneft Tatneft PJSC, Elabuga, Russia*
[4]*Kazan (Volga region) Federal University, Kazan, Russia*

Abstract. The article highlights the problem of oil bearing of the Domanic formation on the territory of the Republic of Tatarstan. Comparing the geochemical characteristics of bitumen of the Semilukskian horizon and oils of the Eifelian-Frasnian terrigenous complex, it was concluded that in the Semilukskian horizon, mobile bitumen are present along with the syngenetic dispersed matter, which, according to gas-liquid chromatography, are identical to the oil of the underlying terrigenous deposits of the Pashian and Timanian horizons.

These bitumens are migratory and reflect the process of upward vertical oil migration, which is responsible for the formation of industrial deposits in the Semilukskian, Sargaevskian, and Rechitskian horizons in those areas where the lithological features of the rocks and the development of superficial fracturing in them make it possible to create a collecting space. The rocks of the Domanic facies should be considered as accumulation or accumulation-generation system, oil deposits of which were formed due to oil systems generated in other sources. New methods of search are needed that allow us to quickly assess the content of migratory hydrocarbons and syngenetic organic matter. This is possible on the basis of a rapid study of the sludge, which will allow to assess the presence of mobile hydrocarbons and their quantity during drilling. An analysis of the spatial distribution of migratory hydrocarbons will allow localizing oil migration channels.

Keywords: Domanic formation, organic matter, bitumen, vertical oil migration, oil deposits, search methods, resources assessment, accumulation system

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Introduction

Despite the high degree of geological study of the central part of the South Tatar arch and its slopes, as well as the large number of oil fields discovered here, the question of oil source in the productive complexes of the sedimentary cover remains unsolved. The active study of high-carbon deposits of the Semilukskian and Rechitskian horizons in recent years has made it possible to address this problem again using new results of geochemical studies of oils and dispersed organic matter.

The widespread opinion that enriched with organic matter rocks of the Semilukskian and Rechitskian horizons are the source for oil generation of the entire sedimentary cover of the Ural-Volga region, including the territory of the South Tatar arch, has long been dominant. However, studies of recent decades convincingly prove the existence of at least two sources of hydrocarbons (Gordadze et al., 2005, Kayukova et al., 2009).

Gordadze G.N. and Tikhomirov V.I. have allocated two genotypes of oils by the composition of hydrocarbons-biomarkers – "Under-Domanic" and "Above-Domanic" – associated with the terrigenous deposits of the Middle Devonian and carbonate, terrigenous deposits of the Upper Frasnian, Famennian, Carboniferous, Permian (Gordadze et al., 2005).

Later on, based on the geochemical differentiation of oils in the Samara region (Romanov et al., 2010), three geochemical groups were identified as part of the two oil genotypes: "Under-Domanic" and "Above-Domanic" oils and a mixed one (the third group representing a mixture of the first two). Two years later, similar results were published by Kiseleva Yu.A. and Mozhegova S.V., who also pointed to the existence, including in the territory of Tatarstan, of two genotypes of oil associated with sources in carbonate and terrigenous complexes (Kiseleva et al., 2012).

Due to the fact that the main oil reserves of Tatarstan are associated with the terrigenous deposits of the Lower Frasnian – with the so-called "Under-Domanic"

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[*] *Corresponding author: Irina N. Plotnikova*
E-mail: irena-2005@rambler.ru

part of the sedimentary cover – the source of its origin, supposedly associated with the terrigenous strata, remains unclear. The question of the formation of industrial deposits in the Sargaevskian, Semilukskian and Rechtskian horizons remains open. Low catagenetic maturity of organic matter (end of PC$_3$, beginning of MC$_1$), indicating lack of generation potential of dispersed organic matter (OM), low permeability and high lithological heterogeneity of rocks, local distribution of oil content, which is not related to structural traps and controlled by a fractured reservoir of complex shape – all this indicates that the classical scheme of generation-migration-formation of the deposit, in this case, does not work, and the formation of deposits in dense rocks of high-carbon sequences of the Sargaevskian, Semilukskian and Rechtskian horizons is controlled by other factors and involves the use of other search criteria.

In this aspect, the most relevant, from our point of view, is the study, first of all, of the paleofacial conditions for the formation of Dominicites, since this will allow restoring the paleotectonic conditions and the geodynamic regime in which sediments were formed and identify factors that determine the uneven distribution of organic matter in the rock, both spatially and by section. Secondly, it is necessary to find out what types of bitumen are present in the pore space of Dominicites at the present moment and how much they are mobile. Carrying out a correlation between the bitumen of high-carbon sequences and oil of fields is also an important task, since the formation of industrial oil accumulations in the carbonate complex, starting from the Sargaevskian horizon and upper, as a result of the dominant upward vertical oil migration, was established for Tatarstan fields over 40 years ago and subsequently it was repeatedly confirmed in practice (Emelyanov et al., 2014; Plotnikova et al., 2013; Ostroukhov et al., 2014; Ostroukhov et al., 2017).

The purpose of this research was to study and compare bitumen of the Semilukskian horizon and oil of the Timanian and Pashian horizons of the Pervomaisky and Bondyzhsky fields.

The objects of research were 25 samples of bitumen from the Semilukskian horizon of the Pervomaisky field from the interval 1662.0-1685.0 m (Figure 1) and 7 samples of oil from the Bondyzhsky and Pervomaisky fields.

The rocks of the Semilukskian horizon are represented by the uneven alternation of calcareous silicate and siliceous limestones (according to the classification of I.G. Teodorovich, 1958).

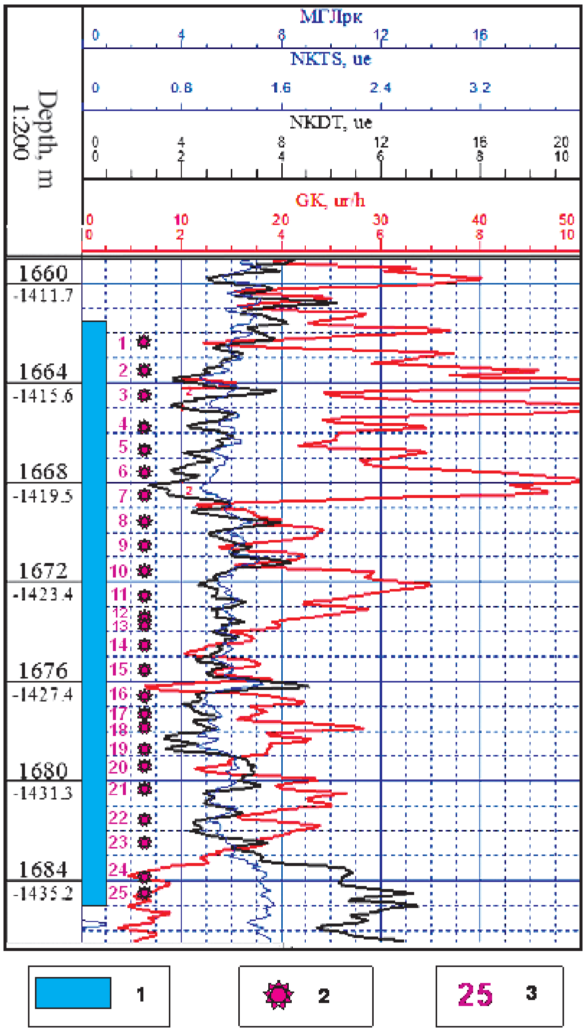

Figure 1. Scheme of sampling cores from the well 467-D for geochemical studies. 1 – core sampling interval, 2 – sampling points, 3 – sample numbers

Methods of the research

The performed analytical works included the determination of group composition of chloroform bitumen A and oils on the basis of generally accepted methods. The first stage was dehydration of oils, and then the polar components of petroleum – oils, resins and asphaltenes were separated. The oil fraction of petroleum was obtained by the method of eluent liquid-adsorption chromatography on silica gel. Petroleum was divided into a number of relatively homogeneous chemically analytical groups that combine compounds of similar physical and chemical properties – oils, resins and asphaltenes. Chromatographic studies were performed on a Crystal 2000M device using the capillary GC method in the temperature programming mode from 100 °C to 300 °C. In the temperature range from 100 °C to 150 °C, the rate of determination of the test substance varies at a rate of 10 °C per minute and in the range from 150 °C to 300 °C – 3 °C per minute, respectively (hydrogen is used as the carrier gas). Pyrolytic studies were conducted on a HAWK instrument.

Results of the research

Features of the group composition of bitumen and petroleum are reflected in Figure 2. The content of

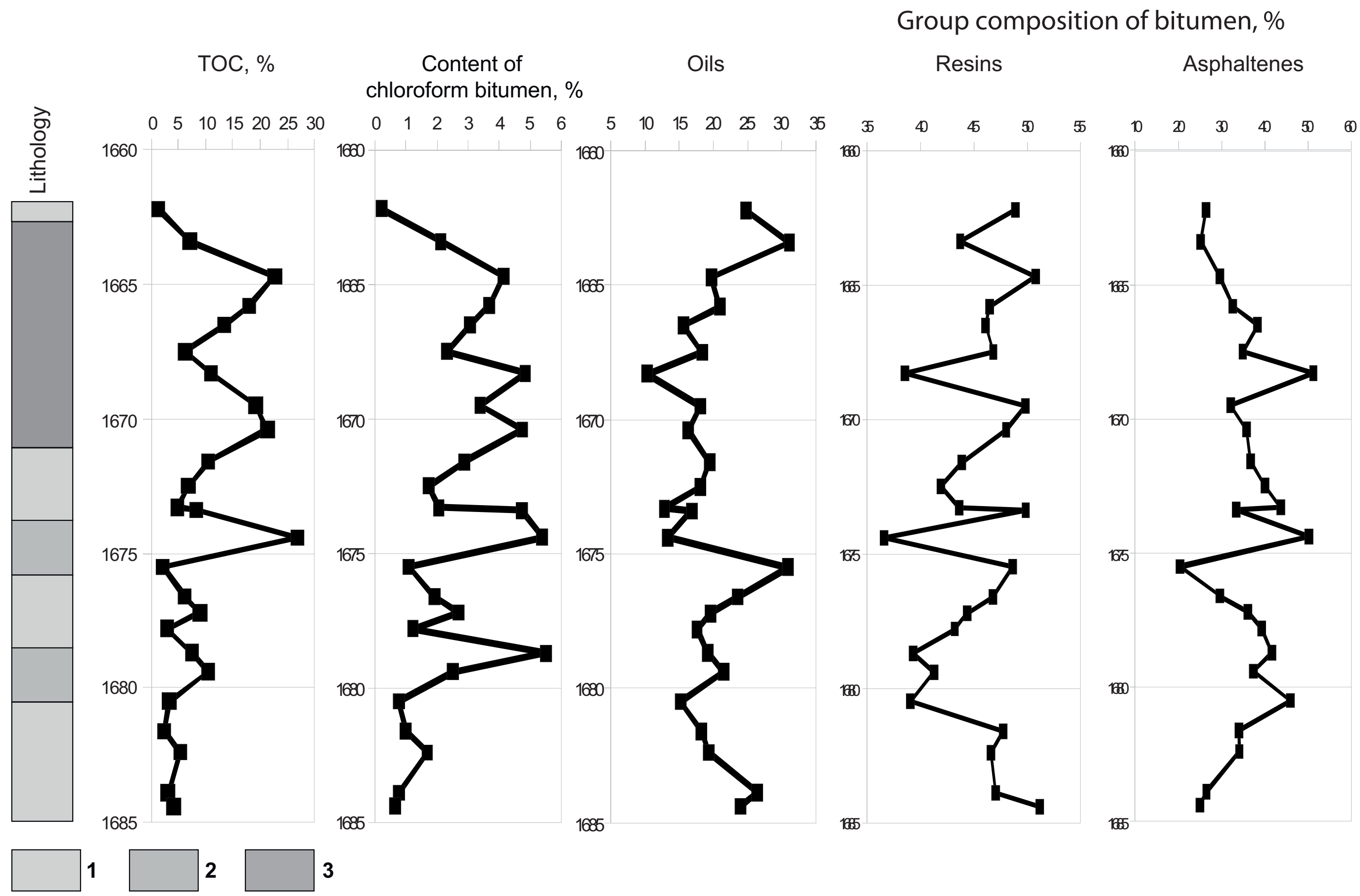

Figure 2. Group composition of bitumen of the Semilukskian horizon. 1 – siliceous limestones, 2 – alternation of silica-limestones and siliceous limestones, 3 – alternation of silica-limestones and siliceous silicates

chloroform bitumen in the composition of domanicites in the investigated range varies from 0.24 to 5.5% (mean – 2.61%) and is unevenly distributed along the section of the investigated interval. The lowest content of chloroform bitumen is characterized by rocks in the roofing part of the interval and its bottom, and the maximum amount is confined to three parts of the middle part of the interval. The bitumen coefficient (BK) in almost all samples exceeds 20, varies from 16.21 to 73.71, and its average value from the results of a study of 25 samples was 31.75.

By its elemental composition, bitumen is almost of the same type: the carbon content is from 70.9% and up to 83.72% (average – 80.98%), hydrogen – from 8.02 to 10.9% (average – 9.38%) , nitrogen – from 0,94 to 2,26 %% (average – 1,62%). Values of the ratio H/C atom for the majority of samples are located in a narrow range – from 1.5 to 1.68 (average – 1.62), with the exception of one sample with a ratio of 1.82.

Asphaltene components with a content of 69.01 to 87.2 %% (medium – 80.36%) prevail in the composition of bitumen. The resin/asphaltene ratio is within a fairly wide range – from 0.73 to 2.38 with an average value of 1.37. The content of oils varies from 10.3 to 30.98%, the average – 19.64%. Virtually all bitumen are resin-saturated, with the exception of four samples in which the content of asphaltenes slightly exceeds them. The components of the alcohol-benzene fraction prevail in the composition of the resins.

In the group composition of petroleum, oils prevail – from 58.18 to 67.54% (average values – 61.28% and 61.7% respectively in the petroleum of Pervomaisky and Bondyuzhsky fields), and in asphalt-resinous components – resins, from 20.51 to 31.47% (average values – 26.87 and 29.39%, respectively, for the petroleum of Pervomaisky and Bondyuzhsky fields).

Previous studies (Ostroukhov et al., 2017; Plotnikova et al., 2017) made it possible to establish that migratory bitumen with a different source of generation are present in the rocks of the Semilukskian horizon, along with the bitumen of the syngenetic dispersed organic matter.

Undoubtedly, the search for this source is a complex task and requires a wide range of additional studies. However, as a working hypothesis, we can assume that the migratory component of bitumen is the oil of the Pashian and Timanian horizons of the Upper Devonian terrigenous complex, and the variety of geochemical characteristics of the bitumen of the investigated interval is due to the varying degree of mixing the "native" syngenetic organic matter of the Semilukskian rocks and oil brought by vertical upward migration.

To test this assumption, we compared the bitumen of rocks and oils of the underlying productive complexes on the basis of the following geochemical coefficients:

P/Ph – ratio of pristane to phytane;

P/nC_{17} – ratio of pristane to n-alkane C17;

Ph/nC_{18} – ratio of phytane to n-alkane C18;

C_{27}/C_{17} – distribution coefficient of n-alkanes in the middle fractions;

$\sum(C_{27}\text{-}C_{31})/\sum(C_{15}\text{-}C_{19})$ – ratio of the number of high-molecular alkanes to low-molecular alkanes. This coefficient is a parameter of catagenetic maturity;

2nC29/C28+C30 – oddness coefficient in the medium-molecular area;

CPI – oddness coefficient in the high-molecular area;

Odd/Even – oddness coefficient;

$P+F/C_{17}+C_{18}$ – the ratio of the sum of pristane and phytane to the sum of n-alkanes C_{17} and C_{18}.

Comparison of bitumen and oils was carried out by comparing the stellar diagrams. Figure 3 shows a comparison of the Pashian horizon oil from two wells of the Pervomaisky field. The almost absolute identity of the oils allowed us to use the average values of the coefficients for further comparisons.

Comparison of bitumen with each other, on the contrary, indicated the presence of significant differences from each other, which is clearly illustrated in Figure 4, which compares five bitumen located at different depths of the studied interval. Despite the proximity of the oddness coefficients, the bitumen differ significantly in other factors, which is due primarily to the various facies conditions for the formation of individual interlayers.

Comparison of the average values of coefficients for oils and bitumen (Figure 5) revealed differences between them only in general and indicated the need for an individual comparison of oils with each of the 25 investigated bitumen.

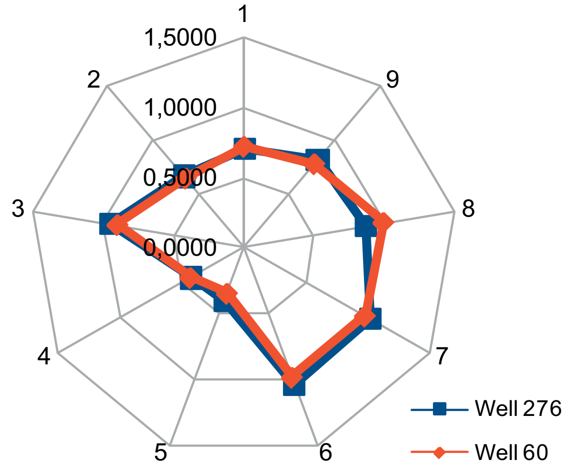

Figure 3. Comparison of the Pashian oils of the Pervomaisky field by geochemical coefficients. Here and further the correspondence of geochemical coefficients to the numbers on the stellar diagram – see in the text

In the course of an individual comparison, very interesting results were obtained.

1. In the Semilukskian section, several bitumens were identified, which by geochemical coefficients are almost identical to the oil of Pashian horizon (Figure 6a). This suggests that in some parts of the section there are traces of upward vertical migration of oil from the underlying horizons of the terrigenous Devonian.

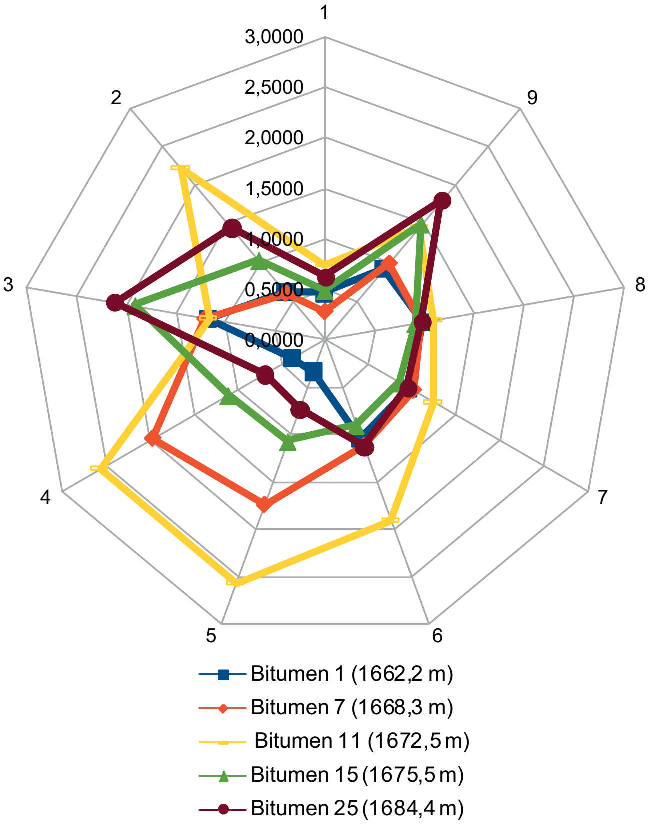

Figure 4. Comparison of bitumen of the Semilukskian horizon from the well 467-D of the Pervomaisky field by geochemical coefficients

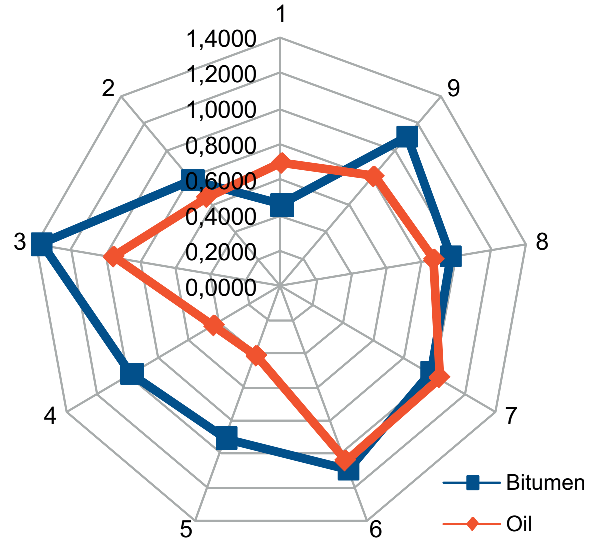

Figure 5. Comparison of bitumen of the Semilukskian horizon from the well 467-D and oil of Pervomaysky fields based on the average values of geochemical coefficients

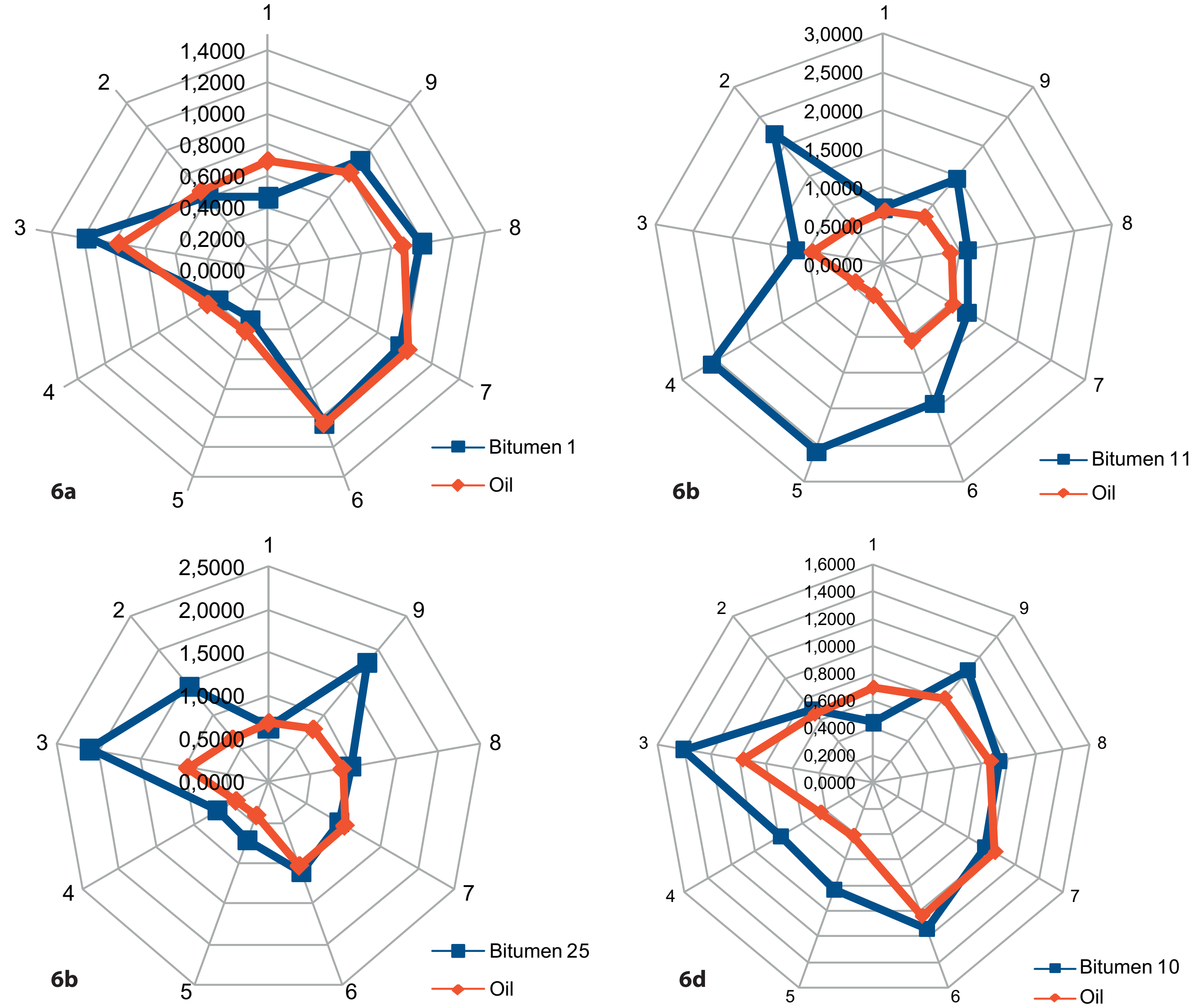

Figure 6. Examples of comparison of different bitumens of the Semilukskian horizon with the oils of the Pashian horizon:a – an example of bitumen, identical to oil; b, c – examples of bitumen that are significantly different from oil; d – an example of bitumen that involves mixing syngenetic organic matter with migration oil

2. In addition to bitumen identical to oil, in the section of the Semilukskian horizon there are bitumens that differ significantly from oils (Figures 6b, 6c) or represent a bias of syngenetic organic matter and Pashian oil (Figure 6d).

Almost complete identity with petroleum was found in 5 bitumen out of 25 studied, all of them located in the upper part of the studied interval (Figure 7). Significant differences from oils are also found for 5 bitumens, which are unevenly distributed throughout the interval. The remaining 15 bitumen samples (60%) are a product of mixing syngenetic organic matter (OM) and introduced hydrocarbons. Thus, practically all the studied bitumens are a product of mixing of syngenetic OM and migration component (oil). Since there is no clear relationship between the types of bitumen and the presence of organic matter in the rock, it seems that the share of the migration component and its distribution along the section is controlled by the capacitive properties of the rocks and their fracturing.

This is also confirmed by the absence of a positive correlation between the share of the oil fraction in the bitumen of the rock sample (the lightest and mobile part of the bitumen) and total organic carbon (TOC) in this rock (Figure 8). Moreover, between these two parameters there is a weak inverse correlation (-0.37), rather indicating, that the distribution of migration hydrocarbons in rocks is not related to the distribution of TOC.

Also for bitumen of the first two types (the first is identical to oil, the second is sharply different from it), the differences in pyrolytic parameters are established. In particular, the average values of S_0, S_1 and ΔS_1 (the difference of S1 values before and after extraction) for bitumen of the first type are higher than those of bitumen of the second type (Table 1).

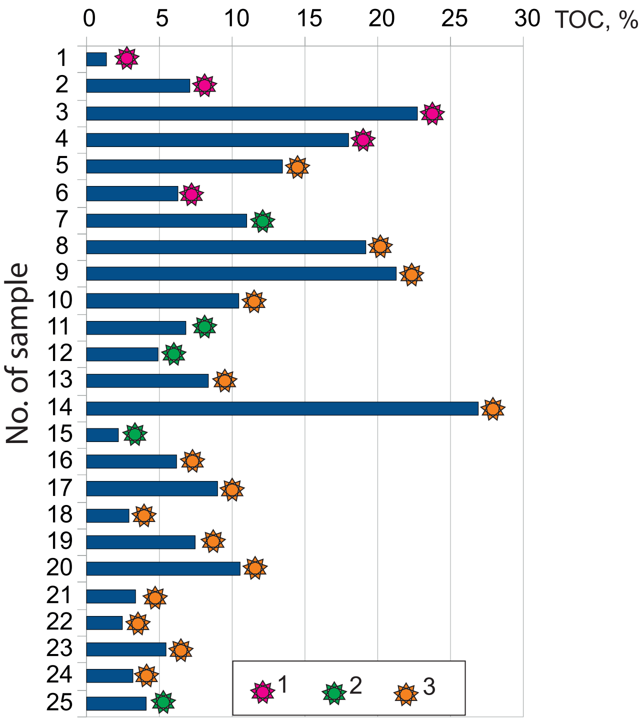

Figure 7. Distribution of different types of bitumen in the section of the studied interval.1 – bitumens identical to oils, 2 – bitumens, significantly different from oils, 3 – bitumens, in which mixing of syngenetic organic matter and migration oil hydrocarbons is supposed

Conclusions

The results obtained are fundamentally new and allow us to present the formation of deposits in the Semilukskian horizon in a different way. The main conclusions are as follows:

Mobile lighter bitumoids are present in the Semilukskian horizon, along with the syngenetic dispersed organic matter, which, according to gas-liquid chromatography, are identical to the oil of the underlying terrigenous deposits of the Pashian and Timanian horizons. These bitumens, undoubtedly, are migratory and reflect the process of upward vertical migration of oil, which is responsible for the formation of industrial deposits in the Semilukskian horizon in those areas where the lithologic features of the Domanicites and the development of superficial fracturing in them allow creating a collecting space.

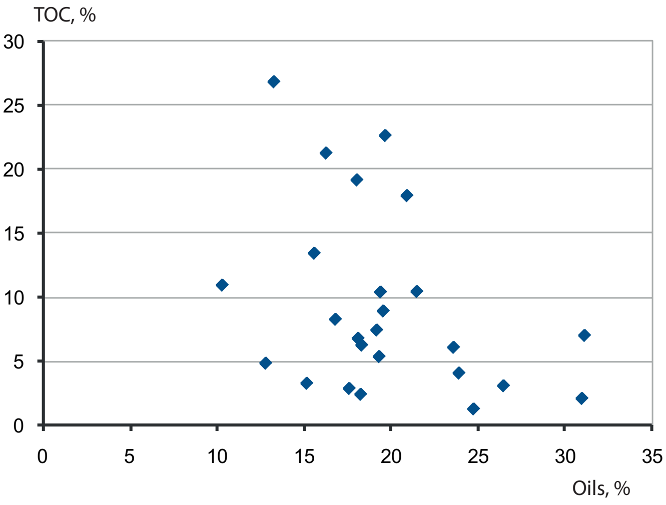

Figure 8. Dependence of the oil fraction content of bitumen from the total organic carbon (TOC) in the rock

The results obtained from the data of gas-liquid chromatography are completely correlated with the results obtained from the distribution analysis in the bituminous hydrocarbons of a number of alkyltoluenes and set forth earlier (Ostroukhov et al., 2017).

The presence of migratory mobile bitumen in the Semilukskian horizon leads to an overestimation of the TOC values in them according to pyrolysis data.

No. of sample	S_0		S_1		ΔS_0	ΔS_1
	Before extraction	After extraction	Before extraction	After extraction		
rocks, contained first type of bitumens (identical to oil)						
1	0,16	-	0,37	0,06	0,16	0,31
2	1,69	-	5,15	0,24	1,69	4,91
3	1,41	-	10,38	0,73	1,41	9,65
4	3,21	-	9,39	0,74	3,21	8,65
6	2,11	-	3,94	0,2	2,11	3,74
average	**1,72**		**5,85**	**0,39**	**1,72**	**5,45**
rocks, contained second type of bitumens (sharply different from oil)						
7	2,09	-	7,32	0,31	2,09	7,01
11	1,83	-	4,53	0,30	1,83	4,23
12	1,69	-	4,11	0,20	1,69	3,91
15	0,74	-	3,1	0,14	0,74	2,96
25	0,74	-	2,12	0,16	0,74	1,96
average	**1,42**		**4,24**	**0,22**	**1,42**	**4,01**

Table 1. Compare of mobile hydrocarbons content in rocks with different types of bitumoids

In this regard, new methodological approaches and analytical techniques are needed to separate and evaluate separately the content in the rocks of mobile migration hydrocarbons and syngenetic organic matter.

Such a method can be created on the basis of an integrated rapid study of sludge (geochemical and mineralogical research in the drilling process). It will be of great practical importance and will allow for an assessment of the presence of mobile hydrocarbons and their number at the stage of drilling out the Domanic Formation. An analysis of the spatial distribution of migratory hydrocarbons, in turn, will allow localizing oil migration canals and identify promising sites for the location of industrial oil deposits in the Semilukskian horizon and the boundaries of their distribution.

Mapping the saturation levels of the Sargaevskian, Semilukskian and Rechitskian horizons by mobile hydrocarbons will be the basis for choosing the location and direction of the inclined and horizontal trunks and will increase the effectiveness of the development of shale strata. The integration of geochemical methods of investigation of sludge and geophysical methods for studying the development of fracturing will make it possible to successfully predict potential sections for the presence of oil deposits. At the same time, promising areas of deposit allocation must be linked, first of all, to the presence of favorable conditions for vertical oil migration (faults, decomposition zones) and its accumulation (a reservoir formed primarily by open fracturing).

Tight high-carbon rocks of the Sargaevskian, Semilukskian and Rechitskian horizons are an unconventional object of oil production, which involves the use of non-traditional new approaches to its prospecting and development. One such approach is the consideration of Domanicites as an accumulation or accumulation-generation system and the assumption that the deposits in these systems could be formed by the accumulation of oil systems generated in other sources. Since at the present time the oil of the Semilukskian, Rechitskian and Sargaevskian horizons is mainly associated with the generation system of the Domanic organic matter, the main search criterion is the presence of organic matter and the degree of its catagenesis in the rocks.

In other words, the basis of the forecast is solely the genetic criteria associated with the dispersed organic matter. However, the high lithological heterogeneity of the rocks, the uneven distribution of OM in them and its low maturity (mainly PC_3) often lead to an overestimate of the resource potential, and the mechanism of migration and accumulation of oil totally does not agree with the low reservoir properties of both Domanicites and the transit zones in contact with them, which in fact are not transit zones.

The use of new methodological approaches, including complex rapid study of sludge and core, will increase the reliability of the separation of productive oil-saturated intervals in the section and allow more accurate estimation and calculation of reserves in tight high-carbon deposits.

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About the Authors

Irina N. Plotnikova – DSc (Geology and Mineralogy), Leading Researcher

Academy of Sciences of the Republic of Tatarstan
20 Baumana St., Kazan, 420012, Russia
E-mail: irena-2005@rambler.ru

Sergey B. Ostroukhov – PhD (Chemistry), Leading Researcher, VolgogradNIPImorneft Branch of LUKOIL-Engineering LLC

98 Lenina Ave, Volgograd, 400078, Russia

Andrey A. Laptev – Head, Oil and Gas Production Department Prikamneft Tatneft PJSC

32 Neftyanikov Ave, Elabuga, 423603, Russia

Ilgam G. Gazizov – PhD (Engineering), Chief Geologist, Oil and Gas Production Department Prikamneft Tatneft PJSC
32 Neftyanikov Ave, Elabuga, 423603, Russia

Vitaliy V. Emelyanov – PhD (Engineering), Deputy Head of the Geological Department, Oil and Gas Production Department Prikamneft Tatneft PJSC
32 Neftyanikov Ave, Elabuga, 423603, Russia

Nikita V. Pronin – Senior Lecturer, Department of Oil and Gas Geology, Kazan (Volga region) Federal University
4/5 Kremlevskaya St., Kazan, 420008, Russia

Fidaniya F. Nosova – Head of Laboratory, Department of Oil and Gas Geology
Kazan (Volga region) Federal University
4/5 Kremlevskaya St., Kazan, 420008, Russia

Ayrat D. Salikhov – Head of the Geology Department, Oil and Gas Production Department Prikamneft Tatneft PJSC
32 Neftyanikov Ave, Elabuga, 423603, Russia

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CHARACTERISTICS OF UPPER TRIASIC SANDSTONE RESERVOIRS IN SYRIA USING ANALYSIS OF LABORATORY METHODS

I.M. Yousef[*]*, V.P. Morozov*
Kazan (Volga region) Federal University, Kazan, Russia

Abstract. The Upper Triassic sandstones of gas-oil reservoirs of Euphrates Graben in Syria are characterized by certain mineralogical characteristics, conditioned by the processes of sedimentogenesis and diagenesis. In the course of the analytical work, it was possible to establish the nature of minerals composing sandstones and their impact on the porosity of rocks. So, for example, a good sorting of detrital grains and their substantial quartz composition is an important factor determining the increased values of porosity. On the other hand, the increased content of clay and authigenic minerals (more than 10-15%) reduces the porosity of rocks studied.

Methods of optical microscopy, X-ray diffraction, electron microscopy and chemical analysis were used when describing sandstone. It is shown that the studied sandstones are quartz. Clay minerals, authigenic quartz and carbonates with a small fraction of amorphous material serve as cementitious material of detrital grains.

Studies with a scanning electron microscope in conjunction with dispersive X-ray spectroscopy have shown that quartz is clastic and amounts to an average of 70%, and up to 10% of authigenic quartz is also present in the samples. The same studies show differences in the morphology of quartz, which are found in all samples.

Key words: sandstone, research methods, Euphrates Graben, Upper Triassic, Syria
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1. Introduction

The purpose of the study was to assess the mineral composition of sandstones and its effect on the porosity of the Upper Triassic gas-oil reservoir, called the Mulussa F Reservoir (MUF). It serves as an important hydrocarbon exploration site in the Middle East in Syria. The discovered gas-oil fields in the Euphrates Graben are an important source of hydrocarbons (De Ruiter, 1995). The MUF reservoir has a thickness of 450 m (Figure 1). It is composed mainly of medium- and coarse-grained fluvial gas- and oil-saturated sandstones, interbedded with floodplain mudstones, lagoon and shallow marine dolomite shales and dolomites, which are most developed in the lower and upper parts of the reservoir. Due to the large gas and oil saturation of the Upper Triassic sandstones, they serve in the region as the main object of hydrocarbon exploration in the Euphrates Graben, as well as their production.

2. Research methods

The data of core material research are used in the work. 55 samples of sandstones were selected from 11 wells that penetrated Upper Triassic Euphrates Graben deposits in the depth range from 1.6 to 4 km. Samples were characterized using, in our opinion, optimal methods of investigation: optical, X-ray, spectrometric and X-ray fluorescence analyzes (Shmyrina, Morozov, 2013). Optical-microscopic analysis served to determine the main rock-forming minerals and the structure of sandstones. X-ray analysis was used to determine the qualitative and quantitative mineral composition of the samples, which is important for the reconstruction of diagenetic rock changes and the assessment of hydrocarbon reservoir (Ferrell, 1998). Scanning electron microscopy, coupled with microprobe analysis, provided a wide range of information on the structure, morphology, chemical composition of grains, allowed estimating the spatial distribution of grains in the rock and paragenesis of authigenic minerals.

3. Results and discussion

3.1. Quartz sandstones and cementing material

Optical microscopic observations together with X-ray analysis showed that sandstone fragments take on average 80% of the rock volume, and authigenic minerals such as kaolinite, illite, chlorite, siderite, dolomite and anhydrite occupy on average of 20% of the rock volume. Most clastic grains are represented by quartz (from 50 to 90%), less frequently by debris.

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[*] *Corresponding author: Ibrahem M. Yousef*
E-mail: ibrahem.youseef@mail.ru

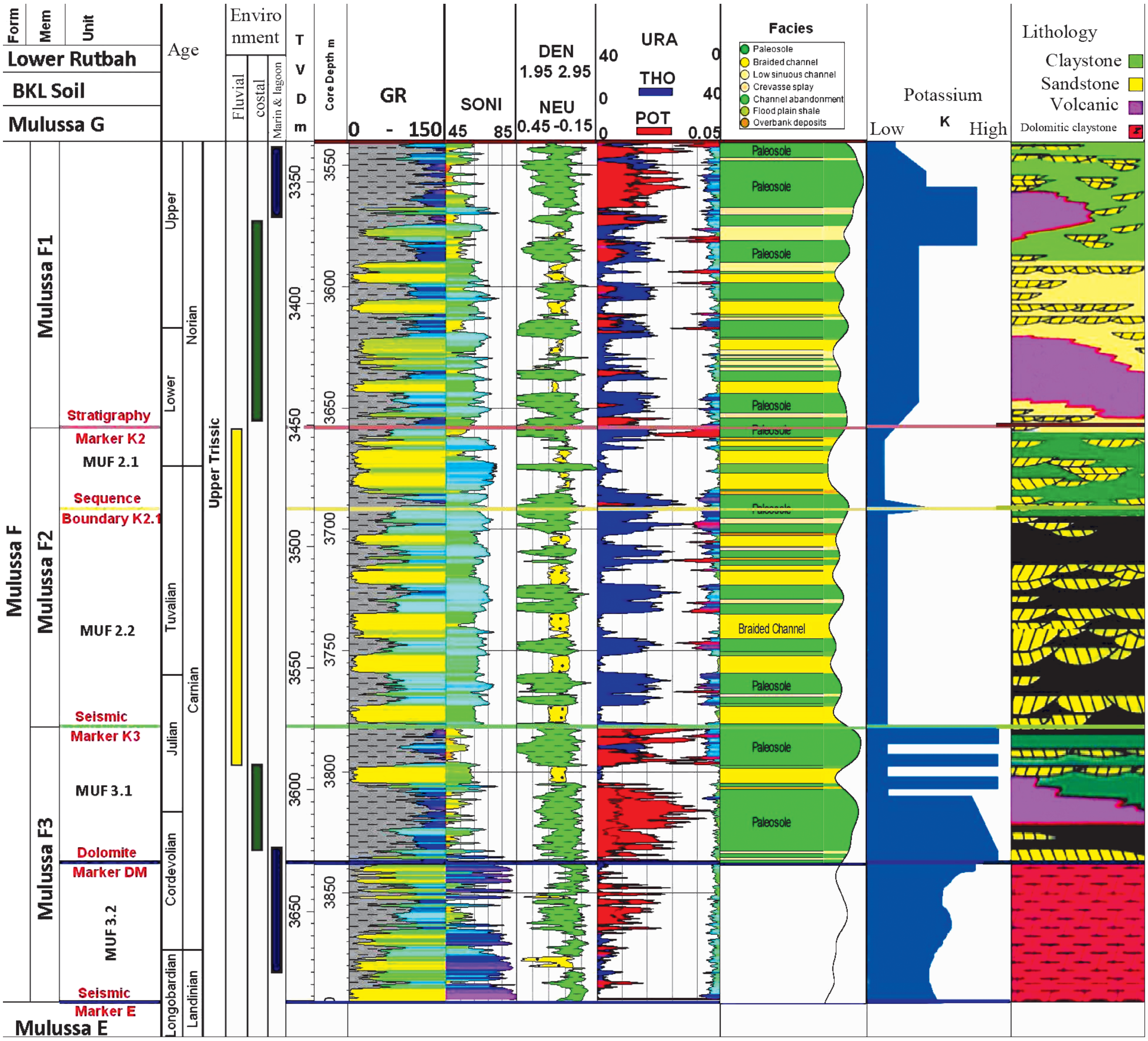

Figure 1. Lithology section of the upper Triassic deposits in the Euphrates Graben, Syria (Yousef, Morozov, 2017)

Clay material is also found in the form of separate spots and layers. It is most widely distributed in fine-grained sandstones and averages 10%. A detailed description of quartz sandstones is given in the Figure 2.

Cementing material can be quite small in them (Figure 2, a), some samples contain up to 20% of clay material (Figure 2, b) and do not refer to reservoir rocks. In other sandstones that are reservoir rocks – carbonate quartz sandstones – the content of dolomite can reach 10% (Figure 2, c), and the siderite content is also up to 10% (Figure 2, d). In the third isolated type of sandstones, the kaolinite content can also reach values of 10% (Figure 2, e).

Most clastic grains of sandstone are rounded or sub-rounded, they have a medium and coarse-grained structure and various sorting. The degree of sorting of detrital material deteriorates from fine-grained to coarse-grained sandstones.

Most clastic grains of sandstones with a low content of cement are compacted – contacts between debris are flat, concave-convex. Often regeneration is observed on the fragments of quartz. Judging by optical-microscopic observations, quartz cement is the earliest in comparison with carbonates. Most quartz grains in sandstones with a relatively high content of cement have spot contacts. The size of fragments varies from 250 to 500 µm and less often reaches 2 mm (Figure 2, f).

One of the features of most coarse-grained sandstones is the presence of clastic grains of quartz with small cracks, which are more developed in the marginal parts of grains (Figure 2, a). Among the fragments of quartz, mono-grains predominate (70%), and fragments of polycrystalline quartz-aggregates (20%) are less common. Both are characterized by corrosion of their surfaces, and for the latter, corrosion along the grain boundaries in the joints (Figure 2, f).

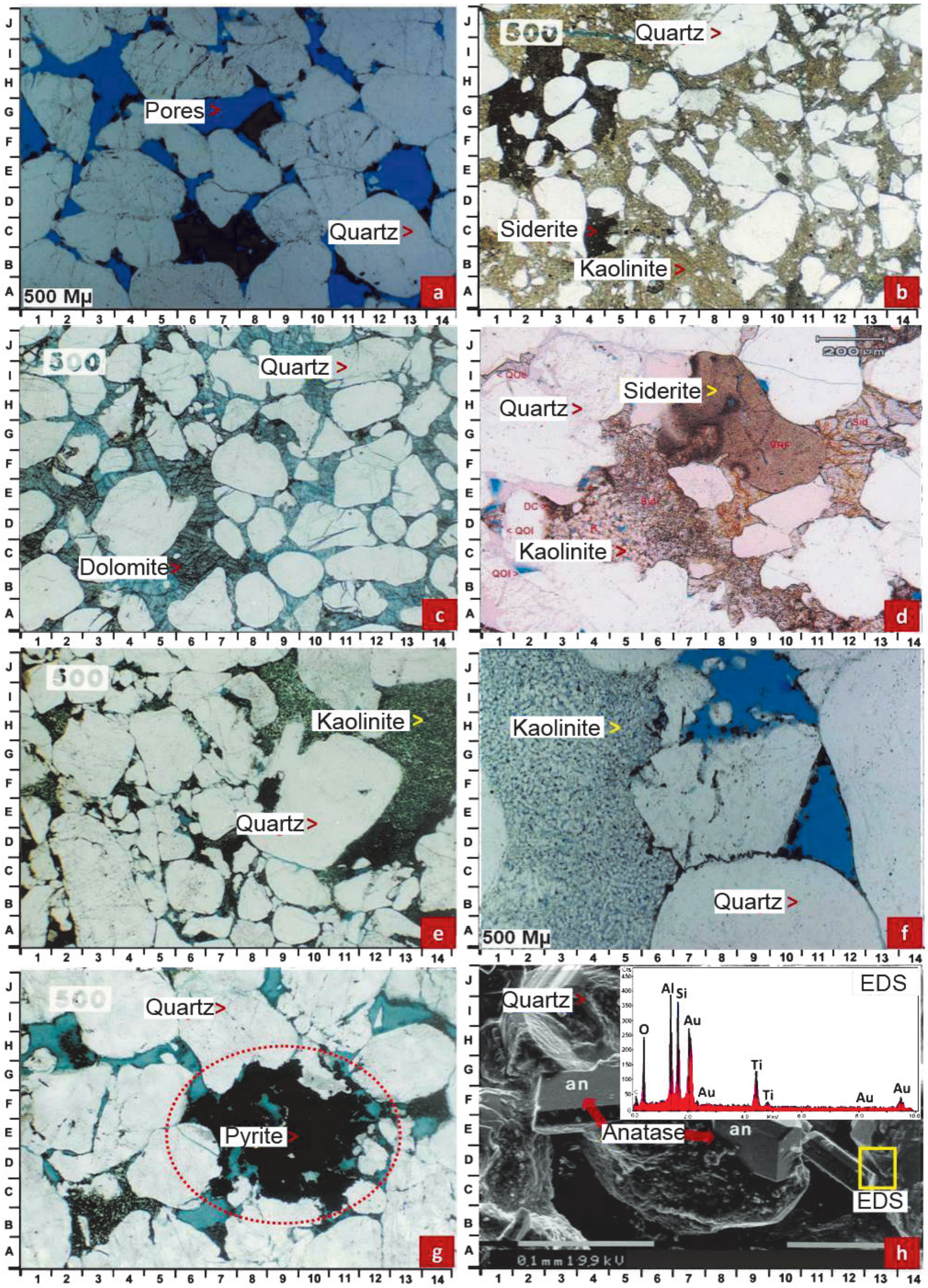

Figure 2. Photos of thin sections. Sandstones of the Upper Triassic: a) – quartz sandstone, medium-grained, moderately sorted; b) – quartz greywacke, medium-fine-grained; cement – clay material, partially replaced by siderite; c) quartz sandstone with poikillite dolomite; d) – quartz sandstone, clastic grains cement the hyppidiomorphic siderite; e) – quartz sandstone, clastic grains are cemented with vermiculite-like kaolinite; f) – dissolution (corrosion) of grains of quartz, feldspars replaced with kaolinite; g) – micro-concretion of pyrite, possibly replacing clay material; h) an electron microscopic photograph, the grains of authigenic anatase are growing on the corroded surface of clastic grains of quartz, the EDS data are given

Feldspars in sandstones are rare, mainly represented by potassium feldspar. Many grains of feldspar are fringed with chlorite and illite. During katagenesis, the feldspar grains become unstable and partially transformed into kaolinite (Figure 2, f, grain on the left). In some samples, the feldspar grains are dissolved and replaced by pyrite (Figure 2, g) or kaolinite (Figure 2, e).

Metamorphic formations are the source of quartz grains, judging by their structure. Some of the quartz grains collapsed during compaction, which can be seen from the formation of cracks in them and corrosion of the surface (Figure 2, f).

Heavy minerals are found among the accessory grains, represented by tourmaline and zircon, less often epidote and monazite. Opaque accessory minerals are clastic magnetite and/or ilmenite, less often authigenic anatase (Figure 2, h).

Clastic grains of sandstone are often cemented with clay material, the content of which can reach 10%. Clay material in some sections forms filling cement, in other sections composes bunch (spotted) cement. The sandstone voidness is formed by granular porosity; the pores are fairly well connected by channels. Some of the pores are filled with clay material, and some remain unfilled. There are pores of sedimentogenic and secondary origin, formed by the dissolution of feldspars.

3.2. Authigenic quartz and other authigenic minerals of sandstones

Authigenic quartz, occupying 1 to 13% of the volume of sandstones, is found in all samples except for those classified as quartz greywackes. Such quartz is easily detected and is represented by microcrystalline elongated pyramidal idiomorphic crystals having a dimension of about 50 μm.

They grow on grains of detrital quartz, forming in the porous space of sandstones (Figure 3, a). Often grains of such authigenic quartz form aggregates of parallel arranged grains (Figure 3, b). It can be considered that authigenic quartz as well as kaolinite and siderite plays the role of cement and clogs the pores, thereby reducing the porosity of sandstones and the connectivity of pores (Figure 3, c). Authigenic quartz in some of the samples studied has the appearance of polycrystalline intergrowths, which tend to slightly increase the surface area of host grain (Figure 3, d, e, f).

Such quartz forms radial syntactic cement, which results from dissolution and growth around detrital grains (Figure 4, a). This radial syntactic quartz form of cement connects the clastic grains and blocks the pores or fills them (Figure 4, b). In the samples under the electron microscope authigenic quartz has a size from 50 to 100 μm (Figure 4, c). This mineral is associated with hematite, which forms thin arcs around detrital grains, indicating that authigenic quartz is formed later on hematite (Figure 4, d). In some intervals of the section, sandstones contain up to 2-7% of anhydrite (Figure 4, e), which forms poikillite cement and is distributed randomly in the pore space. Sandsite is sometimes found in sandstones, the content of which can vary from 1 to 23%. Its grains are found in the pores and have sizes from a few microns to 150 μm. They form spherical aggregates <2.5 mm in size (Figure 4, f). Siderite can also be found in the form of poikillite cement or in the form of concretions filling the voids. The relationship between sideritic cement with authigenic quartz shows that siderite is a later mineral (Figure 4, g) (Worden, 2003).

3.3. X-ray analysis

X-ray analysis was performed for many samples of sandstones. Diffractograms (Figure 5, 1-5, Table 1) shows the mineral composition of sandstone samples. Analysis of diffractograms showed that quartz is the main mineral present in all the samples studied. Its content is from 42 to 80%. The content of other minerals is less: potassium feldspar, mica, albite, kaolinite. Dolomite, siderite, barite, pyrite, halite are also found.

The content of kaolinite can reach 25%. The high content of kaolinite in sandstones most likely indicates intensive chemical weathering in a warm, moist climate during sedimentogenesis (Ketzer, 2003). According to sedimentological data, we believe that kaolinite has a detrital origin, mainly inherited from the original rocks, subject to intensive chemical weathering in a humid warm climate. It was transported and deposited in river surroundings (Burley, 1993).

Limited occurrences of chlorite and illite may indicate the interruption of humid sedimentation by short periods of drought, which contribute to limiting chemical weathering (Bellon, 1994). Some samples contained siderite, dolomite, anhydrite, calcite and pyrite in different proportions (Table 1). We assume that the named minerals were formed during sedimentogenesis (calcite) and diagenesis (siderite, anhydrite, dolomite and pyrite).

In addition, scanning electron microscopy associated with the EDS analysis of elements (EDS graphs) showed the essential presence of Si, Al, Ti, Fe, Ca, S, Mg and O that composes quartz, layered silicates, anatase, siderite, pyrite, dolomite, kaolinite, anhydrite.

3.4. X-ray fluorescence analysis

The analysis showed that in the sandstones the greatest content is of SiO_2 (mainly quartz) with an average value of about 62.52% (Table 2). The analysis also confirmed the electron microscopy data, i.e. presence of iron oxide in the samples. The results of analysis carried out for different samples show that

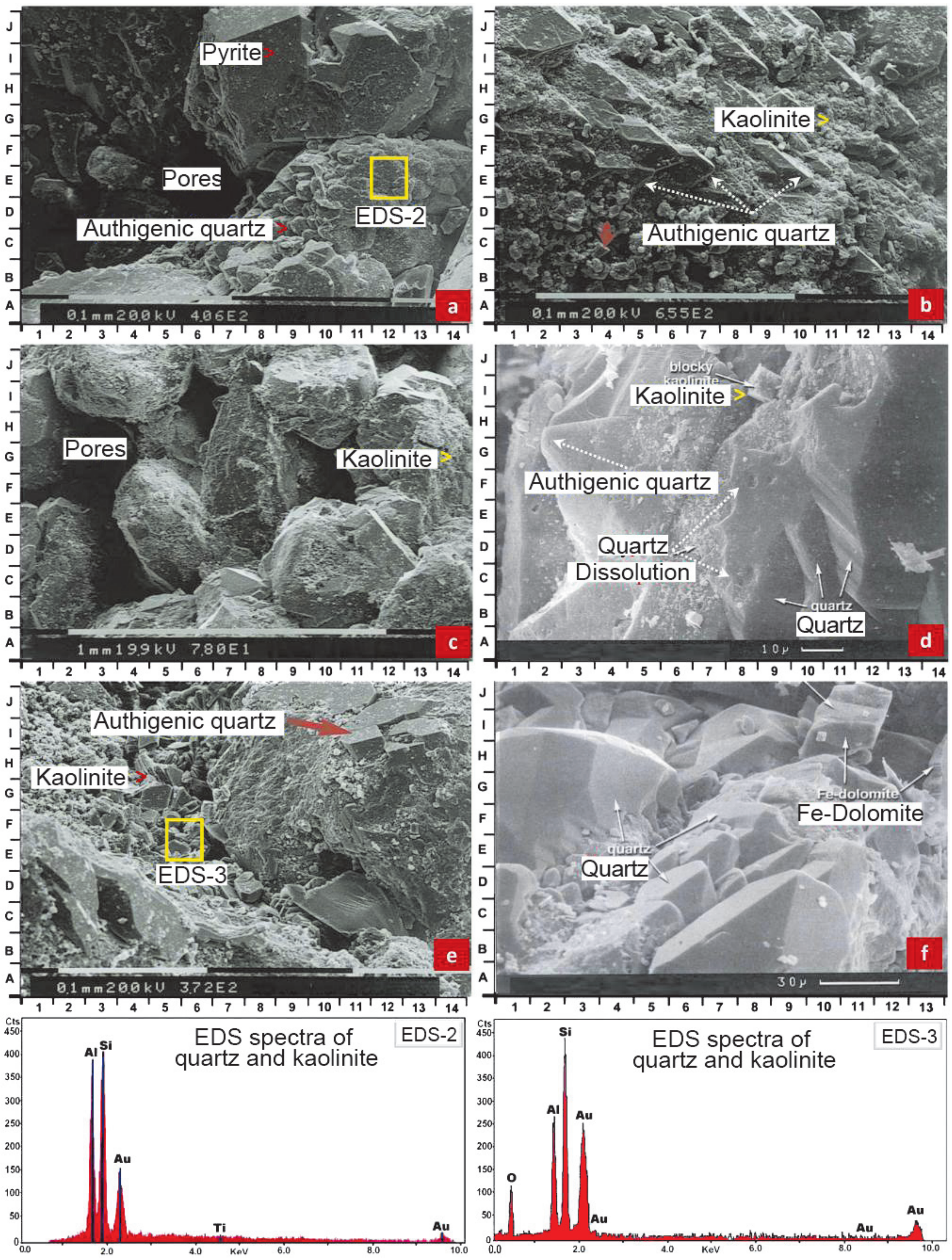

Figure 3. Electron microscopic photographs of sandstones and EDS spectra (below): a) – columnar growths of authigenic quartz crystals covering the pores; b) elongated pyramidal quartz growths growing on detrital grains; c) intergranular porosity, partially overgrown with quartz cement; d) – tabular crystals of authigenic quartz, growing on fragments; e) tabular, leafy growth of authigenic quartz; f) idiomorphic grains of authigenic quartz filling the void space

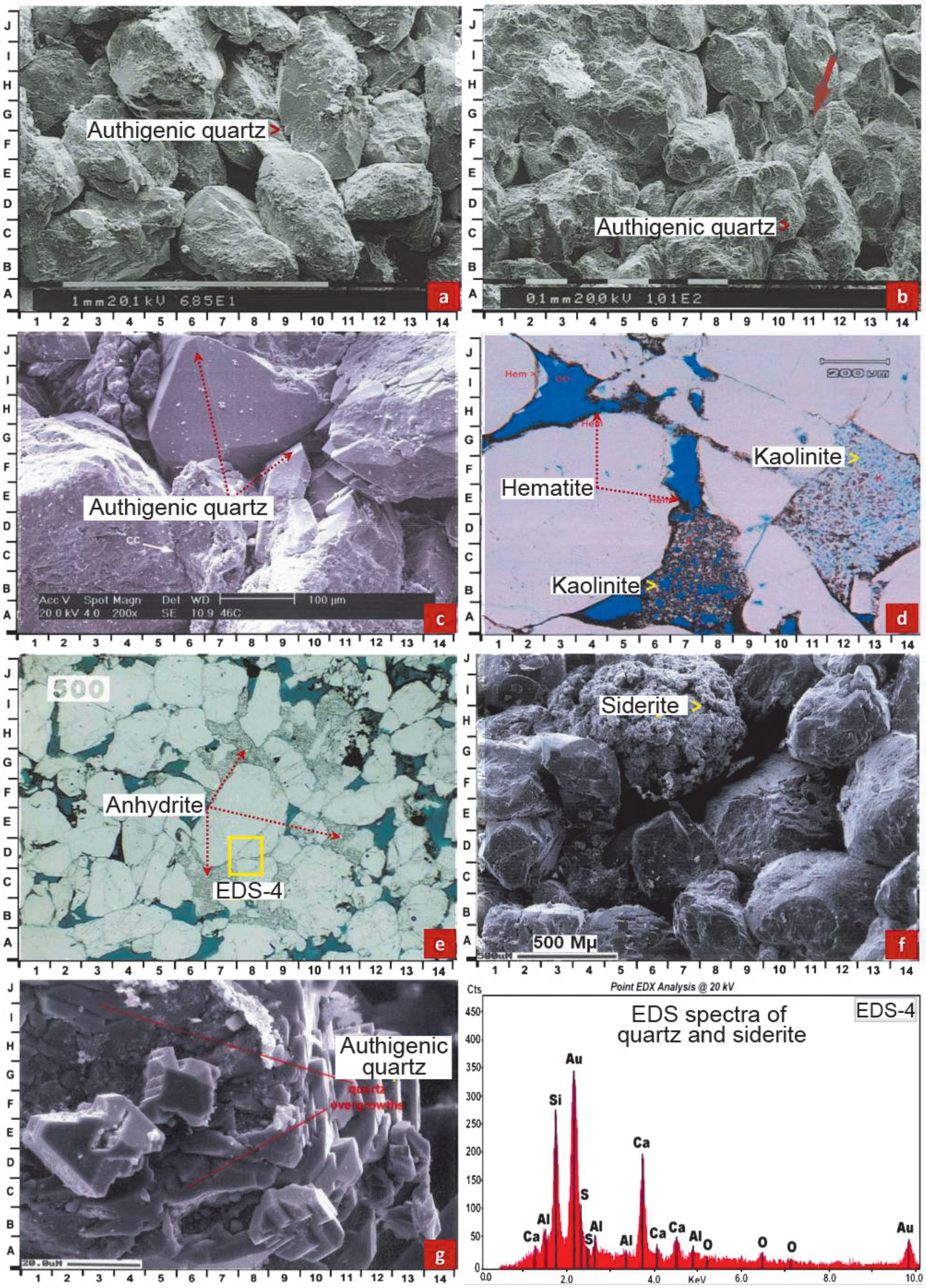

Figure 4. Photos of thin sections, electron microscopy and EDS spectrum. Sandstones: a, b) – accretion of quartz, clogging pores; c) – prismatic hyppidiomorphic crystals of authigenic quartz; d) pores partially filled with hematite and kaolinite; e) – poikillite anhydrite cement; f) – concretion of siderite; g) – grains of clastic quartz, covered with authigenic quartz and siderite crystals

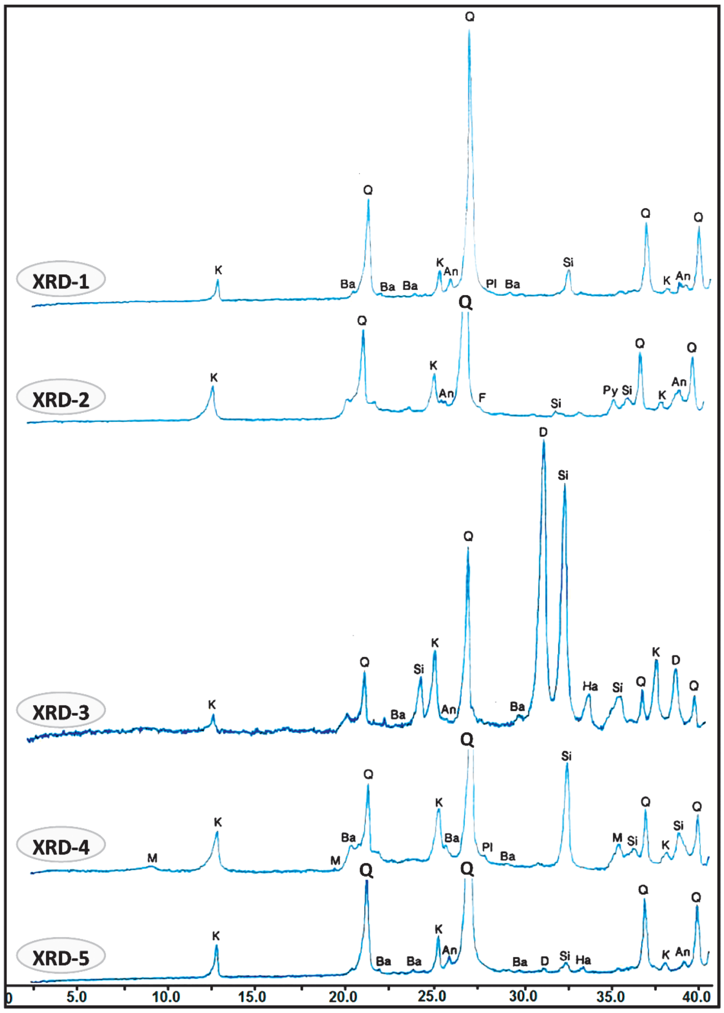

Figure 5. Diffractograms of sandstones and their quantitative mineral composition

Sandstone, analysis of rocks						
Symbol / Sample		XRD-1	XRD-2	XRD-3	XRD-4	XRD-5
M	**Mica**	(-)	(-)	(-)	4.21	(-)
K	**Kaolinite**	7.40	14.14	7.66	8.14	11.20
Q	**Quarz**	81.20	77.49	43.24	67.65	81.18
F	**Fieldspar**	(-)	1.18	(-)	(-)	(-)
D	**Dolomite**	(-)	(-)	26.15	0.00	1.66
Si	**Siderite**	3.53	2.14	17.64	16.69	1.22
An	**Anhydrite**	2.11	1.22	1.00	(-)	1.33
Ba	**Barites**	3.14	2.54	2.12	3.01	2.23
Py	**Pyrite**	(-)	0.84	(-)	(-)	(-)
Pl	**Plagioclase**	2.30	(-)	(-)	(-)	(-)
H	**Halite**	(-)	(-)	2.01	(-)	1.02

Table 1. Mineral composition of sandstone samples

sandstones contain up to 5% Fe_2O_3. In single cases, its content exceeds 5%.

In all samples, the proportion of SiO_2 and Al_2O_3 is quite significant, which indicates the presence of quartz and clay minerals in them.

On the other hand, the increased values of Fe_2O_3, MgO, CaO are probably related to the presence of hematite, siderite, dolomite and calcite.

4. Conclusion

The work shows the mineral composition of the Upper Triassic sandstones (Euphrates Graben, East Syria). In the course of the analytical work, it was possible to establish the nature of minerals composing sandstones and their impact on the

Sample	Si02	Al203	Fe203	MgO	CaO	MпO	MgO	CaO	К20	Ti02	MпO	P205	LOI	Total
S 1	69.93	16.22	2.09	1.24	0.18	0.003	1.24	0.18	4.62	1.42	0.003	0.009	2.01	99.145
S 2	68.85	14.22	3.22	1.79	1.68	0.033	1.79	1.68	3.64	1.22	0.033	0.008	1.02	99.184
S 3	79.01	14.32	2.23	0.2	0.08	0.002	0.2	0.08	0.21	2.06	0.002	0.055	1.36	99.809
S 4	58.65	28.13	7.77	0.36	0.16	0.013	0.36	0.16	0.96	1.63	0.013	0.136	1.24	99.582
S 5	66.91	13.61	1.31	1.05	0.15	0.121	1.05	0.15	2.2	0.78	0.121	0.057	1.65	89.159
S 6	74.73	13.3	0.62	0.4	0.09	0.023	0.4	0.09	1.11	1.1	0.023	0.015	1.48	93.381
S 7	78.02	15.12	2.58	0.09	0.05	0.001	0.09	0.05	0.26	1.92	0.001	0.032	1.39	99.604
S 8	68.81	21.24	1.99	0.49	0.09	0.001	0.49	0.09	2.03	2.31	0.001	0.026	1.58	99.148
S 9	70.88	22.18	1.19	0.29	0.09	0.001	0.29	0.09	0.78	1.92	0.001	0.014	1.78	99.506
S 10	75.69	12.78	2.48	0.96	0.09	0.001	0.96	0.09	3.1	1.17	0.001	0.043	2.15	99.515
S 11	74.41	13.16	3.37	1.04	0.12	0.002	1.04	0.12	3.37	1.19	0.002	0.024	2.01	99.858
S 12	68.98	15.77	4.18	1.47	0.15	0.002	1.47	0.15	4.4	1.28	0.002	0.002	1.65	99.506
S 13	68.27	15.24	4.71	1.48	0.17	0.002	1.48	0.17	4.41	1.28	0.002	0.009	1.89	99.113
S 14	70.76	14.47	5.89	1.06	0.14	0.003	1.06	0.14	3.41	1.36	0.003	0.018	1.67	99.984
S 15	82.9	11.46	1.23	0.35	0.05	0.002	0.35	0.05	1.02	1.19	0.002	0.018	1.25	99.872
S 16	78.74	15.29	0.94	0.11	0.07	0.004	0.11	0.07	0.08	1.93	0.004	0.067	1.89	99.305
S 17	65.69	23.71	2.77	0.64	0.19	0.003	0.64	0.19	1.9	1.87	0.003	0.02	1.68	99.306
S 18	71.88	15.98	2.77	0.84	0.21	0.002	0.84	0.21	2.93	1.51	0.002	0.012	2.33	99.516
S 19	63.71	17.9	2.73	2.26	0.72	0.006	2.26	0.72	5.42	1.41	0.006	0.002	2.14	99.284
S 20	70.51	14.05	1.87	2.18	0.93	0.042	2.18	0.93	3.95	1.08	0.042	0.08	2.15	99.994
S 21	64.51	13.56	2.86	3.12	3.53	0.087	3.12	3.53	3.4	1.11	0.087	0.06	0.6	99.574
S 22	74.89	13.96	2.59	0.93	0.12	0.001	0.93	0.12	3.19	1.35	0.001	0.023	0.99	99.095
S 23	59.34	13.95	3.96	3.15	4.021	0.065	3.15	4.02	4.04	1.01	0.065	0.01	0.12	96.901
S 24	77.75	12.93	2.21	0.71	0.14	0.002	0.71	0.14	2.37	1.29	0.002	0.024	0.99	99.268
S 25	65.61	21.35	0.97	0.15	0.04	0.001	0.15	0.04	0.32	2.33	0.001	0.134	1.87	92.966
S 26	76.13	18.24	0.58	0.12	0.05	0.001	0.11	0.05	0.33	2.13	0.001	0.081	2.15	99.973
S 27	70.95	20.69	1.92	0.36	0.07	0.002	0.36	0.07	1.25	2.14	0.002	0.122	1.36	99.296
S 28	72.56	19.72	0.74	0.07	0.07	0.002	0.07	0.07	0.04	3.64	0.002	0.039	1.99	99.013

*Table 2: X-ray fluorescence analysis (XRF) of samples of the Triassic upper sandstone. * LOI = Loss during ignition at 1050°C*

porosity of rocks. So, for example, a good sorting of detrital grains and their substantial quartz composition is an important factor determining the increased values of porosity. On the other hand, the increased content of clay and authigenic minerals (more than 10-15%) reduces the porosity of rocks studied. The main clay mineral is kaolinite, formed during sedimentogenesis. This role is played also by other layered silicates – chlorite and mica. However, another type of kaolinite – authigenic – on the contrary, increases porosity, because it is formed due to the hydrolysis of feldspars. Other authigenic minerals – calcite, dolomite, siderite, pyrite, found between clastic grains – lead to a decrease in porosity. The complex of analytical methods used in the study made it possible to obtain information supplementing and non-contradicting each other.

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About the Authors

Ibrahem Mohammad Yousef – Geologist, PhD student, Department of Mineralogy and Lithology, Institute of Geology and Petroleum Technologies
Kazan (Volga region) Federal University
4/5 Kremlevskaya St., Kazan, 420008, Russia
E-mail: ibrahem.youseef@mail.ru

Vladimir P. Morozov – DSc (Geology and Mineralogy), Professor, Head of the Department of Mineralogy and Lithology, Institute of Geology and Petroleum Technologies
Kazan (Volga region) Federal University
4/5 Kremlevskaya St., Kazan, 420008, Russia
E-mail: Vladimir.Morozov@ kpfu.ru

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LITHOLOGICAL AND MINERALOGICAL CHARACTERISTICS AND FORMING CONDITIONS OF THE JURASSIC SEDIMENTS ON THE WEST SIBERIAN BASIN

R.R. Khaziev, E.E. Andreeva, Yu.M. Arefiev, A.G. Baranova, S.E. Valeeva, L.Z. Anisimova, K.Yu. Goryntseva*
Institute for Problems of Ecology and Subsoil Use of Tatarstan Academy of Sciences, Kazan, Russia

Abstract. In the present work, lithological and mineralogical features, granulometric composition, as well as reservoir properties of the formation YuV1-1 of the Ety-Purovsky oil field are considered. It is established that the main rock-forming minerals of the reservoir – quartz, potassium feldspar and mica, also fragments of rocks, including carbonate rocks, are also found. Sandstone is diagnosed as carbonate greywack by the examined thin sections. According to the granulometry data, the formation is characterized as fine-grained sandstone with a dominant fraction of grains of 0.1-0.25 mm (47% of the total mass). According to the petrogenetic Passega diagram it was established that the formation was formed under the conditions of the gradation suspension generated in the lower parts of the fast river streams, directly at the bottom, which agrees with the literature data. Moreover, according to design factors (So, Q3, Q1), it is established that the formation is characterized by a poor degree of sorting of the sand material, as well as low roundness of grains and deteriorated reservoir properties, measured in laboratory conditions. It follows from the analysis that the reservoir is characterized by low productivity, and its development requires the use of hydraulic fracturing at an early stage of development.

Keywords: microscopic description of thin sections, granulometric composition, reservoir properties, hydraulic fracturing, oil-bearing formation, sand reservoir

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The Ety-Purovsky field is the largest of the fields developed by the Muravlenkovskneft-NNG branch of JSC Gazpromneft. According to the size of the initial recoverable oil reserves, the field belongs to the category of large, and by geological structure – to the category of complex fields. The field was discovered in 1978, it was put into industrial development in 2003. Currently it is in the third stage of development.

In the tectonic plan, the Ety-Purovsky field is confined to the Nadym-Tazov syneclise; controlled by a dome-shaped uplift – the Purov megaswell. The geological section of the field is represented by Jurassic, Cretaceous, Oligocene and Quaternary formations. The rocks of the Upper Jurassic and Cretaceous age are productive.

To study the material composition and generation conditions, the YuV1-1 formation was selected, confined to the Vasyuganskian suite of the Callovian stage of the Upper Jurassic. The choice of the development object was made based on the following facts: 1) 20% of the recoverable reserves are concentrated in the YuV1-1 formation; 2) the formation is characterized by considerable thickness (from 8 to 25 m in different parts of the field); 3) an acidic interval-wise fracturing was used on the YuV1-1 formation at the initial stage of field development in order to intensify the inflow of production wells (the average oil flow increased by 2-3 t/d on the wells).

The object of the study was a core material selected from a potentially productive interval. Samples were selected from 2 wells in the field in an amount of 6 pieces (from the roof, middle and bottom parts of the formation).

The study of the selected samples included:

1) Microscopic analysis of thin sections;
2) Granulometric analysis of core samples;
3) Investigation of the reservoir properties.

Microscopic analysis made it possible to establish that the sandstones of the YuV1-1 formation have a polymictic composition. The clastic material is represented by grains of quartz (about 30%), potassium feldspar (35-40%), biotite (5%); in a small amount

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*Corresponding author: Evgenia E. Andreeva
E-mail: aee8277@rambler.ru

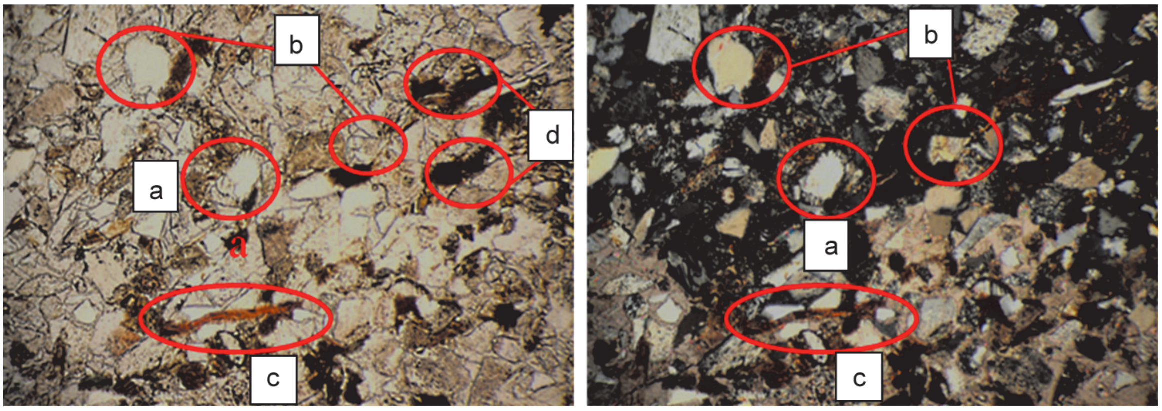

Figure 1. Photo of sample No. 1 thin section (well 1511, sampling depth 3320 m) a-quartz; b – potassium feldspar; c – biotite, d – carbonaceous organic

contains hornblende, muscovite and other minerals. Also there are fragments of carbonates. The shape of most grains is abnormal; the degree of their roundness is weak, the ratio of length to width is close to 1 (Figure 1). Cement is mainly contact-porous; and by the method of formation – cement of pores and voids is corrosive (cementation with partial dissolution of detrital material). The cement content averages 10-15% of the total volume of the thin sections. In all samples, carbonaceous vegetable organics are found everywhere (approximately 15% of the total sample). Thus, in terms of their mineralogical composition, the sandstones of the YuV1-1 formation refer to carbonate greywackes.

According to the granulometry data, the samples are distinguished in the granulometric composition typical for the YuV1-1 formation with the dominant fraction of 0.1-0.25 mm (~ 47% of the clastic part) (Table 1, Figure 2) characterizing the reservoir rocks as fine-grained sandstone.

To determine the transfer mechanism of terrigenous material, Passega genetic diagram was used (Frolov, 1992); the design parameters C and Md were used to determine the mechanism of sediment formation; Q3 and Q1 were used to evaluate the degree of sorting ($S_o = \sqrt{\frac{Q3}{Q1}}$). The values of the parameters are taken from the cumulative curves plotted from the granulometry data (Figure 3, Table 2).

As can be seen from the graph in Figure 4, the cloud of points distribution falls on the P-Q-R area corresponding to the field of the gradation suspension formed in the lower parts of the fast river streams, directly at the bottom. According to the literary data (Dopolnenie k proektu probnoy ekspluatacii..., 2005), the YuV1-1 formation was formed in delta conditions in the territory of the field. As noted in (Frolov, 1992), a good or average degree of sorting is characteristic for sandstones formed under such conditions. The data of the calculated sorting factor confirm this.

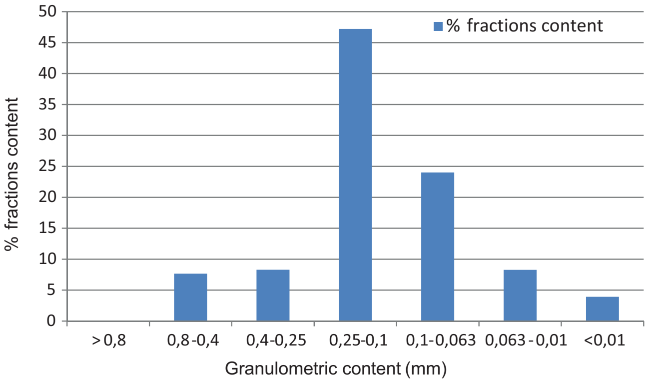

Figure 2. The averaged histogram of the fractions content in the YuV1-1 formation

No. sample	Fraction, mm							
	> 0,8	0,8 - 0,4	0,4 - 0,25	0,25 - 0,1	0,1 - 0,063	0,063 - 0,01	< 0,01	∑ %
1	-	2,28	5,93	45,49	28,78	11,61	5,04	99,13
2	-	8,04	8,59	44,94	24,94	10,29	2,53	99,33
3	-	5,9	7,17	53,1	22,48	6,68	4,51	99,84
4	-	9,1	8,2	44,1	24,9	8,18	5,13	99,61
5	-	14,53	12,04	45,1	19,06	5,79	2,65	99,17
6	-	6,13	7,85	50,49	23,93	7,17	3,66	99,23
Average	0	7,63	8,29	47,2	24,02	8,28	3,2	99,38

Table 1. Data of the granulometric composition of samples No 1-6 of the YuV1-1 formation

No. sample	C, μm	Md, μm	Q3,μm	Q1, μm	So	Degree of sorting
1	300	110	180	60	1,73	Average
2	530	120	240	75	1,78	Average
3	410	140	220	75	1,71	Average
4	560	140	240	70	1,85	Average
5	680	160	260	90	1,69	Average
6	460	140	220	70	1,77	Average

Table 2. Calculation parameters for determining the mechanism of sediment formation and grain sorting

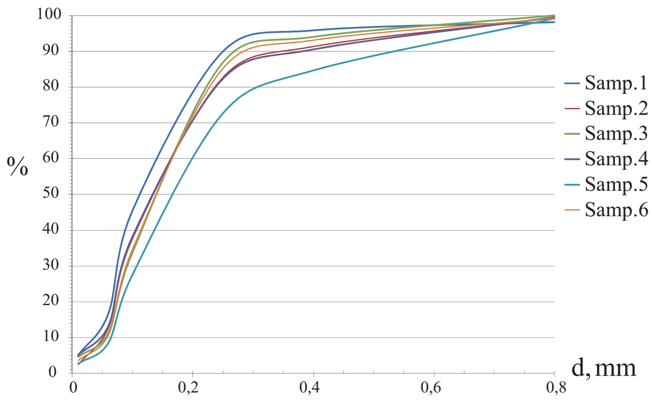

Figure 3. Cumulative curves of samples No.1-6 of the YuV1-1 formation

No. sample	Kpor(%)	Kper(mD)	Category of reservoir (According Khanin)
1	11	7,3	4
2	8	1,2	5
3	12	10,7	4
4	16	2,4	5
5	15	10,5	4
6	5	0,9	6

Table 3. Reservoir properties of the YuV1-1 formation

Under laboratory conditions, reservoir properties were measured for all 6 samples: porosity and permeability coefficients. The results are shown in Table 3.

As can be seen from Table 3, according to the Khanin's classification of reservoirs (Burlin, 1976; Gimatutdinov et al., 1982), sandstones belong to the 4-6 categories and are estimated as "low productive". Obviously, in view of the deteriorated reservoir properties, the productive formation already at the initial stage of development was characterized by a small amount of recoverable reserves and, as a consequence, a low rate of oil extraction. This circumstance, most likely, was one of the main reasons for applying the mechanical method for intensifying production at the initial stage of development.

Conclusions

Based on the above data, the authors draw the following conclusions:

1) Polymictic carbonate greywackes, fine-grained, medium-sorted are the main type of reservoir rocks. Experience of works (Shvanov, 1987; Frolov, 1992; Yezhov, 2009; Nedolivko et al., 2011) shows that feldspars are subject to the process of pelitization, which, in turn, is accompanied by a deterioration of reservoir properties (reduced open porosity and permeability).

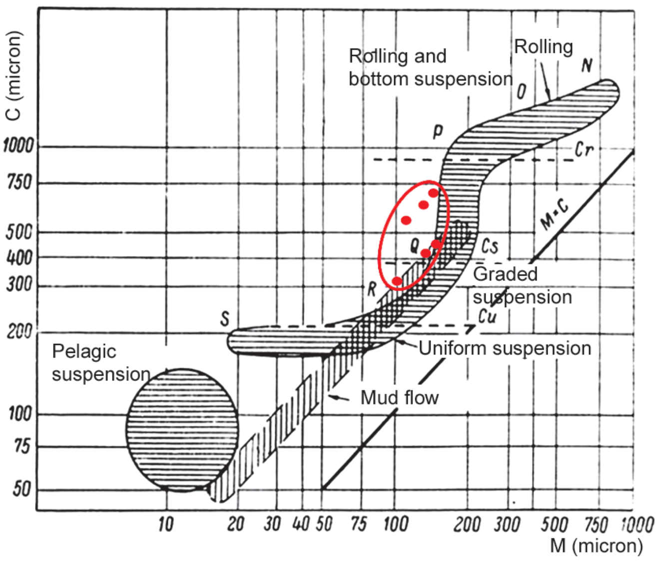

Figure 4. Passega diagram (Frolov, 1992) for determining the mechanism of sediment formation

2) It has been established that all samples are characterized by an average degree of sorting by granulometric analysis and comparison with a general sampling of data from literature sources; taking into account the fact that roundness of grains is characterized as low according to the study of thin sections, the YuV1-1 formation should be considered low-productive.

3) According to Khanin's classification, the formation is characterized as low-productive. This entails certain difficulties in the development of recoverable reserves by conventional methods. Development of such formations is carried out using hydraulic fracturing. Hydraulic fracturing is most often used at later stages of development of oil fields (Zhdanov, 2008) with the aim of increasing the inflow of production wells or increasing injectivity of injection wells. However, as the results of the studies showed, the application of hydraulic fracturing may be justified at the early stages of oil field development due to lithological features, degraded reservoir properties and, as a result, low productivity of the reservoir.

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About the Authors

Radmir R. Khaziev – Researcher, Laboratory of Geological and Environmental Modeling, Institute for Problems of Ecology and Subsoil Use of Tatarstan Academy of Sciences
28 Daurskaya St., Kazan, 420087, Russia

Evgenia E. Andreeva – Senior Researcher, Laboratory of Geological and Environmental Modeling, Institute for Problems of Ecology and Subsoil Use of Tatarstan Academy of Sciences
28 Daurskaya St., Kazan, 420087, Russia
Phone: +7 843 298 59 65, e-mail: aee8277@rambler.ru

Yuri M. Arefiev – Senior Resercher, Laboratory of Geological and Environmental Modeling, Institute for Problems of Ecology and Subsoil Use of Tatarstan Academy of Sciences
28 Daurskaya St., Kazan, 420087, Russia

Anna G. Baranova – Senior Resercher, Laboratory of Geological and Environmental Modeling, Institute for Problems of Ecology and Subsoil Use of Tatarstan Academy of Sciences
28 Daurskaya St., Kazan, 420087, Russia

Svetlana E. Valeeva – Resercher, Laboratory of Geological and Environmental Modeling, Institute for Problems of Ecology and Subsoil Use of Tatarstan Academy of Sciences
28 Daurskaya St., Kazan, 420087, Russia

Lilia Z. Anisimova – Resercher, Laboratory of Geological and Environmental Modeling, Institute for Problems of Ecology and Subsoil Use of Tatarstan Academy of Sciences
28 Daurskaya St., Kazan, 420087, Russia

Ksenia G. Goryntseva – Junior Resercher, Laboratory of Geological and Environmental Modeling, Institute for Problems of Ecology and Subsoil Use of Tatarstan Academy of Sciences
28 Daurskaya St., Kazan, 420087, Russia

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THE CRITERIA FOR THE SELECTION OF WELLS FOR HYDRAULIC FRACTURING

O.V. Salimov[1], *A.V. Nasybullin*[1], *R.Z. Sakhabutdinov*[1], *V.G. Salimov*[2*]

[1]*Institute TatNIPIneft Tatneft PJSC, Bugulma, Russia, Bugulma, Russia*

[2]*Volga-Kama Regional Branch of the Russian Academy of Natural Sciences, Bugulma, Russia*

Abstract. Various methods of selection of wells for hydraulic fracturing are analyzed. It is established that all methods can be divided into three large groups: criteria in the table form of boundary values of parameters, statistical methods of pattern recognition, methods of engineering calculation.

The complication or use of additional parameters only leads to a reduction in the number of wells at which hydraulic fracturing is possible.

It is shown that the use of reservoir properties of rocks, which are already used by hydraulic fracturing simulators, is not practicable as selection criteria. It is required to include in the selection criteria only those additional factors on which the effectiveness of hydraulic fracturing depends directly.

Key words: well selection criteria, expert estimates, hydraulic fracturing

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Currently, the selection of wells for hydraulic fracturing (fracturing), as a rule, is carried out by expert assessments of specialists and based on the available field experience. This process is not strictly formalized, therefore different groups of specialists often come to different conclusions.

When selecting wells it is necessary to solve a number of issues:

1. Is it advisable to carry out hydraulic fracturing at a specific well?
2. What kind of hydraulic fracturing technology should be applied?
3. What treatment scale should we choose?
4. What increase in production rate can be obtained?
5. Will the cost of hydraulic fracturing pay off?

Items 4-5 require simulation in MProd, MNpv simulators or in hydrodynamic programs, and they are rarely performed.

Criteria for selecting wells for hydraulic fracturing are based on field experience and do not need any geological justification. Criteria are changed in connection with the improvement of hydraulic fracturing technology and access to new facilities. PJSC Tatneft processed many wells that did not meet the criteria, with positive results. On the other hand, often wells meeting all criteria without exception were not effective. That is, the criteria are the statistical rules for testing hypotheses, the adherence to which will ensure a fairly low percentage of errors of the first and second kind. Zero hypothesis – the well, which will be selected for fracturing, will be effective. An error of the first kind – the well does not meet the criteria, but the hydraulic fracturing on it will be effective. An error of the second kind – the well meets the criteria, but the hydraulic fracturing on it will be ineffective. Criteria are developed on the basis of long field practices so as to minimize the sum of errors of the first and second kind.

Sometimes we can find statements that the criteria are bad, not geologically sound, and so on. What happens if we tighten the criteria? Then there will be a lot of wells left overboard, on which the hydraulic fracturing would be effective, but we rejected them. If we will soften the criteria, many inefficient wells will appear, which in their parameters meet the criteria. There are criteria that do not need any justification at all. For example, a well should be technically sound, and oil reserves are at the level of profitability. These are axioms.

Usually, the criteria for selecting wells are a table with a list of parameters and their boundary values. As the pilot works conducted, experimental processes and experience accumulated, the tables are gradually being improved.

The TatNIPIneft Institute created criteria for the selection of wells for the fracturing, considering the works of many specialists (R.G. Abdulmazitov, G.A. Orlov, R.T. Fazlyev, M.Kh. Musabirov and others), starting around 1997. There are several guideline documents on this issue, but in them all the parameters are mostly reproduced. The difference is only in numerical values for boundaries. Let's compare the selection criteria for 2015 and 2006. In the new criteria, the oil-saturated

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*Corresponding author: Vyacheslav G. Salimov
E-mail: salimov@tatnipi.ru

thickness of the reservoir decreased from 1.5 to 0.8 m; thickness of overlapping and underlying screens from 5 to 4 m. Now it is allowed to conduct simultaneous fracturing of two layers with a distance between them not exceeding 20 m; but it was no more than 3 m. The zenith angle of the well in the formation interval is no longer regulated. The additional requirements for producing wells decreased: the watercut of the production is not more than 90% (it was not more than 50%), the reservoir pressure is not less than 0.5 from the initial (was no less than 0.7 from the initial), the distance to the nearest injection well is not less than 200 m (it was not less than 300 m). The reduction in requirements is due to the fact that a large number of wells that do not meet the criteria are rejected in practice. If criteria are tightened or additional criteria are introduced, wells suitable for hydraulic fracturing can remain literally one.

A positive aspect is the additional requirements for acid fracturing, which was not in the previous version of the selection criteria. This is the solubility degree of rock in hydrochloric acid, the heterogeneity of the rock, Brinell hardness, the distance from the water-oil to the lower perforations. Criteria for the use of acid fracturing have also been developed by other authors (Zharlgapov, Nikulin, 2014).

Similar tables of criteria are used in other oil-producing enterprises. For example, in (Al'mukhametova, Evdokimov, 2014), based on the analysis of the efficiency of hydraulic fracturing at the Priobsky field, it was established that the main criteria for the success of hydraulic fracturing operations are: oil saturated thickness – not less than 3 m; thickness of overlapping and underlying screens – not less than 3 m; the ratio of the current reservoir pressure to the initial pressure is not less than 0.9; watercut production – not more than 30%; the angle of the borehole deviation from the vertical in the interval of the formation is no more than 10°; depth of the well – no more than 3000 m.

Another method, actively recommended by some specialists, is the use of pattern recognition programs in various modifications.

For example, in work (Pichugin et al., 2007), an approach is proposed for predicting the efficiency of hydraulic fracturing on the basis of methods of neural network modeling, probability trees and support vector machines. The disadvantage is that the chosen methods, like any other statistical methods, do not allow achieving a high quality prediction without preliminary analysis of the results of hydraulic fracturing, careful preparation and formation of a database.

In work (Zalevskii et al., 2006), in order to determine the conditions for the most effective application of fracturing technology, calculations were performed using mathematical methods of statistical analysis, in particular, Mann-Whitney statistics and Wald's sequential diagnostic analysis. Preliminary for all 684 fracturing operations conducted at fields of the Manufacturing Facility Uraineftegaz, a local database was developed that characterizes the geological conditions of the formations, the geological and physical conditions of their bottom-hole zones, the current values of the production indices at the time before, during and after the fracturing, and technological parameters of hydraulic fracturing.

Despite the novelty and sophistication of the mathematical methods involved, these approaches have not been widely distributed. The reason is that it is necessary to create and maintain extensive fracturing databases. As the authors of this approach write, the maximum efficiency from the use of an intelligent forecasting system can be obtained only if there is feedback, in the mode of continuous support of activities for the implementation of measures at wells (Pichugin et al., 2009).

Other approaches have been proposed, for example, using the mathematical apparatus of fuzzy logic (Galiullin et al., 2011; Perminov, Valeev, 2013). The authors of these papers recommend using a complex of two mathematical applications: cluster analysis and fuzzy logic. Cluster analysis allows automatically compiling a rating list of candidate wells and, on its basis, selecting wells that are prioritized for hydraulic fracturing. It is reported that the use of the fuzzy logic method makes the clustering algorithm more robust to errors and geological uncertainty of the main parameters.

There are other approaches to the problem of wells selection for hydraulic fracturing. For example, in (Serebrennikov et al., 2014), a generalized information is presented on the features of a complex approach to the validation of candidate wells for hydraulic fracturing, including: 1) the formation of pre-selection and the ranking of wells (sections of fields) by methods of Data mining; 2) expert evaluation of the criteria characterizing the wells and areas of the field for implementing the hydraulic fracturing. The main geological-technological and technical criteria revealed empirically, used in the analysis by Data mining methods, as well as factors whose formalization is a rather complex task are shown.

There are suggestions for using trees instead of decision tables. In work (Gaidamak, Pichugin, 2015) the possibility of application of the decision tree method for selection of candidate wells for fracturing is investigated. A method for identifying indicators that significantly affect the success of the hydraulic fracturing is described. The negative effect of increasing the spatial density of the fracturing performed on subsequent hydraulic fractures is established. A method is proposed for improving the quality of the forecast by varying the threshold value of success.

In work (Kulikov et al., 2016) principles of an express-method of wells selection for carrying out stimulation are presented. The method is based on the use of graphical correlation of the current flow rate values and the values of fluid potential index for the wells of a given deposit.

Engineering calculations and various proxy models for the selection of wells are used. A fundamentally new computerized technology was developed at the RITiMPS department of the TatNIPIneft Institute, based on an analysis of the state of impact elements. For the selection of wells-objects, geological conditions and technological indicators of the development efficiency, determined by the LAZURIT program, and the characteristics of the well itself, permitting fracturing, are used.

The program for selecting wells for the fracturing is based on criteria that have been repeatedly tested in Tatneft PJSC. The validity of the criteria is confirmed by the field practice, as evidenced by the achieved level of success (87%). The scientific basis of the method was developed jointly with the specialists of Tatneft PJSC (Sultanov et al., 2010).

The well selection methodology tested at a number of LUKOIL-Perm fields for intensifying oil extraction and increasing oil recovery is close to this approach, which includes the estimation of residual recoverable reserves in differentiated production wells; determination of the residual recoverable reserves production duration by wells; choice for the subsequent analysis of wells with high values of residual recoverable reserves and their production duration; assessment of the wellbore zone conditions; selection of technologies for conducting activities (Mordvinov et al., 2006).

Since no matrix of solutions can provide a 100% guarantee of the success of hydraulic fracturing, many researchers offer additional criteria. For example, in work (Solov'eva et al., 2009), the necessity of using an additional criterion for the selection of an object for fracturing is justified. Its essence consists in revealing the vertical conductivity of non-reservoirs separating oil-saturated strata from aquifers, through the actual pattern of watering the reservoir and the location of the candidate well for the fracturing.

Methods for selecting wells for specific geological conditions are known, for example, analysis of the fracturing operation results performed on wells with low reservoir pressure of RN-Purneftegaz LLC has formed the basis for the development of wells selection with low reservoir pressures for fracturing operations (Borkhovich et al., 2012).

Often statements are made that in the selection criteria of wells for fracturing it is necessary to include reservoir (filter-capacitive) rock properties. We will show the fallacy of this situation on the example of the results of pilot industrial works for fracturing into Mendymskian, Domanic and Sargaevskian deposits of the Republic of Tatarstan.

Using the apparatus of mathematical statistics, according to the actual values of porosity and clay content of the Domanic deposits, the curves of their theoretical distributions were reconstructed (Figures 1, 2). For this purpose, the mean values and root-mean-square deviations of each of the parameters were calculated. Then, using the function EXCEL NORM.DIST, the distribution curves of each parameter were restored. On the basis of the results of numerous studies, it was assumed that these distributions obey the normal law.

The root-mean-square deviation for small samples (n <10) was estimated by the sample size. It is known that with a normal distribution, as an estimate of the scattering characteristic, we can use the sampling range

$$R = x_{max} - x_{min}, \tag{1}$$

where x_{max} and x_{min} – the maximum and minimum values in the sampling, respectively.

It is shown, that

$$MR = \alpha_n \sigma, \tag{2}$$

where M – the symbol of mathematical expectation; α_n – a function of the sample size, the values of which are given in the tables; σ – root-mean-square deviation.

Thus,

$$M\left(\frac{R}{\alpha_n}\right) = \sigma\ . \tag{3}$$

At small n (n<10), this estimate of the parameter σ has a rather significant efficiency, but at large n it is ineffective in comparison with s. For the sample size n = 6, the parameter α_n=2.534 (Smirnov, Dunin-Barkovskii, 1969).

It can be seen from the figures that the distributions of the studied properties of the formations have a significant overlap that does not allow their effective differentiation with respect to the properties studied. If we use the property values as a boundary criterion at the points where the curves intersect, then this will lead to large errors of the first and second kind.

For example, let the porosity value be 6%. Then the probability that the treatment of this formation will be successful, according to Figure 1, will be approximately 13%. The probability that the treatment of this formation will be unsuccessful, will be approximately 17%. Then, according to the formulas of probability theory, if this formation is chosen for processing, the probability of success will be 13/(17+13)×100=43%, which is approximately half of all wells. If the porosity value is 10%, then the probability of successful treatment is about 10%, and the unsuccessful about 4%. Probability of treatment success is 10/(10+4)×100=70%. Conclusion with a probability of at least 95% can be given only in situations where we are far from the center of the

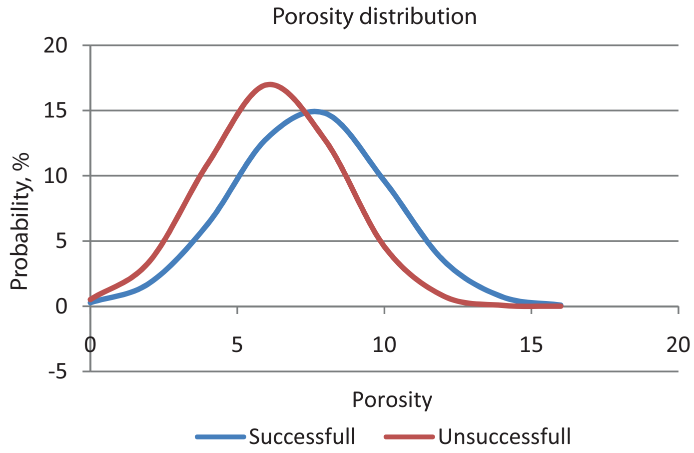

Figure 1. Theoretical distribution of porosity for successful and unsuccessful fracturing processes

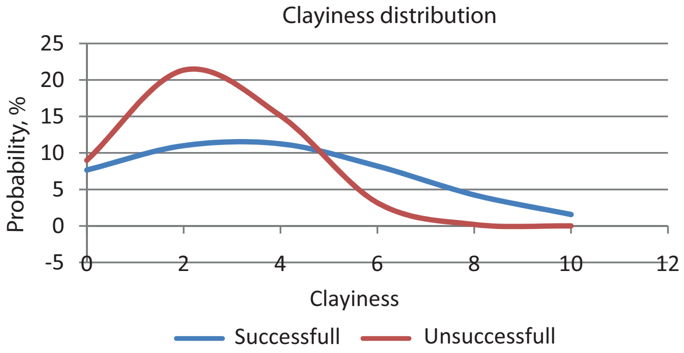

Figure 2. Theoretical distribution of clay content for successful and unsuccessful fracturing processes

parameter distribution. For example, with a porosity of 14%, the probability of success is approximately 0.7, and the failure rate is 0.07. Then the reliability of the conclusion on the success will be 0.7/(0.7 + 0.07) = 0.91. Despite the extreme situation, we do not reach the required level. There is nothing we could do, nature works by its own laws.

In this example, we tried to show that the "scientific justification" and the introduction of some new criteria for selecting wells for hydraulic fracturing (especially associated with the reservoir properties) is a dead-end path.

Hydraulic fracturing is carried out in reservoirs with any reservoir properties. For example, the permeability can be from units of nanodarsi (in shales) to hundreds of millidarsi (in sandy rocks). And everywhere hydraulic fracturing is carried out, changing only the technology used. But permeability is a reservoir property of the rock. The same applies to porosity and clay content – these are also reservoir properties. The hydraulic fracturing simulators take into account the reservoir properties and the values of the process fluid leaks, therefore, in the selection criteria for wells, there is no need for limitations on the reservoir properties of rocks.

There are situations in which the attraction of additional selection criteria is simply necessary, for example, when designing acid fracturing in carbonate sediments. The work of the TatNIPIneft Institute showed that the rock hardness by the Brinell is the necessary criterion in this case (Ibatullin et al., 2011). Although the simulator takes into account the hardness of the rock, however, starting from some minimum hardness value, the conductivity of the fracture becomes zero. Therefore, it makes sense to screen out such losing options in advance. Hardness does not play a significant role during proppant fracturing.

The second situation is the choice of intervals for fracturing in thick shale strata. The purpose of the hydraulic fracturing is to obtain a branched grid of fractures, covering as much as possible the largest volume of the formation. The difference of technology lies in the use of low-viscosity fracturing fluids. Brittleness and rock toughness begins to play a major role in these conditions. Since no single indicator allows predicting the creation of the best grid of fractures, a complex indicator is used that includes both indicators, which is called fracability (Jin et al., 2014).

The mathematical model of the fracability index in terms of brittleness and rock toughness is defined as follows

$$FI = \frac{B_n + K_{IC\_n}}{2}, \tag{4}$$

where B_n – normalized brittleness; K_{IC_n} – normalized rock toughness.

$$B_n = \frac{B - B_{\min}}{B_{\max} - B_{\min}}, \tag{5}$$

where B_{min} and B_{max} – minimum and maximum brittleness of the investigated formation, respectively.

$$K_{IC\_n} = \frac{K_{IC\_\max} - K_{IC}}{K_{IC\_\max} - K_{IC\_\min}}, \qquad (6)$$

where K_{IC_max} and K_{IC_min} – minimum and maximum rock toughness of the investigated formation, respectively.

The *FI* index is in the range from 0 to 1. The interval with *FI = 1* is considered as the best candidate for fracturing, and the interval with *FI = 0* is the worst.

The main goal of hydraulic fracturing design in shale sediments is to increase hydrocarbon production by selecting candidates with the highest fracability index. It is reported that this index has been successfully used to optimize hydraulic fracturing and to drill horizontal wells in the Barnett shale play.

Conclusions

1. Criteria for selecting wells for hydraulic fracturing depend on the area of works and vary with time. The main form of the criteria is to represent them in the form of a table of parameter boundary values.

2. Distributions of reservoir properties for a set of successful and unsuccessful fracturing processes largely overlap, not allowing to effectively recognize them.

3. Reservoir properties (porosity, permeability, clay content) do not reflect the efficiency of fracturing processes. Moreover, they cannot act as criteria for selection of candidate wells.

4. If the factors on which the hydraulic fracturing efficiency depends are determined, it is possible to include them in the selection criteria for the wells. However, the parameters that the fracturing simulator takes into account (such as porosity, permeability, etc.) cannot act as well selection criteria for fracturing.

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About the Authors

Rifkhat Z. Sakhabutdinov – DSc (Engineering), Managing Director, Institute TatNIPIneft Tatneft PJSC

32 M.Djalil St., Bugulma, 423326, Republic of Tatarstan, Russia. E-mail: rifkat@tatnipi.ru, tel: +7 85594 78 627

Oleg V. Salimov – PhD (Engineering), Chief of Hydrofrac Research Laboratory, Well Operation and Workover Department, Institute TatNIPIneft Tatneft PJSC

32 M.Djalil St., Bugulma, 423326, Republic of Tatarstan, Russia. E-mail: sov@tatnipi.ru, tel: +7 85594 78 984

Arslan V. Nasybullin – DSc (Engineering), Head of IT and Reservoir Simulation Department
Institute TatNIPIneft Tatneft PJSC
32 M.Djalil St., Bugulma, 423326, Republic of Tatarstan, Russia
E-mail: arslan@tatnipi.ru
Tel: +7 85594 78 641

Vyacheslav G. Salimov – PhD (Geology and Mineralogy), Head of Subsurface Geology Group
Volga-Kama Regional Branch of the Russian Academy of Natural Sciences
21 Voroshilov St., Bugulma, 423326, Republic of Tatarstan, Russia
E-mail: salimov@tatnipi.ru, tel: +7 85594 78 406

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RESULTS OF SCIENTIFIC AND TECHNICAL SUPERVISION OF HYDRAULIC FRACTURING OPERATIONS

I.Kh. Makhmutov[1], *O.V. Salimov*[1*], *I.I. Girfanov*[1], *R.Z. Zayatdinov*[1], *A.U. Mansurov*[1], *A.V. Kochetkov*[2]
[1]Institute TatNIPIneft Tatneft PJSC, Bugulma, Russia, Bugulma, Russia
[2]Engineering Center Tatneft PJSC, Almetyevsk, Russia

Abstract. The paper presents actual results of the research conducted as part of a field pilot project which consisted in interpretation of minifrac test data and evaluation of the efficiency of the scientific and technical supervision of fracking operations. The research program involved 11 wells targeting Devonian terrigenous reservoirs.

Minifrac tests in one perforation interval were performed only in seven wells, that is approximately in 64% of total well count. A reliable fracture closure estimate was obtained only in six wells (55%), beginning of pseudoradial flow was observed only in one well out of 11 wells (9%). Hence, conventional minifrac tests should be supplemented with other diagnostic injection tests.

Analysis of the performance of hydraulic fracturing operations conducted according to this pilot project plan indicates that fracture modelling, and scientific and technical supervision of fracking operations performed by Hydrofrac Research Laboratory of Institute TatNIPIneft Tatneft PJSC have yielded beneficial effects, namely 1.44 times increase in oil production rates.

Key words: hydraulic fracturing, scientific and technical supervision, minifrac test data interpretation, hydraulic fracturing performance

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In May-June 2015, Tatneft PJSC conducted pilot commercial development to assess the impact of multivariate modeling with implementing optimization calculations and scientific and technical support of works on the results of hydraulic fracturing. TatNIPIneft Institute of Tatneft PJSC was appointed as the executor of works.

The main tasks of pilot commercial development were:

- Analysis of hydraulic fracturing;
- Interpretation of the mini-fracturing data (mini-fracturing is test injection with operating flow before the hydraulic fracturing);
- Analysis of the reasons for getting STOPs. If the proppant prematurely forms a cork in the fracture during injection, this situation is known as "proppant blockage" or "STOP" – the working pressure will rise dramatically to the technical limit of the equipment (Economides Michael et al., 2002);
- carrying out optimization calculations;
- comparative assessment of the technological efficiency of hydraulic fracturing with modeling and scientific and methodological support by TatNIPIneft;
- issuing recommendations on improving the technology of hydraulic fracturing for the conditions of Tatarstan.

The article gives concrete results of this work concerning interpretation of the mini-fracturing and effectiveness of the scientific and technical support of hydraulic fracturing.

In the vast majority of cases, the mini-fracturing was not amenable to interpretation in accordance with the classical canons (Barree et al., 2007). The difficulties in interpreting the mini-fracturing were caused by the following factors.

1. The injection was performed simultaneously in several open intervals of perforation, or the formation was separated by very dense layers into several interlayers. In this case, it is difficult to recognize and divide the closing of the fracture in each individual formation.

2. Pseudo-radial flow regime is achieved only in rare cases, which does not allow correctly determining reservoir pressure and formation permeability. After the fracturing, there are alternating flow regimes: linear, bilinear and pseudo-radial (Cinco-Ley, Samaniego, 1981). Pseudo-radial flow is a steady flow to a well that has undergone a fracturing from the pseudo-radial drainage area of the formation.

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[*] *Corresponding author: Oleg V. Salimov*
E-mail: sov@tatnipi.ru

3. Premature termination of pressure drop recording.

4. Distortion of the pressure drop curve due to reduction of wellhead pressure to zero (well level is set), gas entering the well from the formation, presence of residual crosslinked gel in the borehole.

5. Lack of hydraulic communication with the formation (no hydraulic shock), STOP during the mini-fracturing. In this case, a qualitative interpretation of the pressure drop record is impossible.

6. Artifacts of the curves arising from the impact of the end effects – the resistance at the end of the crack. For example, the end of the derivative pressure line on the regression analysis graph goes down. But this is not a point reflecting the closing of the crack, but a decrease in resistance at the ends of the crack, since the position of this point varies with the change in the interval of the curve study.

7. Long period of closure and no closure of the fracture in shale deposits during the recording of the pressure drop. The pressure decreases slowly, for several hours.

There are also some features of computer simulators of hydraulic fracturing in terms of interpretation of mini-fracturing. For example, in the FracPRO program, the analysis of mini-fracturing is carried out always on bottomhole pressure, therefore, a preliminary simulation of the injection process is required. The MinFrac program analyzes both wellhead and bottomhole pressure. It is not necessary to simulate a mini-fracturing. The results of mini-fracturing and hydraulic fracturing analysis for 11 wells included in the program of pilot commercial development are summarized in Table 1.

Mini-fracturing in one interval of perforation was carried out only in seven wells. In one well (8677B of Oil and Gas Production Department (NGDU) “Aznakaevskneft” (“AzN”)) STOP was obtained already with a mini-fracturing due to the lack of hydrodynamic connection with the formation. In 10 wells, there was connection with the formation, as evidenced by the appearance of hydraulic shocks when the injection was stopped. Nevertheless, in two wells out of 10, STOP was obtained during fracturing.

The point of fracture closing is confidently found only in six wells. In five wells this could not be done, so the parameters for re-calculation of the fracturing design were not determined by the results of the process (redesign of the crack). The beginning of the pseudo-radial flow was noted only in one well of 11.

Let us consider some examples.

Mini-fracturing in well No. 24019 of Oil and Gas Production Department “Leninogorskneft” (“LN”) was conducted through two intervals of perforation (Figures 1, 2).

The logarithmic derivative GdP / dG monotonically increases. GdP/dG is a special function called the G-time according to Nolti, which allows the pressure drop characteristic to be linearized and helps to identify the fracture closure (Economides Michael et al., 2002). Bending down at the very end of the record is an artifact. The closure point is set at this point conditionally.

Well No., Oil and Gas Prod. Dept.	Formation	Hydraulic connection, STOP	Number of perforation intervals	Presence of closure point	Determination of the origin of pseudo-radial flow
11304, «AN»	D0	Hydraulic shock	1	yes	yes
20154, «AN»	D1(a+b1+b3)	Hydraulic shock	3	yes	no
20191, «AN»	D1b3	Hydraulic shock	1	yes	no
20659, «AN»	D0+D1d	Hydraulic shock	2	yes	no
2133b, «AN»	D0	Hydraulic shock, STOP	1	no	no
8677B,«AzN»	D1a	STOP during mini-frac and hydraulic frac	1	no	no
2881bn, «AzN»	D1a	Hydraulic shock, STOP	1	yes	no
750, «AzN»	D1a	Hydraulic shock	1	questionable	no
39458, «LN»	D1(a+b2)	Hydraulic shock	2	questionable	no
24019, «LN»	D1(a+b2)	Hydraulic shock	2	no	no
22107, «JN»	D0	Hydraulic shock	1	yes	no

Table 1. Results of the mini-fracturing and hydraulic fracturing analysis

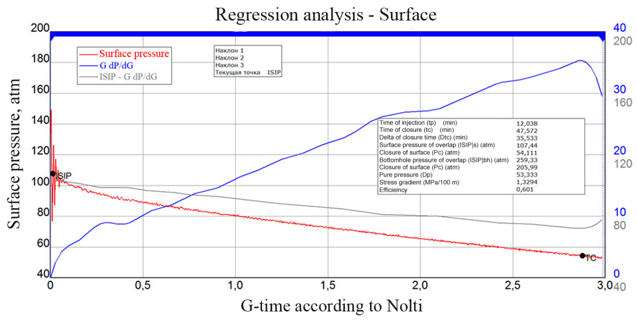

Figure 1. Well № 24019 of Oil and Gas Production Department "LN". Linear time analysis Nolti G

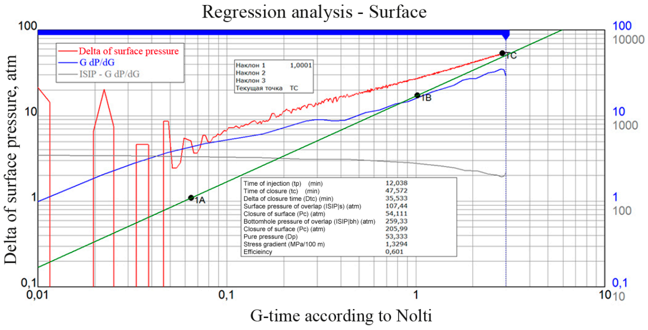

Figure 2. Diagnostic chart. Well No. 24019 of Oil and Gas Production Department "LN"

However, there is no closure of the crack. Moreover, the surface pressure curves and ISIP-GdP/dG monotonously diverge from the very beginning of the pressure drop (ISIP – instantaneous stopping pressure). The impression is as if there were no cracks. These curves should, according to theory, in the presence of a crack, go about the same way and disperse only after the point of closure.

On the diagnostic logarithmic graph (Figure 2), the slope of the pressure lines GdP/dG is about 0.5, which indicates that the crack, if it exists, is still open. There is no change in the sign of the derivative to minus or its stabilization. The tangent on this graph is drawn with an angular slope of 1, which corresponds to a linear flow from the crack to the formation. The actual slope of tangents to the curves is approximately 0.5, which corresponds to the bilinear flow (finite conductivity crack).

In well No. 39458 of Oil and Gas Production Department "LN" mini-fracturing is conducted also through two intervals of perforation. The resulting record is difficult to interpret, since three extrema are clearly distinguished on the logarithmic derivative (Figure 3). The ISIP-GdP / dG curve diverges from the pressure drop curve at the beginning of recording, the point of divergence approximately corresponding to the position of the first extremum. The tangent to the first extremum gives the values of the gradient of the fracturing pressure of 1.56 MPa / 100 m and the liquid efficiency is 0.353. However, the tangent to the second extremum also gives adequate values of the parameters: 1.28 MPa/100 m and 0.541.

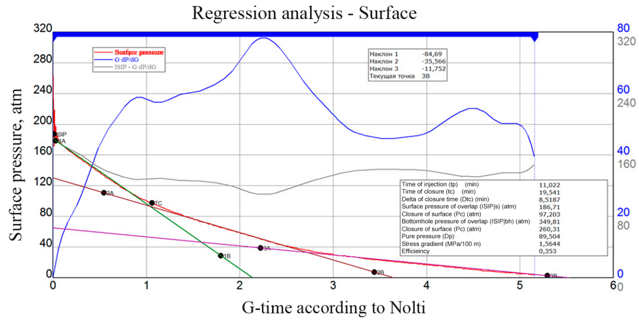

Figure 3. Well No. 39458 of Oil and Gas Production Department "LN". Linear time analysis Nolti G

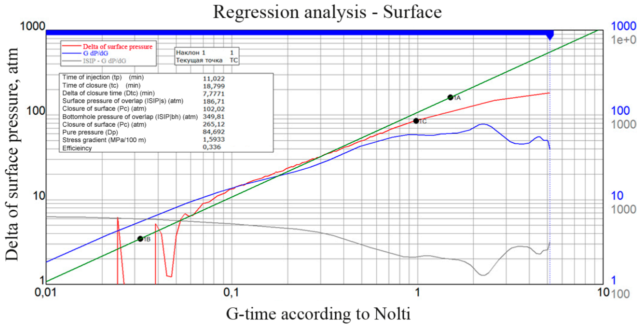

Figure 4. Diagnostic chart. Well No.39458 NGDU "LN"

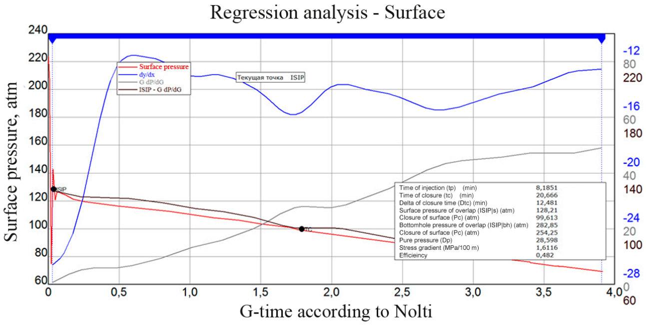

Figure 5. Well № 21336 NGDU "AN". Linear time analysis of Nolti G

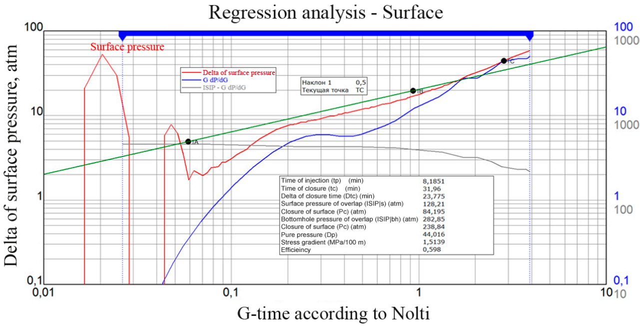

Figure 6. Diagnostic chart. Well № 21336 of Oil and Gas Production Department "AN"

However, the data from diagnostic graph allow us to conclude that the position of closure point is more correct at the time Nolti G, equal to 1 (Figure 4).

Figures 5 and 6 show graphs of the pressure drop analysis in the well 21336 of Oil and Gas Production Department Almetyevneft ("AN"). The surface pressure drop curves and ISIP-Gdp/dG go together without disintegrating throughout the entire recording. The curve

Well No., Oil and Gas Prod. Dept.	Oil production rate before hydraulic fracturing, t/day	Oil production rate after hydraulic fracturing, t/day	Oil production rate on 01.01.2016, t/day	Increase in oil production rate on report date, t/day
11304, «AN»	4,1	4,29	8,73	4,63
20154, «AN»	4,38	7,76	7,94	3,56
20191, «AN»	9,29	14,73	12,33	3,04
20659, «AN»	5,57	5,57	2,5	0
21336, «AN»	5,98	6,64	27,16	21,18
8677Б, «AzN»	0	1,43	0,94	0,94
28816н, «AzN»	0	6,4	6,4	6,4
750, «AzN»	0,04	0,71	2,05	2,01
39458, «LN»	2,57	8,88	11,65	9,08
24019, «LN»	2,75	5,96	4,41	1,66
22107, «JN»	1,65	10,38	13,06	11,41

Table 2. Data on the efficiency of hydraulic fracturing

Gdp/dG increases monotonically and does not show a tendency to deviate downward.

The clamping point on the chart is set arbitrarily, probably, the crack did not close or formed. However, on the diagnostic chart, the slope of the lines is close to 0.5, which speaks for the bilinear flow and the presence of a crack.

The closure pressure can be conditionally predicted at the very end of the curve. However, the derivatives themselves continue to grow monotonically.

The examples given show how carefully we should approach the analysis of the mini-fracturing. In many cases, the mini-fracturing in its standard version does not give practically meaningful information.

Mini-fracturing through several intervals of perforation deserves particular attention. The theory for such a case is absent. In a rare case, all cracks are joined simultaneously. But they can close together and successively one after another, distorting the pressure drop curve. Therefore, it is recommended to perform a mini-fracturing separately for each interval of perforation, isolating them with double packers.

Virtually all the fracturing processes, like mini-fracturing, were a joint fracturing of the formations. Despite the fact that low-permeability reservoirs were subjected to processing (up to 10 mD), the hydraulic fracturing technology remained the same, traditional, based on the use of cross-linked gel. Technologists of LLC Leninogorsk-RemServis with some modifications applied the proppant supply with stops. In addition, a stepwise increase in the concentration of proppant was used.

In conclusion, the effectiveness of the fracturing operations carried out in accordance with the pilot commercial development plan with the participation of TatNIPIneft was evaluated during May-June 2015. For comparison, the efficiency of fracturing operations was taken as an average for each oil and gas production department for 2015. The analysis was based on official data from corporate information systems "Tatneft-Neftedobycha" and ARMITS, verified by independent sources (databases). The results are summarized in Table 2.

The average increase in oil production rate in the Oil and Gas Production Department "AN" after conducting hydraulic fracturing in 2015 is 3.53 tons per day. The average increase in oil production through five wells of pilot commercial development – 6.48 tons per day.

The average increase in oil production in the Oil and Gas Production Department "AzN" after conducting hydraulic fracturing in 2015 is 4.58 tons per day. The average increase in oil production rate for three wells of pilot commercial development – 3.12 tons/day (Well 8677B is a lateral shaft, well 28816 is injection, and in its area there are six reactive production wells (Nos. 10993, 19528, 4990A, 768, 8257, 8258)). The increase in oil production from the site is 6.4 tons per day.

The average increase in oil production rate in Oil and Gas Production Department "LN" after conducting hydraulic fracturing in 2015 is 3.89 t /day. The average increase in oil production through two wells of pilot commercial development – 5.37 tons/day.

The average increase in oil production rate in Oil and Gas Production Department Jalilneft ("JN") after conducting hydraulic fracturing in 2015 is 5.36 tons/day. The average increase in oil production rate for one well of pilot commercial development is 11.41 tons per day.

Thus, averaging the figures for all 11 wells, we obtain an average increase in production rate for wells of pilot commercial development 5.81 tons/day.

Averaging the figures for all Oil and Gas Production Departments, we obtain an average increase in oil production after fracturing 4.03 t/day.

The average increase in oil production rate for wells on which the simulation and scientific and technical support of the TatNIPIneft fracturing processes was carried out, is by 1.78 tons/day more than for wells without scientific and technical support. The multiplicity of the increase in production rate is 5.81/4.03 = 1.44 times.

Conclusions

1. Long periods of the fracture closure are noted, despite the high enough permeability of the formations.
2. No pseudo-radial flow is achieved in any of the analyzed wells.
3. The classical mini-fracturing has a number of disadvantages associated mainly with an ambiguous interpretation of the pressure drop curve in order to determine the change in the slope angle.
4. When several layers are opened with one filter (joint hydraulic fracturing) or with the development of multiple cracks, between which there is an additional interaction, the determination of closure pressure becomes ambiguous due to the multiple closures arising from the difference in stresses in the formations. The pressure drop curves can be difficult to interpret, so in such cases a combination of a step test and injection/outpour test is recommended.
5. For shale deposits water fracturing, linear gel technology, and hybrid technologies (water and linear gel) should be used.
6. Modeling and scientific and technical support of the fracturing processes by the TatNIPIneft Institute gave a positive result (the multiplicity of the increase in the production rate was 1.44 times) in comparison with the results of the hydraulic fracturing performed unaccompanied.

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About the Authors

Ilgizar Kh. Makhmutov – Deputy Head of Well Operation and Workover Department
Institute TatNIPIneft Tatneft PJSC
32 M.Djalil St., Bugulma, 423326, Republic of Tatarstan, Russia
E-mail: remont@tatnipi.ru, tel: +7 85594 78 993

Oleg V. Salimov – PhD (Engineering), Chief of Hydrofrac Research Laboratory, Well Operation and Workover Department
Institute TatNIPIneft Tatneft PJSC
32 M.Djalil St., Bugulma, 423326, Republic of Tatarstan, Russia
E-mail: sov@tatnipi.ru, tel: +7 85594 78 984

Ildar I. Girfanov – Engineer, Hydrofrac Research Laboratory, Well Operation and Workover Department
Institute TatNIPIneft Tatneft PJSC
32 M.Djalil St., Bugulma, 423326, Republic of Tatarstan, Russia
E-mail: gii@tatnipi.ru, tel: +7 85594 78 998.

Aidar U. Mansurov – Engineer, Hydrofrac Research Laboratory, Well Operation and Workover Department
Institute TatNIPIneft Tatneft PJSC
32 M.Djalil St., Bugulma, 423326, Republic of Tatarstan, Russia
E-mail: mau@tatnipi.ru, tel: +7 85594 78 998

Radik Z. Ziatdinov – Research Assistant, Hydrofrac Research Laboratory, Well Operation and Workover Department
Institute TatNIPIneft Tatneft PJSC
32 M.Djalil St., Bugulma, 423326, Republic of Tatarstan, Russia
E-mail: zrz5969@tatnipi.ru, tel: +7 85594 78 660

Alexander V. Kotchetkov – Engineer, Selective and Large-Volume Bottomhole Treatment Department
Engineering Center Tatneft PJSC
43 Fakhretdin St., Almetyevsk, 423450, Republic of Tatarstan, Russia
E-mail: KochetkovAV@tatneft.ru, tel: +7 8553 37 14 26

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SAFETY IN APPLYING BINARY MIXTURES FOR OIL PRODUCTION STIMULATION

N.M. Kuznetsov[1], E.N. Aleksandrov[2]*

[1]Semenov Institute of Chemical Physics of the Russian Academy of Sciences

[2]Emmanuel Institute of Biochemical Physics of the Russian Academy of Sciences

Abstract. The article considers theoretically, on a qualitative level, the rates of filtration and decomposition of ammonium nitrate, depending on the time of heat release and on the rate of nitrate entry into the porous space of the reservoir near the perforations. It is assumed that field tests at different rates of nitrate solution injection into the well will yield quantitative data on filtration, heat transfer and kinetics of heat release in the reservoir. To estimate the temperature increase in the reservoir under the action of the binary mixture reaction (nitrate + oxidant), the temperature was calculated when the nitrate was decomposed in an aqueous solution (300 g of water per 1 kg of nitrate), taking into account the oxidation of a small fraction of oil in the reservoir near the well with oxygen released during the decomposition of nitrate.

Keywords: oil production, binary mixtures, nitrate, explosive safety, skin layer

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Introduction

The binary mixture (BM) is ammonium nitrate (AN) and the initiator of its exothermic decomposition (ID), whose aqueous solutions are pumped into the bottomhole zone of the treated well in order to increase oil recovery by heating and removing the "skin layer" responsible for the shortage from the depths of about half of the explored reserves. Aqueous solutions of AN and ID are pumped into the well through separate channels, and they react in the zone of the productive formation, releasing hot gases whose mass is equal to the mass of the nitrate pumped into the well. Hot gases are released into the reservoir under the pressure created by the reaction. Explosion safety in (Aleksandrov et al., 2016) was achieved by adjusting the reaction process of the BM in the well in order to keep the temperature in the reaction zone below 320 °C. T = 320 °C is the lower limit of temperature, after which an explosion of small portions (1-5 cm^3) of a working solution of ammonium nitrate (AN 67%, water 33%) was recorded on the stand.

Cases of nitrate explosions in operated oil wells in order to stimulate oil production with the help of BM cannot be found in the available literature. To confirm the safety of the AN used to enhance the oil recovery of oil reservoirs, a justification based on the modern theory of explosive processes and on the experiment performed at the stand and/or in the wells is needed. The selection of reagents and the creation of conditions are the basic factors, in which, during the course of the BM reaction, the released heat is mainly absorbed by non-nitrate molecules, as it is during the explosive reaction in the well, with the reservoir rocks and water whose share in the reservoir oil-containing fluid of hard-to-recover reserves is usually close to 0.9; and in non-recoverable reserves the share of water is close to 99.99 (Aleksandrov et al., 2016; Kuznetsov, 2016).

The impact of the BM on the processes in the reservoir depends on the temperature of the medium and on the rate of introduction of reagents into the porous space of the oil reservoir near the perforations. The rates of filtration and nitrate decomposition are theoretically investigated in the present paper, depending on the time of heat release and on the rate of AN entry into the porous space, which is on the average 20-40% of the volume of the reservoir near the perforations. To estimate the increase in temperature in the reservoir under the reaction BM (AN + ID), the temperature at the nitrate decomposition in the aqueous solution (300 g of water per 1 kg of nitrate) was calculated taking into account the oxidation of a small fraction of oil in the reservoir near the well with the oxygen released during the nitrate decomposition.

The article consists of three sections. In the first two sections, the modes of fast and slow injection of BM solutions into the formation near the well are considered. The third section shows the results of calculating the temperature, which is established in a closed volume of the porous space, reservoir filled with an aqueous solution of nitrate, which, as a result of its decomposition and partial (0.01-0.03) oxidation of oil contained in the formation fluid water + oil, warms up the bottomhole zone, contributing to the complete removal of the skin layer that blocks oil access to producing wells

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[*] *Corresponding author: Nikolay M. Kuznetsov*
E-mail: n-m-kuznetsov@yandex.ru

(Aleksandrov et al., 2016; Aleksandrov, Aleksandrov, Kuznetsov, etc., 2013). It should be noted that in the experiments at the wells only the rapid introduction of reagents into the formation has been studied.

I. Fast input mode of 10-20 tons of BM in the reservoir (within 1 hour)

In this case, according to practice, a comparatively small amount of hot steam or a BM heated with special additives accelerating the decomposition of nitrate in the BM reaction is first introduced into the reservoir. As a result, a relatively thin hot layer is created near the perforations in the reservoir. Then a cold BM is introduced under a pressure of hundreds of atmospheres. The cold BM leaves the perforations in the form of jets and, before it has heated up in a thin hot layer near the perforations, penetrates through it into the cold porous rock, displacing oil and water from the pores in the bottomhole zone.

By the time of injection completion in the bottomhole zone of 2-3 tens of tons of BM into the reservoir, there is a layer of rock of approximately cylindrical shape, filled in the pores with a solution of nitrate. We call it layer 1. For porosity ¼, the volume (V) of this layer is four times larger than the volume (V_p) of the introduced solution of nitrate. The radius of the cylinder (that is, the thickness of layer 1) is expressed by the formula:

$r = (V_p/\pi L)^{1/2}$,

where L is the length of the perforated part of the tube. Hence, at $V_p = 80$ m^3 and $L = 4$ m, $r = 2.52$ m. The actual boundary of the layer 1 filled with the BM solution will be blurred according to the filtration law, forming a transient sublayer of thickness ~ 1 m, in which the filling of the pores with the solution of injected reagents changes from ~ 100% to almost zero. According to the experimental data, with a rapid injection of a large portion of the BM aqueous solution (tens of m^3) into the well for an hour to 2 hours, the heat release in the reservoir lasted from day to 4 days (Kuznetsov, 2016), i.e. two orders of magnitude longer than the BM input time.

When an inhomogeneous jet stream passes through a thin layer near the perforations, as experience has shown, small regions with a high temperature remain (Aleksandrov et al., 2016). According to the theory (Kuznetsov, 2016), heat is then transferred to a rock containing a fixed solution when the BM injection to the well is stopped. When it is heated due to the heat of the BM reaction and the oxidation of oil, a heat wave is formed by the liberated oxygen (Kuznetsov, 2016). Let us note that the same state of the reservoir can be obtained by creating a hot layer near the perforations before injecting the entire volume of the cold BM in the reservoir, and after such input.

The heat wave is analogous to the combustion wave. Like laminar combustion, it moves slowly through the substance. To propagate into the detonation wave, the propagation of combustion must be accelerated. For this, combustion must become turbulent. But with the propagation of combustion in the pores, its turbulence is impossible due to friction and, accordingly, small Reynolds numbers (Landau, Lifshitz, 1986). Therefore, the possibility of detonation in the case under consideration should be excluded.

II. The slow input mode (for 10-20 hours) of 20-30 tons of BM aqueous solution into the reservoir. Injection of BM solutions into the porous space of the reservoir

This case has not yet been fully implemented in practice, but its implementation in different versions would be useful for obtaining quantitative experimental data on the kinetics of heat release in the reservoir. When analyzing the motion of the BM and the heat in the reservoir, we use the analogy between the processes when the BM is injected into the well and into the reservoir and when natural gas components are used in the gas burner. Gas leaving the burner in a closed air space without ignition, eventually forms a mixture with air, which can explode, for example, when lighting a match or a spark in an electrical appliance. However, when the burner is running, only the products of gas combustion enter the surrounding space, and the possibility of an explosion is thereby excluded. Similarly, nitrate in the reservoir can not explode if it decomposes in the reservoir near the perforations. This condition can be satisfied if the BM is injected slowly enough. In this case, the proofs of explosion safety given in the first section become superfluous.

The dependence of the nitrate volume (y) the reservoir on time (t) is described by the equation:

$$dy/dt = J - y/\tau, \qquad (1)$$

where J is the injection rate of nitrate into the reservoir, and τ is the decomposition time of nitrate upon interaction with the second component of the BM.

The solution of equation (1) is expressed as:

$$y = \exp\left(-\int_0^t dt/\tau\right)\int_0^t \exp\left(\int_0^z dz/\tau\right) J dz. \qquad (2)$$

For variables J and τ (depending on time), equation (2) is solved only numerically. If J and τ are constant, then the integrals in (2) are taken and

$$y = J\tau\,[1 - \exp(-t/\tau)]. \qquad (3)$$

From here

$$y = J\tau \text{ at } t/\tau >> 1. \qquad (4)$$

This intermediate asymptotic with an accuracy of 5% occurs even at $t/\tau = 3$. The amount of decomposed nitrate (Y) in the asymptotic form (4) is:

$$Y = J(t - \tau) \approx Jt >> y. \qquad (5)$$

The yield to the intermediate asymptotic (4) is obtained in the approximation of a constant value of τ. But in time (4), according to (5), the large amount of nitrate (in comparison with y) will be decomposed, and a lot of heat will be released, respectively. This will lead to a rise of temperature in the reservoir near the perforations and to a decrease in the time τ by an order of magnitude or more. Accordingly, an intermediate asymptotic with a constant value of τ is not reached and to compute y it is necessary to know the dependence of τ on time and solve equation (1) or integrals in (2) numerically. The function $\tau(t)$ can be found as the solution of the inverse task from the experimental data of the supposed practical implementation of the slow introduction of the BM.

III. Calculation of temperature

To determine the temperature that can be achieved in the reservoir under the action of BM (with ammonium nitrate), we present the temperature calculation for the decomposition of nitrate in an aqueous solution (300 g of water per 1 kg of nitrate) filling the porous rock, and oxidation of oil with oxygen released during the nitrate decomposition in the reaction:

$$NH_4NO_3 \rightarrow N_2 + 2H_2O + 1/2O_2 + Q_1. \qquad (I)$$

Q_1 = 2600 kJ/(kg of nitrate) (Andreev, Belyaev, 1960).

In the oxidation of oil in reactions:

$$\mathbf{1/3}C_nH_{2n+2}+1/2O_2 \rightarrow 1/3(C_{n-1}H_{2n}+CO_2+H_2O)+Q_2, \qquad (II)$$

the heat Q_2 = 2380 kJ/(kg of nitrate) is released. The temperature is calculated for the isochoric process. The energy of the reaction products (I) was calculated in the ideal gas approximation. The energy of translational, rotational, and vibrational degrees of freedom of molecules was taken into account. The desired temperature for the release of heat Q_1+Q_2 is determined by the transcendental equation of energy balance:

$$E_{\text{п}}+E_{\text{в}}+E_{\text{к}}+E_{\text{исп}}+E_{1\text{п}}= Q_1+Q_2, \qquad (III)$$

where $E_{\text{п}}$, $E_{\text{в}}$, $E_{\text{к}}$, $E_{\text{исп}}$ и $E_{1\text{п}}$ – are the increments in the energy of translational and rotational motion of molecules, the energy of intramolecular vibrations, the heat of evaporation of water, and the increment in thermal energy of the solid rock, respectively. All these terms, like Q_1+Q_2, are attributed to 1 kg of nitrate. From one mole of nitrate in the reactions (I) and (II), 1 mole of N_2, 8/3 mole of water, and 1/3 mole of CO_2 are formed. In addition, the products will remain from an aqueous solution of nitrate containing 30% by weight of water, and another 1.2 moles of water. Total in products will be 8/3 + 1.2 ≈ 3.9 moles of water. To recalculate from one mole of nitrate to one kilogram, the above amounts of moles are multiplied by 12.5. The characteristic temperatures of intramolecular vibrations of molecules necessary for calculating E_k are: for nitrogen, 3300 K; for water – 5260 K, 5400K, 2295K; for carbon dioxide – 1995 K, 3380 K, 960 K, 960K (Kratkii spravochnik fiziko-khimicheskikh velichin ..., 1957). The heat of evaporation of water at normal temperature (273 K) is 600 kcal/g ≈ 2.51 kJ/g.

It is believed that the pore volume in the rock is four times smaller than the rock volume along with the pores and is three times less than the volume of the porous rock minus the pore volume. The rock density and density of nitrate are taken equal to 1.3 g/cm^3 and 1.735 g/cm^3. The average heat capacity of the rock in the temperature range 273-1273 K is about 1.1 kJ/(kg K) (Kratkii spravochnik fiziko-khimicheskikh velichin ..., 1957; Spravochnik. Fizicheskie velichiny ..., 1991). Equation (III), taking into account the above data, was solved by the iteration method. The temperature increment was found to be 366 K. In this case:

$$T = 366 + T_1, \qquad (IV)$$

where T_1 is the initial temperature of the reservoir, depending on the depth of occurrence of the oil-bearing rock. At a depth of 1 km, for example, $T_1 \approx 300$ K. Here it follows from (11): T = 670 K.

After the rock has been heated, the introduction of new portions of the nitrate solution into the reservoir will lead to an additional increase in temperature. The mechanism for raising the temperature is similar to what happens to the temperature of water that filled the glass when a stream of hotter water flows into it, and the excess water pours out.

Conclusions

1. The ratio of the characteristic filtration times of the BM in the porous rock of the reservoir and the heat release during the nitrate decomposition essentially depends on the rate of introduction of the BM into the well.
2. The initiation process of the BM must be controlled so that the exothermic decomposition of the nitrate occurs mainly in the reservoir, and not in the well. The ability to control the reaction process of the BM was thus discovered in the work (Aleksandrov et al., 2016).
3. The use of the BM for the stimulation of oil production is safe at any rate of its introduction into the reservoir, if paragraph 2 is fulfilled.

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About the Authors

Nikolay M. Kuznetsov – DSc (Physics and Mathematic), Professor, Chief Researcher

Semenov Institute of Chemical Physics of the Russian Academy of Sciences

4 Kosygina str., Moscow, 119334, Russia

E-mail: N-M-kuznetsov@yandex.ru

Evgeniy N. Aleksandrov – DSc (Chemistry), Head of the Laboratory of Gas Analysis and Ecotoximetry

Emmanuel Institute of Biochemical Physics of the Russian Academy of Sciences

4 Kosygina str., Moscow, 119334, Russia

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INTEGRATED ECOLOGICAL-ECONOMIC MODELING OF REGIONS WITH THE USE OF GIS TECHNOLOGIES

G.N. Bulatova[*]*, N.I. Afanasyeva, D.A. Semanov*
The Central Research Institute of Geology of Industrial Minerals (CNIIgeolnerud), Kazan, Russia

Abstract. The paper shows the process of modeling the integrated map “Scheme of the ecological and economic regionalization of the territory of the Russian Federation on the basis of the mineral and raw materials base of natural adsorbents” using GIS technologies.

The map is based on three main groups of indicators: natural, economic and environmental. The ecological content of the map is characterized by indicators that are potential or actual sources of pollutant release into the environment (nuclear power plants, nuclear reactors, radioactive waste storage and disposal sites, nuclear test sites, industrial enterprises, railways, operating and under construction oil pipelines, hydrocarbon fields, etc.). The economic component of the map is the reserves estimated by the indicators of study and development, the relationship to the subsoil fund and forecast resources. The natural group of indicators is represented by the mineral and raw material base of natural adsorbents (fields and objects of forecast resources) that can be used to prevent harmful emissions and for the ecological and economic rehabilitation of contaminated areas.

Based on the analysis of cartographic data, the ecological and economic areas of the territorial distribution of man-caused environmental impacts and the presence of adsorption raw materials are identified. As an example, a description is given of the ecological and economic model of the regionalization of the Privolzhsky Federal District using the GIS “Mineral resource base of natural adsorbents of Russia” developed at the Federal State Unitary Enterprise TsNIIgeolnerud.

Keywords: ecological and economic area, mineral, use, data base, adsorbent, geoinformation, mapping, modelling, Privolzhsky Federal District

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Economic activity and the functioning of production complexes inevitably lead to the accumulation of a huge amount of gaseous, liquid and solid waste into the environment. However, the ecological capacity of the natural environment is limited, which leads to a direct ecological danger caused by the inability of natural biota to withstand the destabilizing effect of anthropogenic impact. In addition, negative qualitative changes in the habitat are also caused by social and economic consequences, therefore, the issues of its protection, preservation and rehabilitation become more demanding.

In solving problems on the protection of the environment, the elimination of the negative impact of man-made factors, natural adsorbents – mineral-rock formations that have unique adsorption, ion-exchange and filtering properties – will undoubtedly play a big role.

Interest in natural adsorbents is explained by their cheapness and availability. They cost ten times cheaper than synthetic ones (artificial zeolites, silica gels, alumogels, activated carbon, etc.), while at the same time, in many areas of use, they produce the same or close to them effect. By means of simple and accessible methods of activation and modification, it is possible to increase the adsorption activity of natural adsorbents by 2-5 times, to create on their basis new products with prescribed properties that are not inferior to artificial analogues. And in this case, the cost of products obtained is 3-5 times lower than that of synthetic products.

In Russia, more attention is paid to assessing the environmental situation in a particular region, city, specific territory, and hence the need for accurate, reliable and objective information about the territorial resource status of natural adsorbents for use in environmental purposes. Environmental problems often require immediate and adequate actions, the effectiveness of which is directly related to the speed with which information is processed and presented.

One of the effective forms of representation and analysis of spatial information is the map, since almost all the objects studied (natural, industrial, social, etc.) are geographically bound and have multicomponent characteristics and connections. The map as a model created on the basis of geoinformation technologies, acquires the status of an “instrument” for the analysis, synthesis and evaluation of spatial information. Geoinformation modeling creates not only new

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[*] *Corresponding author: Gulnara N. Bulatova*
E-mail: gulnara.bulatova@bk.ru

information models and information resources, but also allows imagining with fewer costs possible processes where the components of nature, economy and man closely interact.

The specialists of the Federal State Unitary Enterprise CNIIgeolnerud developed a geoinformation system (GIS) for the territorial resource status of Russia's natural adsorbents – the GIS "Mineral resource base of natural adsorbents of Russia" (Bulatova et al., 2010). The purpose of the GIS is informational and analytical support for the research and use of the mineral and raw materials potential of natural adsorbents (zeolites, zeolite-containing rocks, bentonites, opal-cristobalite rocks, palygorskites, vermiculite, glauconites, etc.) for environmental purposes in ecologically unfavorable regions of Russia.

As a result of these studies, an information and cartographic model (ICM) was created, on the basis of which an integrated map "Scheme of ecological and economic zoning of the territory of the Russian Federation on the basis of using mineral and raw materials base of natural adsorbents" was built.

The materials of FSUE CNIIgeolnerud (Kazan), Kaluga branch of FSUE VIEMS, the State balance of mineral resources of the Russian Federation, and the Federal State Statistics Service served as information basis for the construction of the ICM.

The factual data bank consists of databases that contain primary geological and economic information about fields and facilities of forecast resources, enterprises that develop natural adsorbents, volumes of extraction and production, prices for mineral raw materials and products, sources of technogenic pollution, semantic support in the form of terminological directory, as well as software that provides data entry.

A map data bank consists of digital maps united by a common plan, arranged and coordinated in scale, coordinate systems, content and conventional signs. To maintain the cartographic databases and issue thematic maps, the professional GIS system ArcView GIS 3.2 was used. The structure and composition of the cartographic database is shown in Table 1.

The information-cartographic model is cartographic and related to it factual information (Table 2).

The process of modeling the integrated map was carried out in several stages:

- collection and preparation of primary factographic, cartographic information;
- integration of factual and cartographic information on the basis of selected indicators;
- sequential selection, description and mapping of the territory's regionalization objects on the map (geological and economic areas);
- statistical analysis of primary geological data, interpretation and mapping of zoning results using GIS technologies;
- elaboration of justifications of priority directions for the use of natural adsorbents for environmental purposes.

Based on the developed model, three types of maps were identified in the structure of a cartographic data bank: geological, economic, ecological and integrated. Figure 1 shows the structure of factographic and cartographic resources, information flows and their connections.

The I type of maps combines maps reflecting the geological and economic characteristics of the state of mineral resource base of natural adsorbents of Russia

- The map *"Mineral and raw materials base of natural adsorbents of the Russian Federation"* shows the

Sl. No	Map Name / Groups of thematic layers	Mineral resource base of natural adsorbents	Map of geological and economic feasibility study for the development of the MRB of NA	Location map of technogenic pollution	Scheme of ecological and economic regionalization
	1	2	3	4	5
1	Subsoil areas of natural adsorbents	+	+		+
2	Regionalization objects		+		+
3	Objects of the producing and processing industry		+	+	+
4	Objects of transport infrastructure	+	+	+	+
5	Ecological situation of the territory			+	+
6	Objects of technogenic load that affect the state of the environment			+	+
7	Objects of socio-economic infrastructure	+	+	+	+
8	Objects of energy infrastructure			+	+
9	Objects of territorial-administrative regionalization	+	+		
10	Objects of the basic topographic framework	+	+	+	+

Table 1. Structure and composition of the cartographic database

Groups of thematic layers	Thematic layer	Main characteristics of the object in the database
1. Subsoil areas of natural adsorbents	Objects of the State Balance of Reserves Objects of the State Cadastre of fields and occurrence of minerals	General information (name of the object, type of mineral); Geographic and administrative situation (the federal district, the subject of the federation, geographical coordinates); License; Geological and economic characteristics of the object (geological and industrial type, study and development of the object, state of the subsoil fund, scale of the object); Scope of use.
	Objects of forecast resources	General information (name of the object, type of mineral); Geographic and administrative situation (the federal district, the subject of the federation, geographical coordinates); Mineragenic characteristics (mineragenic rank of the object, geological-industrial type); Study and recommendations for further development; Scope of use.
2. Regionalization objects	Borders of ecological and economical regions (EER) by types of technogenic pollution	Name of EER; Type of raw materials; Explored reserves of adsorption raw materials at the fields of the distributed and undistributed reserves; Forecast resources (P1, P2, P3).
	Geological and economical regions (GER)	Name of the GER; Type of raw materials; Explored reserves of adsorption raw materials at the fields of the distributed and undistributed reserves; Forecast resources (P1, P2, P3); Production.
	Industrial and raw materials units	Name of the industrial and raw materials unit; Type of raw materials; Explored reserves of adsorption raw materials at the fields of the distributed and undistributed reserves; Forecast resources (P1, P2, P3); Production.
3. Objects of the producing and processing industry	Mining enterprises	Name of the enterprize; Mineral resource; Lisence; Production.
	Processing enterprises	Name of the enterprize; Mineral resource; Lisence; Range of products; Volumes of production.
4. Ecological situation of the territory	Ecological state of the area	Assessment of the ecological state of the area
	The level of urban pollution	Air pollution assessment
	Radioactive contamination of the area	Pollution level of the area.
	Ecological situation of rivers	Assessment of the rivers state in terms of water quality
5. Objects of technogenic load that affect the state of the environment	Nuclear power plants, CHP plants, regional power plants, industrial enterprises, mineral deposits, radioactive waste disposal sites, nuclear test sites, nuclear reactors, etc.)	Name of objects Subject of the Russian Federation

Table 2. Composition and structure of the information-cartographic model

Groups of thematic layers	Thematic layer	Main characteristics of the object in the database
6. Objects of transport infrastructure	Car roads	Type of object (by importance)
	Railways	Type of object (by importance)
7. Objects of energy infrastructure	Oil pipelines	Type of object
	Gas pipelines	Type of object
8. Objects of socio-economic infrastructure	Settlements	Administrative status
9. Objects of territorial-administrative regionalization	Federal Districts Subjects of the Russian Federation	Territory name The administrative status of the territory (the federal district, the subject of the federation)
10. Objects of the basic topographic framework	Coordinate grid Hydrography	Nomenclature of sheets of scale 1:1,000,000 The name (rivers, lakes, water reservoirs, seas, oceans)

Table 2. Composition and structure of the information-cartographic model (continue)

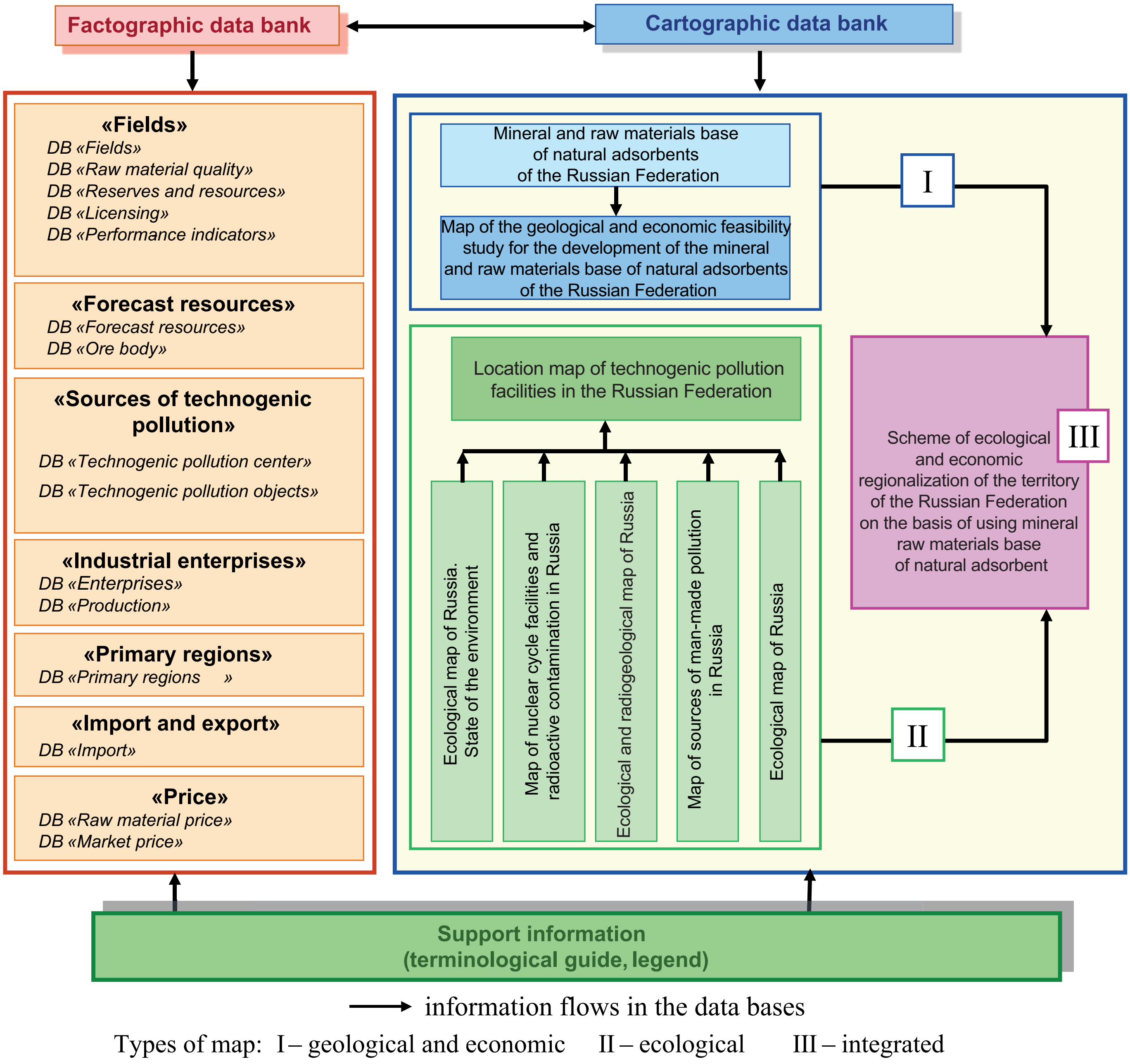

Figure 1. The structure of factographic and cartographic resources

location of natural adsorbents on the territory of Russia (129 fields and 54 facilities of forecast resources).

- The *"Map of the geological and economic feasibility study for the development of the mineral and raw materials base of natural adsorbents of the Russian Federation"* reflects the current state, use and prospects for the development of the mineral resource base of natural adsorbents of Russia. The map identifies objects of geological and economic zoning: *industrial and raw materials sites, geological and economic areas.*

The II type of maps reflects the ecological condition of the territory, intensity and types of man-made impact on the environment.

The *"Location map of technogenic pollution facilities in the Russian Federation"* shows technogenic systems and facilities that negatively affect the ecological state of the environment, including the geological environment. It was created on the information base of previously published thematic maps, namely, "*Map of sources of man-made pollution in Russia*" (1995), "*Map of nuclear cycle facilities and radioactive contamination in Russia*" (1995), "*Ecological map of Russia. State of the environment*" (1999),"*Ecological and radiogeological map of Russia*" (1995).

The main result of the simulation was the creation of an **integrated map (the III type)** of ecological and economic zoning: *"Scheme of ecological and economic regionalization of the territory of the Russian Federation on the basis of using mineral raw materials base of natural adsorbent".* The map is based on three main groups of indicators: natural, economic and environmental.

The natural group of indicators is characterized by the mineral and raw materials base of natural adsorbents (fields and objects of forecast resources). Analysis of the resource potential state of natural adsorbents (Afanasyeva et al., 2009; Distanov, Konyukhova, 2005) shows that Russia has the necessary raw materials to use for environmental purposes. Their total explored reserves amount to more than 3.2 billion tons; the forecast resources for P1 + P2 category are 2.4 billion tons.

An important economic component of the map is the reserves estimated by the indicators of study and development, the relationship to the subsoil fund. The ecological content of the map is characterized by such indicators as the degree of ecological condition of the territory (satisfactory, moderately acute, acute and tense); industrial enterprises making the largest contribution to the pollution of the territory; radiation pollution associated with technogenic factors; railways; existing and under construction oil pipelines, etc. Hydrocarbon fields, fields of metals and other minerals, potential or actual sources of pollutants into the environment are also indicated on the map.

Thus, on the basis of the analysis of cartographic data, the areas of the territorial distribution of man-caused environmental impacts were identified. The objects of natural adsorbents put on the map are intended to play the role of a mechanism for solving environmental problems and ensuring the ecological and economic safety of the population. As a result, 13 ecological and economic regions were separated in the territory of the Russian Federation by types of technogenic pollution and nearby fields of adsorption raw materials.

Let us consider the model of ecological and economic zoning in the Privolzhsky Federal District (PFD) as an example.

The technogenic impact on the geological environment in the PFD manifests itself unevenly. In the north of the district in the Republics of Udmurtia, Bashkortostan, in the Kirov, Perm, and Nizhny Novgorod regions, the sources of pollution of the geological environment are forest, paper, energy and engineering industries. While in the southern part of the Privolzhsky District contamination of the geological environment occurs at the expense of the mining and metallurgical industry, where in the settlements there are numerous dumps of overburden, substandard ores, tailing dumps that occupy a large part of the surrounding lands and become permanent sources of air pollution, soils, surface and groundwater. Such are the settlements in the Orenburg and Perm regions.

Significant sources of pollution are numerous oil fields in the Republics of Tatarstan, Bashkortostan, Udmurtia, Orenburg, Samara, Saratov, Perm regions. Increased technogenic loads exist in the regions of large cities and industrial hubs in the Republics of Udmurtia and Tatarstan, Orenburg, Samara, Ulyanovsk, Saratov regions at the expense of chemical and petrochemical industries, machine-building complexes, ferrous and non-ferrous metallurgy, oil processing, production of construction materials that have constant negative impact on the ecological situation.

If agricultural production in the northern regions of the PFD is of moderate intensity, then in the south – fields of grain crops, where mineral fertilizers are excessively used, are also a source of contamination of the geological environment.

In the Privolzhsky Federal District there is a developed transport infrastructure. The operating length of the public railway tracks is 15228 km, the length of the hard-surface roads is 162.3 thousand km, and the inland navigation routes – 6453 km.

Elevated concentrations of pollutants in the air (solids, sulfur dioxide, dioxide and nitric oxide, carbon monoxide and specific pollutants) are typical for areas with a high level of production development, high population density and a developed transport infrastructure. Absolute indicators of emissions of pollutants into the atmosphere in the Privolzhsky Federal District make up 5,172,874 thousand tons per year (Kiryushin, 2016). The “leaders” with the largest emission indicators are such regions as the Orenburg region, the Republic of Bashkortostan, the Republic of Tatarstan, the Samara region and the Perm region. The next group of emissions includes the Nizhny Novgorod and Saratov regions, the Republic of Udmurtia. The regions with the lowest absolute emissions are the Republic of Mari El and the Republic of Mordovia (Figure 2). In 2006, the cities of Balakovo, Kazan, Naberezhnye Chelny, Nizhnekamsk, Saratov, Syzran are included in the list of cities in Russia with the highest level of air pollution (Ecology and Nature Protection, 2008).

Analysis of the calculation of the pollution specific values (in this case, emissions of pollutants into the atmosphere) in relation to the size of the territory, showed that there are significant differences in the values between the subjects (Figure 3). By the least emissions of specific values, such subjects as the Kirov region, the Penza region and the Perm region are allocated. At the same time, such regions as the Samara region, the Republic of Tatarstan and the Orenburg region have high values, both in terms of absolute and specific emission indicators (Kiryushin, 2016).

The Orenburg region has the highest rate of pollutant emissions from all sources of emissions per inhabitant – 544 kg/person. Specific volume of

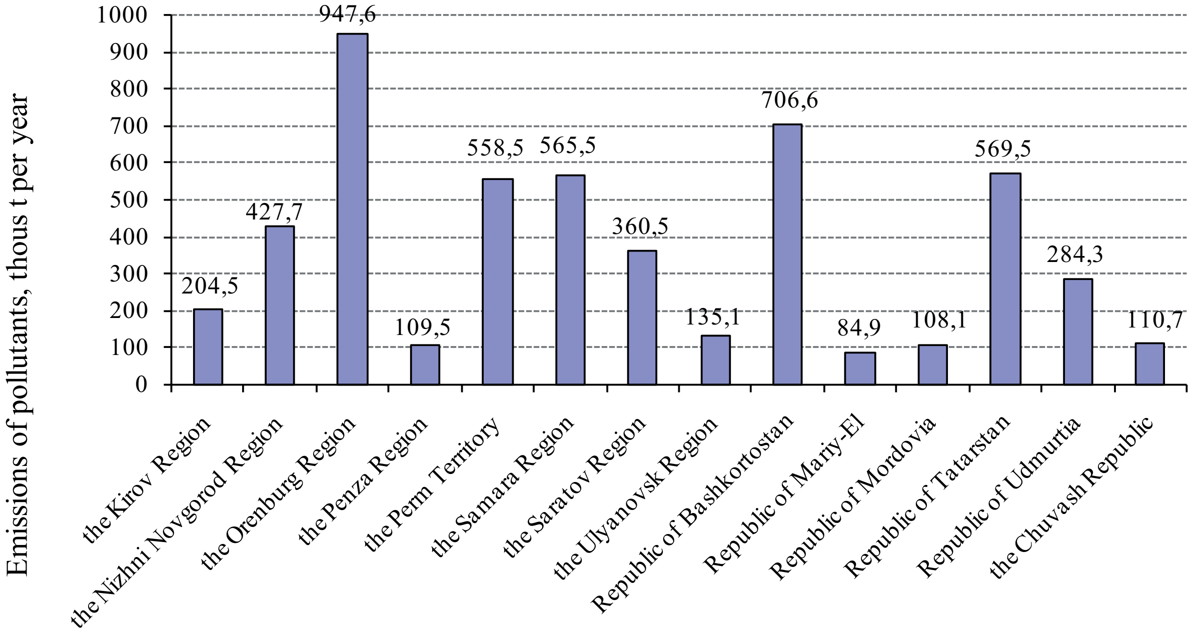

Figure 2. Total emissions of pollutants into the atmosphere according to the subjects of the Privolzhsky Federal District

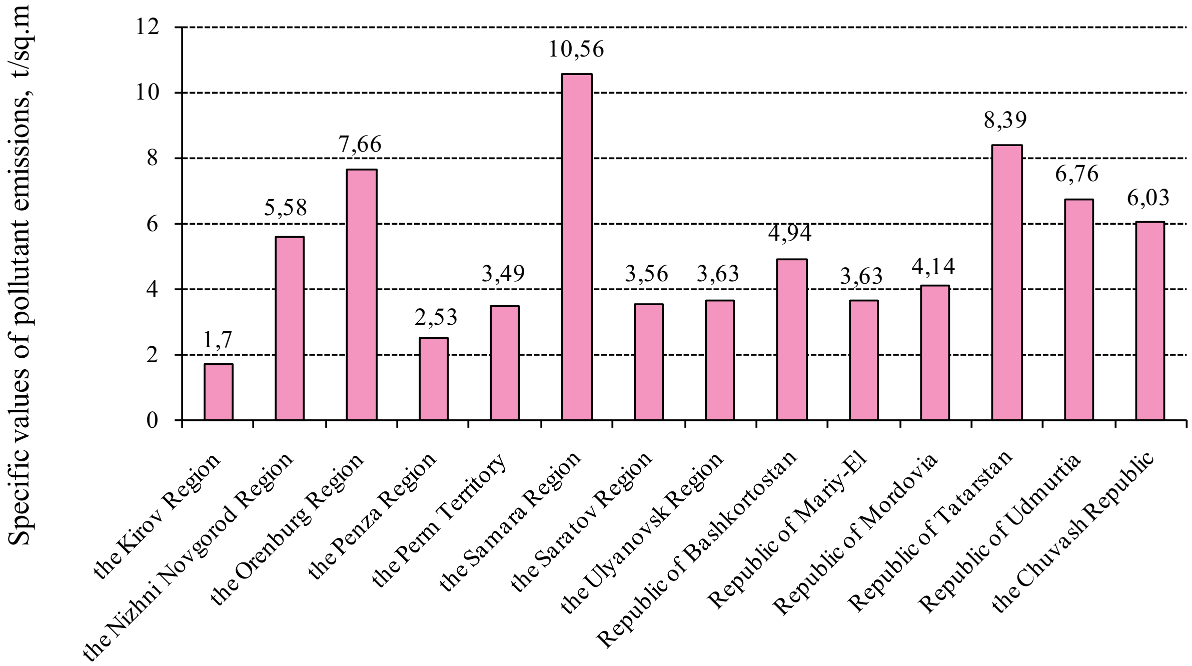

Figure 3. Specific values of pollutant emissions into the atmosphere according to the subjects of the Privolzhsky Federal District

pollutant emissions per capita in the atmosphere is higher than the average for the PFD in Perm Territory (257 kg/person) and Samara Region (222 kg/person) (Ekologiya i okhrana prirody..., 2008).

The PFD has numerous fields of adsorption raw materials (diatomites, flasks, bentonite-like clays, glauconites, etc.) that can be used for ecological and economic rehabilitation of ecologically unfavorable areas. On the territory of the District, according to the ecological situation and the availability of adsorption raw materials, two ecological and economic regions (EER) – Privolzhsky and Orenburg (Figure 4, 5) are allocated.

Privolzhsky ecological and economic region occupies the Saratov, Samara, Ulyanovsk regions, the eastern part of the Penza region, the Republic of Tatarstan and

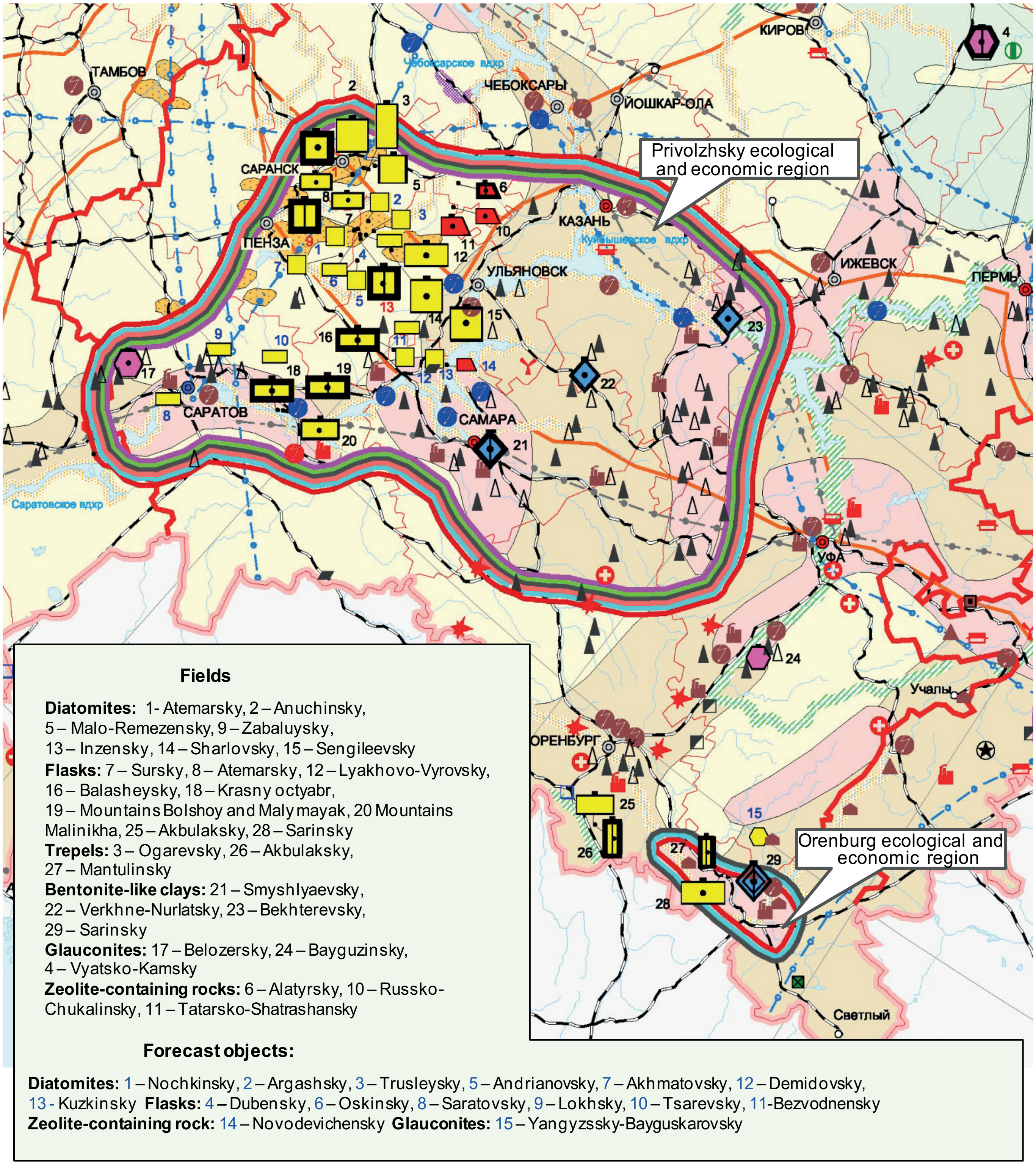

Figure 4. Model of ecological and economic zoning of the Privolzhsky Federal District on the basis of the mineral and raw materials base of natural adsorbents

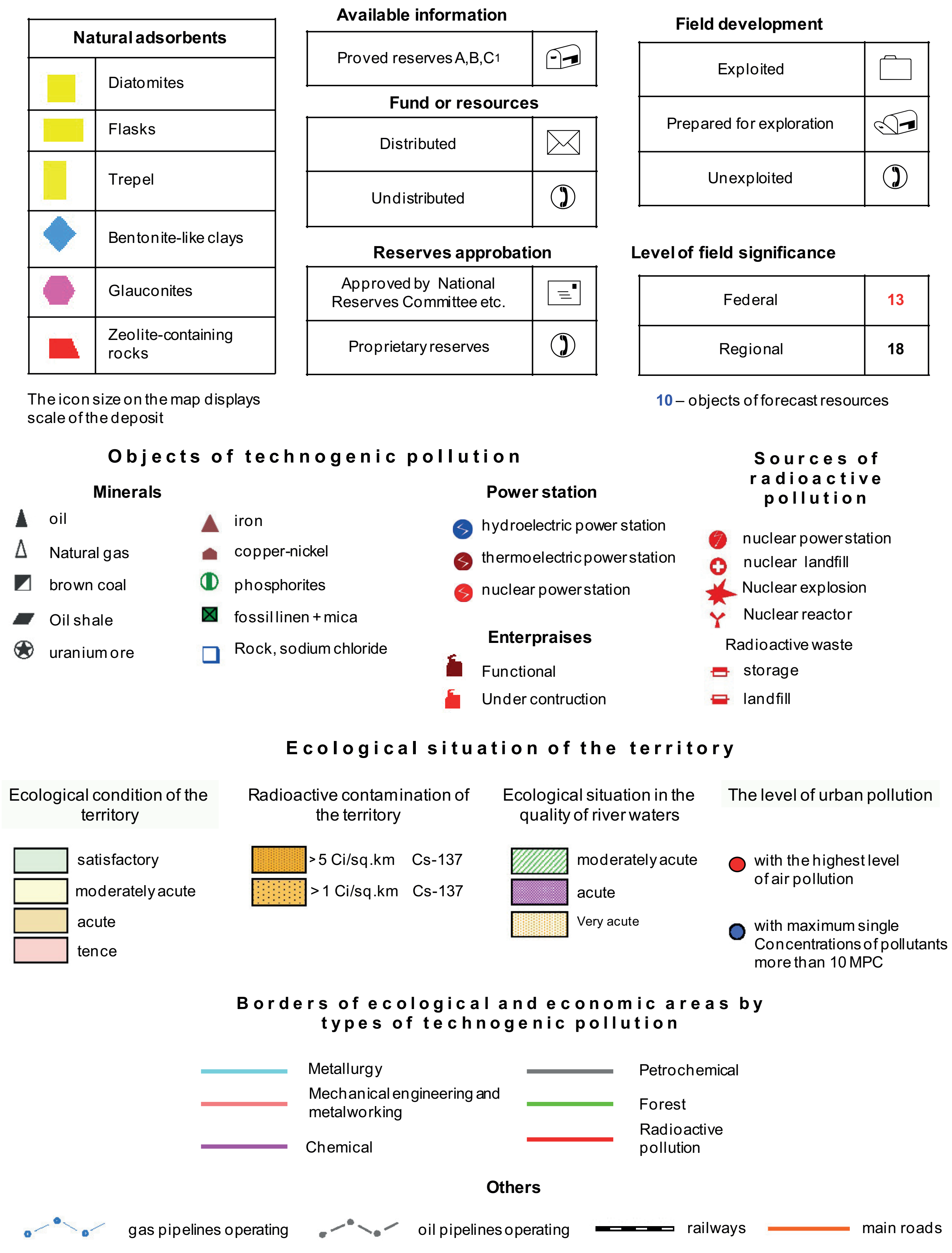

Figure 5. Legend to the model of ecological and economic zoning of the Privolzhsky Federal District

The explored reserves of adsorption raw materials				Forecast resources
Raw materials	Total	Undistributed reserves	Distributed reserves	
Bentonite-like clays	46,255 mln. tons	22,888 mln. tons	23,367 mln. tons	P_1 -2,1 mln. tons P_2 – 13 mln. tons
Glauconite	10,33 mln. m^3	6,96 mln. m^3	3,37 mln. m^3	-
Diatomite	148,02 mln. m^3	29,85 mln. m^3	118,17 mln. m^3	61,65 mln. m^3
Flask	596,7 mln. m^3	184,3 mln. m^3	412,4 mln. m^3	57 mln. m^3
Tripoli	58,18 mln. m^3	34, 06 mln. m^3	24,12 mln. m^3	-
Zeolite-containing rocks	94,54 mln. tons	0,57 mln. tons	93,97 mln. tons	9,05 mln. tons

Table 3. Reserves and forecasted resources of the Privolzhsky EER

The explored reserves of adsorption raw materials			
Raw materials	Total	Undistributed reserves	Distributed reserves
Flask	23,88 mln. m^3	23,88 mln. m^3	-
Tripoli	12,39 mln. m^3	0,53 mln. m^3	11,86 mln. m^3
Bentonite-like rocks	14,38 mln. tons	-	14,38 mln. tons

Table 4. Reserves of the Orenburg EER

Mordovia. Strong and acute ecological situation in the region is created by a powerful industry – enterprises of ferrous and non-ferrous metallurgy, chemistry. Dozens of oil refineries operate on the territory of the region, which have a negative impact on the environment. The largest number of them is located in the Samara region, Saratov region, the Republic of Tatarstan. Significant sources of pollution are oil fields in the Republic of Tatarstan, Samara, Saratov, Ulyanovsk and Penza regions. The Balakovo NPP and the nuclear reactor in Dmitrovgrad are potentially dangerous. In addition, the "Chernobyl radioactive trace" can be traced in the Penza and Ulyanovsk regions.

The Privolzhsky ecological and economic region has significant reserves and forecast resources of bentonite-like clays, opal-cristobalite rocks (flasks, diatomites, trepel), glauconites and zeolite-containing rocks (Table 3), which are potential sources of adsorbents.

As the model of ecological and economic regionalization shows, in areas with intensive oil production and refining, bentonite-like clays of Bekhterevsky and Upper Nurlatsky (Republic of Tatarstan), Smyshlyaevsky (Samara region) fields can be used for desulfurization of oil products at oil refineries, gas drying, purification of drinking and sewage water. Glauconite sands of the Belozersky field (Saratov region) for the rehabilitation of territories contaminated with oil spills. Opal-cristobalite rocks can be used for cleaning sewage and drinking water, air in the concentration areas of industrial enterprises, and in the area of radiation contamination of arable land, preventing their transfer to plants (areas of the Penza region). Flasks are also suitable for these purposes, for example, of the Surinsky field. To clean the radioactive waters of the Balakovo NPP, flasks of the Volsky group can be used (Mountains Big and Small Mayaki, Red October, Malinikha Mountain).

The Orenburg ecological and economic region is a region of concentration of mining and metallurgical enterprises creating a tense ecological situation. Natural adsorbents available in the region (Table 4), like bentonite-like clays of the Sarinsky field and opal-cristobalite rocks (the Sarinky field flasks and the Mantulinsky field tripoli) can be used to treat sewage and drinking water, gases and air at mining plants, thereby preventing pollution of the natural environment .

Conclusion

The information-cartographic model created with the help of the GIS, as a digital product, covers information about the mineral resource base of natural adsorbents, enterprises developing natural adsorbents, the ecological situation in Russia's regions and sources of man-made pollution. The database on the Privolzhsky Federal District contains more than 200 technogenic pollution facilities, 28 fields and 16 forecasted resources.

The obtained results of geoinformation mapping make it possible to identify zones of ecological tension and thereby determine priority measures for rational nature management and ensuring environmental safety of the regions.

The developed model of ecological and economic zoning of the territory based on the use of the mineral and raw materials base of natural adsorbents can become the basis for subsequent, more detailed studies in the field of nature management and environmental protection for all regions of Russia.

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About the Authors

Gulnara N. Bulatova – PhD (Geography), Senior Researcher, Department of Economics and Information Support of Subsoil Use

The Central Research Institute of Geology of Industrial Minerals (CNIIgeolnerud)

4 Zinina St., Kazan, 420097, Russia

Tel: +7 843 238 03 26, e-mail: oktiob@geolnerud.net

Nadezhda I. Afanasyeva – PhD (Geology and Mineralogy), Leading Researcher, Department of Industrial Minerals

The Central Research Institute of Geology of Industrial Minerals (CNIIgeolnerud)

4 Zinina St., Kazan, 420097, Russia

Dmitry A. Semanov – PhD (Chemistry), Senior Researcher, Department of Economics and Information Support of Subsoil Use

The Central Research Institute of Geology of Industrial Minerals (CNIIgeolnerud)

4 Zinina St., Kazan, 420097, Russia

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