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RESEARCH OF MINING AND GEOLOGICAL CONDITIONS FOR GEOLOGICAL EXPLORATION IN PRE-CAUCASIAN REGION

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Taking into consideration natural depletion of reserves of hydrocarbons in Mesozoic deposits of the majority of operated deposits of North Caucasus and for the purpose of further development of oil and gas producing industry in the region it is necessary to involve a carbonaceous complex of Jura of West Pre-Caucasus with the burial depth of more than 5300 m in the development.

When drafting engineering design for a construction of exploratory wells in complex mining and geological conditions driven by anomalously high overburden pressure and temperature, use of thoroughly studied field geological information and taking into consideration the experience of boring similar wells is important.

The paper provides analysis of geophysical data, the results of complex studies of reservoir porosity and permeability features of rocks picked out of core-samples of the first exploratory well on Krupskaya zone (porosity, permeability, electrical, acoustic, lithological characteristics), pressure-and-temperature conditions. The information obtained allowed to specify technological parameters of boring and tailing-in and to give recommendations regarding the way of exploratory wells boring and use of borehole equipment.

In order to avoid the development of significant hydrodynamic pressure in the borehole which provokes gas showings it is necessary to keep on a certain level of minimal values of mud rheology parameters (dynamic shear stress $\tau = 70 \div 135$ dPa; plastic viscosity $\eta = 25 \div 35$ mPa·s). For the purpose of real-time keeping of overbalance with anomalously high overburden pressure, control and regulation of calculated head pressure a stripper head should be included into the equipment configuration. Furthermore well head equipment and blowout preventer equipment must be designed for expected gradient of overburden pressure.

Key words: hydrocarbon deposit, complex mining and geological conditions, anomalously high overburden pressure, geological exploration, drilling of holes, reservoir features of rocks, porosity, permeability.

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Introduction. The development of natural gas industry in the region of North Caucasus started in the end of 1950s with the discovery of the range of hydrocarbon deposits on Stavropol dome and Kanevsko-Berezansky swell. The major part of the deposits of this region is in the final stage of development and is characterized by low levels of overburden pressure.

Problem statement. Natural depletion of gas, oil and condensate in Mesozoic deposits that contain major pools of hydrocarbons on the territory of Pre-Caucasus demands active involvement of pays in the development. Hydrocarbons production maintenance on a certain level during many years was possible due to the discovery and launching the development of small deposits.

As the result of geological exploration within the boundaries of Pribrezhno-Novotitarovsky and Dneprovsky areas starting from the end of 1980s there were explored more than ten gas deposits in Pont-Meotian laydowns on the depth of 700-1400 m, as well as five oil and gas condensate fields of chokrak stage on the depth of 2800-3100 m. Whereas small reserves of gas and liquid hydrocarbons in each of discovered deposits and due to the relatively small remoteness from earlier equipped gas-field areas allowed to put them into production in 2-3 years after discovery and consequently to contain a fall in exploitation rates of hydrocarbon raw materials.

One of the priority guidelines of geological exploration is the study of deep-sunk deposits. In this respect the layouts of hydrocarbons in carbonaceous complex of Jura of West Pre-Caucasus region are considered to be the most prospective.

Methodology. The paper contains the results of study of core materials collected when deep exploratory boreholes were drilled in the deposits of West Pre-Caucasus region, laboratory investigation of reservoir porosity and permeability features of rocks and the analysis of field data with respect to pressure-and-temperature conditions of hole drilling using computational and analytical methods of determination of mining and geological conditions with the graphic representation and extrapolation.

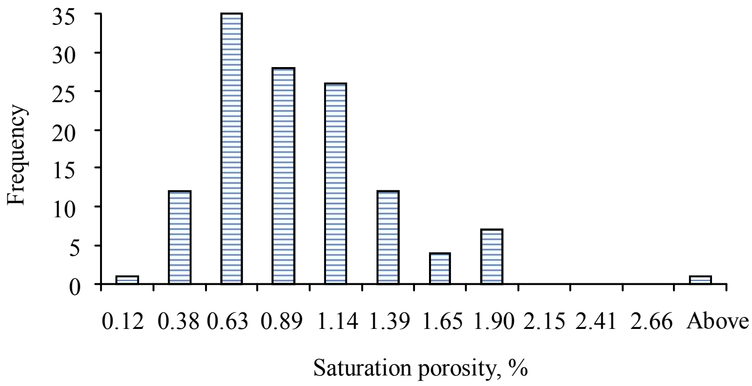

Fig.1. Distribution of porosity values of carbonate rock

Discussion. The drilling of the first exploratory borehole on Krupskaya zone to the depth of 5665 meters was stopped due to very complex mining and geological conditions: deep depth and anomalously high values of overburden pressure ($K_{an.overburd.pres.} > 2.0$) and temperature (above 200 °C) [5].

The conducted laboratory investigations showed that the main volumes of determination of reservoir porosity and permeability features of rocks were performed on limestones, which were represented like compact algoid varieties and have miniscule values of porosity (from 0.12 to 2.92 %, in average 0.84 %), the samples with the porosity reaching 2.92 % (Fig.1) occur more rarely. Predominantly the rocks are impermeable (less then $0.01 \cdot 10^{-15}$ m^2). However, thanks to the widely developed fracturing and existence of numerous differently oriented stilolite veinlets and fissures some varieties of limestones have permeability reaching $123.8 \cdot 10^{-15}$ m^2. The values of permeability, at the same time, are not dependent on the character of fissility; average permeability in vertical direction is frequently higher than the permeability along bedding.

The impact of dolomitization on reservoir porosity and permeability features is not so noticeable due to its unevenness and weak development. Due to the fact that dolomitization varieties are often more clayish they are characterized by lowered fissure permeability and having to some extent increased porosity (Table 1).

Table 1

Characteristics of reservoir porosity and permeability features of rocks

Parameter	Limestones (5625.6-5656.9 m)	Dolomitic limestones (5628.15 -5642.3 m)
Saturation porosity, %:		
Variation limits	0.12-2.92	0.29-3.81
Standard deviation	0.45	1.00
Permeability across bedding, 10^{-15} m^2:		
Variation limits	0.01-173.7 (fissures)	0.01-4.00 (fissures)
Average	2.09	0.49
Standard deviation	16.86	1.03
Permeability along bedding, 10^{-15} m^2:		
Variation limits	0.01-123.8 (fissures)	0.01-17.9 (fissures)
Average	1.92	1.05
Standard deviation	12.47	2.42

In the process of studying petrophysical relations between different parameters the results of determination of reservoir features of rocks (porosity, permeability), their electrical, acoustic and some lithological characteristics were used.

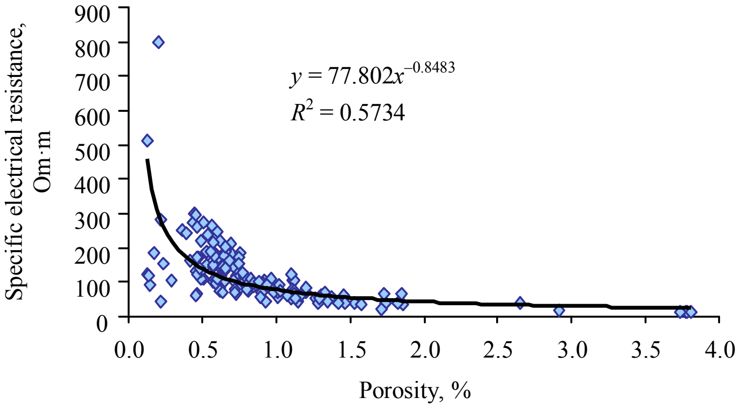

Fig.2. Relation between porosity and specific electrical resistance of the rocks

A significant relation between porosity and specific electrical resistance was established; this relation is described by exponential function (Fig.2). Rather high correlation between porosity of the rocks and velocity of propagation of ultrasonic vibrations was set (Fig.3, 4).

According to the data obtained from luminescence-Bitumenological analysis low content of bitumoids (from 0.000156 to 0.00125 %) with same composition (light recovered part) is specific for limestones; this is due to the presence of a significant quantity of secondary migrational bitumoids. An average content of particulate organic carbon for limestones from a borehole is equal to 1.1 %. However, there were indicated rather high fluctuations of its content (from 0.11 to 2.84 %) conditioned by presence of secondary carbon, which is frequently concentrated in stilolite veinlets and on the walls of insulated cracks.

Results of core materials studies showed that on the depth of 5680 m in the drilling sludge in fractions less then 2 mm there are noticeable amounts of black buildups, which obviously represent thermally transduced oil or bitum. According to laboratory determinations the content of particulate organic carbon in these buildups is equal to 12.11 % and content of luminescent substances liquefiable in chloroform is equal to 0.005 %. Similar buildups are frequently met in pores, caverns or fissures of limestones or secondary dolomites from productive parts of a profile cut.

Determination of water soluble forms of reconstituted sulfur content in core material ($H_2S + HS^-$) was led on samples of limestone (core sample interval of 5644.4-5644.5 m). The first sample contained 30.76 mg/dm^3 $H_2S + HS^-$, the second one contained 39,2 mg/dm^3, average content of $H_2S + HS^-$ is equal to 36.85 mg/dm^3.

The applied iodometric method of analysis allows to determine the sum of all forms of sulphide sulphur (H_2S, HS^-, $S_2O_3^{2-}$, SO_3^{2-}). Content of $S_2O_3^{2-}$, SO_3^{2-}, as a rule, is not significant or is absent at all in natural water and can not be determined separately due to instability of compounds.

Determination of hydrogen disulfide or hydrosulfide-ion in the reservoir fluid is known to be dependent on alkali-acid conditions of medium: in weakly acidic conditions of geochemical medium reconstituted sulphur compounds exist mainly in the form of H_2S, in alkaline conditions

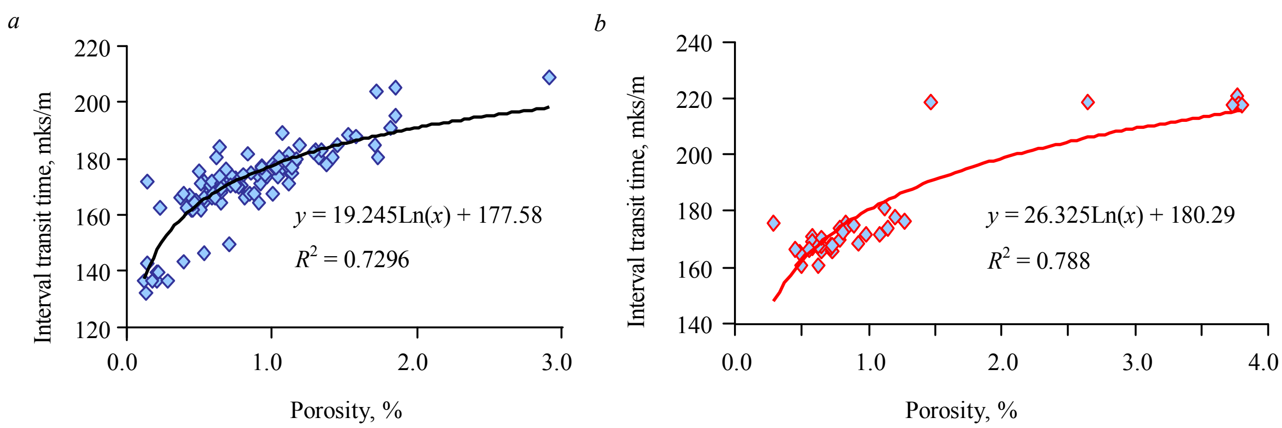

Fig.3. Relation between porosity and interval transit time of ultrasonic fluctuations in limestones (*a*) and dolomitic limestones (*b*)

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(pH = 8,5÷9,0) – in the form of HS^-. As the result of determination of water-insoluble sulphide sulphur content of H_2S in core material was equal to 0.05 %. Concentration of finely granular pyrite (FeS_2) with the flake size up to 6 mm may be visually fixed in the rock.

Thus, the results of the investigations conducted allow to obtain only qualitative evaluation of free hydrogen disulphid in rocks [1, 2, 9, 13].

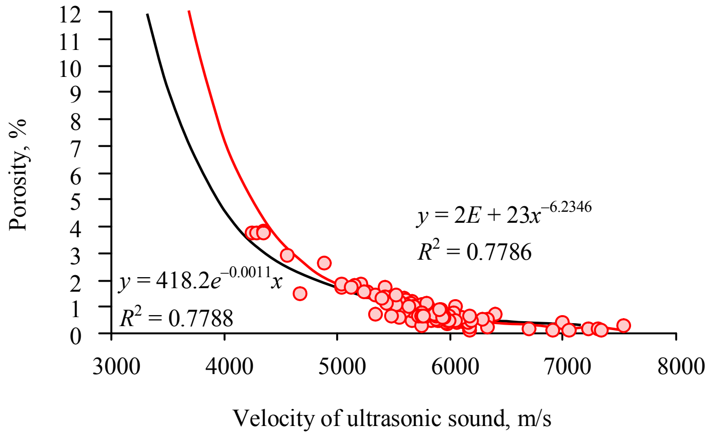

Fig.4. Relation between porosity and velocity of propagation of ultrasonic sound in carbonates

The most ancient deposits on the face of the borehole are represented by limestones of Gerpegemskaya set, which occupy a stratigraphic framework from the upper parts of the Callovian – the Oxfordian to the bottom parts of the Kimmeridgian.

The character of core material may be considered as the indicator of fracturing of profile cut: if from the upper part of core sample interval up to the depth of 5646.2 m core is non-porous with rare horizontal and inclined fissures, under this depth core is represented by dark grey pelitomorphic limestone ratchels (3-5 cm) with thin differently oriented carbon-bearing veins. The most bottom part of a profile cut is represented by grey up to light-grey, lumpy, fine grained, recrystallized, unevenly dolomitized limestone with bioclastic admixtures. Sometimes limestones may contain thin veins of crystallized dolomite with the admixtures of sulphides (pyrite) and veins of black highly oxidized bituminous substance, there exist the significant quantities of black buildups with content of organic carbon of 12.1 % which, obviously, are thermally transduced oil or bitum. Similar formations usually are met in pores, caverns or fissures of limestones or in the secondary dolomites [10-12].

The indicated above limestones are composed by algae of different composition (predominantly blue-green algae). Microgranular mass has lumpy or clotty composition. Probably, they are a sort of biogenic bodies, the formation of which happened in shallows under conditions of constant wave action [12, 15].

Thus, this part of a profile cut (on the depth above 4000 m) is more likely to be composed by fractured and possibly cavernous, to different extent dolomitized limestones of bioherm origin and is characterized by anomalously high pressures. The zone of anomalously high pressures prevails.

Anomalously high overburden pressures are dedicated to the zones of high speeds of sedimentation in Neogene time and Quaternary time. In clay profile cuts there is a slow outflow of pore water which is squeezed out under the geostatic load; the squeezed water runs into limited in volume reservoir rocks as well as into the water drive closed-loop systems. Depending on the reasons stated above each aquifer system contains reservoirs with normal and with anomalously high overburden pressures.

V.S.Kotov (KrasnodarNIPIneft) led the analysis of how overburden pressures vary depending on the depth of burial in sedimentary rocks of Azovo-Kubanskaya oil-and-gas bearing area using a large massive of field data:

– Jurassic deposits – Uzhno-Sovetskaya, Samurskaya, Labinskaya, Benokovskaya, Yaroslavskaya, Shirvanskaya, Barkaevskaya, Shedokskaya, Urupskaya, Krasno-Dagestanskaya, Pobeda, Besskorbenskaya, Sovetskaya, Yubileynaya, Temirgoyevskaya, Kurdzhipskaya, Lovlinskaya, Cherkesskaya, Tulskaya, Novovlsdimirskaya, Otradno-Kubanskaya, Temirgoevskaya, Chamlikskaya, Vostochno-Kubanskaya zones;

– Cretaceous deposits – Abadzeiskaya, Apsheronskaya, Armavirskaya, Beysugskaya, Berezanskaya, Brukhovetskaya, Velikaya, Generalskaya, Kanevskaya, Kanelovskaya, Kropotkinskaya, Zarechnaya, Kuzhorskaya, Kuschevskaya, Labinskaya, Ladozhskaya, Leningradskaya, Maykopsaya,

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Medvedovskaya, Nekrasovskaya, Novopetrovskaya, Rashevatskaya, Sokolovskaya, Temirgoyevskaya, Chaykinskaya, Shedokskaya, Shirvanskaya, Uzhno-Sovetskaya, Stavropolskaya, Kukolovskaya, Abkhazskaya, Defanovskaya, Belyaevskaya, Suzdalskaya areas;

– Paleocene deposits – Berezanskaya, Brukhovetskaya, Velikaya, Vostochno-Kaluzhskaya, Gluboky Yar, Kaluzhskaya, Kanelovskaya, Kluchevaya, Krilovskaya, Ladozhskaya, Novominskaya, Novo-Dmitrievskaya, Holmskaya, Armaviro-Ubezhinskaya, Nikolayevskaya, Ubezhinskaya areas;

– Eocene deposits – Novo-Dmitrievskaya, Kipyachaya, Glubikiy Yar, Karskaya, Kaluzhskaya, Akhtirskaya, Abino-Ukrainskaya, Zibza – Glubokiy Yar, Levkinskaya, Chernomorskaya, Severnaya areas;

– Oligocene deposits – Afipskaya, Dish, Kliuchevaya, Ladozhskaya, Novo-Dmitrievskaya, Troitskaya areas;

– Miocene deposits – Varenikovskaya, Adaguskaya, Kesrovskaya, Kudako-Kievskaya, Severo-Krimskaya, Dzhiginskaya, Blagoveshenskaya, Kurchanskaya, Armaviro-Ubezhinskaya, Uxhno-Andreevskaya areas;

– Jurassic deposits (additionally) – Koshehablskaya, Zapadno-Dinskaya areas.

Hydrostatic pressure is known to be changed linearly with the increase of burial depth, gradient of overburden pressure varies from 0.01 to 0.02 MPa/m when geostatic gradient is equal to 0.022 MPa/m.

The analysis of overburden pressures gradients referred to areas shows that anomalously high overburden pressures with the anomaly coefficient more than 2.0 was fixed only in Kukolovskaya area (Mesozoic deposits) as well as in Kimmeridgian limestones (K_a = 2.02÷2,13) and in Callovian clayed sandstone (K_a = 1.95÷2.04) in Koshehablskoye deposit (Table 2).

Table 2

Overburden pressures in Jurassic and Early Cretaceous deposits

Borehole number	Rotary table elevation, m	Test run depth, m	Age of deposition	Overburden pressure, at / MPa	Anomalous overburden pressure coefficient K_a
			Koshehalbskoye deposit		
1	141	4818.5	J_3okI	683 / 69.21	1.47
2	138	5235	J_3klII	677 / 68.63	1.34
4	146	5015	J_3okII	716 / 72.55	1.48
5	142	5370	J_3klIII	823 / 83.33	1.58
9	148	5465	J_3klV	1033 / 104.66	1.95
10	155	4834	J_3km	999 / 101.2	2.13
		4706.5	J_3km	919 / 93.14	2.02
11	137	5492	J_3klV	726 / 73.53	1.37
			Kukolovskaya zone		
1	–	2977	K_1	669 / 67.79	2.25
2	–	2750	K_1	596 / 60.40	2.17
3	–	2660	K_1	509 / 51.58	1.91
			Medvedovskaya zone		
1	–	4272.5	K_1	706 / 71.54	1.65
2	–	4190	K_1	740 / 74.98	1.77

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The analysis of field and laboratory materials regarding overburden pressures shows that upper Jurassic deposits are characterized by complex mining and geological conditions and may be drilled through with the density of drilling mud from 2.0 to 2.2 g/cm^3. This is proved by the results of drilling inside the north bead of Zapadno-Kubansky downfold in the borehole Misgastovskaya where upper Jurassic deposits between the depth 4980 and 5700 m were drilled through with the drilling mud density varying from 2.02 to 2.2 g/cm^3.

Estimating the hydrocarbon prospective resources inside Krupskaya structure the gas and condensate composition as well as volumetric data (porosity, gas saturation, compressibility factor) were accepted by analogy with Koshehbalskoye deposit where the cut of upper Jurassic deposits and thermobaric conditions of its burial are close to Krupskaya area.

Table 3

Temperature and burial depth pattern from borehole in Krupskaya area (data taken from PS «Kubangazgeofizika» Ltd «Georesurs»)

Depth, m	Temperature, °C	
	Accepted in project	actual
970	41	61
1850	75	83
2180	88	91
3470	138	130
3770	150	143.5
4090	162	147.5
4580	182	152
4900	194	161
5060	200	168
5586	221	192
6150	243	210 (designed)

Taking into account complex thermobaric conditions of drilling through, the measurements of temperature were made from time to time along the borehole when drilling (Table 3). These data were used to show temperature against depth along the borehole pattern (Fig.5). The temperature on the depth of 6150 m equal to 210 °C was determined on the straight parts of these patterns.

The obtained results allow to determine the temperature of the layer on the basis of geothermal gradient (G_T) [8]:

$$G_T = \frac{H}{T - T_o} = \frac{5586}{(192 - 20)} = 32.5 \text{ m/°C}, \quad (1)$$

and thus temperature on the depth of 6150 m

$$T_{6150} = \frac{6150}{32.5} + 20 = 209.2 \text{ °C}. \quad (2)$$

Temperature measured when drilling on the depth of 5402 m was equal to 197 °C. In this case geothermal gradient

$$G_T = \frac{5402}{(197 - 20)} = 30.53 \text{ m/°C}, \quad (3)$$

and temperature on the depth 6150 m

$$T_{6150} = \frac{6150}{30.53} + 20 = 221.4 \text{ °C}. \quad (4)$$

Thus, the layer temperature on the depth of 6150 meters is expected to be between 209.2-221.4 °C.

On the basis of field geophysical data an uneven zone of anomalously high pore pressures was identified; the part of it is represented by alteration of beds with different gradient of pressure: from 1.41 to 1.74 MPa/100 m. In the bottom-hole area of exposed section

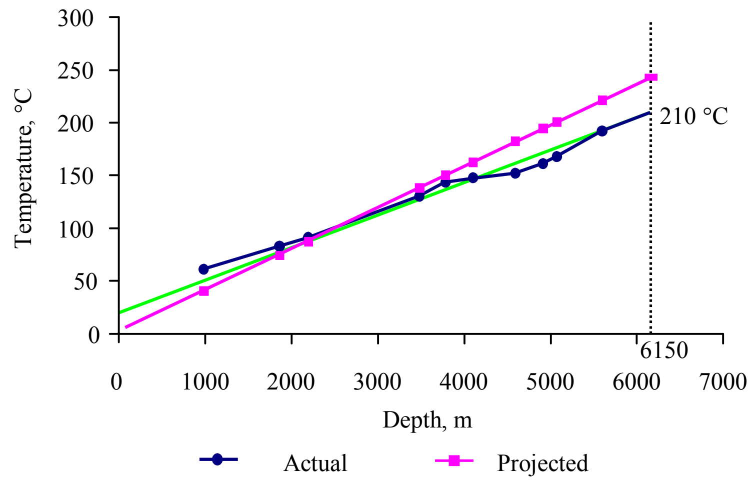

Fig.5. Temperature versus depth along borehole curve pattern

(5300-5400 m) pressure gradient grows from 1.41 to 1.64 MPa/100 m within 100 m. The value of the estimated pressure gradient in the bottom-hole area (5660 m) is expected to be between 1.83-1.90 MPa/100 m and this value may be maximally extended up to 1.94-1.95 MPa/100 m. Pore pressure gradient on the depth of 5681 m is equal to 2.04 MPa/100 m.

The results of pressure measurements made by bottomhole pressure gauge showed the following:

– equivalent measured pressure of drilling mud column of 2350 kg/m^3 density on the depth of 5405 m is equal to 1175 kgf/cm^2 (115.3 MPa) instead of calculated pressure equal to 1270.2 kgf/cm^2 (124.6 MPa), which means that the decrease in equivalent pressure created by drilling mud column in statics is equal to 95.2 kgf/cm^2 (9.3 MPa);

– equivalent measured pressure of drilling mud column of 2050 kg/m^3 density on the depth of 5402 m is equal to 1157.58 kgf/cm^2 (113.56 MPa) instead of calculated pressure equal to 1107.41 kgf/cm^2 (108.64 MPa), which means that the increase in equivalent pressure created by drilling mud column in statics is equal to 50.17 kgf/cm^2 (4.92 MPa);

– difference in measured equivalent densities of drilling mud in various intervals of borehole including wellhead part and plugged back total depth proves the instability of equivalent pressure distribution created by drilling mud along the borehole.

When developing an engineering design for a construction of exploratory boreholes it is necessary to take into account the difference between actual and designed parameters; for this purpose actual field materials obtained from earlier drilled boreholes in similar zones should be used [4].

For example, on the basis of earlier drilled boreholes there were revealed the following:

– overburden pressure gradient on the depth of 5680 m is equal to 2.07 MPa/100 m in comparison with the designed value of 1.80 MPa/100 m;

– hydraulic fracturing of the rocks has minimal value of 2.50 MPa/100 m in comparison with the designed value of 2.24 MPa/100 m;

– content of H_2S – 0.033-0.3 %; CO_2 – 1.0-6.5 %, which was not estimated by the project;

– actual borehole construction is not designed for the expected overburden pressure gradient and action of acid medium;

– overburden pressure on the depth of 5681 m is equal to 117.50 MPa, the maximum permissible overburden pressure for a column of 245 mm in diameter is 88.5 MPa according to the design.

Conclusion. Obtained field-geological information about complex mining and geological conditions of drilling through Jurassic deposits of West Pre-Caucasus within the borders of Zapadno-Kubansky downfold allowed to specify technical parameters of drilling and tailing-in producing reservoir. Overestimated mud rheology parameters determine the development of significant hydrodynamic pressures in a borehole and provoke gas showings [3]. Thus, mud rheology parameters should be kept at minimal values (dynamic shear stress $\tau = 70 \div 135$ dPa; plastic viscosity $\eta = 25 \div 35$ mPa·s) [6]. Change of mud drilling structure is highly recommended.

For the purpose of keeping a necessary overbalance on the layers with anomalously high pressure, control and regulation of the designed pressure on the well-head it is necessary to additionally include a stripper head in the arrangement of equipment. The drilling equipment used should satisfy real mining and geological conditions of drilling up to the designed depth regarding the parameters of bearing force and capacity of equipment [7, 14].

Well-head equipment and blowout preventer equipment must be designed for expected gradient of overburden pressure. For pressure testing of the equipment, for well killing operations when borehole abandoning due to gas, oil and water showings it is necessary to use special pump installation: SPM-TWS 1300 designed for pressure values of 126.8-31.7 MPa and capability of 2.5-10.7 kW or a pump installation of fracturing YLC140-1860 or a hydraulic fracture machine SYL2500-140.

Chemical agents used for drilling mud preparation should completely correspond with thermobaric and mining and geological conditions of the deposit to prevent mud foaming.

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