DISCUSSION ARTICLE

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An in-depth study of the crystalline basement of sedimentary basins is a dictate of the time

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Abstract. The history of studying the crystalline basement in the Republic of Tatarstan, the state of implementation of the super-deep drilling program is given.

The scientific substantiation of the replenishment of exploited oil and oil-gas fields is provided by feeding them with deep hydrocarbons through oil supply channels connecting the deep source of hydrocarbons with sedimentary cover deposits. The crystalline basement is of interest for the search for hydrocarbon deposits, but its role as a transit for replenishing deposits of hydrocarbon sedimentary cover in the process of constant degassing of the Earth is more attractive and justified. To use these processes, a fundamentally new approach to the construction of geological and hydrodynamic models of oil fields is proposed, taking into account the fundamental principles of geological science on the formation and reformation of oil deposits and the deep processes of Earth degassing.

Prospects are substantiated for the development of "old" fields that are in long-term development, for the calculation of oil recovery factor taking into account oil entering the reservoir from the depths of the Earth, the need for adjusting methods for calculating and accounting reserves, changing levels of material balance, and scientific and practical suggestions for accounting when calculating reserves and designing the development of fundamental principles of field geology.

Further prospects for the introduction of hydrodynamic development methods and their significant expansion due to the opening of the processes of replenishment of sedimentary basin deposits with deep hydrocarbons and the reformation of deposits at a late stage of development are shown.

Keywords: crystalline basement, degassing of the Earth, formation and reformation of oil deposits, hydrocarbons, replenishment

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The problem of hydrocarbon prospecting in the thickness of the crystalline basement in the Republic of Tatarstan (RT) was first raised by B.M. Yusupov in 1936, who insisted on deep oil prospecting drilling along the ancient basement in the northwestern regions of Tatarstan, including Kabyk-Kupersky area, where oil manifestations were established in it. The author argued, "the idea of the futility of the crystalline basement is outdated, since the oil and gas potential of the basement is an indisputable fact" (Yusupov, 1982).

However, targeted drilling to assess the oil and gas potential of the crystalline basement (CB) in the Republic of Tatarstan was not carried out until the early 70s of the last century.

A super-deep drilling program on a crystalline basement for various regions of the Republic of Tatarstan (Muslimov et al., 1980) was developed in 1969 in Tatarstan under the guidance of Professor V.A. Lobov. The theoretical concept of the abiogenic genesis of oil, created by outstanding scientists N.A. Kudryavtsev, P.N. Kropotkin, V.B. Porfir'ev, V.A. Krayushkin and others, was the scientific basis of a comprehensive program for studying the deep bowels of Tatarstan, the beginning of the implementation of which is dated to the 70s of the last century.

The program has combined the following main areas:

- Targeted drilling of the Precambrian base with parametric ultra-deep wells (to a depth of 5-7 km);
- Deepening the crystalline basement into the rocks for the first hundreds of meters by individual exploration wells drilled into the productive horizons of the Devonian;
- Opening of local ancient erosion-tectonic protrusions of the Archean-Proterozoic strata;
- Opening of basement rocks at 550 m by exploration and some production wells.

The main objective of this program was to search for structural inhomogeneities in the body of CB, decompressed permeable zones with circulation of gas-saturated solutions and possible accumulations of hydrocarbon fluids.

As a result, it was possible to approve the drilling of the first ultra-deep well No. 20000 on the crystalline basement on the Minnibaevskaya area of the Romashkinskoe field, which was drilled in March 1973 (Fig. 1).

Based on unique geological data from the well 20000, it was justified to drill another superdeep well 20009-Novoelkhovskaya (the discovered basement thickness was 4077 m) (Muslimov et al., 1976; Muslimov, Kaveev, 1988).

Amazing and unexpected results of drilling these wells and testing about 20 objects in them made it possible to assess the potential oil-prospecting object of the crystalline basement (Fig. 2).

But with the transition of Russia to the capitalist system, this program didn't last for long, not to mention its completion. By inertia, for some time, work was still being done on testing the objects allocated for research in an ultra-deep well 20009. In modern Russia, there are currently no conditions for continuing work on the study of CB associated with the drilling of super-deep wells. Currently, management requires research in order to quickly obtain practical results. But the most important thing that in the leadership of the geological and oil and gas industries today there are no figures with deep state thinking, able to analyze global trends and predict the development of industries for 40-50 years in advance. Such titans were in Soviet times. This is evidenced by the very fact of drilling superdeep wells in the CB in the Republic of Tatarstan. When in an atmosphere of monopoly domination of the biogenic theory of the oil origin and the widespread ban on research on the abiogenic origin of oil, these experts supported our projects on forbidden topics, overcoming their rejection of these views. Without their support, work on the CB in the Republic of Tatarstan would not have been possible. Today it is not necessary to expect the start of some powerful breakthrough work.

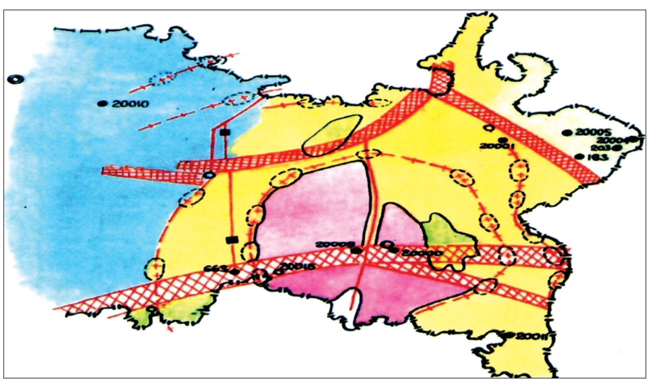

Fig. 1. Project map of the super-deep wells of the Republic of Tatarstan

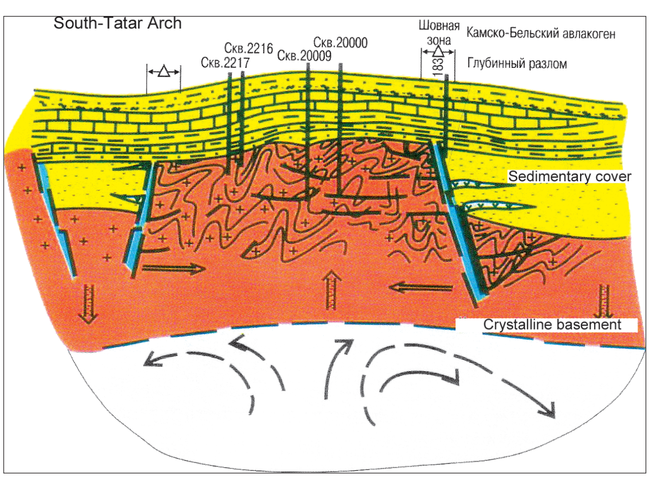

Fig. 2. Hydrodynamic model of the Tatar arch

But our geologists, specialists and scientists should not despair and need to fully use the results of unique 40-year research on this issue in the Republic of Tatarstan.

Briefly, these results are as follows:

1. The close connection of fields in the sedimentary cover and their structure with geological structure of the basement. This connection is traced not only in higher order structures, but also in details (A.V. Postnikov, L.P. Popova). By studying the geological structure of the basement, we facilitate the search for oil in overlying fields. We can say that the knowledge of the basement is the key to the search for oil in the sedimentary cover.

2. The oil and gas generating and oil conducting role of the basement, as the following factors may indicate (Muslimov et al., 1998; Muslimov, Plotnikova, 1998):

- The genetic identity of oils from the Paleozoic complex of the South Tatar Arch and the bitumen of the basement. It argues for the dominant role of vertical oil migration, which lacks a sufficient source in the sedimentary cover over the South Tatar Arch;
- The confinedness of sedimentary cover oil fields to faults in the basement makes it possible to consider it both as an intermediate link in the migration of oil and gas fluids and as an independent search facility;
- A distinct tendency to increase gas readings, expand the spectrum of methane homologs and the relative increase in the content of its "heavy" homologs (pentane and hexane), the appearance of helium with increasing depth;
- A clear discrepancy between the initial forecast resources of Tatarstan, from which more than 3.5 billion tons of oil has already been extracted, and obtained on the basis of geochemical analysis of Paleozoic dominicites with an estimate of their oil source material in the amount of only 709 million tons for the entire sedimentary stratum, indicating the impossibility of industrial hydrocarbon accumulations due to the oil generating potential of sedimentary rocks.

3. Justification of the search for hydrocarbons in the rocks of the crystalline basement. There are very good reasons, obtained recently as a more in-depth study of the basement. Based on seismic profiling and deep sounding data, a plastic-scaly basement structure was established.

4. The role of the crystalline basement in the constant "feeding" of oil deposits in the sedimentary cover with new resources due to the inflow of hydrocarbons through hidden cracks and gaps from the depths. We have shown the existence on South Tatar Arch of a single oil generation source for oil and natural bitumen deposits. The formation of deposits occurs due to vertically ascending migration of oil and gas fluids through faults that cross the crystalline basement and below the sedimentary cover horizons. This is indicated by temperature research of N.N. Khristoforova (Khristoforova et al., 1999) (Fig. 3).

CDP seismic surveys carried out in the Republic of Tatarstan in the late 1980s and early 1990s on profiles passing through superdeep and parametric wells turned out to be informative. Subvertical dynamic anomalies were revealed from them (Trofimov, 2014) (Fig. 4).

Naturally, the results of such studies required a deeper study of the problem. 20 years ago in Tatarstan, a group of specialists from the Tatneft association, TatNIPIneft, Kazan State University, Arbuzov Institute of Organic and Physical Chemistry under the leadership of R.Kh. Muslimov and I.F. Glumov conducted research on the phenomenon of replenishing the oil reserves of the terrigenous Devonian deposits of the Romashkinskoe field. It was aimed at solving problems of great scientific and practical importance for increasing the recoverable oil reserves of the developed fields (Plotnikova et al., 2011; Plotnikova, Salakhidinova, 2017).

An analysis of the geological and field data of the long-term operation of production wells of the Romashkinskoe field made it possible to justify the presence of modern hydrocarbons into the industrial oil reservoir of the Pashian horizon of the Romashkinskoe field (Plotnikova, 2004; Plotnikova et al., 2011; Plotnikova, Salakhidinova, 2017) and to located inflow of new portions of hydrocarbons. When analyzing geological and field data, a number of criteria were developed that made it possible to single out from the total number of production wells those in which hydrocarbon inflow was most likely recorded. Such wells are called abnormal. Comprehensive analysis of geological and field data performed at TatNIPIneft 2005-2006 led by R.R. Ibatullin, S.G. Uvarov, allowed to distinguish from the entire well stock those that met certain criteria of anomalies. Wells with accumulated oil production of more than 0.5 million tons, working life of more than 40 years, accumulated oil and water factor of not more than 0.5 m^3/t, growing production rates (more than 100 tons/day) during the course of at least 5 years during the period of falling oil production were attributed to abnormal wells.

Figure 5 shows the ratio dynamics of average production rates of abnormal wells to average production rates of normal wells over 40 years of their operation. As you can see, the maximum values of this parameter were recorded in 1962, 1976 and 1991, that is, with a frequency of 14 years. Moreover, the difference in the flow rates is more noticeable in the early years of development, then it damps as the technogenic impacts on the formation intensify and the total use of in-circuit water injection under excess injection pressure is made. Then, against the background of a decrease in water flooding, the intensity of its manifestation increases again.

The inflow of light hydrocarbons into the Devonian terrigenous formations is confirmed by the dynamics

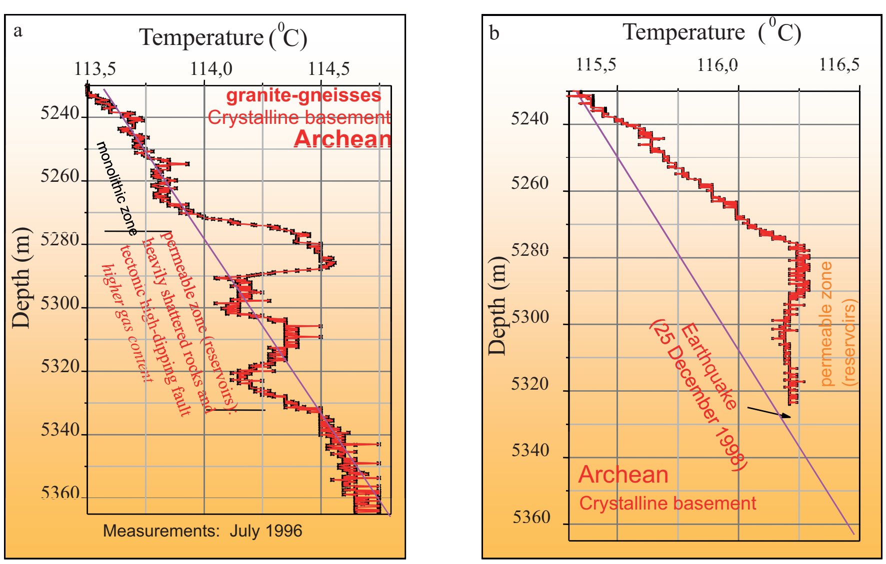

Fig. 3. a – Insteady-state temperature regime (1996, July). Thermogram of super deep well 2009-Novoelkhovskaya. b – Steady-state temperature regime (1999, January). Thermogram of super deep well 2009-Novoelkhovskaya (Khristoforova et al., 1999).

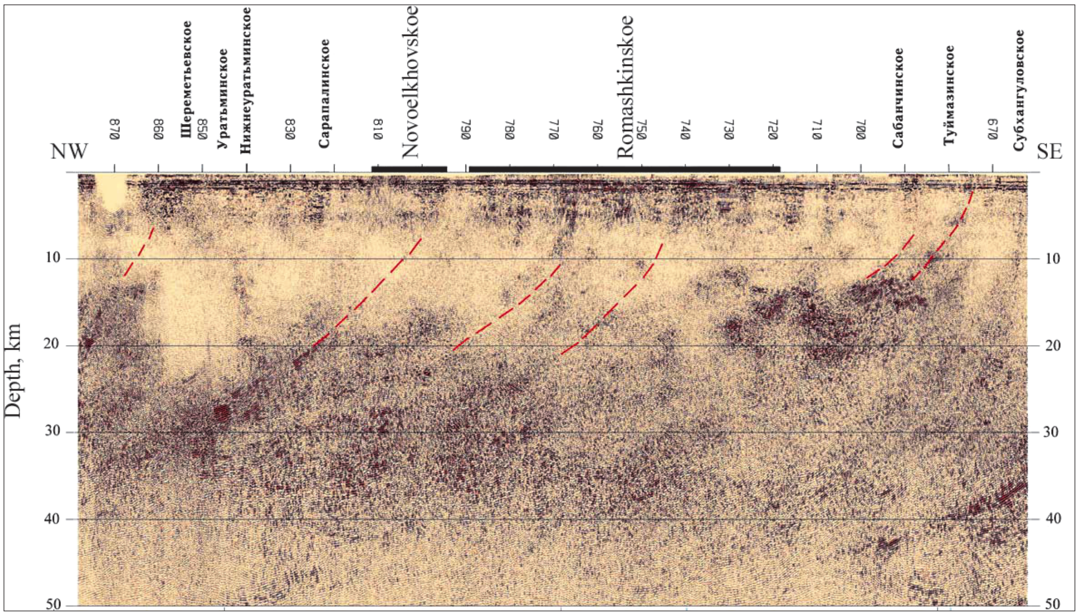

Fig. 4. Illustration of the confinement of oil fields of the South Tatar arch to subvertical dynamic anomalies. The latter, in turn, are associated with the deep structures of the Earth's crust (Trofimov, 2014).

of oil densities, recorded according to the results of the analysis of density changes in piezometric wells.

An analysis of the dynamics of oil density (Fig. 6) from 184 piezometric wells located within the oil fields of Tatarstan (including Romashkinskoe) showed that from 1982 to 1998 the density decreased twice - in 1985 and 1995 (10 years). In 1991, a relative decrease in density was also noted (against the background of three previous and three subsequent years). At the Romashkinskoe field, the dynamics of oil density (according to 58 piezometric wells) is somewhat different. Its minimum values were recorded in 1983, 1985 and 1994.

It should be noted that the revealed frequency of decreasing oil density primarily indicates the frequency of light hydrocarbon and other gases (CO_2, CH_4, N_2, etc.) entering the sedimentary stratum and reservoir, however this does not exclude the fact that deep degassing occurs throughout the entire period, but less actively (Plotnikova, 2004).

The geochemical study of oils from abnormal wells unequivocally testifies to their difference in a number of parameters obtained according to group, elemental, chromatographic and mass spectrometric analyzes and as a result of isotope studies (Ashirov et al., 2000). The results of the studies allow us to differentiate oil from abnormal and normal wells, as well as to identify the relationship of the chemical composition of oils with the geodynamic situation of the area.

As a result, we can conclude that there is a fact of migration of hydrocarbons from the zones of basement destruction to the sedimentary cover over zones of numerous faults and we can say with full confidence that the lower horizons of the Romashkinskoe field are fed by the " breathing " basement.

Numerous analyzes carried out allow us to re-examine oil fields as an ever-developing, fueled by hydrocarbons from the depths of the subsoil.

The confinement of the oil migration paths to the

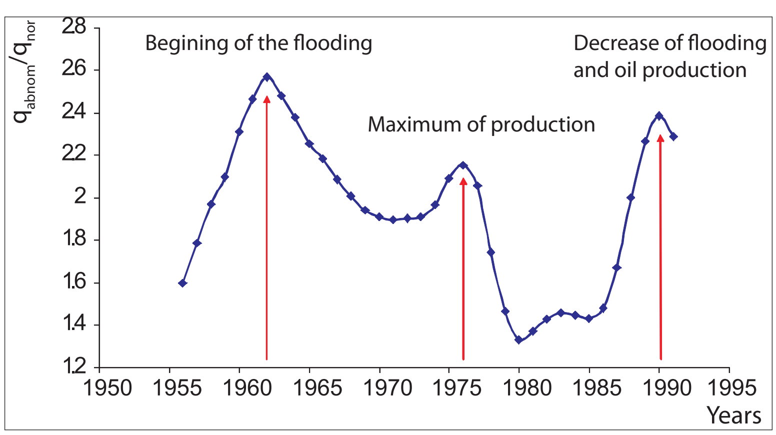

Fig. 5. The dynamics of the ratio of average production rates of abnormal wells to average production rates of normal wells of Minnibaevskaya area over 40 years of their operation (Khisamov et al., 2012)

fault zones, the young age of the oil deposits, as well as the occupancy of the structures by less than 100%, suggest that the process of formation and reformation of oil deposits continues, and thus, the presence of modern oil migration and replenishment of reserves is under development.

This process can be argued from the point of view of the inorganic origin of oil, since the process of deep generation of hydrocarbons and their continuous discontinuous flow into the upper horizons of the earth's crust and sedimentary cover is natural, subject to certain geotectonic conditions.

Traditionally, until recently, it was customary to attribute the reserves of oil and gas fields to non-renewable natural resources, and to associate the formation of deposits with a long (millions of years) period of hydrocarbon generation and their transfer in a droplet state by formation water to the place of trapping. However, the natural release of oil and gas to the day surface, observed over centuries and millennia, as well as the degassing of the rift valleys of the World Ocean and the suction of oil and gas jets at its bottom, established in the second half of the last century, made us doubt this.

Classical examples of the restoration of oil deposits in the Caucasus region, Volgograd Volga region, Tatarstan, considered in the works of N.A. Kas'yanova, M.N. Smirnova, R.Kh. Muslimov et al., V.P. Gavrilov, A.V. Bochkarev, S.B. Ostroukhov et al. have initiated the study of the influence of modern geodynamics on the oil content of the sedimentary cover and the reformation of oil and gas deposits during their long-term development, including the restoration of reserves of previously depleted deposits and changes in the phase composition of hydrocarbons in them. To date, a large number of cases of excess hydrocarbon production over estimated reserves at many fields in Russia and the CIS countries have been recorded. Deposits of the Tersko-Sunzhensky district of the Chechen Republic, Western Kuban, Volgograd region, the Republic of Tatarstan, Samara region, Ishembay and Kinzebulatov groups in the Republic of Bashkortostan - this is not an exhaustive list of objects where the fact of replenishing deposits has already been proved (Ashirov, 2000; Bochkarev, 2010; Gavrilov, 2007; Earth Degassing..., 2006; 2008; 2011; Goryunov et al., 2015; Zapivalov, 2012; Kazantsev, Kazantseva, 2007).

Detailed studies of this process in a monitoring mode, carried out at the Pamyatno-Sasovsky field (Lower Volga region) of LUKOIL-VolgogradNIPImorneft LLC in the period from 1998 to 2002, demonstrated not only the need to study the spatio-temporal patterns of the fluid regime of the reservoir, but also the practical feasibility of organizing similar monitoring studies at any developed oil field (Kas'yanova, 2010).

We do not even need to look for more convincing factors for replenishing hydrocarbon reserves in exploited fields. The phenomenon of recharge can already be considered not just a hypothesis. We see this recharge visually and even evaluate it.

So far, only one way can be proposed to determine the volume (quantity) of oil obtained through recharge. From the total oil production at the facility that we know reliably, we subtract the production from the conventionally exploited deposit (site) from the state-owned reserves, then oil production from modern enhanced oil recovery methods, then production due to the reorganization (regeneration) of the deposit. The remainder can be taken as a contribution to the total oil production from the reservoir in question.

The work should begin by analyzing the state and compiling a fundamentally new innovative project for the development of the field.

To do this, we need a completely new model of a higher generation, new technologies for field and analytical research of the reservoir, new technologies for oil recovery and assessment of the role and volume of reformation of deposits and deep recharge. Moreover, the reformation can occur in two ways: without taking into account the recharge and taking it into account. Reformation without taking into account recharge occurs during the long-term operation of deposits due to gravitational factors, changes in fluid flows in the reservoir and other phenomena associated with development processes. In this case, geological

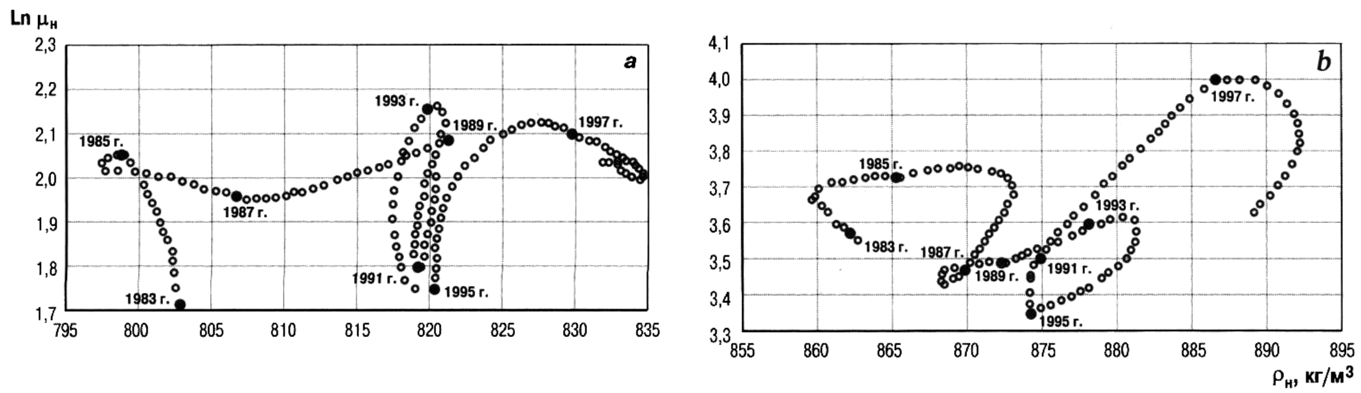

Fig. 6. Changes in the density and viscosity of Devonian (a) and Carbon (b) oils from the Romashkinskoe field during development

(balance) reserves do not change, and recoverable reserves increase. Recharge strengthens these processes and increases both geological (balance) and recoverable resources of the reservoir. Studying the problem revealed a lot of questions.

First of all, it is necessary to solve the problem of reliable accounting of geological and recoverable oil reserves of fields without taking into account recharge. This task seems trivial, but a problem nevertheless exists.

The industry has long overdue the need to reassess the geological resources of all oil and gas fields, since the balance and recoverable reserves, in the old, long-established sense, leave overboard the so-called substandard reservoirs and layers. According to experts, they can make up to 15-20 % of the approved. Moreover, geological reserves mean the entire amount of oil in the bowels, regardless of whether it can be extracted from the bowels today or not (Zakirov, 2006; Muslimov, 2003).

Such a geological model should be based on a fundamentally new approach than is currently accepted in the official documents of the State Reserves Committee of Russia. It should include not only the so-called "conditional reservoirs", as is officially accepted, but also the so-called and substandard oil-containing formations, as shown in (Zakirov et al., 2009; Muslimov, 2012). In this model, faults, crushing zones, and fractures, obtained using various methods of seismological studies and which can serve as oil supply channels, should be shown. As a result, we get a modern, fundamentally new geological model of the field (deposit).

Further, to build the necessary fundamentally different geological and filtration model, the basic geological model should be supplemented by constant monitoring and its adjustment as new data are obtained on changes in the geochemistry and geological properties of the reservoirs, including the composition of oil and dissolved gas, reservoir temperature, dynamics of flow rates, pressures, gas factor, etc.

Extraction due to enhanced oil recovery methods must be considered separately. For the Romashkinskoe field, the methods for increasing the oil recovery factor at the late stages of development were generalized in our work (Muslimov, 2014). The main techniques are as follows: the allocation of small block sizes, isolated geological bodies, the use of modern hydrodynamic enhanced oil recovery methods, then the use of tertiary enhanced oil recovery methods of a higher generation (additional production of residual reserves in the areas developed up to the design level of recovery factor), the use of forced fluid withdrawal.

In exploited fields, it is necessary to organize special integrated geological-field and geochemical studies in monitoring mode for a long time to obtain quantitative parameters of hydrocarbon inflow. This work is very complex and goes far beyond the scope of routine work stipulated by licensing agreements and development projects.

All this requires changes in the documents of the Central Design Commission for the design of development.

In addition to accounting for the volumes of deep recharge of deposits, it is necessary to evaluate production due to the reorganization (regeneration) of deposits in time. According to the hypothesis put forward by the mechanism of oil reservoir regeneration, residual oil, migrating through the pore channels under the action of a pressure gradient, which is caused by the difference in the specific gravity of the displacing agent and the residual oil, will accumulate at the top of the reservoir and flow to the area where the internal energy supply for it will be minimal under given thermodynamic conditions (Dyachuk, 2015).

The replenishment and reformation of the deposits determine the expediency and necessity of using hydrodynamic methods for developing oil deposits as the most suitable for the natural conditions of the deposits formation by the migration of fluids.

Firstly, it must be assumed that the recharge processes are not going on in all developed fields. Basically, they are characteristic of the largest oil and gas fields, and in supergiant fields (Romashkinskoe, Samotlor, Urengoy) they can be counted in dozens. In small and medium-sized fields, the significance of these processes will be significantly lower, or they will not be at all.

Secondly, it should be borne in mind that this recharge is pointwise and it is necessary to determine how to look for these recharge sections.

To solve the problem of the practical use of recharge processes, approval of new documents on the organization of reserves calculation, on the design of development systems, and instructions on the study and monitoring of recharge and reorganization of deposits (Ministry of Natural Resources) is needed.

We'd most like if the features of stable production of long-developed fields, taking into account reformation and replenishment, would initiate a wide discussion of the problem with the aim of changing the rules and design methods for developing oil fields with new approaches to determining the geological reserves of oil and gas fields, based on the fundamental principles of geology. These discussions mobilize the general public to make fundamental changes to the science and practice of developing hydrocarbon deposits. Obviously, this may push official bodies (the State Committee for Reserves, the Central Control Committee, and others) to overdue changes. Then these changes can become a reality by the middle of this century.

The need for detailed geological studies of the crystalline basement receives an additional impetus due to the established relationship between shale and similar sedimentary deposits with the crystalline basement.

The experience of the USA and other Western countries shows great prospects for the oil and gas content of tight rocks, which they believe are based on shale formations. But the latter, based on the experience and accumulation of these types of rocks, are only part of the general concept of tight rocks. At the conference (Earth degassing..., 2006) it was said, "On the one hand, the concepts of" shale oil and gas "and" oil and gas of dense rocks "can be considered inconsistent, primarily because of the criteria for their allocation, and on the other, it must be understood that the latter completely absorb the first. The term "crude from tight rocks - low permeability reservoirs", which is the most general and commonly used in the US oil industry, is more often used today to denote the whole variety of unconventional oil sources, for the production of which special technologies are required, including drilling horizontal and branched-horizontal wells, multistage hydraulic fracturing, microseismic and microscan observations".

The South Tatar arch is a very young structure that experienced a rise on the border of the Neogene and the quarter. The tectonic activation on the vault continues today, which leads to the filling of significant traps with new portions of young oil (Mingazov et al., 2012) In long-trapped traps, oil becomes younger due to the inflow of light and ultralight deep oil, and ultralight-permeable section rocks also accumulate ultralight oil having a very high penetrating ability.

In the USA, light oil is first extracted. But this produced oil is only part of the incoming deep oil due to the low efficiency of the adopted oil recovery technologies. Therefore, the oil recovery factor is extremely low (8-12 %). This indicates great potential for creating new technologies for oil displacement from the deep part of oils of these mixed traps.

Currently, efforts need to be concentrated on the creation and development of methods for extracting young deep oil from mixed reservoirs. The issue of extracting the organic part of hydrocarbons of such deposits (from kerogen) can be resolved only in the long term.

However, obtaining information for the second direction should be carried out now, using wells drilled on the terrigenous Devonian, to collect information on the mineral composition of the Sargaev-Rechitskian complex, its fluid saturation, OM content, its thermal maturity, and the generation potential of these deposits. All of these studies, which are currently underway, will determine the distribution boundaries of Domanic facies rocks in the context, provide all the necessary information about it, and significantly reduce the cost of studying shale strata in the future, when the introduction of technologies for in-situ processing of shale becomes profitable.

As for simply ultra-low permeability rocks, which make up a significant part of the sedimentary deposits of the Republic of Tatarstan, the presence of kerogen is not necessary. There may be oil only in the first group. Accordingly, other technologies are needed that are not exclusively associated with in-situ pyrolysis of hydrocarbons.

The foregoing requires increased attention to the study of the crystalline basement and especially its relationships with fields of sedimentary cover of any genesis and geological structure.

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