

DISCUSSION ARTICLE

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The features of crystalline basement fields development

S.N. Zakirov, V.K. Utoplennikov, E.S. Zakirov**Institute of Oil and Gas Problems of the Russian Academy of Sciences, Moscow, Russian Federation*

Abstract. The article is devoted to research and development of deposits in granitoid reservoirs. The basis is the analysis of the development of the unique White Tiger field. Positive and negative experience in the development of this field deserves attention, for example, for the fields of the Timan-Pechora basement and other oil and gas provinces. Particular attention is paid to geological and geophysical, fluid studies of wells, the results of the operation of wells and reservoirs in general. Considerable difficulties are created when creating 3D geological and hydrodynamic models of deposits in granitoid reservoirs. As a result, there is a need for new laboratory and downhole research and the creation of laboratory and other equipment. It is concluded that for research and development of deposits with granitoid reservoirs, experience in the development of conventional deposits is not enough. A number of relevant recommendations are proposed.

Keywords: granitoid reservoirs, crystalline basement fields, features of geology and development, studies of wells and deposits, modelling

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One of the most promising areas of prospecting and exploration of oil and gas fields is associated with the basement. The long-term successful experience of oil production from the White Tiger field in the granitoid basement on the shelf of Vietnam is widely known. For a long time (more than 30 years) this field provides Vietnam with high volumes of oil production. Up to 90 % of oil production is made from the basement. However, the exploitation of this field posed a number of problems to the scientific community in the oil and gas industry. The article is devoted to the consideration of relevant tasks from the point of view of developing new, in terms of problematic, oil and gas fields.

The basement of the White Tiger field within the central zone of the uplifts of the Mekong Depression is of the pre-Cenozoic (T-J-Cr) age (Utoplennikov et al., 2005). It is composed of various plutonic rocks, mainly of granitoid composition, and is divided into three complexes of different ages: Hon-Hoai – Late Triassic, Din-Kuan – Late Jurassic, Ka-Na – Late Cretaceous. The Ka-Na complex, being the most productive, is represented mainly by granites. It composes almost completely the central arch of the field and individual blocks of the northern and southern arch. The granites

of the Ka-Na complex are propped up, and in separate blocks, fields of the earlier Hon-Hoai and Dean-Kuan complexes break through. They are fragments of island arcs, paleosubduction and paleorift zones.

For Russia, the basement of the Timan-Pechora oil and gas province deserves attention. Despite the different ages of consolidation, it has much in common with the basement of the Mekong Depression on the Sunda shelf of Vietnam in terms of the composition of their formations, the history of geological development, and tectonic structure.

Most researchers determine the basement age of the Timan-Pechora plate as the Baikal (V-R). Granitoid arrays are of greatest interest for the search for hydrocarbon deposits. They form large undulating uplifts representing fragments of island arcs, microcontinent, and rifts (Utoplennikov et al., 2019).

If the expected discoveries of oil deposits in the basement will relate to granitoids, then we should expect extremely limited zones of oil inflow to the wellbore associated with fractures (both natural and man-made). Using conventional methods of geophysical well surveys (GIS), it is problematic to isolate such zones. It is necessary to adapt GIS methods to new possible situations.

In addition, improving methods for mapping oil and gas deposits both in area and in section are required. It is extremely necessary to forecast the reservoir properties of the reservoir, taking into account the material composition and the stress-strain state of the rocks.

*Corresponding author: Vladimir K. Utoplennikov
E-mail: vutoplennikov@ipng.ru

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The pre-computer era revealed the incorrect methodology of laboratory experiments of terrigenous reservoirs, and, consequently, the calculation of reserves, the results of 3D computer modeling and the creation of new development technologies (Zakirov et al., 2007b; Zakirov et al., 2008b; Zakirov et al., 2012). Nevertheless, the pre-computer research methodology in the fields of physics and petrophysics, laboratory research, geophysical and hydrodynamic studies of wells, has not undergone significant changes. The research methodology for the pre-computer era is called the Absolute Pore Space Concept (APS Concept). The research methodology for the computer age (which began in 2000) was called the Concept of Effective Pore Space (EPS Concept) (Zakirov et al., 2007b; Zakirov et al., 2008b; Zakirov et al., 2012; Zakirov et al., 2006).

The basics of the EPS Concept were reported and discussed at an expanded meeting of the Central Development Commission (CDC Rosnedra) (Zakirov et al., 2006). At the Rosnedra CDC meeting, the EPS Concept was approved by the following clause: To recognize the need to switch to the compilation of 3D geological and hydrodynamic models of reservoirs based on the concept of effective pore space (Session of the Central Commission for the oil and gas development, 2006).

This excursion into the past is given because the EPS concept has not yet been included in the life of the oil and gas industry of our country. It is despite the fact, that the EPS Concept allowed the creation of new field development technologies that could not be created when focusing on the obsolete APS Concept. As an example, we refer to articles (Zakirov et al., 1988; Kusanov, 2011) about the technology effective for carbonate reservoirs by one of the authors of this article. The article (Zakirov et al., 1988) outlines a new technology for the vertical-lateral cycling process. This technology has been effectively implemented at the unique Karachaganak field. It was created thanks to the ideas of the EPS Concept. Such a development technology could not be created, and therefore implemented, if we follow the APS Concept.

The EPS Concept and the vertical-lateral cycling process technology are discussed in this paper because, despite the recognition of the Central Committee of Rosnedra, they still have not received widespread implementation even in conventional oil fields. In particular, we refer to an article (Zakirov et al., 2007a) devoted to a new technology, which was never implemented by anyone, of vertical-lateral waterflooding at the final stage of oil field development.

The authors give the cited deviations because in the future, cited and other examples should not be allowed in the upcoming more complicated fields for development. We also do not deny that in order to overcome the corresponding problems, a variety of laboratory and field

studies will be required to introduce a new, adequate Concept of effective pore space (instead of the unrealistic Concept of absolute pore space).

In the case of basement reservoirs, representative deep oil samples should be taken with minimal depressions. Based on their research, forecast should be made of the change in oil composition with depth. Appropriate work is needed to build the most accurate fluid model of the reservoir. Forecast errors of only this model can have irreversible consequences from the point of view of further oil production. Since the allocation of an additional phase with a decrease in pressure with its subsequent dissolution in the process of increasing pressure is not an equilibrium process at all stages of the process under consideration. These processes cannot be described by the equations of local thermodynamic equilibrium (Lobanova, Indrupskiy, 2012).

Fortunately, in relation to the White Tiger field, the issue with the fluid model practically does not arise. However, when switching to less permeable reservoirs, serious problems are potentially possible with high-quality deep oil sampling, if only because of the phenomenon of adsorption of oil components on the rock surface (Shcherbyak et al., 2017). When sampling, capture of free oil components is possible. Therefore, the extraction process itself may introduce errors in the assessment of oil composition. A separate problem is the requirement to preserve the conditions of the natural state, because a single degassing can disrupt the structure of the liquid phase due to the precipitation of resins and paraffins.

The problem of determining the reservoir parameters of the constituent rocks in the laboratory is closely related to the question of sampling. In relation to the basement fields, it makes sense to abandon numerous laboratory experiments and go on to determine the properties of the reservoir in a natural occurrence. To do this, the conduct of specialized hydrodynamic research of wells (well test) suggests itself. In the limit, in addition to traditionally determined parameters, when combining well testing with well logging, it is possible to differentially determine reservoir properties along the well path, with simultaneous assessment of reservoir properties and dynamic parameters of multiphase filtering, including relative phase permeability curves (RPP) and capillary pressure functions. Appropriate methods for terrigenous reservoirs are reflected, for example, in (Zakirov et al., 2003; Indrupskiy et al., 2008; Zakirov et al., 2008a). It is important that this overcomes the problem of the practical impossibility of determining the three-phase functions of relative phase permeabilities in laboratory conditions. Instead, the corresponding relationships are reliably determined at the scale of the formation.

The problem under consideration is especially important for 3D computer simulation, since when

constructing a 3D model, it is necessary to integrate different-sized data related to various characteristic spatial steps. Let us suppose that at the lowest level (corresponding to the smallest spatial step), only equations are used. And the hydrodynamic specialist wants to transfer the measured parameters to a larger, rougher scale, actually performing the upscaling procedure. Will the same equations be executed on a larger scale? The answer is no (Zakirov, 2007). It turns out that when switching from scale to scale, the type of equations being solved changes its form. Additional terms appear that require their adequate definition.

But with regard to scaling in the oil and gas industry, the task is somewhat simplified. It is necessary to correctly recalculate the absolute phase permeability, realizing that when switching from scale to scale, the matrix of the absolute permeability tensor is completely filled. But with respect to phase permeabilities, the following remarkable theorem holds: if in the 3D geological model all the model cells are assigned one RPP curve, determined, for example, on a core, then RPP scaling is not required. The best agreement between the results of calculations on the 3D hydrodynamic model compared to the simulation on the 3D geological model will be obtained without any scaling of the RPP functions.

Thus, if the RPP functions are determined as a result of well exploration, the stage of scaling is overcome by determining the RPP at the reservoir scale. In this sense, the determination of RPP based on a digital core does not overcome the problem of scale. This is an interesting lesson for service companies and mathematicians, but it has nothing to do with development problems.

In theory and practice of developing conventional oil and gas fields, deformation processes in terrigenous reservoirs have long been identified (Strizhov,

Khodanovich, 1946). Therefore, a need arose for appropriate laboratory equipment and experimental techniques. The required equipment and research methods were developed by an American professor (Fatt, 1958). Until now, it was his ideas that have been used and applied in relevant laboratory experiments.

Unfortunately, the Fatt technique suffers from a lack of consideration of reservoir conditions in the study of deformation processes. One of the article authors has created and implemented a realistic methodology for conducting deformation studies in terrigenous reservoirs. Corresponding experiments proved the necessity of conducting deformation experiments only when natural reservoir conditions are taken into account (Zakirov, 1998).

Examples of the studies results of natural deformation processes are shown in Fig. 1-3. Experiments were carried out to reduce and restore the inter-pore pressure (experiments were conducted at the Gubkin Russian State University of Oil and Gas) on three core samples. Obviously, the results presented do not agree with the conventional ones.

Unfortunately, to this day, both the equipment and the methodology for conducting studies of deformation processes in carbonate and granitoid, fractured reservoirs are lacking. But it is precise that one will have to deal with in research experiments, in the design and development of real deposits, with “new” properties and parameters. This is also evidenced by the pilot laboratory studies begun by the authors.

So science and technology are in dire need of research in developing the basement fields. The article does not address the issue of technical weapons for exploration and maintenance. Today, even with reference to conventional fields, the equipment and technology for testing, completion and liquidation of production,

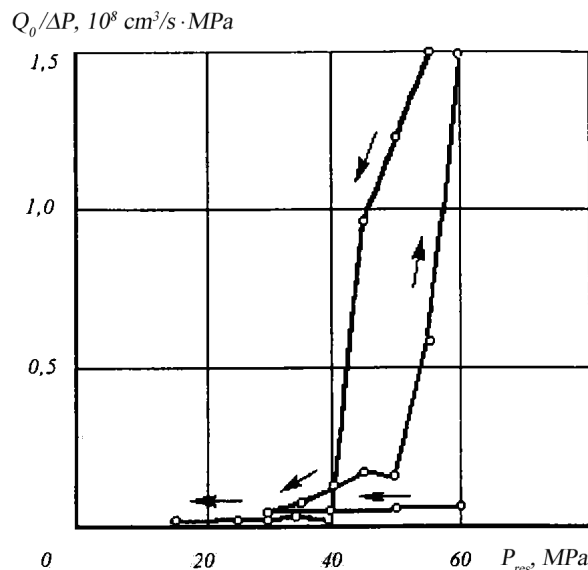


Fig. 1. The dependence of the productivity coefficient on the changing in-situ (reservoir) pressure for core No. 298 (well No. 8 of the Tengiz field)

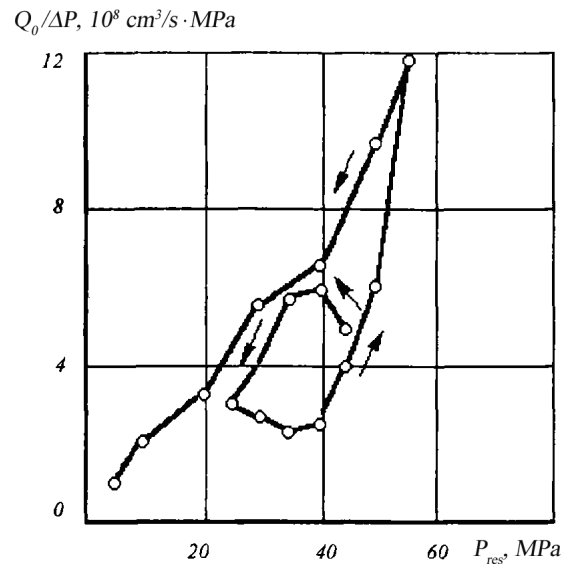


Fig. 2. The dependence of the productivity coefficient on the changing in-situ (reservoir) pressure for core No. 150 (well No. 8 of the Tengiz field)

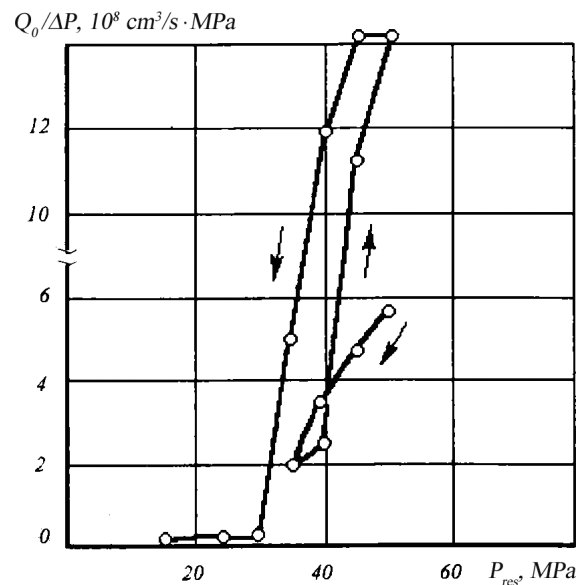


Fig. 3. The dependence of the productivity coefficient on the changing in-situ (reservoir) pressure for core No. 150 (normal to stratification, well No. 8 of the Tengiz field)

injection, prospecting, exploration, and observation wells are not suitable (Zakirov et al., 2016a; Zakirov et al., 2016b). The authors' concerns and considerations for overcoming serious environmental problems are not taken into account or solved by anyone. The corresponding problems, figuratively speaking, must be foreseen and resolved in advance even regarding conventional fields.

A reliable determination of fluid contacts is imperative. The absence of an initial oil-and-gas concentration at the White Tiger field and the zonal deterioration of the reservoir properties downward due to the intersection of tectonic disturbances predetermined the vertical distribution of injection wells. The inability to exploit deep producing wells with an acceptable production rate forces them to turn into injection wells.

As a result, the development system was formed, not on the basis of scientific ideas, but due to the peculiarities of the geological structure. Fortunately, an effective system with oil displacement based on a bottom-up hydrodynamic model was implemented in practice, taking into account the structural features of the subduction-obduction model.

However, the existing system for maintaining reservoir pressure in some cases was not effective enough. There were a number of injection wells with an accumulated injection volume of millions of cubic meters of water. Water injection into these wells was not very effective, because in the mode of connectivity of fractured-cavernous zones of faults, water flows from such injection wells to production wells, without carrying out useful work to displace oil.

The reserves of the field even within the limits of the developed blocks of the White Tiger field were revised several times, always upward. From the theory of solving inverse problems, it is known that the drained pore volume is the first parameter determined fairly confidently from the development history. Therefore, we should remove the restriction on the amount of oil reserves in 3D geological and hydrodynamic models and not tie them to the calculation of reserves. Artificial retention of reserves at pre-fixed levels leads to a significant distortion of the structure of the 3D model. Recent experience suggests that the oil and gas reserves, even with competent estimates, are not unshakable. This is due to the deep flow of oil and gas. Negative reserves also arise due to depressurization of wells and equipment.

The adaptation of the development history in an automated mode is effective only if there is factual information about the flow rates of the components and the pressure in the wells. If these parameters are not present, then no fine-tuning of the 3D model is possible.

Therefore, in the basement fields, development control should be maximized. It is advisable to switch to the use of intelligent wells using all kinds of sensors, with interval-wise control of inflow to production wells and control of injection zones into injection wells. Then, information on the occurring in the processes in the volume of the reservoir will continuously accumulate in 3D hydrodynamic models due to the assimilation of these measurements. It is desirable that the principles of 3D geological modeling are not violated during adaptation (Zakirov et al., 2014).

Based on the updated reservoir model, it is possible to automatically control the operation of production and injection wells, taking into account the limitations of the operation of ground equipment, including limiting parameters of pipeline capacity (Zakirov, 2000; Zakirov, Zakirov, 1997).

As a result, the development of basement fields will become more efficient and adaptable to the conditions of the processes occurring in the reservoir. It will be possible to manage the development in a closed cycle, based on a permanent 3D reservoir model (Zakirov et al., 2015).

The development system must be formed in such a way as to allow its adaptability to changing reservoir conditions. It should also provide information by measuring indirect parameters, additional exploration and the specified location of the sealing wells and new prospecting and appraisal wells with the maximum possible deepening into the basement body and taking into account the geological model of its structure. But most importantly, due to a well-organized system of reservoir pressure maintenance, it is possible to effectively displace oil to production wells, with

maximum coverage of the void space by water flooding (Zakirov et al., 2002).

The main conclusion from the foregoing is as follows. Oil and gas subsoil use is not adequately prepared for scientifically sound, environmentally friendly technologies for oil and gas production from the most difficult in terms of geological conditions basement fields.

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About the Authors

Sumbat N. Zakirov – DSc (Engineer.), Professor, Chief Researcher, Institute of Oil and Gas Problems of the Russian Academy of Sciences

3, Gubkina st., Moscow, 119333, Russian Federation

Vladimir K. Utoplennikov – PhD (Geology and Mineralogy), Senior Researcher, Institute of Oil and Gas Problems of the Russian Academy of Sciences

3, Gubkina st., Moscow, 119333, Russian Federation

E-mail: vutoplennikov@ipng.ru

Ernest S. Zakirov – DSc (Engineer.), Professor, Chief Researcher, Institute of Oil and Gas Problems of the Russian Academy of Sciences

3, Gubkina st., Moscow, 119333, Russian Federation

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