Key Factors for Hard-to-Recover Hydrocarbon Resources Development on Land and the Arctic Shelf: Smart Technologies vs. Smart Specialists

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Abstract. This article deals with one of the development paths which is currently not given almost any attention by oil and gas companies, despite the fact that it can contribute economically and environmentally when developing hard-to-recover resources on the Arctic shelf. The suggested development path is based on an understanding of the "smart" nature phenomenology and training of modern creative professionals in the base universities. This development path can be called "intensive". It allows to substantially reduce expenses while obtaining higher hydrocarbon influx rate and preserving the natural potential of reservoirs created by the nature itself. Today's specialists working on development of information technologies using big data, neural networks and machine learning call this development path "nature-like technologies". However, considering natural reservoirs which contain oil and gas, we can talk about a natural-only phenomenon.

1. Introduction

At the moment, when faced with the problems of developing hard-to-recover resources (HTRR) of oil and gas, operator companies try to use modern technologies of scientific and technical progress, innovative IT developments, developments of artificial intelligence (AI), machine learning (ML), multistage or acid fracking and other expensive technologies in order to solve these problems. Companies drill horizontal and multibranch wells with intelligent well completion, create smart fields. This path brings certain results, but it is very expensive. This development path can be called "extensive" (see Fig. 1).

Figure 1. Operator companies usually use the extensive path of development of technologies for extraction of HTRR.

There is another path which is currently not given almost any attention by oil and gas companies, even though it can be as efficient as the extensive path for development of hard-to-recover resources on
land and the Arctic shelf. This development path is based on smart and creative personnel and can be called "intensive", since it allows to significantly reduce expenses while obtaining higher hydrocarbon influx rate and preserving the natural potential of reservoirs created by the nature itself (see Fig. 2). Today’s specialists working on development of information technologies using big data, neural networks and machine learning call this development path "nature-like technologies". However, considering natural reservoirs which contain oil and gas, we can talk about a natural-only phenomenon.

**Figure 2.** The intensive path of development of technologies for extraction of HTRR which operator companies are ought to learn how to use in order to reduce operating costs and increase the efficiency of extraction.

If the increase in production output is understood as an increase in volumes of extraction of raw hydrocarbon deposits, these two paths of development can be displayed in the form of the following graphs (see Fig. 3).

**Figure 3.** The extensive development path (left-hand side) allows to increase volumes of oil and gas extraction while increasing the operating costs; the intensive development path (right-hand side) allows to increase volumes of raw hydrocarbons extraction while decreasing the costs.

The extensive development path requires the use of such technologies as machine learning, developments of artificial intelligence, development of smart wells and smart fields, multi-stage or acid fracking in horizontal wells, and other expensive advanced technologies. The second intensive development path requires training of skilled creative engineers who are able to study and understand the laws and phenomenology of "wise" nature and apply these laws to increase volumes of oil and gas extraction while significantly reducing operating costs. These two paths can be illustrated by the well-known Dupuit equation which can be divided into two component parts: geological and technological factors (see Fig. 4). We suggest to focus on the second (left part of the Dupuit equation) and, as we believe, more effective development path (geological factors) while using available possibilities and advanced solutions of the first path (technological factors) which can be accessed by Russian oil and gas companies.
**Figure 4.** Definition of the term “HTRR” in accordance with the Dupuit equation

*Sources: Report of Shpurov I.V., FBU GKZ (Federal State-Funded Institution State Commission for Reserves of Commercial Minerals), 2018*

2. **Implementation of Intensive Development Model**

The most productive wells in the world in the history of oil and gas extraction can serve as an example of a successful implementation of the intensive development path. The exceptional productivity of these wells has to do with the formation of super reservoirs in carbonate formations having unique filtration-capacity properties (FCP) with hypogenic karst. Such wells with record-breaking recovery rates and extraction volumes were drilled in the northern part of the “gold belt” in Mexico early last century and allowed this country to take the second place in the world for oil production at the time. These wells were drilled with primitive shock rope drilling technology without using loaded drilling mud (see Fig. 5). Cerro Azul-4 (the most productive well in the world) has been used for almost 100 years and has produced about 12.5 million metric tons of total oil production. Despite its lower initial daily production, Potrero del Llano-4 has produced about 13 million metric tons of total oil production during the entire period of the well development. Such productive wells are found nowhere else in the world after Mexico, although they should have appeared in carbonate reservoirs in the Middle East, in the Timan-Pechora, Volga-Ural and Caspian basins, in Indonesia, Canada and other regions. It can be explained by the fact that slow shock rope drilling technology has been replaced by the era of rotary boring that uses clay drilling mud and other flush liquids with specific rheological properties for removing sludge from the well. Despite the fact that this technology has substantially increased the speed of well boring, it has created significant overburden on productive formations during exposing and their extensive damage. In addition, according to the established regulations and safety requirements of the oil and gas industry, it was instructed to expose productive formations using loaded drilling mud in order to avoid uncontrolled gas and oil emissions and prevent emergency situations at oil drilling rigs. Therefore, very often it was not possible to develop wells immediately after boring and special technologies for bottom-
hole formation zone treatment and improved recovery (such as fracking, acid treatment, plasma impulse excitation, implosion, etc. [1]) had to be used to enable the inflow of hydrocarbons from the formation.

| Name of well  | Year of drilling | Initial daily production, BOD |
|---------------|------------------|------------------------------|
| Cerro Azul-4  | 1916             | 260 000                      |
| Potrero del Llano-4 | 1910       | 115 000                      |
| San Diego de la Mar-3 | 1908       | 80 000                       |
| Juan Casiano-7 | 1910             | 72 000                       |
| Alamo-2       | 1920             | 45 000                       |

**Figure 5.** Wells with record-breaking recovery rates and extraction volumes which were drilled in the northern part of the "gold belt" in Mexico early last century.

Some wells in Texas are comparable with those in Mexico in terms of productivity. For example, the Yates oil field in the Permian basin had a well with an initial daily recovery rate of up to 200,000 barrels (BOD). This well was bored in fractured tight karst carbonate reservoirs with large solution cavities [8]. Cavernous cavities, caverns and fractures are filled with oxidized oil, secondary calcite, gypsum and sulfur. The products from wells of this field contain H₂S (see Fig. 6). The size of large cavities varies from 0.3 to 6.4 m, the average size is 0.9 m with a modal value of 0.6 m.

![Image of core samples from the Yates field in Texas](image1)

**Figure 6.** Large cavities in core samples from the Yates field in Texas filled with calcite, sulfur and oxidized oil.

3. Result and Discussion

3.1. Global Distribution of Hypogenic Karst, "Smart Hydrocarbons" and "Smart Reservoirs" Concept
Study figures show that hypogenic karst has a wide global distribution which presumably exceeds the distribution of "traditional" epigenic (surface) karst [2,8]. Meanwhile, in the oil and gas basins, hydrocarbons contribute to the formation of fractured karst super reservoirs with high filtration-capacity properties which provide significant daily and cumulative oil production even in tight formations that have not been considered by geologists as potential reservoirs for oil and gas production. Thus, we can talk about the "smart nature" concept or about "smart hydrocarbons" in particular which contribute to the formation of "smart reservoirs" with unique filtration-capacity properties.

Besides creating high filtration-capacity properties of reservoirs which, however, are usually unevenly distributed, the hypogenic karst creates conditions for through-formation migration of hydrocarbons to the reservoirs, i.e. for the formation of oil and gas deposits in them.

In addition to the development of a conceptual model for the formation of hydrogen sulfide and fractured karst reservoirs [2,3,7] and justification of a cluster type irregular cellular net with an hierarchy of different-scale fractures and matrix blocks for computer simulation of the development process [4,10], a complex of geological and geophysical methods for studying and detecting fractured karst zones has been suggested which can be used for locating, exploring and developing deposits of hard-to-recover resources including Paleozoic carbonate formations on the Arctic shelf of the Barents Sea [2,5,8,9].

In accordance with the obtained results, we can apply a new advanced concept: "smart hydrocarbons" and "smart reservoirs" during development of oil and gas deposits in tight carbonate reservoirs, shale formations, metamorphosed rocks and other reservoirs of complex structure containing hard-to-recover resources including Arctic shelf deposits. This concept is suggested as an alternative to hydraulic fracturing when boring vertical, inclined and horizontal wells in tight fractured formations. Moreover, this new concept can be used as an alternative to acid treatments and acid fracking when boring vertical, inclined and horizontal wells in karst carbonate reservoirs, as well as an alternative to boring multibranch and multilateral wells in tight fractured reservoirs (see Fig. 7).

![Figure 7](image_url)

**Figure 7.** The concept of the Saudi Aramco company (left-hand side) which is based on increasing the number of multibranch wells from maximum to extreme reservoir contact (extensive path) and the alternative concept (right-hand side) which is based on boring one curved horizontal well to maximize the intersection with the fractured karst zones which serve as supply channels and provide extreme reservoir contact (intensive path)

3.2. Evolution of Complex Network Structures is the Basis of the "Smart Hydrocarbons" and "Smart Reservoirs" Concept
The proposed "Smart Hydrocarbons" and "Smart Reservoirs" concept is based on complex network structures. Under close examination one can see that the structure of the human brain, some highly molecular compounds of oil, fractured natural reservoirs, block structure of the earth crust, and the large-scale structure of the Universe are remarkably similar (see Fig. 8), which may be evidence to similar dynamics in the development of these seemingly different complex self-similar systems. The evolution of such biological and non-biological structure systems can be compared to the formation of a giant brain. Such network structures ensure not only an energy-efficient state of the entire system, but are able to store and encode large amounts of valuable information. Study results (including those of mathematical modeling) show that the formation of such systems is associated with the evolutionary dynamics of the process and not with the nature of random events. It seems probable that this evolution is based on the same basic principles of the laws of nature which are not known to scientists at the moment and can’t be used to develop advanced "nature-like technologies". Therefore, the high-priority task of researchers is to understand these basic principles and learn how to use them effectively for the development of oil and gas deposits on the Arctic shelf.

Figure 8. From left to right: 1: structure of neurons in the brain (according to V.K. Tolstykh); 2: structure of natural diamondoids of oils; 3: structure of fractures in the core (according to K.I. Bagrintseva); 4: block structure of the earth crust according to 3D seismic data; 5: large-scale structure of the Universe.

4. Conclusion
1. The experience of exploring oil and gas fields in different regions of the world shows that all reservoir formations both traditional (such as sandstones, limestones, dolomites, etc.) and non-traditional (such as shales and tight carbonates, basement rocks, coal beds, etc.) are fractured and always have local spots which occupy not more than 20% of the area and give more than half of the hydrocarbon extraction volume. These spots are called "sweet spots".
2. The zonality (linear local distribution) of sweet spots in traditional reservoirs, fractured carbonates and shales, as well as in other tight formations is associated with uneven development of tectonic fracturing and secondary leaching processes occurring along fractures.
3. The zonal location of sweet spots must be taken into account when developing more accurate geological and hydrodynamic models of deposits. The use of seismic data is often not enough. The location of sweet spots should be determined using a special complex of geological and geophysical methods and production data which should be selected for each specific field.
4. To simulate the development process and compare different development scenarios in tight fractured reservoirs containing HTRR, special programs for performing hydrodynamic calculations that take into account the hierarchy of fractures and matrix blocks using the dual permeability model and irregular cellular nets must be used.
5. The use of the "smart hydrocarbons"/"smart reservoirs" concept and advanced technologies for 3D seismic interpretation, boring of horizontal wells and underbalanced reservoir drilling (UBD) with the use of oil-base mud (OBM) [6,9] allows to effectively develop deposits of HTRR in tight fractured sandstones, limestones, basement rocks and shale formations.
6. In order to improve the efficiency of extraction of HTRR and implementation of the "smart hydrocarbons"/"smart reservoirs" concept, "smart", skilled and creative experts in modern computer developments, machine learning, big data analysis, 3D seismic interpretation and other information technologies are needed more than ever. These specialists must also have deep fundamental knowledge of traditional oil and gas geology and related contemporary sciences in order to apply an interdisciplinary approach which allows to understand the processes of evolutionary dynamics of complex systems of natural reservoirs with HTRR. In order to train such specialists, the Government of the Russian Federation should focus not only on creating new research centers such as Skolkovo, but also on contributing to rebuilding scientific centers in the base oil and gas universities of Russia, whose scientific and technical developments have been significantly diminished since the collapse of the Soviet Union.

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