International Journal of Innovative Studies in Sciences and Engineering Technology (IJISSET)

ISSN 2455-4863 (Online) **www.ijisset.org** *Volume: 4 Issue: 8 | 2018*

Petroleum Geology: Science and Practice in the 21th century. New Ideas and Paradigms

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Making the next giant leap in Petroleum Geosciences!

Abstract: *Oil-and-gas-saturated stratum is an integral interrelated system of rocks (minerals) and fluids (oil, gas, and water). Being a «living» fluid-rock system, it is subject to the laws of autoregulation. It is necessary that research and practical efforts be focused on study and control of the oilfield «life».*

Keywords: *origin of petroleum, «life» of an oilfield, rehabilitation cycles, residual oil, metasomatism.*

In petroleum geology of the 21st century the ideas of modern non-linear dynamics with its concepts of chaos and self-organization begin to dominate.

Basic concepts

A.

Hydrocarbons are reported to occur in all strata of the Earth's crust and are supposed to occur in the cosmic space, too. As to genesis of hydrocarbons, there are various authoritative positions.

Owing to his petroleum longevity, the author has left behind the classical organic hypothesis, although it was his personal discovery in 1958 when a specific oil-source rock («Bazhenov suite») was first distinguished in the Upper Jurassic system of West Siberia, based on the study of test wells. It was stated in the author's Ph.D. thesis in 1962. Nevertheless, now the author holds to a different scientific paradigm, which does not imply adherence to any of the existing oil origin hypotheses. «*Road to the Truth passes through a court martial of Thought sitting in session incessantly inside one's mind*» (Olzhas Suleimenov, a Kazakh writer and diplomat).

It is virtually impossible to create a general theory of oil origin. To look at regional oil-source rocks as a sole indispensable prerequisite of oil formation is a wrong position.

As early as in the middle of the 20th century, A.I. Levorsen arrived at the conclusion that oil-source rocks have no concern with actual prospecting and exploration works. In his *Geology of Petroleum* [1] he stated: «The problem of oil-and-gas origin now loses its significance as a necessary prerequisite in planning the exploration works. The reason is that petroleum-like hydrocarbons are discovered in almost any non-reservoir rocks. The amount of residual oil [micro-oil] dispersed in these rocks exceeds all the proved reserves in the Earth. Therefore, ***there is no need in search for special source rocks***» (*in a reverse translation from the Russian edition: Publishing House «Mir», Moscow, 1970, «Conclusion», p. 488*).

Various kinds of paleo-reconstructions can hardly be considered a reliable guide in choosing favorable petroleum objects, because each fluid-rock system is subject to secondary, superimposed processes. It is especially important to take into account metasomatic processes. This is why we often deal with young deposits and modern porosity-and-permeability characteristics of a reservoir; their transformation may proceed very rapidly. The age-analogy principle and the exemplar-based method for evaluation of reserves' categories do not meet the reliability requirements in solving problems of petroleum geology. N.A. Eremenko and G. Chilingar [2] took up the position that in a very short geological time reservoir may turn into a caprock and a caprock into a reservoir.

Oil-and-gas accumulations are traced in all types of rocks and at all stratigraphic levels both onshore and offshore. In fact, we live in a hydrocarbon civilization. Our planet is actually a large overall petroleum polygon.

New evidence and facts refuted the myth of «Peak Oil». Oilfields can be discovered in most unexpected places and conditions. The oil recovery rates depend on various natural, technogenic, and market fluctuations including human factor. A great variety of hydrocarbon sources, both conventional and unconventional, have been discovered and are still being discovered; innovative methods and technologies for hydrocarbon production and utilization are being created; on the whole it shows that Peak Oil is dead. ***The era of hydrocarbon civilization will never end!***

B.

- Oil-and-gas-saturated stratum is an integral interrelated system of rocks (minerals) and fluids (oil, gas, and water). An oilfield is a «***living» fluid-rock system***, subject to the laws of ***spontaneous autoregulation***. It is necessary that research and practical efforts be focused on study and ***control of***

the oilfield «life». This «life» depends on a great number of rapidly changing factors (gradients); oil deposits may be formed, then dissolve, and after that re-generate again. This is why many of oil-and-gas accumulations are young.

- During the development of an oilfield, the ***perturbation threshold*** for breaking the equilibrium of this fluid-saturated system can be defined with the value of formation depression. There are strong reasons to estimate the critical value of formation depression as 5-8 MPa. This value is almost universal and applicable for all types of reservoirs.
- Fluid-dynamic systems (oilfields, deposits) are in many respects focal and in all likelihood fractal objects with non-uniform productivities.
- As a first approximation, dynamics of the states of a hydrocarbon deposit can be described with an evolutionary equation

$$\mathbf{p}\partial t = Z(\mathbf{p}, a, t) ,$$

where $\mathbf{p} = (p_1, p_2, ..., p_k)$ is a chosen set of dynamic variables describing the system state, $\mathbf{a} = (a_1, a_2, ..., a_l)$ is a set of the system's parameters, t is the time variable, and Z is a non-linear operator of the said variables **p**, universal for all types (or at least for a sufficiently wide class) of oilfields, which is to be determined on the basis of empirical regularities of the evolution of hydrocarbon accumulations.

This is the usual form for the dynamic equations in such spheres as dynamics of mechanical systems, fluid dynamics, theory of classical physical fields, atomic systems, evolution of galaxies etc.; in all these fields, equations of this type make the basis of a successful research of most sophisticated processes and phenomena.

The equations of transfer and balance of hydrocarbon masses and accompanying materials seem to be the most appropriate basis for constructing fluid-dynamic models. It is especially important in proving the empirical law of critical state threshold for oil-and-gas-saturated systems equal to formation depression of 5-8 MPa.

Practical recommendations:

1. At present, forced commercial development of oilfields is being practiced all over the world in order to quickly produce easy-to-extract oil with the use of all available super-intensive methods and technologies. As a result, the ***residual oil*** (reserves) now amounts to 55-70%. To extract this residual (hard-to-extract) oil from the productive strata, conceptually new ideas and technologies are required.
2. In petroleum geology, both research and practice (prospecting and developing works) are to be guided by locating zones (foci) of active gradient fluid behavior at each specific moment of time. Nowadays a lot of such innovative techniques are available, including aerial and space survey. The ***DFM-method*** developed by V.B. Pisetsky [3] and the ***SAM-technology*** (spectral analysis of microseisms) by G.V. Vedernikov [4] are highly recommended. These technologies make it possible to distinctly determine the highly productive foci during the prospecting and developing works.
3. In the process of developing an oilfield and especially at its active stage, it is necessary to use ***rehabilitation cycles***, in order to restore the energy potential of the stratum and filtration properties of the rock as well as to facilitate fresh formation of hydrocarbon masses. In the long run it will provide for an increased longevity of the object, higher ***final oil recovery***, and beneficial effect for the environment.

Due to various reasons, many wells, separate zones and oilfields have to be abandoned. At such wells and zones, temporary conservation should be performed in order to apply rehabilitation cycles. After that, their renewed development will become possible (for instance, in the Mexican bay, North Sea, West Siberia etc.). This idea has been confirmed in a recent article by I.A. Dyachuk [5]. However re-formation of deposits according to the principle of capillary-gravity segregation seems to be a simplified model: natural processes are much more complicated.

4. Dolomites in carbonate rock masses formed through late metasomatism are of a special interest. Nano-scale metasomatic processes not only increase porosity and permeability but also often facilitate formation of prolific carbonate reservoirs. It is possible to initiate an accelerated technogenic process of ***metasomatic dolomitisation*** in order to create or renew highly-productive foci at an oilfield.
5. It is highly desirable to organize ***research-and-development polygons*** in various petroleum regions, like the one at the giant Eugene Island oilfield in the Mexican bay (GBRN, Global Basin Research Network).

Regular observations are required with constant monitoring of the current changes inside the fluid-saturated stratum. «Thousands of observations and thousands of measurements are needed to avoid a single error» (Omar Khayyam, a mediaeval astronomer and philosopher). It should be kept in mind that for the Kola Superdeep Borehole in Russia (12 262 meters) many preliminary geological and geophysical models proved inadequate.

Geofluid-dynamic monitoring of the Earth's depths lags much behind cosmic monitoring, and this retardation may prove fatal for civilization.

Today's problems

- The ***era of big oil*** in the abyssal Paleozoic of West Siberia [6] is not finished yet. The author has devoted much effort to solving this problem. A.A. Trifimuk, an outstanding Russian petroleum geologist, used to say that the Paleozoic is «a golden substrate of West Siberia».

- In the foreseeable future, the task of large-scale industrial development of Russian Arctic off-shore petroleum resources, which are of merely prognostic character, will have to face insurmountable difficulties and can only help in solving some geopolitical problems whereas the vast on-shore transpolar territory of West Siberia is a quite another, already half-solved problem.

- Bazhenites and shale oil in West Siberia may look inspiring but in fact no breakthrough can be expected here in near future.

According to recent data [5], sediments of the Bazhenov formation geochemically belong to metal-bearing black shales; as compared with the world-average values for black shales, the Bazhenov formation is three times richer in U, Zn, Sr, Ba and 1.5 times richer in As, Co, and Tb. The concentration of uranium in the rocks is 2 to 171 g/ton, with the average value 40.9 g/ton. The resources of uranium in this region can be approximately estimated as 3 billion tons.

So, a reasonable question arises whether it may prove commercially viable to produce uranium and other metals from West-Siberian bazhenites, at least in separate promising regions (maybe together with oil).

Main conclusion:

- At present, efforts should be focused, ***first***, on the efficient well-targeted development of the active oilfields in order to produce the residual (hard-to-extract) oil in a soft, sparing and non-damaging way (Improved Oil Recovery) and ***second***, on discovering new hydrocarbon accumulations, including secondary ones, throughout the whole stratigraphic section, with all depth horizons and various rock-fluid associations, in regions where a well-developed diversified infrastructure is already available.

Otherwise, huge masses of the already approved residual reserves will remain in the Earth' depths waiting for future «discoveries» of the already discovered oil.

- To solve these problems, the whole potential of the powerful Russian science is required; the management of subsurface resources must be science-intensive.

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