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Oil and gas possibility of crystalline basement taking into account development in it of non-structural traps of combined type

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Abstract. In this communication, from the perspective of modern views, the following issues are highlighted. A brief overview of the regions – large oil and gas bearing basins, in which hydrocarbon deposits are currently being developed in the deposits of the crystalline basement, is provided. The problems of non-anticline-type collector traps, usually non-structural, combined, widely developed in basement deposits, are considered. The existing characteristic features of oils in deposits from a crystalline basement are voiced. As a result of the study, ever-increasing volumes of world oil production from base sediments were noted, the difficulty of identifying and classifying traps in it, and the almost lack of originality of the composition of oils in the foundation compared with oils in the overlying or adjacent parts of the sedimentary section, are shown.

Keywords: crystalline basement, oil fields, hydrocarbons, combined traps, oil composition, oil and gas potential

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Introduction

The problem of oil and gas content of the crystalline basement has occupied the minds of scientists and manufacturers for the second century, as it has great scientific and economic importance in connection with the focus on increasing the resource base of countries – oil producers. The International Scientific and Practical Conference "Hydrocarbon and Mineral Resources of the Crystalline Basement", held in September 2019 in Kazan, aroused great interest of the scientific community, testifying to the relevance and significance of the stated problems. As noted in the work (Muslimov, Plotnikova, 2019), it was in Tatarstan in the second half of the 70s. after receiving the inflow of deep carbonated highly mineralized liquid from a depth of 5099 m in the well 20,000-Minnibaevskaya, the study of the crystalline basement for its oil content began. Thanks to the staging of broad and comprehensive research, there is a huge scientific and production potential in this region.

Regions and countries with hydrocarbon fluids in the crystalline basement

Recent publications (Gutmanis et al., 2013; Trice, 2014; Koning, 2003, 2019) provide publicly available information on hydrocarbon reservoirs (HC) in fractured crystalline formations and their resources from about 30 countries. The deposits of the crystalline basement are large oil and gas reservoirs in various parts of the world.

In South America, basement fields are being developed in Venezuela and Brazil. In North Africa, the extraction of oil and gas from the basement is carried out in Morocco, Libya, Algeria and Egypt. Significant reserves in the basement ledges are known in Russia (the oil and gas basin of Western Siberia), as well as in China. In the USA, the most significant hydrocarbon production from the basement includes a number of areas: California (Wilmington and Edison), Kansas (Eldorado and Orth) and Texas (Apco). In Southeast Asia, Viet Nam is the main source of oil production. The recent large discovery of gas in Tertiary fractured granites in the south of Sumatra led to active exploration of basement deposits in Indonesia.

Although basement fields have been exploited for many decades, since the mid-90s., interest in their development has particularly increased due to a number of cumulative factors. These include: the momentum gained from major discoveries in Viet Nam and Yemen; the emergence of modern borehole tools (especially borehole logging images and acoustic logging), new seismic methods (for example, shear wave seismic attributes) and complex drilling methods. The increase in oil prices also contributed to the reassessment of those drilling projects on the basement that were previously considered high-capacity or uneconomical.

Oil and gas accumulations in the basement are open in deposits with a significant oil-bearing floor and are not always in the roof of the basement. So, in the Hugoton-Penhandle field (USA), oil comes from weathered granites from the interval 458-1068 m, in La Paz field (Venezuela) – from fractured basement rocks in the depth interval 1615-3350 m. The thickness of oil-saturated in the Auguila-Naafora field parts of the basement is 450 m, in Zeit Bay – 330 m, in Oymash – the interval of oil-saturated basement is 3612-3850 m, on the White Tiger field the oil content of the granitoids of the basement is about 2000 m (3050-5000 m) (Shuster, 2003). Koning (2019) presents several orthodox cases of world practice when fields in the basement are discovered many years after the discovery and long-term operation of the sedimentary stratum of the basin. For example, there is a giant La Paz field in Venezuela, in which the oil in the basement was discovered much later (after 30 years) of exploitation and production from overlying sedimentary deposits. Now, taking into account the basement, the maximum production is 11500 bbl/d, and the initial production averaged 3600 bbl/d. Similar developments occurred in the Octongo oil field in the Nequen River Basin in Argentina, which was discovered in 1918 in sedimentary deposits lying above the basement. The second life of the field began only at the end of the last century. The oil was obtained from the basement, the production of which averaged 3000 bbl/d.

The most famous examples of successful development of reservoirs in the basement are the coastal areas of Viet Nam, where the Cuu Long basin accounts for 95 % of hydrocarbon production in the country, and 85 % of this value falls on the fractured granite basement. Marib Al Jawf has large reserves of the West Yemen oil and gas basin. The development of chalk sand formations at the Kharir field began by SOCO in 2004, and already in 2005 Hunt Oil successfully continued the production of hydrocarbon fluids from basement rocks. Four drilled wells on the basement (depths up to 3383 m) showed high results (up to 6500 bbl/d). Other important discoveries were made in Argentina at the Cuyo and Neuquen fields. Hydrocarbon fluids here are obtained from destroyed Permian-Triassic volcanic rocks (up to 11,000 bbl/d) (Gutmanis et al., 2013; Koning, 2003).

Type of traps prevailing in crystalline basement fields

Assessing the prospects of oil and gas potential is impossible without studying the formation and structure of traps. As world practice in oil and gas exploration shows, combined traps account for almost 5 times more deposits than reservoirs – HC reservoirs controlled by one leading factor (lithological, stratigraphic, tectonic, geodynamic, hydrogeological, etc.). The importance of assessing the nature (type) of traps and their prospects in terms of resources is evidenced by long-term studies conducted by a group of specialists (Dolson et al., 2018). The authors show the importance of discovering deposits in the world reserves of hydrocarbons with traps of various origins: combined, stratigraphic, structural. Moreover, the traps named as "unknown" are allocated to a special type, which has not yet found a classification term. Most likely, we mean "traps" of shale formations, clinoform structures, as well as traps in the protrusions of the crystalline basement, if, as a result of weathering, the latter serve as a reservoir of hydrocarbons.

The basis of the methodology for searching for oil and gas deposits in complex traps is the interpretation of the seismic data of the CDP performed in accordance with modern requirements of geological exploration in conjunction with drilling materials, and well logging based on seismic and geological analysis. When searching and exploring oil and gas deposits in traps of a complexly shielded type, including a non-anticlinal structure, the combination of geological and geophysical methods and the rational sequence of their application is not less, but, apparently, even more important than when searching for structural objects. Prediction and subsequent discovery of hydrocarbon deposits in traps of the type under consideration is a more laborious scientific search, during which all available geological and geophysical materials are used and generalized from a certain angle. High-resolution three-dimensional seismic survey helps determine the best location for the optimal intersection of fractured or weathered basement rocks (Krupin, Rykus, 2011; Oknova, 2012; Petroleum Geology..., 2018).

For a long time, when setting up exploration work of the reservoir in the basement rocks, they were underestimated. However, in various regions of the world, accumulations of oil and gas in the rocks of the basement are open and industrially developed. HC accumulate in intrusive, effusive, metamorphic and cataclastic rocks of the basement with secondary porosity. Cataclasites (associated with rock faults that are formed during brittle deformations at high pressure values) have high secondary porosity. The formation of cataclasites plays an important role in the total secondary porosity of deformed base rocks. The presence of oil and gas reservoirs in metamorphic and igneous rocks is a universally recognized fact; obviously, the time has come to consider cataclastic rocks as reservoirs when setting up exploration work (Morariu, 2012).

According to a number of researchers (Dmitrievskii et al., 2012), based on a detailed study of the hydrocarbon deposits of the Viet Namese shelf, a differential pressure is created as a result of heat shrinkage processes, which ensures that micro-oil from overlapping sedimentary rocks is drawn into the cooling intrusion. Active fluid dynamic processes lead to the formation of additional capacity throughout the entire volume of the granite intrusion and the accumulation of hydrocarbon fluids within it. The influence of deep fluids provokes not only the formation of voids, caverns and cracks, but also a drastic change in the structure of granitoids with the formation of a crumbling substrate. Oil production in such zones reaches 2 thousand tons/day (Shuster, 2003).

Figure 1 shows the trend in the reservoir properties of granitoids at the White Tiger field, which indicates that with this type of fracturing and with a decrease in porosity, the permeability of the reservoir remains almost constant with depth and quite high (Huy et al., 2012).

Here are some examples of the structure of hydrocarbon fields in the crystalline basement, indicating the complexity and combination of trap types (Fig. 2, 3).

Oimash field is located in the Karakiy district of the Mangistau region and is located 50 km from the city of Aktau (Republic of Kazakhstan). The field was discovered in 1980, and in January 1981, the industrial oil and gas potential of granite intrusion was established. The first inflow of oil from granites with a flow rate of 248 m^3/day through 9 mm nozzle was obtained in well 12 from the interval 3720-3773 m. Metamorphic and igneous rocks of the Paleozoic age basement and Meso-Cenozoic sediments of a platform cover with a maximum thickness of 4450 m were discovered by deep drilling. Hydrocarbon accumulations in massive fissure-cavernous igneous and metamorphic rocks are, as a rule, confined to buried ledges of the basement, broken by faults into blocks and covered by metamorphic or sedimentary rocks. Based on the results of testing, 4 deposits were identified, of which three were oil and one gas-oil. Industrial oil and gas potential has been identified in the Lower Jurassic, Middle Triassic, Paleozoic host rocks and granite intrusion (Krupin, Rykus, 2011). The main oil reserves are associated with Paleozoic granitoids (Fig. 2).

According to (Krupin, Rykus, 2011), processes of different tectonic intensities, which appeared in several stages during the Mesozoic geological history of the region, are of great importance in the implementation of capacitive properties at the Oymash field. They affect all types of rocks of the Early Mesozoic and Paleozoic granite intrusions, creating in them differently oriented discontinuous disturbances, zones of fracturing, cataclase and milonitization.

The Lankaster field, discovered in 2009 on the shelf of Western Scotland (water level 160 m) at a basement depth of 1,220 m, had reserves of up to 25 million barrels of oil. Rising up to 8000 bbl/d in 2017, a message appeared about the discovery by Hurricane Energy of another major field on the shelf of the North Sea off the coast of the UK (Halifax structure), whose reserves are estimated at up to 1 billion barrels of oil. Hurricane Energy believes that Halifax and Lancaster are two parts of the same giant oil basin. The structure of oil reservoirs – complex combined traps, is shown in Fig. 3.

Figure 4 shows the distribution model of the Fault zone grid and Weathered interval over tonalites/granodiorites of the acid igneous rock family (Tonalite/Granodiorite) with explanations needed when planning exploration wells taking into account the model of fault zones (Trice, 2014)

Geochemical features of hydrocarbon fluids in basement fields

The main source of oil in the fields of the crystalline basement is the organic matter (OM) of the oil source sedimentary strata encircling the ledges of the basement, which is recognized by most researchers dealing with the problem of hydrocarbon accumulations in the basement. That is why the geochemical features of the

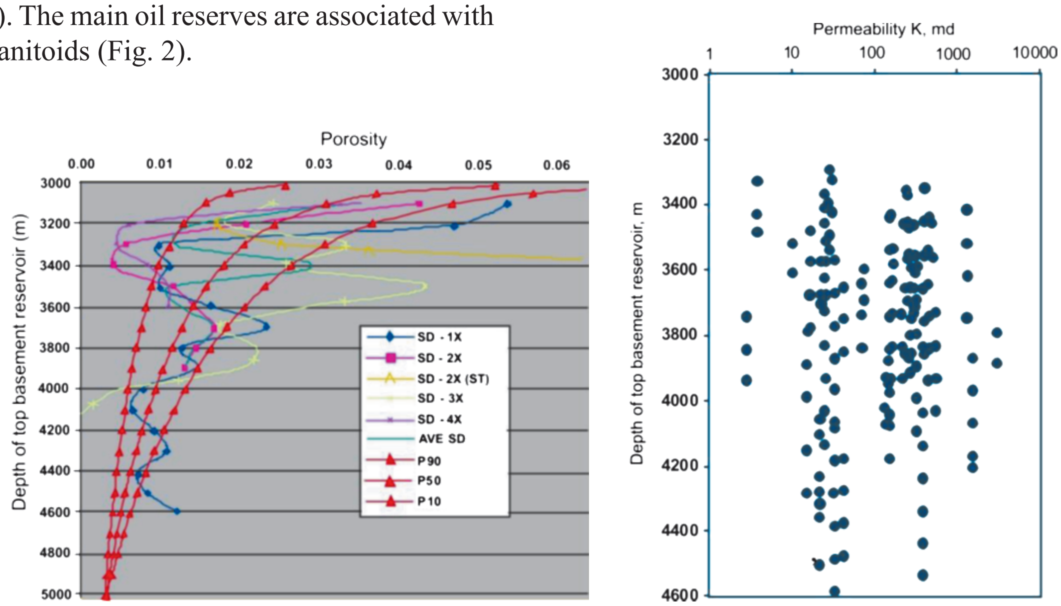

Fig. 1. Change in porosity and permeability of basement rocks in different wells with depth at the White Tiger field (Huy et al., 2012)

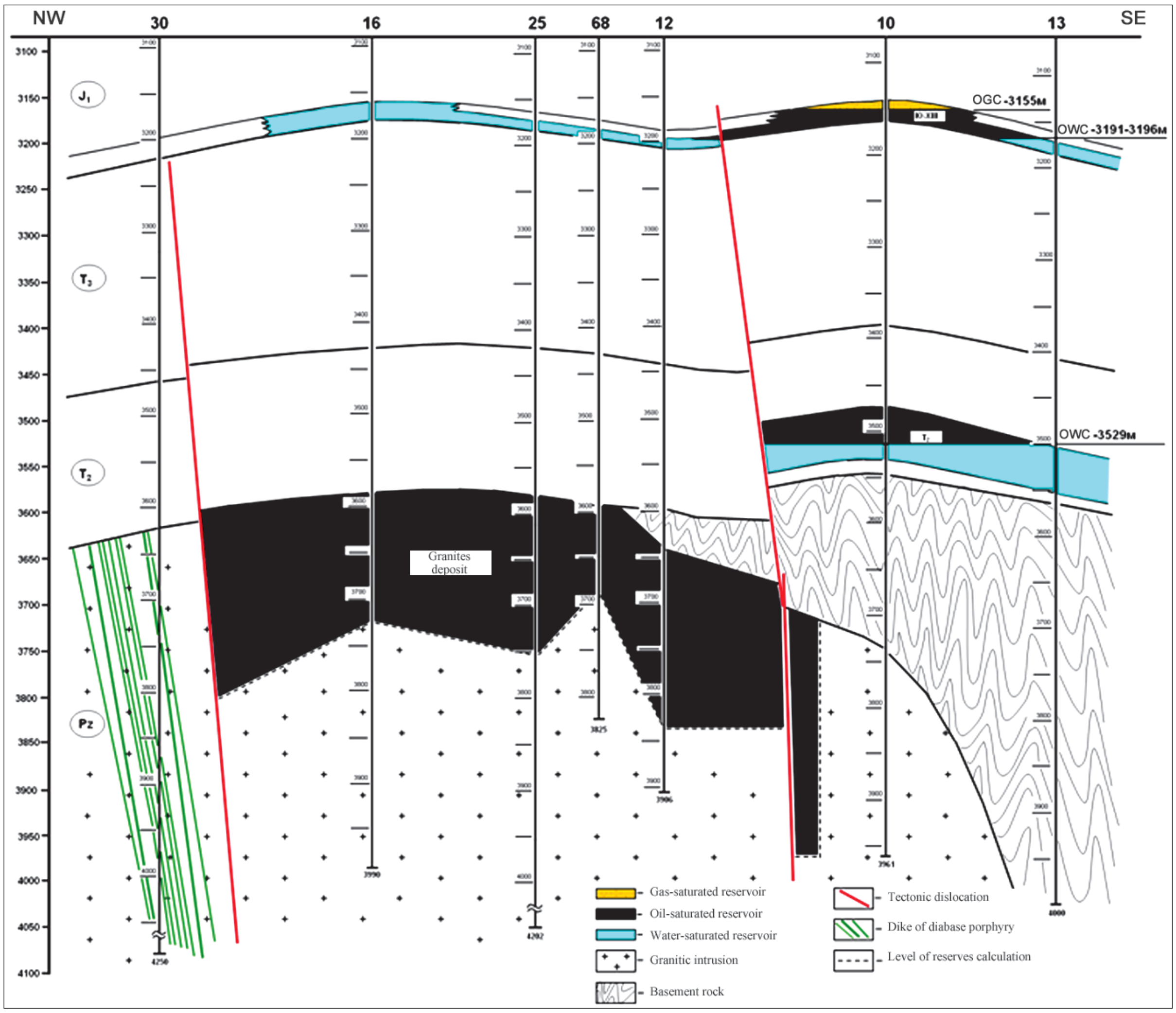

Fig. 2. Oimash field, geological profile along the well line 30-25-12-10-13 (Krupin, Rykus, 2011)

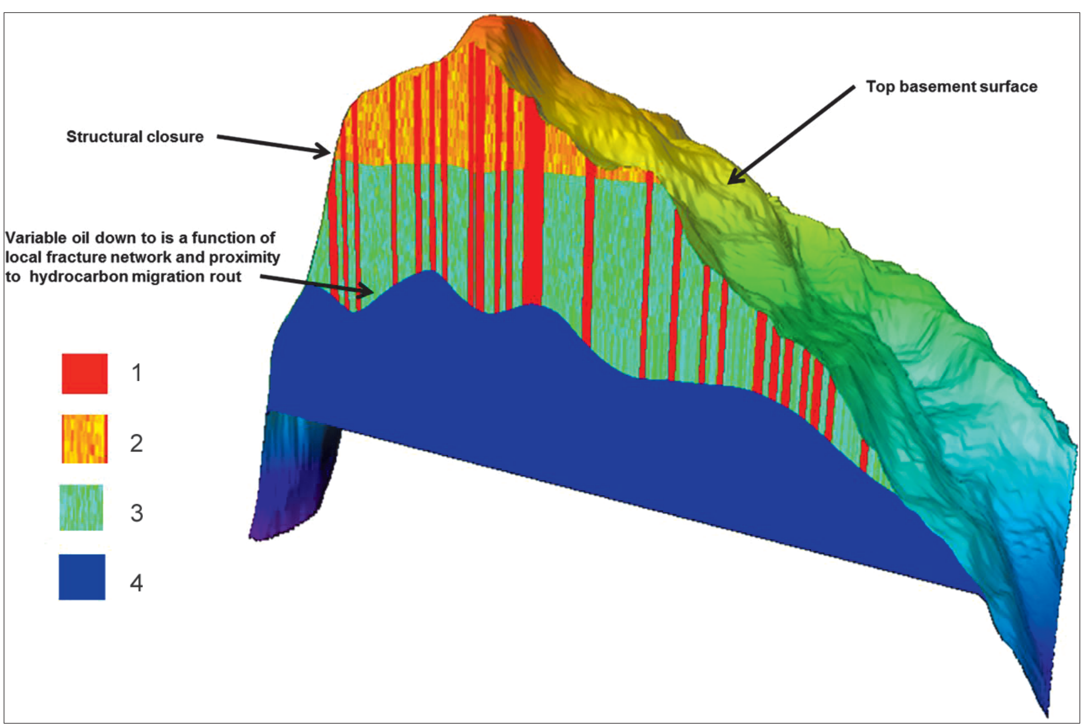

Fig. 3. A volumetric conceptual 3D model of the reservoir of the Lankaster field, constructed through the crest of a crystalline array, depicting the distribution of fluids in a reservoir-trap (Trice, 2014). 1 – fault zone in an oil-saturated formation; 2 – predominantly oil-saturated formation (pseudomatrix in the circuit structure); 3 – reservoir with highly variable water saturation; 4 – water-saturated layer (pseudomatrix outside the circuit structure).

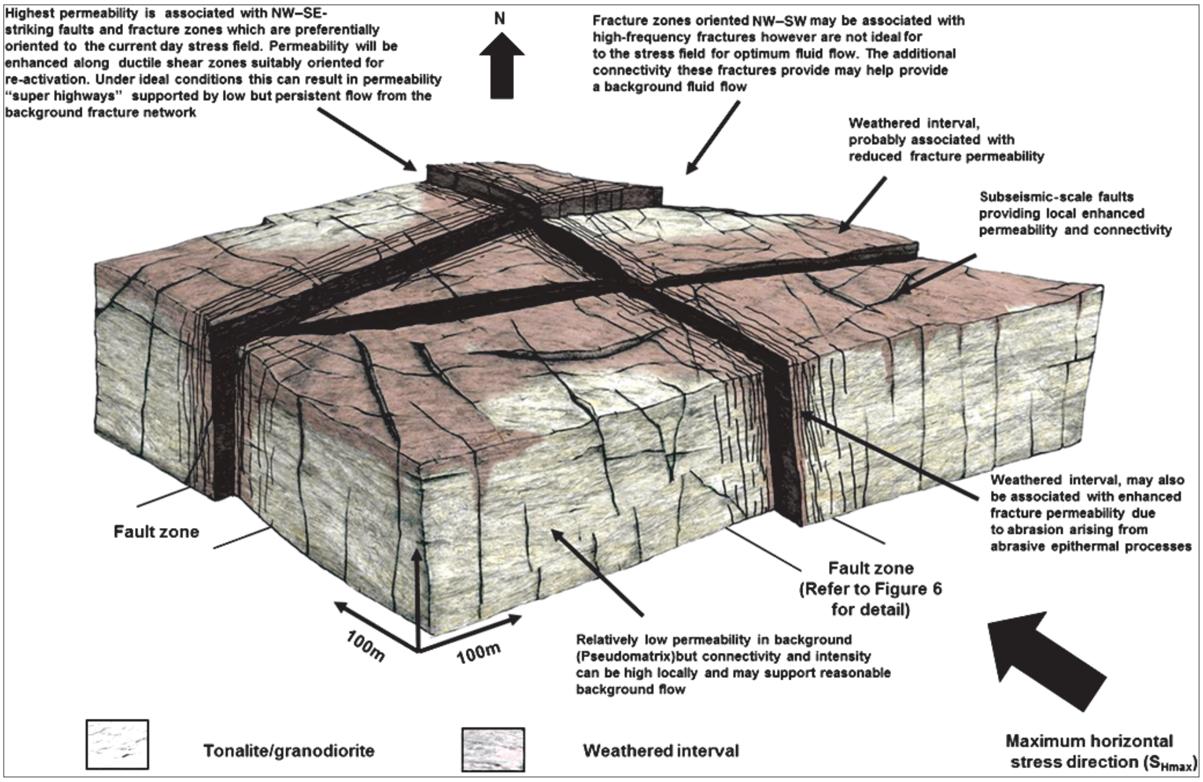

Fig. 4. A conceptual model of a fracture network in the Lankaster field (Trice, 2014)

fluids of the basement fields obey the same laws as the oils occurring in the sedimentary strata of oil and gas basins. In the sedimentary section of the Earth's crust, according to the vertical evolutionary zonality of the formation and transformation of hydrocarbons associated with an increase in depth, temperature gradient, pressure and type of source organics, the composition of the hydrocarbon systems generated in the bowels is transformed – from heavy oils to light and condensates. Their characteristic features are associated with the processes of ontogenesis. Oils contain clear traces of the initial OM, which generated this oil.

According to (Karimov et al., 2019), in the Kyulong basin of Viet Nam, through the contact of the protrusive granites of the pre-Cenozoic basement with the Cenozoic sedimentary cover, there was a lateral migration of fluids from the oil source strata of the Oligocene age to the base – into voids and zones of increased fracture (Fig. 5), into formed fractured-cavernous reservoir of an unconventional trap of a combined type.

The oils from the deposits in the basement and in the Lower Oligocene at the White Tiger field are characterized by close values of almost all the studied hydrocarbon parameters, which correspond to the oils of the mesocatagenesis zone. Such proximity is indicated in many works (Shuster, 2003; Dmitrievskii et al., 2012; Serebrennikova et al., 2012; Punanova et al., 2018, and others). The molecular mass distribution of n-alkanes indicates the generation of oils by organic matter containing coastal algae or land plants; the conditions for its sedimentation are suboxidative. Biomarker

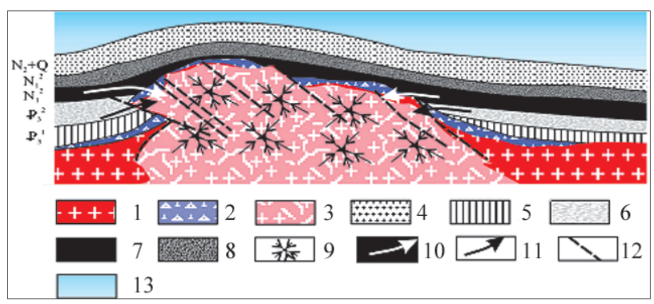

Fig. 5. A fragment of the model for the formation of oil deposits in the granite arrays of the Kyulong basin (present) (Kerimov et al., 2019). 1 – basement; 2 – area of disintegrated granites (protrusion); 3 – weathering zone; 4– Pliocene quarter; 5 – zone of overripe OM; 6 – the main zone of gas formation; 7 – the main zone of oil formation; 8 – zone of immature OM; 9 – conditional areas of hydrocarbon accumulation; 10-11 – the direction of movement of hydrocarbons: 10 – gas phase, 11 – liquid phase; 12 – breaks; 13 – water layer.

parameters confirm the maturity of these fluids. The sedimentary Oligocene and base oil are also close in Trace Element (TE) characteristics (determined by the Dalat Institute for Nuclear Research, Viet Nam): they have low concentrations of V and Ni (0.14 and 3.5 g/t in the basement, and 0.10 in the Lower Oligocene and 2.2 g/t), and in the predominance of Ni (V/Ni <1) they form the nickel type of metallogeny (Fig. 6).

Close results were obtained in detailed geochemical studies (Mosca et al., 2019) conducted in the Cuu Long and Nam Con Son basins (Viet Nam). Data on carbon isotopes in oils and extracts from organic matter indicate a non-marine sedimentation environment. The stage

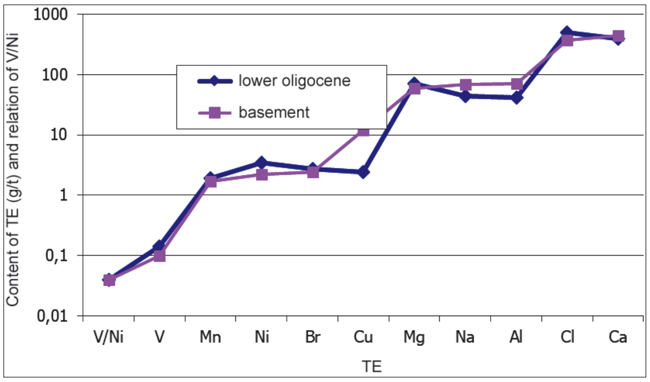

Fig. 6. The content of TE in oils of the White Tiger field

of oil maturation corresponds to the mesocatagenetic stage (refractive index R_0 = 0.78-0.84 %). An analysis of biomarkers based on C_{27}-C_{28}-C_{29} steranes, a high ratio of tricyclic terpanes C_{26}/C_{25}> 1 and a low ratio of C_{29}/C_{30} <1 for hopanes in OM, typical of lake sediments, similar to the distribution of these hydrocarbons in the oils of the Cuu Long basin, confirms them of lake origin and connection with hydrocarbon generation by sedimentary strata of the Oligocene and Miocene. The predominance of light HC together with a very high ratio of pristane/phytane (7-14) is consistent with the generation of oils from OM deposited in an acidic medium. In addition, the content of small amounts of tricyclic terpanes, in significant homogopans (up to C_{33}), the dominance of C_{29} steranes over C_{27} indicates the contribution of terrestrial OM.

At great depths, with active tectonic processes, an additional supply of hydrocarbon fluids containing increased concentrations of light compounds (from C_5 to C_{13}), usually more catagenically transformed (Mosca et al., 2019), can be observed. This is quite clearly confirmed by the data on the Trace Element composition of naphthides, which are characterized by a set of more migratory capable elements (As, Hg, Eu, La, Nb) with respect to V, Ni, Mo, Co and the nickel specialization (Punanova, Rodkin, 2019).

An interesting area for determining the origin of hydrocarbons in the structures of the pre-Jurassic basement of the West Siberian oil and gas basin is the Rogozhnikovsky group of fields of the Krasnoleninsky arch with a Permian-Triassic rock complex at the base. About 100 wells have been drilled here, opening more than 10 km of pre-Jurassic rocks, and almost 30 % of them are reservoirs. The source of oil in this complex can be both the Lower Jurassic oil source Togurian pack and the Late Paleozoic sedimentary deposits. The work (Korzhov et al., 2013) presents the results of experimental studies on the feasibility of interlayer migration of oil hydrocarbons in the near-contact zones of the basement and cover based on the determination of the most migratory saturated hydrocarbons in the rocks of productive Jurassic and Pre-Jurassic sediments of the CP765 North Rogozhnikovskaya well. To clarify the lithological conditions of inter-layer migration of hydrocarbons and the possibility of deep “recharge” of deposits, a detailed lithological-petrographic description of core material was performed. The authors concluded that the oil deposits in the Triassic rocks of the weathering crust were formed as a result of the inflow of hydrocarbons from the lower parts of the Tyumen Formation. The content and molecular mass distribution of saturated hydrocarbons are evidence of inter-layer movements of Jurassic oils into the reservoirs of the weathering crust and basement. Based on the analysis of geological and geochemical indicators, a number of researchers also believe that the oils of the Jurassic and Pre-Jurassic complexes (the zone of contact between the basement and the cover) in the Shirotniy Priobye, Shaimsky, Krasnoleninsky, Khanty-Mansiysk regions of the West Siberian oil and gas basin form a physicochemical characteristic close to hydrocarbon composition group with a single fluid dynamic system and a common focus of oil and gas formation. Only Jurassic deposits are recognized as oil deposits. At the Tolumsky field of the Shaimsky district, it is assumed that the formation of deposits in the upper part of the Paleozoic complex and the Vogulka layers of the Jurassic (1800-2000 m) occurs due to the migration of hydrocarbons from the Upper Jurassic deposits, in particular, the Mulimyinsky suite, which is the oil source. The results of geochemical studies of oil from the Rogozhnikovsky field in the upper part of the Triassic effusive rocks (Turin series, depth interval 2568-2607 m) in the Krasnoleninsky arch indicate that the main source of the pre-Jurassic oils could be clays of the Sherkalinsky Formation of the Lower Jurassic, which have significant generation potential (Korzhov et al., 2013; Punanova, Shuster, 2012, 2018; Shuster, Punanova, 2016; Shuster et al., 2011).

The geochemical characteristics of the oils when they occur in the erosion protrusions of the crystalline basement are different, however, the genetic proximity of the oils from the basement and from sedimentary deposits also appears here. Under these conditions, oil forms in the hypergenesis zone. And a striking example is the oil accumulations of the Mara and Western Mara deposits (Venezuela) (Punanova, 2014; López, Lo Mónaco, 2017). The density of oils reaches 0.991 g/cm^3, sulfur content – 5.54 %, asphaltenes – 18 %. The oils of the Western Mara region (erosive crystalline ledge) are classified as very heavy, with very high sulfur contents (5.6-6.2 %), enriched due to chemical weathering and loss of light fractions with trace elements with industrial concentrations (in g/t) of V (954-999) and Ni (91-96). The oils of the Mara region are medium-heavy, with a lower sulfur content (2.5-3.0 %), V (206-260) and Ni (14-24) (Fig. 7).

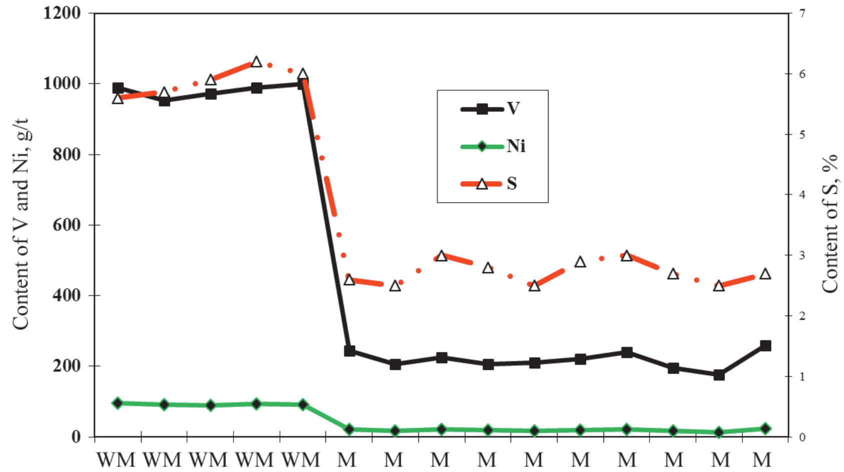

Fig. 7. Changes in the content of vanadium, nickel and sulfur in the oils of the deposits of Venezuela Western Mara (WM) and Mara (M) (according to analytical data (López, Lo Mónaco, 2017))

Geochemical data on the content of biomarkers (López, Lo Mónaco, 2017) indicate that the oils of both regions are genetically unified, are associated with the marine type of the initial OM and are generated by the oil source layer of the La Luna formation (analogous to Domanica), and the observed differences in physicochemical properties and the content of elements are explained by biodegradation processes, which manifested themselves on a large scale in the Western Mara area.

Afterword

It is worth recognizing that the naturally destroyed crystalline rocks of the basement are a global geological phenomenon. Despite proven commercial success, the delay in the implementation of many projects stemmed from the fact that the discovery of hydrocarbon deposits in the basement historically occurred rather by accident, than as a result of targeted exploration programs. Nevertheless, in recent years there has been a successful change in this trend, which leads to numerous discoveries and an increase in the number of developments in the basement.

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