DISCUSSION ARTICLE

DOI: https://doi.org/10.18599/grs.2019.4.27-33

Mixgenetic concept of of oil and gas fields formation in basement and sedimentary cover on the shelf of South Vietnam

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Abstract. According to the geodynamic model of oil and gas formation, the most favorable conditions for the oil and gas fields are formed in the mobile zones of the Earth's crust, especially in areas of active continental margins, characterized by high seismicity, the presence of deep faults, the development of subduction and riftogenic processes. Therefore, it is logical that most of the world's oil and gas deposits are concentrated in rifts or in the vicinity of paleo- and modern subduction zones.

The study of the unique oil deposits in the granite basement of the White Tiger field, using data from other fields in the world, allows concluding that the formation of oil deposits in the basement can occur not only due to the resources of adjacent oil and gas deposits.

Taking into account modern geodynamic ideas, in the context of the Earth's internal geospheres, at least three oil generation zones can be distinguished: mantle-asthenospheric abiogenic synthesis; subduction-dissipative biomineral synthesis; stratospheric-biogenic synthesis.

Obviously, all these three zones, as a single open system for the generation of hydrocarbons, will be interconnected only in conditions of deep faults, active continental margins and other parts of the Earth's crust. This suggests that there are deep generation zones, which are currently fueling the developed fields.

Keywords: subduction, riftogenic processes, geodynamics, granitoid basement, Earth's crust, deep faults

Recommended citation: Utoplennikov V.K., Drabkina A.D. (2019). Mixgenetic concept of of oil and gas fields formation in basement and sedimentary cover on the shelf of South Vietnam. *Georesursy = Georesources*, 21(4), pp. 27-33. DOI: https://doi.org/10.18599/grs.2019.4.27-33

In the geodynamic model of oil and gas formation developed in recent years, three of the most favorable geodynamic regimes are distinguished for this process: rift, subduction, and stratiform.

The combination of these modes found its unique embodiment on the continental shelf of South Vietnam, where a close spatial relationship of oil and gas fields with rifts and subduction zones is traced (Utoplennikov et al., 2005; Areshev et al., 1996a, 1996b; Areshev et al., 2001)

The formation of the geological main features and the development history of the southeastern outskirts of the Asia-Pacific region is due to the interaction of three megalithospheric plates: Eurasian, Indo-Australian and Pacific.

In the southeastern part of the Eurasian Plate, the shallow Sunda shelf and the deep-water Philippine Plate stand out in the convergence zone of these megaplates and are, in fact, a system of paleo- and modern subduction zones and rifts (Fig. 1).

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The widespread development of rifts is a characteristic feature of the continental shelf of Vietnam.

Within the southern shelf, the structural reflection of these processes was the formation of the South Konshonsky, Mekong, Malay, West Natunsky and other rifts. Their structure is complicated by internal uplifts – buried oblique blocks limited by oncoming fall faults in the pre-Cenozoic crystalline basement – the White Tiger, Dragon, Sea Turtle, Conchon, and others, which are collision zones of paleosubduction. In the interblock depressions, the accumulation of terrigenous sedimentary, including oil source strata, was represented by layers of dark gray and black mudstones of the Lower Oligocene.

Strong tectonic fracturing and variability in the secondary processes of the basement and sedimentary cover rocks have contributed to the formation of hydrocarbon (HC) accumulations in them, which migrated into the host sedimentary rocks (Areshev et al., 1996c). This was especially pronounced in the Mekong (Cuu Long) rift basin, in which the ledges of the basement are characterized by a large volume of oil-saturated granites (White Tiger, Dragon, Black Lion deposits) and others, with oil and gas levels up to 2000 m (Fig. 2).

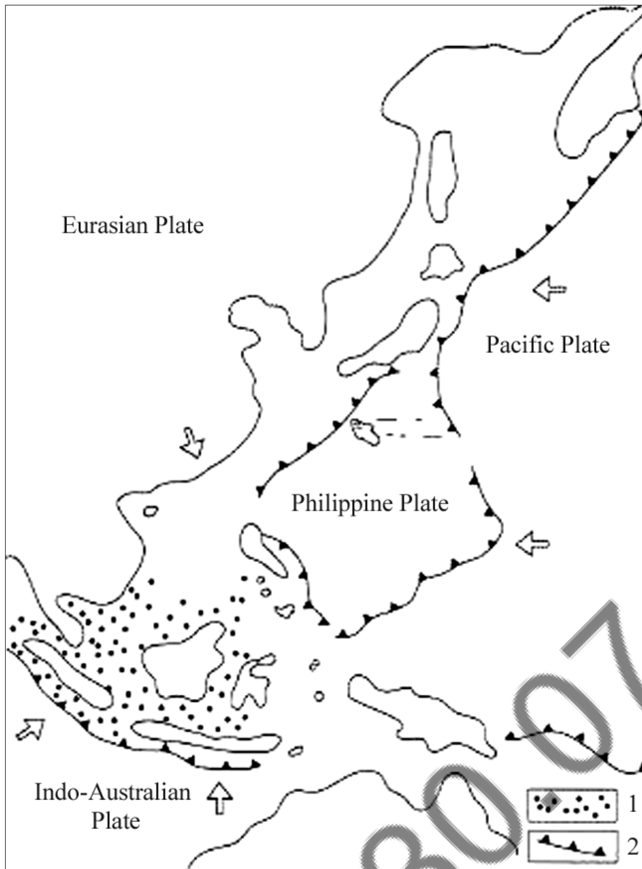

Fig. 1. The position of the plates in Southeast Asia and the northwestern part of the Pacific Ocean: 1 – Sunda shelf; 2 – subduction zones, arrows indicate the direction of tectonophysical stresses (Park, 1993).

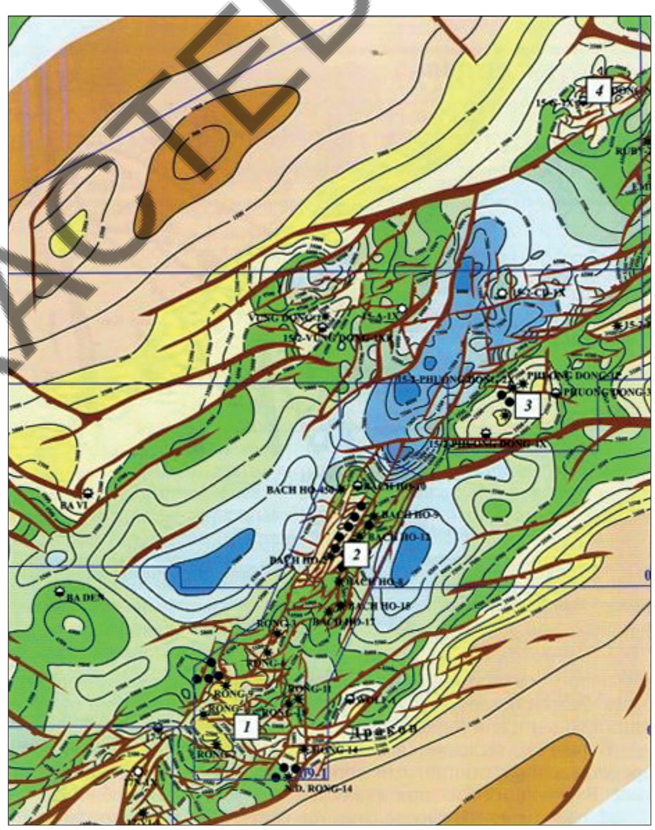

Fig. 2. The layout of oil and gas fields in the Cuu Long basin: 1 – Dragon; 2 – White Tiger; 3 – Rang Dong; 4 – Black Lion.

The large oil reserves identified in the granitoid protrusions of the crystalline basement on the southern shelf of Vietnam suggest that the formation of oil fields was not only due to the oil resources of the Oligocene deposits. An additional source of hydrocarbons could be the organic matter of oceanic crust sediments, which are drawn into the mantle in the zones of subduction of lithospheric plates during subduction processes.

In the upper rear parts of the deepening lithospheric plates, where the crust heating is still relatively small, a temperature regime is created favorable for the sublimation and thermolysis of organics located in the sediments of the movable plate. At this stage, sedimentary rocks are almost completely freed from nutrients, and droplet-forming oil and thermal gas are formed. Together with thermal waters, abundantly contained in oceanic sediments, under the influence of superhydrostatic pressures, hydrocarbons were unloaded in the marginal parts of the continental crust and in the bowels of accretionary prisms.

In subduction zones, favorable conditions are also created for inorganic oil synthesis. The components necessary for the formation of synthetic oil are abundantly found in submantle crust zones.

A significant part of them is represented by carbon dioxide and water, which are extracted from sinking sedimentary rocks and feed the upper layer of the mantle. In addition, the deep zones of the Earth are enriched with CO, CO_2, CH_4, H_2, on the basis of which, as is commonly believed, natural synthesis of oil is possible. It is necessary, first of all, to allocate CH_4 and H_2, which make up a large part of the deep fluid gases and ensure their reducing character.

According to (Gold, 1986), methane in the bowels of the Earth at high pressures behaves like a liquid. It is a good solvent and is therefore able to tolerate heavier hydrocarbons, organometallic compounds and trace elements, which are then deposited at relatively shallow depths due to pressure drop.

As they move toward the Earth's crust, reducing deep fluids are enriched with components from mantle rocks, including metals such as Fe, Ti, Ni, Co, Cr, capable of playing the role of catalysts or being their component (Lurie et al., 2003).

An indication of the mantle methane-hydrogen reducing fluid used to transfer ore elements to the upper horizons of the lithosphere can be found in the presence of native zinc copper (native brass) in the granites of the basement of the White Tiger deposit (Dmitrievskii et al., 1992). Silver-barite mineralization was also noted there.

Findings of native brass associated with sponge gold and native chromium in mineralized crushing zones of igneous rocks in Yakutia are associated with the flows of deep reducing fluids of methane-hydrogen composition coming through a system of tectonic disturbances. It is characteristic that the polytype modification of gold found in association with zinc in Yakutia corresponds in structure to the gold phase obtained by laboratory tests in a stream of hydrogen at a temperature of about 600 °C (Khodyrev et al., 1985). Thus, it can be assumed that the methane-hydrogen stream in the basement of the White Tiger already existed at the high-temperature pneumatolytic stage of the development of the granitoid array. In addition to the above, we also note that the formation of native gold, silver, zinc, aluminum, and iron was discovered in Kamchatka in the modern ore-forming hydrothermal system Uzon, in the thermal fields of which oil leaching is observed (Karpov et al., 1985). Here, native metals arrived with deep fluid flows through a system of steeply falling tectonic disturbances that inherited the zone of a deep fault.

As is known, various metals are used as catalysts for industrial inorganic synthesis of hydrocarbons, primarily Fe, Ni, and Co. Under natural conditions, Fe-Mn-containing silicates, aluminosilicates, and ore minerals can be natural catalysts. According to (Rudenko, Kulakova, 1986), "almost all rocks with a silicate and aluminosilicate composition and containing heavy metal oxides even in low concentrations have sufficient catalytic activity for polycondensation processes". This is also indicated by M.I. Novgorodova (Novgorodova, 1986), assuming that in a medium where CO, CH_4, H_2, H_2O are present, at temperatures of 250-450 °C, hydrocarbon synthesis is possible under the catalytic effect of ore minerals, mainly magnetite and finely divided layered aluminosilicates (mica, chlorites clay minerals).

Among the various ways of synthesizing hydrocarbon mixtures, the possibility of using bifunctional catalytic systems including, in addition to the metal component, aluminosilicate catalysts of acid-base action – clays and zeolites (Ione, 2000) is also indicated. It was shown that in the presence of metal oxide systems mixed with clays, SiO_2, Al_2O_3 and zeolites at 220-450 °C and pressures from 1 to 100 atm, HC synthesis with a wide variation in the content of naphthenes, iso-paraffins and aromatic compounds in their composition is possible (Ione, 2000).

Thus, the above suggests that under natural conditions the most active process of the catalytic synthesis of hydrocarbons at elevated pressures and temperatures can occur in rocks with a high content of minerals – aluminosilicates and silica, acting as catalysts in the reaction of inorganic components of gas: carbon monoxide, hydrogen and methane.

Such rocks, represented mainly by granitoids, compose almost the entire granite shell of the Earth's crust (before the seismic section of Konrad).

Hydrocarbon gases, penetrating the faults and weakened zones into the upper horizons of the lithosphere, have filled the fractured-pore space of the rocks of the Earth's crust. Approximately at depths of 3-10 km, where the temperature and geobaric conditions are most favorable for the formation of oil, its synthesis took place.

Analysis of gas-liquid inclusions in the basement rocks of the White Tiger field showed the presence in the bubble voids of minerals, in closed pores and microcracks of both light and heavy hydrocarbons up to hexane, which indicates the oil nature of the gases. In some quartz grains in granites, inclusions of gasoline fractions are noted, but hydrogen and methane are predominant (Table 1)

Under the microscope, traces of oil are observed in microcracks, small pores, kaolinized feldspar crystals, in cleavage cracks of biotite, and in clusters of fine crystalline zeolite-lomontite (Fig. 3).

It is obvious that the aluminosilicate minerals composing granitoids played the role of natural catalysts here. Secondary changes in minerals that occurred under the influence of auto-metasomatic processes contributed to a more active manifestation of their catalytic properties.

As is known, in heterogeneous catalysis, the activity of the catalyst depends on the size and properties of its surface, i.e. the catalyst must have a porous structure or be in a highly dispersed state. In granitoids, for example, epimagmatic kaolinite $A_{14}[Si_4O_{10}](OH)_8$, which aggregates provide highly dispersed contact with the reacting substance, corresponds to feldspars. It should be noted that Ti, which is invariably present in a small amount in igneous rocks, is a good activator for Al-Si catalysts.

It forms not only independent minerals (sphene, sagenite, etc.), but also freely integrates into the structural positions of the crystal lattices of layered silicates, isomorphically replacing Si in silicon-oxygen tetrahedra, which enhances the action of titanium as an activator.

Comparison of the compositions of mobile oil from the reservoir zones of oil-saturated granitoids at the White Tiger field with hydrocarbon substances from a dense low-permeability matrix showed that their bitumen differ in the composition of paraffins and biomarkers, while the matrix bitumen are less mature. Apparently, the limited amount of microvoids in the rock matrix did not show the full potential of the hydrocarbon fluids contained in them, their resource was exhausted and the isomerization process did not proceed further.

There is a vertical zoning in the oil distribution at the White Tiger field: relatively light and almost identical oils in the basement and in the Lower Oligocene terrigenous complex and medium oils in the Upper Oligocene and Lower Miocene deposits. This fact, apparently, can be explained by the fact that, in contrast to geologically isolated oils in sedimentary rocks of the Upper Oligocene and Lower Miocene, base oils and Lower Oligocene deposits are associated with a deep source of oil fluids characterized by a lower density.

It can be assumed that such a deep source is represented by at least two reaction zones: the mantle-asthenospheric and subduction-dissipative.

The mantle-asthenospheric oil generation zone is located in the thermobaric conditions of the warmed upper mantle (asthenospheric protrusion) and submantle subcrustal zones. Thermodynamic calculations and

H_2 cm^3/kg	CH_4 cm^3/kg	C_2 - C_6 cm^3/kg	Total all gas-liquid inclusions cm^3/kg	CH_4 / $C_2 \div C_6$	i C_4 / n C_4	i C_5 / n C_5
9,8 (46)*	20,8 (46)	8,0 (46)	38,7 (46)	9,6 (46)	2,3 (21)	1,0 (44)
1,9-20,2	0,2-140,5	0,1-82,4	6,2-210,4	0,6-25,2	0,7-15,3	0,2-5,0

*Table 1. The composition of gas-liquid inclusions in granitoid rocks of the basement of the White Tiger field (CPB). * The numerator indicates the average content and the number of analyzes (in brackets), the denominator – the spread of values.*

Fig. 3. Granite. Dark brown bitumen in the leaching pores in plagioclase. Increase × 40 Nicoli + Depth 4307 m, Well BT 448.

experimental data show that the synthesis of petroleum hydrocarbons is already possible at temperatures of 700-1100 °C (Ione, 2000; Rudenko, Kulakova, 1986). It was shown that the geostatic pressure corresponding to such temperatures not only inhibits the thermal destruction of hydrocarbon systems, but also stimulates the polymerization and synthesis of hydrocarbons (Kropotkin, 1986).

If at temperatures above 1000 °C there is a mostly unstable equilibrium mixture of CH_3 and H radicals, then at the turn of 700 °C a stable state of CH_4 radicals is achieved, paraffins and light gasoline fractions are formed.

Thus, in the mantle-asthenospheric zone, the initial stage of oil radicals' generation and the abiogenic synthesis of predominantly light oil systems are carried out.

Under the influence of global geodynamic processes, expressed in the lithospheric shell of the Earth's crust in the form of deep faults, cracks, subduction zones, etc., favorable macrokinetic conditions were created for emanational degassing of the Earth's interior. At the same time, a powerful halo of invasion of asthenospheric petroleum hydrocarbons arose, which, together with a methane-hydrogen stream, rushed under great pressure into the upper horizons of the lithosphere.

A subduction-dissipative oil generation zone is formed in the Zavaritsky-Benioff zone when the oceanic crust submerges beneath the continental crust. In this case, due to the dissipation of viscous friction energy, the subducting crust can be heated up to 1000 °C and more. This heat is sufficient for the palingenic processes, i.e. partial remelting of the solid substance of the crust or its transformation into a visco-plastic state. However, at the initial stage of deepening to 10-12 km, the crust warming up is still relatively small and there are areas with a temperature regime of 150-450 °C, which is favorable for thermolysis and sublimation of nutrients, which are dragged along with oceanic sediments into the sub-zone.

In the same areas, under conditions of high warming and pressure, not only the processes of organic matter transformation into hydrocarbons of the oil series occur, but also mineral abiogenic synthesis of oil is carried out with the catalytic participation of aluminosilicates and ore minerals that make up the rocks of the sialite crust.

Both primary hydrocarbon fluids and products of deep mineral oil synthesis flowing from the asthenospheric foci of the upper mantle also passed through the subduction zone of oil generation.

The active geodynamic situation that existed throughout geological history in the South-Asian region and, in particular, in the area of the modern shelf of southern Vietnam, led to the appearance of deep faults and cracks in the Earth's crust. The resulting pressure drop contributed to the appearance of macrokinetic conditions for the migration of deep oil to the upper horizons of the lithosphere. The oil released from different oil generating zones along the route was mixed, enriching each other with biogenic and abiogenic hydrocarbon radicals.

Reaching the Earth's surface, gas-oil mixtures mainly dispersed in space, without forming industrial clusters.

Only with the formation of rifts in the Oligocene time on the continental shelf of Vietnam, the filling of rift depressions with terrigenous sediments and the overlap of the basement ledges with a powerful sedimentary cover, the formation of industrial oil accumulations became possible.

In other words, buried rift structures were a kind of trap for deep oil. In turn, in the sandy-clay rocks of the rift depressions, their own oil-generating processes proceeded according to the principles of the organic sedimentary-migration concept. The maturation of oil in the oil source strata was facilitated by the inflow of deep heat, as indicated by increased positive temperature anomalies in the White Tiger, Dragon and other oil-bearing areas of the South Vietnamese shelf. Apparently, the main coolant was methane-hydrogen fluid, which has a very high heat capacity. Under its influence, in the zones of increased permeability of the crushed crust, which are rift structures, the accelerated formation of petroleum hydrocarbons occurred.

In addition to the temperature factor, the rifts are characterized by seismic activity, the flow of highly heated deep fluids, consisting of water vapor, hydrogen, carbon dioxide, methane and other components. All this also favorably affected the conversion of organic matter (OM) to oil.

This type of oil generation, which occurs as a result of catagenetic transformations of organic matter in the geological structures of the Earth's sedimentary shell, could be called stratospheric, and the zones in which these processes take place are called stratospheric oil generation zones.

Within the stratosphere, the processes of oil and gas formation occur in various geological settings. This occurs most actively in the conditions of rifts, especially the intercontinental sea rift. Large hydrocarbon reserves are known for platform margins and within the foredeep. The processes of oil and gas formation are much weaker under conditions of syneclise, not complicated by rifts, as well as intra-platform and some intermountain troughs characterized by a depressive geodynamic regime.

Unlike subduction and riftogenic regimes, the depressive regime is characterized by a relatively lower heating of the bowels and, therefore, a more "sluggish" course of oil and gas formation (Gavrilov, 1998). To activate them, the initial precipitation is required to dive to a depth of 2-5 km, i.e. to get into the most favorable thermobaric conditions (to the main phase of oil and gas formation according to N.B. Vassoevich).

Thus, in the context of the Earth's internal geospheres, at least three oil generation zones can be distinguished:

- Mantle-asthenospheric abiogenic synthesis;
- Subduction-dissipative biomineral synthesis;
- Stratispheric-biogenic synthesis.

Obviously, all these three zones, as a single open system for the generation of hydrocarbons, will exist only in conditions of active continental margins, characterized by high seismicity, the presence of deep faults, and the development of subduction and riftogenic processes. Therefore, it is logical that most of the oil and gas fields of the Sunda shelf, including the shelf of South Vietnam, are concentrated in rifts or in the vicinity of modern or ancient subduction zones.

The proposed mixtgenetic concept of oil and gas formation not only brings together "organics" and "inorganics", but also significantly expands the potential of oil and gas resources in regions characterized by manifestations of global geodynamic processes. This is especially true for the active margins of the continents, which are influenced by convection movements of the warmed matter of the upper mantle and injections of asthenospheric plumes.

From the point of view of the mixtgenetic concept, there is an explanation for such a phenomenon that has attracted the attention of oil industry workers in recent years as the modern active generation of hydrocarbons and the renewability of natural oil and gas reserves.

It is known that in many fields the initially estimated oil reserves were repeatedly depleted during their long-term operation. Nevertheless, the prevailing point of view is the non-renewability of hydrocarbon resources, which is based on the classical "organic" theory of the genesis of oil and gas. In fact, many data indicate that oil migration processes are much faster than the proponents of the organogenetic sedimentation hypothesis suggested, as numerous examples of modern replenishment of hydrocarbon reserves in the bowels indicate (Gavrilov, Skaryatin, 2004). This is also confirmed by the White Tiger field, where many wells developing a basement continue to operate in the flowing mode for 12-15 years from the start of commissioning with a flow rate of about and more than 1000 t/d at the same time, cumulative production has long exceeded the estimated initial reserves.

It is obvious that, in addition to the geological redistribution of hydrocarbons during the operation of the fields, there must be some centers of modern oil and gas production and replenishment of depleted reserves. On the continental shelf of South Vietnam, such foci are, apparently, deep oil-generation zones, which, through faults and cracks in the lithosphere crossing the synthesis zones, can still feed oil deposits in rift and subduction oil-bearing structures and blocks of the crystalline basement.

In conclusion, we note that the authors consider the ideas about the existence of inorganic oil synthesis in the deep spheres of the Earth not as an alternative to the organic origin of oil, but as a powerful additional source of hydrocarbon raw materials. A mixtgenetic approach to the problem of oil and gas formation, combining two seemingly irreconcilable points of view, expands the search criteria and the possibilities of identifying promising areas. It also makes it possible to estimate hydrocarbon reserves in active tectonic zones with great optimism and to make cost-effective development of deposits, taking into account the likely replenishment of deposits during their operation.

Financing

The article was written in the framework of the government task (the theme "Development of scientific and methodological basements of the search for large hydrocarbon accumulations in non-structural traps of a combined type within platform oil and gas basins", No. AAAA-A19-119022890063-9).

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Manuscript received 02 September 2019;
Accepted 07 October 2019; Published 30 October 2019