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Criteria for hydrocarbon potential of the basement reservoirs: a case study of offshore South Vietnam

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Annotation

Based on the study of the geological structure of oil and gas fields in the basement of the Cuu Long basin, along with previously published materials from other researchers, several key criteria for hydrocarbon potential have been identified. These criteria can be effectively used to predict and substantiate the prospects for hydrocarbon accumulations in the basement rocks: geodynamic, structural-geomorphological, tectonic, petrographic, and fluid dynamic.

Keywords

Basement, Cuu Long basin, hydrocarbon, rift

Theory

Basement plays have long been developed and successfully produced in many basins in the world including Vietnam, Indonesia, Libya, Venezuela, Russia, USA, Egypt... White Tiger field located in the Cuu Long basin, is known as a giant basement oil field with estimated reserves of 1 to 1.4 billion barrels recoverable. The oil discovery problem of the unique pool in granites of the White Tiger field has great scientific and practical importance in light of the discovery and development of oil fields in basement rocks in various world basins.

The Cuu Long basin is a major Cenozoic sedimentary basin of the continental shelf of Vietnam. This basin has overlaying Cenozoic strata of varying age, origin, spatial distribution, and fragmented Mesozoic basement complexes. As a result of multiple tectonic processes, the basement complexes, which are mostly composed of felsic intrusive and subordinate sedimentary rocks, are frequently severely fractured, fragmented, and partially hydrothermally altered. During the crustal rifting and basin formation processes, Cenozoic sedimentary units covered the basement rocks, which had previously been subjected to weathering before subsidence. Within the basement complexes, these processes produced a network of fractures with adequate pore space and permeability, known as horst and grabens, which are examples of local substantial structural heterogeneity. These characteristics have all helped to create a distinct kind of hydrocarbon reservoir in the basement granitic rocks of the Cuu Long Basin, which have emerged as Vietnam's main targets for oil and gas development.

Several important criteria for hydrocarbon potential have been determined based on the geological structure of the oil and gas fields in the Cuu Long basin's basement as well as previously published data from other researchers. The following criteria: geodynamic, structural-geomorphological, tectonic, petrographic, and fluid dynamic can be used to predict and substantiate the prospects for hydrocarbon accumulations in the basement rocks.

Geodynamic criteria: as shown by Areshev [1, 2], oil and gas fields are concentrated within Cenozoic rift basin: Cuu Long, Nam Con Son, Malay, Sarawak, West Natuna. Significant industrial accumulations of hydrocarbon are located in the Cuu Long basin, the formation of which is associated with the intensive intense rifting processes during the Oligocene. A similar pattern has been identified in other regions. According to the author, the majority of hydrocarbon fields in other sedimentary basin worldwide are associated with Mesozoic and Cenozoic rifts, such as the Melut, Sirten, North Sakhalin, Shelikhov, Ishikari-West Sakhalin, East, Pearl, Siam... rifts. In Russia, hydrocarbon

accumulations in the basement of Eastern and Western Siberia are confined to the zone of development of the riftogenic geodynamic regime [3, 4]. This regime of territory development is associated with active processes in the upper mantle, specifically its uplift and divergent spreading under the lithosphere. In the Earth's crust, this manifests as the intense subsidence of the basin floor and its filling with volcanic-sedimentary and sedimentary strata, increased heat flow, and complex differential movements of individual blocks. All these factors influence the processes of hydrocarbon generation.

Structural-geomorphological criteria: in the Cuu Long basin, all discovered fields are associated with morphological prominent protrusions, complicated by faults and divided into blocks (fig. 1). According to classical concept of massive deposit structures, an elevated protrusion covered by a low-permeability layer is a potential hydrocarbon accumulator. During the formation of high-amplitude uplifts exposed to the surface under hypergenesis conditions, systems of fractures and vugs formed within the basement uplift. According to many researchers, the Oligocene sedimentary deposits adjacent to the basement rocks are the sources of hydrocarbons that filled these void spaces. Until the Late Oligocene, the basement protrusions of the Cuu Long basin were exposed to the surface and subjected to varying degrees of active physical, and chemical weathering, denudation, and erosion. As a result of these processes, numerous fractures, pores, and vugs of various sizes appeared in the surface parts of the protrusions, leading to the formation of void spaces that later became hydrocarbon reservoirs. The clay-siltstone layer that accumulated in the early Miocene, covering the basement protrusions, acts as a fluid seal, retaining hydrocarbons within the basement rocks. Neotectonic movement is a necessary factor for the formation of fractures, fault zones, and the renewal of these zones. In the absence of neotectonic activity, previously formed fracture zones are likely to be healed by secondary minerals, significantly deteriorating their porosity and permeability.

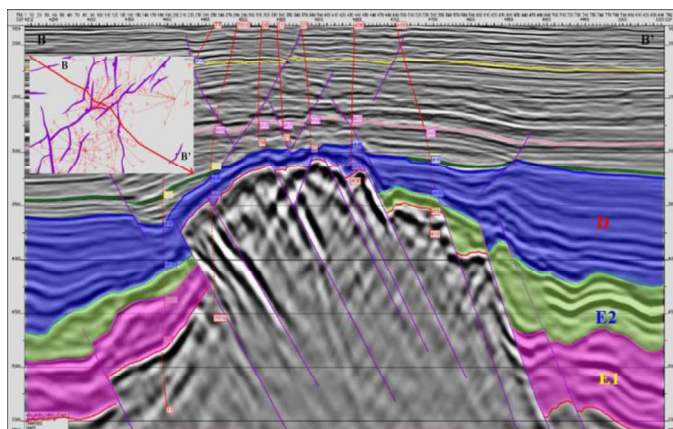


Figure 1. Seismic section BB' through White tiger field

Tectonic criteria: Tectonic activity in the Cuu Long basin has resulted in the formation of a complex block structure of the basement, which was formed under the influence of tectonic processes. The effects of tectonic activity are manifested in the formation of fault zones and associated areas of crushing, cataclasis, and mylonitization. A series of faults has divided the basement surface into several depressions and uplifts.

At the White Tiger field, faults are categorized into four age groups (fig.2): Relatively ancient faults: these are traced only within the basement. Faults traced in both the basement and Oligocene

sedimentary deposits, but not extend beyond the Oligocene; younger faults: these are traced from the basement to Miocene and Quaternary deposits. Faults traced only in the sedimentary cover. Faults are not only as fluid-conducting channels but also as zones of fault zones, and high-capacity reservoirs. They are the main reservoir of oil.

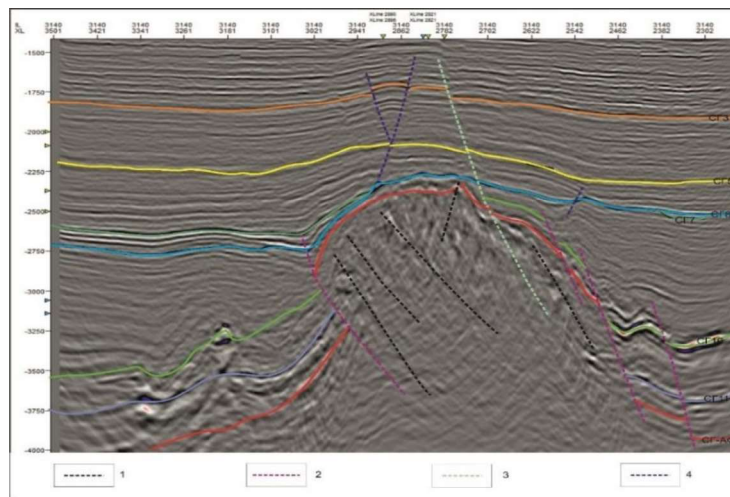


Figure 2. Types of fault systems at the White Tiger field. 1) faults located only within the basement; 2) faults traced both in the basement and in the Oligocene sedimentary deposits; 3) faults traced from the basement to the Miocene and Quaternary deposits, including faults traced only in the sedimentary cover - 4

Fluid-dynamic criteria. The analysis of the flow rate dynamics of production wells exploiting basement, Oligocene, and Miocene deposits shows that the highest flow rates and accumulated volumes for all objects are achieved by wells located near active tectonic faults (fig. 3).

The presence of degassing signs, indicated by gas saturation in the intervals of the section, suggests ongoing fluid migration processes from basement rocks to the sedimentary strata. This can be a direct indication of a high probability of hydrocarbon deposits in the basement rocks.

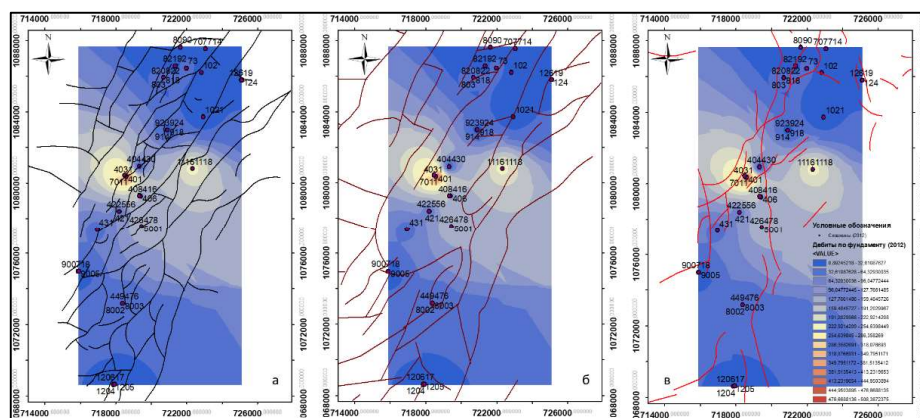


Figure 3. Maps of initial flow rates of production wells along the basement of the White Tiger field with fault systems of different ages: a) faults in the basement; b) faults in the Lower Oligocene; c) faults in the Lower Miocene

Petrographic criteria

The primary targets for oil exploration are granitoid masses. According to Shuster et al. [4, 5], granitoid account for over 80% of the hydrocarbon reserves in basement rocks. For example, oil inflows from granites at fields like White Tiger (Vietnam), Augila-Naafora (Libya), Zeit Bay (Egypt), La Paz (Venezuela)... can reach up to 1000-2000 tons per day. The Lancaster field (UK) commenced production in June 2019 and is producing 17000 bpd from 2 production wells [6]. About 11% of the total explored hydrocarbon reserves in basement rocks are associated with metamorphic rocks, found in fields such as Wilmington (USA), Requiun, Weizuan (China) ... Approximately 6% of the reserves are linked to volcanic rocks, as seen in fields like Carmopolis (Brazil), Tanjung (Indonesia), and Pandra (India).

In the Cuu Long basin, hydrocarbon deposits are closely related to unconventional reservoirs, including fractured and fracture-cavernous zones developed within basement rocks. The basement rocks are mainly composed of granites, granodiorites, diorites, and quartz diorites. Only at the Dragon field are rocks of high-grade regional metamorphism, such as biotite gneisses and amphibolites. Fractures and caverns were formed due to two main factors: primary – contractional shrinkage during cooling and crystallization of magmatic rocks, secondary – tectonic activity, hypergene and hydrothermal processes. Hydrothermal processes were particularly active in the basement rocks, leading to the formation of many secondary materials such as quartz, chlorite, limonite, calcite, pyrite, kaolinite, and zeolites, which partially fill secondary voids. These processes not only filled fractures with secondary minerals like calcite and zeolite but also expanded existing fractures through leaching.

Conclusions

A set of key criteria for the hydrocarbon potential of the basement in the Cuu Long Basin has been identified and substantiated. These criteria include geodynamic, tectonic, fluid-dynamic, structural-geomorphological, and petrographic factors. This set of criteria allows for targeted application in the assessment and prediction of the prospects of similar structures in basement rocks in other regions of the world.

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