Core Analysis Experience for Fractured Basement Rock at J/V "Vietsovpetro", Vietnam

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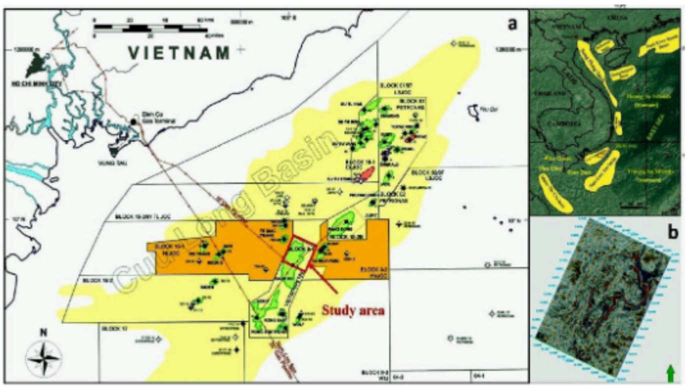
Abstract

This study presents a comprehensive methodology for core analysis of fractured basement rock at J/V "Vietsovpetro". The process begins with a detailed visual description of the core sample, followed by a fracture study to determine fracture density, azimuth, strike, and dip. Probe permeability and radioactivity are measured using traditional methods. The conventional core plug sampling approach is found to be unsuitable for highly heterogeneous fractured basement rock. A new core plug sampling approach is proposed, which involves increasing the core plug diameter and sampling frequency to better preserve vug-macrofractures. Post-cutting core plug analysis includes determining gas permeability, porosity, cut-off porosity, grain density, acoustic velocity, compressibility, capillary pressure curves, and wettability. The study also highlights the need for additional analysis of initial residual water saturation in the reservoir using preserved core, trace element analysis, and determination of radioisotope age. Certain parameters such as electrical properties and cation exchange capacity are deemed unnecessary for fractured basement rock. The findings of this study are crucial for improving the reliability of core analysis results and have significant implications for oil and gas exploration and production.

Keywords: *core analysis, fractured basement, Bach Ho*

1. Introduction

One of the key objectives of the most recent exploration plan is fractured basement [1]. According to [2], there are fractured basement reservoirs in over 25 basins in more than 30 nations. The most well-known is the White Tiger offshore oil field located in Vietnam's Cuu Long Basin. The reservoir has produced 180 MBBL cumulatively since it was found in 1986. Roughly 85% of Vietnam's hydrocarbon output comes from fractured basement rocks [1, 3]. In addition, when possible fractured basement play fairways are identified early on, oil companies may be encouraged to alter their drilling strategy and focus instead of avoiding basement targets by designing wells that optimally intersect the dominant fracture systems [4]. Therefore, determining the characteristics of fractured basement rocks is necessary. Some methods have been published by many scientists around the world, such as using high-resolution 3D seismic and logging datasets [2], geophysical well log data [5], several qualitative and quantitative well logging procedures [6], dual media approach [7], etc. In addition to using the available well logs, 2D seismic data, etc. the basement reservoirs can be detected and assessed using the core analysis results. These core analyses include description for the rocks and determination of porosity, permeability, fluid saturation and grain density [5]. In every stage of the petroleum business, core retrieval and analysis are crucial. Reducing uncertainty in reservoir appraisal is the primary objective of core analysis, which provides data typical of the reservoir under in-situ conditions. Coring and core analysis technology have been mentioned in many research. While [8] presented an overview of current and future trends and advancements in this technologies, [9] provided summary of hydrate coring management and analysis, [10] offered pressure-coring methods in boreholes and in situ pressure core analysis. For "intact" oil and gas reservoir features, core analysis offers the only precise and quantitative assessment available. It ought to offer the basis for evaluating formations in order to construct both static and dynamic reservoir models [11]. According to [12], core generated data have been merged with other field data to reduce reservoir uncertainties that can't be solved by other sources of information like well logging, well testing, or seismic. Therefore, in order to improve the reservoir evaluation procedures, they presented an overview of existing and emerging advancements and trends in core analysis and coring technologies. In addition, since core damage is a major problem during coring and handling, accurate data calibration for exploration is put at risk, therefore [13] have mainly focused on identifying and mitigating it. In this paper, they provided a useful manual for coring and downhole rock sampling as well as explaining and analyzing the various coring techniques. Recently, there area many studies have mentioned cores and core analysis. Developments in gas hydrate drilling investigations-related wireline pressure coring, core handling, and core analysis were presented in study [14]. The obtained results show that while gas hydrates have been the primary focus of these applications thus far, the technology can also be used to other unconventional hydrocarbon resources, particularly those associated with shale oil and gas. Besides, to assist and calibrate the estimation of rock properties, [15] discussed core analysis, applications, and coring types. The findings show that real reservoir rock samples can only be obtained via coring, and thus real reservoir rock can only be handled through core analysis. In other study, based on the analysis



Fig, 1. Location map of study area [17]
Rys. 1. Mapa lokalizacyjna obszaru badań [17]

of core, properties of basement fracture reservoir were determied. By identifying the orientation of the fractures, the most suitable drill direction can be forecasted when looking for a reservoir [16]. In order to minimize data uncertainties and assure efficient quality control of test data, [11] described the necessity for a core analysis management architecture and a best practice guide for core analysis data collecting.

Up to now, a number of authors have conducted research at Bach Ho field. While [17] conducted eismic attribute analysis in Lower Miocene reservoir characterization, northeast Bach Ho field, [18] make an effort to analyze the basement reservoir's fracture distribution and to determine the variables affecting the reservoir's quality in this zone, [19] researched on the production performance of Bach Ho field's granite-fractured basement reservoir, [20] presented the procedure to generate chemical system at pilot scale and trial industrial application for miocene reservoirs in Bach Ho field. However, no studies have mentioned core analysis for fractured basement rock. Thus, the aim of this study is to perform provides a thorough approach for J/V "Vietsovpetro" core investigation of fractured basement rock. The results of this study have important influences for oil and gas exploration and production as well as for enhancing the dependability of core analysis results. The contents mentioned here are drawn from the experience of analyzing core for more than 35 years at Vietsovpetro combined with the requirements for core data that are necessary for the exploration, log interpretation, reserve assessment, building field development plan and enhancing oil recovery for Bach Ho fractured basement reservoir.

2. Study area

According to information from the Vietnam Energy Association, Bach Ho mine was discovered in 1975 and began operating on September 6, 1988. This is the largest oil field on the continental shelf of the Cuu Long basin, located in the Southeast, 145km from the coast of Vung Tau, exploited by Vietsovpetro. Vietsovpetro did not begin to develop the Bach Ho "buried-hill" until the middle of the 1980s. Figure 1 displays the location map of study area. At Bach Ho, igneous and metamorphic rocks that have not undergone significant alteration make up the majority of the matrix found in between hydrocarbon-filled fractures [18]. Basal andesite, poocfia diaba, and crystalline magmatic granitoid from the Jura and Cretaceous ages make up the basement.

The unusual nature of the oil pay zones in the fractured basement is attributed to their remarkably high levels of heterogeneity, anisotropy, and permeability. Because of the impact of the Cuu Long Basin's tectonic context, the research region is regarded as a narrow sub-thought and a tertiary structural unit of small scale [17]. Figure 2 shows basement distribution in the Bach Ho region, Cuu Long Basin, Vietnam.

3. Methodology and data

3.1. Core analysis before cutting core plugs (using original core set)

** Core description*

Visually describe the state of the core sample, color, preliminary petrographic characteristics, degree of fracturing, fracturing characteristics, oil trace... in order to preliminarily identify the rock type, porous-permeability characteristics and oil sign of the collected core set.

** Fracture study*

The fracture density, fracture azimuth, fracture strike and fracture dip are determined along entire oriented North-South core set using traditional method. Obtained results are presented in the form of histograms of fracture density, true azimuth, true strike and fracture dip, and that are used to correct FMS, FMI data, build an overall picture of fracture density and fracture development orientation for the whole reservoir. These results are useful for designing the new wells, building well trajectory, choosing perforation interval, selecting well completion techniques, etc. Therefore, it is necessary to take oriented core instead of traditional core to study fracture system for the fractured basement reservoir.

** Determination of probe permeability*

Probe permeability is measured along entire core set using traditional method. Obtained results were used to build the permeability profile by depth for quick assessment of productivity of the coring depth interval.

** Determination of radioactivity*

Total radioactivity and elemental spectrum radioactivity are measured along entire core set using traditional method. Obtained data will be used to correct the depth of log data (depth shift) and to calibrate gamma log data.

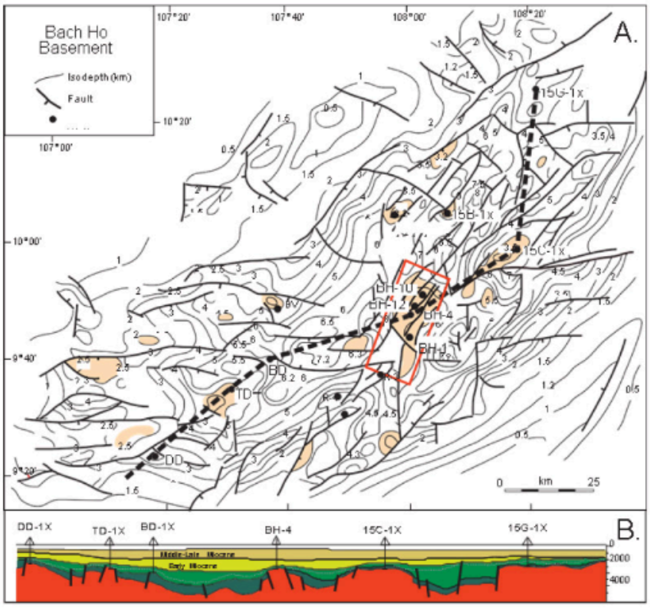


Fig. 2. Basement distribution in the Bach Ho region, Cuu Long Basin, Vietnam [18]
Rys. 2. Rozmieszczenie skał podłoża w regionie Bach Ho, Cuu Long Basin, Wietnam [18]

3.2. Core plug sampling approach for fractured basement rock

The conventional core plug sampling approach applied to homogeneous sedimentary rock is no longer suitable for highly heterogeneous fractured basement rock because the small diameter standard core plugs (Φ≤1.5") usually contain only microfractures and tight matrix (the rock part containing vug-macrofractures is often broken during cutting core plugs). This is the reason why the core analysis results will not accurately reflect the porous-permeability characteristics of the rock. In order to overcome this weakness, it is proposed to apply the new core plug sampling approach to best preserve the vug-macrofractures present in the rock by increasing the core plug diameter (Φ≥2") and increasing the core plug sampling frequency.

- Conventional core plug sampling approach (Figure 2): Standard diameter core plugs of Φ≤1.5" are cutted at regular intervals along the entire core set at a frequency of 3-4 plugs/1 m core.
- New core plug sampling approach (Figure 3): Full size cores are sampled from the top to the bottom of core set by cutting the entire core set into separated cylinders, or cutting large diameter core plugs (□>2") at a frequency of 10-15 plugs/1 m core.

3.3. Core analysis after cutting core plug (using core plug)

** Determination of gas permeability*

Full size cores or large diameter core plugs are proposed to use to determine vertical and horizontal permeability using traditional method, except some adjustments to the coreholder of measuring equipment. Thanks to the application of new core plug sampling approach, permeability for almost entire core set will be determined. The core permeability is used to correct the permeability interpreting results by log, FMS, FMI and welltest. Permeability data by FMS, FMI and welltest is used to design new well position, build well trajectory, choose perforating interval, build dynamic model.

** Determination of porosity*

Full size cores or large diameter core plugs are recommended to use to determine porosity using traditional method. Thanks to the application of new new core sampling approach, porosity for almost entire core set will be determined. The core porosity is used to correct the porosity interpreting results by log. Porosity by log interpretation is used to locate new well position, build well trajectory, choose perforation interval, assess OOIP, build geological model.

** Determination of cut-off porosity*

Cut-off porosity is an important value used in log interpretation to determine reservoir effective porosity. Effective porosity is used for assessing OOIP, building reservoir geological model.

For sedimentary rock: Porosity usually has a strictly linear relationship with gas permeability, therefore, porosity cut-off is determined based on relationship between gas permeability and porosity (Kg-Φ) corresponds to gas permeability cut-off (Kg*). Gas permeability cut-off is determined based on relationship between gas permeability and oil permeability when oil permeability is zero.

For fractured basement rock: Porosity has a very discrete relationship with gas permeability (core data shows correlation Kg-Φ has very low regression coefficient: <0.3), therefore, the determination of cut-off porosity by traditional method for sandstone is no longer applicable. Instead, porosity cut-off (Φ*) is recommended to be determined based on the correlation between dynamic porosity (Φdyn) and effective porosity (Φeff) when dynamic porosity equals to zero {Φdyn=Φeff*(1-Sro-Srw)}. The philosophy of this solution is that oil and water coexisted in the vug-fractures will be immobile when dynamic porosity is zero, i.e., then there is only residual water and residual oil in the pore space (Srw+Sro=1).

** Determination of grain density*

Grain density for fractured basement rock is determined by traditional method. Grain density is used to calculate the

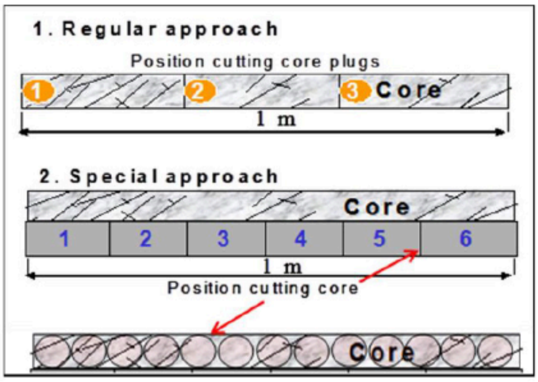


Fig. 3. Scheme of core plug sampling for fractured basement rock
Rys. 3. Schemat pobierania próbek korka rdzeniowego dla spękanej skały podłoża

porosity and correct the porosity interpreting results by log density.

** Determination of acoustic velocity*

Full size cores or large diameter core plugs are proposed to use for determining the rock acoustic velocity using traditional method. Acoustic velocity is used to calculate the porosity and correct the porosity interpreting results by log acoustic.

Noted that, the relationship between acoustic velocity and porosity for fractured basement rock is very weak, acoustic velocity for one core plug (one porosity value) can be quite difference when measuring direction changed (due to the effect of fracture development orientations in the core). Thus, caution should be taken when using porosity interpreting results by acoustic log for this type of rock.

** Determination of compressibility*

Full size cores or large diameter core plugs are proposed to use for determining compressibility using traditional method. Rock compressibility is used for OOIP assessment by material balance method, reservoir simulation, etc.

There are some contradictory opinions about skeletal effect for fractured basement reservoir. Specifically, effective overburden pressure increased due to reservoir pressure reduction during reservoir production will only impact on the skeletal frame of the reservoir and no impact on reservoir pore space (this can be occurred in the whole reservoir or only locally). Therefore, caution should be taken when using the compressibility for OOIP assessment and reservoir simulation.

** Determination of capillary pressure curves*

Full size cores or large diameter core plugs are proposed to use for determining capillary pressure curves using traditional method. Obtained capillary pressure curves showed the coexistence of microfractures and vug-macrofractures in the fractured basement rock. Those were well reflected by the presence of two parts of capillary pressure curve with different slope angles (that controlled by different forces – capillary and gravity: Capillary force impacts on fluids in microfractures and gravity impacts on fluids in vug-macrofractures). Based on this physical basis, the cut-off macrofractures aperture can be determined using capillary pressure value corresponding to the abrupt change point of slope angles on the capillary pressure curves. Calculated result shows that the cut-off macrofractures aperture for Bach Ho fractured basement rock is approximately 60 μm.

** Determination of wettability*

Full size cores or large diameter core plugs are proposed to use for determining the rock wettability using Amott method. The contact angle measuring method is not recommended because the fracture surfaces are often very rough due to the presence of secondary minerals, this leads to potential error for the measured contact angle.

The rock wettability has a decisive influence on the selection of fluid that employed for displacing oil in the secondary and tertiary production processes, decision of injecting gas or water depends on rock wettability (oilwet or waterwet).

** Determination of oil displacement efficiency*

It is necessary to determine the capillary oil displacement efficiency (imbibition displacement) and hydrodynamic oil displacement efficiency (forced displacement). Hydrodynamic oil displacement efficiency is determined by traditional method including water flood and gas injection. Full size core or large diameter core are suggested to use to increase the study pore volume and to increase the number of fractures in the core aiming to enhance the reliability of the experimental results. Oil displacement efficiency is used to calculate recoverable oil reserves and build FDP.

** Determination of relative permeability*

Full size core or large diameter core plug is suggested to use for experimental study to determine relative permeability. The relative permeability is used to build FDP and run reservoir simulation, etc. There are two methods for determining relative permeability: Steady-state flow and unsteady-state flow. The steady-state method is proposed to use to determine relative permeability for fractured basement rock based on:

- The rock specific porous structure (dual porosity and dual permeability).
- The physic of flows in fractured medium: Forced displacement in fractures only, not significant in matrix, only spontaneous mechanism is efficient for recovering matrix oil: expansion, capillarity, gravity drainage and dispersion.

- The nature of steady-state flow method: Several phases (oil, gas, and water) are injected simultaneously into the core sample at different volume ratio. At each volume scale: The effective permeability is determined directly using differential pressure between the two core ends and the saturation of each phase is determined directly for the entire core pore volume using the material balance method. For fractured basement rock: Simultaneous phases flow occurs mainly in macrofractures and at the same time occurs the mass transfer between fluid existed in the macrofractures and microfractures owed the phases flowing time in the core elongated. These factors make an important contribution to ensuring the high reliability of relative permeability determination results.
- The nature of unsteady-state flow method: Only one phase (gas or water) is injected into the sample to displace oil at a relatively high flow rate (high rate to eliminate the influence of capillary end effect). The effective permeability and its corresponding saturation of each phase are determined indirectly only at the core outlet end cross-section after the water/gas breakthrough by graphic or computed techniques. For fractured basement rock: Simultaneous phases flow quickly occurs only in macrofractures that driven by strong viscous force, no occurrence of mass transfer between fluid existed in macrofractures and microfractures, these cause large error to the determined results of effective permeability and saturation of each phase on the core output cross-section. Therefore, it is not to suggest to use this method to determine relative permeability for fractured basement rock.

** Determination of the secondary mineral compositions*

The secondary mineral compositions and their contents are determined by traditional methods. Obtained results are useful for designing well completion and choosing workover solutions.

** Determination of rock types*

Rock types are determined by petrographic analysis using thin section. Each basement rock type has specific mineral compositions and contents. The mineral composition and content significantly influence the logging results including GR, RHOB, NPHI. Thus, rock type is an important input data that used for interpreting log RHOB, NPHI to determine porosity (using BASROCK software).

4. Results and discussion

4.1 Parameters that do need to additionally analyze

** Determination of initial residual water saturation in the reservoir using preserved core*

For sedimentary rock (granular porous rock):

Residual water saturations are determined in laboratory by different techniques (restored state cells, centrifuging). The cut-off value of residual water saturation is determined by well-known laboratory correlation of gas permeability and residual water saturation (Kg-Srw) based on gas permeability cut-off value. This data is used in resistivity log interpretation to determine net pay and oil saturation for OOIP assessment.

For fractured basement rock: It is impossible to determine the residual water saturation cut-off value by method applied for sedimentary rock as mentioned due to the weak correlation between gas permeability with residual water saturation (regression coefficient is very low: < 0.3). For this reason, the residual water saturation (initial oil saturation) used to assess OOIP for the Bach Ho fractured basement reservoir was taken assumedly.

The potential error reserve of the Bach Ho fractured basement reservoir (calculated with the assumed residual water saturation value of 0.15 similar to the residual water saturation for oil reservoir in fractured carbonate rock according to world experience) and the fact that formation water has not been encountered in more than 35 years of production has posed the necessary to determine the actual residual water saturation for this reservoir in order to correct OOIP and improve production efficiency.

Residual water saturation of the Bach Ho fractured basement reservoir can be determined accurately in the laboratory using preserved core that taken with an oil-based mud (the sample should be taken at the moment before injecting water into the reservoir). However, due to the lack of previous experience working with fractured basement reservoir, Vietsovpetro did not carry out taking preserved core to determine the initial residual water saturation for the Bach Ho fractured basement reservoir.

** Trace element analysis*

Determination of trace elements, rare earth elements present in magma rock with extremely small concentrations in ppm to determine the origin and geodynamic context forming magma rock.

** Determination of radioisotope age*

Determine the absolute age of the rock (radioisotopic age U-Pb, Rb-Sr, Sm-Nd, K/Ar,..) and the source domain of the rock-generated magma lava (using isotope ratios - IR).

4.2 Parameters that do not need to analyze.

** Determination of electrical properties (formation factor and resistivity index)*

For sedimentary rock, formation factor and resistivity index are used to calculate water saturation by Archie's equation $Swn=(a*Rw)/(\square m*Rt)$ based on the abnormallyhigh resistivity at oil zones and abnormally low resistivity at water zones. Calculating water saturation for fractured basement rock according to Archie's equation is no longer appropriate because this rock has a very high resistivity, thus cannot distinguish oil-bearing zones from the tight matrix zones by log resistivity. Thus, it is no need to study core electrical properties for fractured basement rock.

** Determination of cation exchange capacity (CEC)*

CEC is perceived as the ability of some rock minerals (clay minerals) to exchange ions with the ions that existed in contacted water. This data is useful for correcting cementation factor (m) and saturation exponent (n) for sedimentary rock. However, as mentioned above, values of m and n were not investigated for fractured basement rock, thus, no need to determine CEC for this type of rock.

5. Conclusions

This study introduces a novel core plug sampling method for fractured basement rock, aiming to enhance the reliability of core analysis results by better preserving vug-macrofractures in large diameter core plugs and full-size cores. The Amott method is advocated for determining wettability, while the steady-state method is recommended for ascertaining relative permeability for fractured basement rock. The type of rock is identified as a crucial input for log interpretation to determine porosity. When utilizing rock compressibility for fractured basement reservoirs, it is imperative to consider the skeletal effect. The study finds it unnecessary to determine the formation factor, resistivity index, or cation exchange capacity for fractured basement rock. Lastly, the study underscores the necessity of using preserved core taken with oil-based mud to determine the initial residual water saturation. This is a critical step for correcting Original Oil In Place (OOIP) for fractured basement reservoirs. These findings provide valuable insights and recommendations for future research and practices in the field of core analysis for fractured basement rock. This study contributes significantly to the body of knowledge and has potential implications for oil and gas exploration and production.

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Conflicts of Interest

The authors declare no conflict of interest.

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Doświadczenie w analizie rdzeniowej spękanej skały podłoża w J/V "Vietsovpetro" w Wietnamie

W pracy przedstawiono kompleksową metodologię analizy rdzeniowej spękanej skały podłoża w J/V "Vietsovpetro". Proces rozpoczyna się od szczegółowego wizualnego opisu próbki rdzenia, po którym następuje badanie pęknięć w celu określenia gęstości, azymutu, uderzenia i zanurzenia. Przepuszczalność sondy i radioaktywność mierzy się tradycyjnymi metodami. Stwierdzono, że konwencjonalna metoda pobierania próbek zatyczek rdzeniowych jest nieodpowiednia w przypadku bardzo niejednorodnych spękanych skał piwnicznych. Zaproponowano nowe podejście do pobierania próbek czopu rdzenia, które polega na zwiększeniu średnicy czopu rdzenia i częstotliwości próbkowania w celu lepszego zachowania makropęknięć typu vug. Analiza korka rdzeniowego po cięciu obejmuje określenie przepuszczalności gazu, porowatości, porowatości odcięcia, gęstości ziaren, prędkości akustycznej, ściśliwości, krzywych ciśnienia kapilarnego i zwilżalności. W pracy wskazano także na potrzebę przeprowadzenia dodatkowej analizy początkowego nasycenia resztkowego wodą zbiornika z wykorzystaniem konserwowanego rdzenia, analizy pierwiastków śladowych oraz określenia wieku radioizotopowego. Niektóre parametry, takie jak właściwości elektryczne i zdolność wymiany kationów, uważa się za niepotrzebne w przypadku spękanej skały piwnicznej. Wyniki tego badania mają kluczowe znaczenie dla poprawy wiarygodności wyników analiz podstawowych i mają znaczące implikacje dla poszukiwań i wydobycia ropy i gazu.

Słowa kluczowe: *analiza rdzenia, spękane podłoże, Bach Ho*