# Comparative Study of the Selected Basement Discoveries around the World with Special Emphasis to Anding Utara of Peninsular Malay Basin

by

Noor Ilyana Binti Ismail

Final report submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Petroleum Engineering)
JANUARY 2011

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

## CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Petroleum Engineering Programme
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in partial fulfillment of the requirements for the
BACHELOR OF ENGINEERING (Hons)

(PETROLEUM ENGINEERING)

Approved by,

Dr Swapan Kumar Bhattacharya
Associate Professor
Petroleum Engineering Department
Universiti Teknologi PETRONAS
Bandar Seri Iskandar, 31750 Tronoh
Perak Darul Ridzuan, Malaysia.

(A.P Dr Swapan Kumar Bhattacharya)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2011

“There is a value in every single thing that happens especially to one’s life regardless if it is good or bad; it is the nature way of teaching, through what is called experience. One year is too long in a mind of a fresh student, who has not yet exposed to the real life and real adventure, but as a final year student, it is not enough to load it with all the knowledge and exposure to carry a project individually. Final year project is where it all begins, the next stage of a regular student to become a successful person, by learning hardship through experience”, *Noor Ilyana Ismail.*

# ABSTRACT

A technical comparison of the selected basements discoveries have been made based on geology, geochemistry, reservoir characteristics and production behavior of selected basement reservoirs to find an analog to Anding Utara Field. Anding Utara, a fractured basement discovery in the Peninsular Malay Basin could not be developed yet due to inconsistent production testing results. Thus, Anding Utara has become an engineering challenge to put it on production. Four basements discoveries, White Tiger field of Vietnam, Zeit Bay field of Egypt, Jatibarang field of Indonesia and Yaerxia field of China, have been compared of which the Yaerxia field is seen as similar behavior with Anding Utara field. These two fields have same lithology (phyllite), nearly equal reservoir pressure and also both have high wax content (exact value of Anding Utara is not known). However, Anding Utara field has higher reservoir temperature (270 °F) and higher GOR (4210 scf/stb) compared to the Yaerxia field but, the fracture density is comparatively low. The Yaerxia field, with lower temperature (187 °F) and lower GOR (350-584 scf/stb), shows stable production for almost nine years because of its high fracture density (39 counts/m). The Anding Utara on the contrary shows inconsistent production even with high temperature and high GOR only because of low fracture density (0.1-1 fractures/m). From the study, it confirms that the fracture distribution and connectivity plays an important role in hydrocarbon production from the basement reservoirs. Artificial fracturing by hydraulic fracturing and matrix acidizing to increase the permeability, and horizontal wells to connect extensive vertical fractures are suggested here as a possible engineering solutions for the Anding Utara to put it back on production.

# ACKNOWLEDGEMENT

I would like to take this opportunity to thank all parties involved in completing the project to a great success. Honorably thanking Geosciences & Petroleum Engineering Department of UTP for giving me the opportunity to carry out this final year project. I am grateful to PETRONAS (PMU & Carigali) for giving me permission, data and necessary help to complete this project. I am also thankful to Anding Utara Development Team of PETRONAS Carigali for details discussion and comprehensive data support to complete my research study. Personally I would like to thank the following for their respective contribution to the project.

- Mr. Dr Jaizan Hardi Mohamed Jais, General Manager, PMU
- Mr. Ahmad Abeed Mohd Lotfy, PSC Data Management Team, PMU
- Mr. Zainal Abidin Juni, Petroleum Exploration Team, PCSB
- Mr. Ahmad Adnan B A Aziz, Petroleum Exploration Team, PCSB
- Mr. Firdaus B Mohamad, Petroleum Exploration Team, PCSB
- Mrs. Puteri Nurlina Bt Mokhtar, Petroleum Exploration Team, PCSB
- Mr. Peter Abolins, Principal Geochemist, PCSB

My best regards to my parent and family for their support. It was hard earlier to time spend and scheduling but with their willingness and motivation, I made it through all the way. I would like to special thank my supervisor, A. P. Dr Swapan Kumar Bhattacarya for the passionate and patience in spending precious time with me and countless effort in giving me knowledge and skills certainly deserves my highest appreciation and deepest gratitude. Heartfelt appreciation goes to lecturers and my fellow friends who have spent time to provide additional support and advice.

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# CHAPTER 1
# INTRODUCTION

## 1.1 PROJECT BACKGROUND

Anding Utara Field is located in offshore Peninsular Malaysia in area of water depth approximately 74 m. The productive reservoir in Anding Utara Field is a fracture Jurassic Metamorphic Basement High within a pull-apart basin form by extensional faulting during basin development. It is about 12 km long and 7 km wide. From data provided by PETRONAS Carigali Sdn Bhd (PCSB), correlation indicated that Anding Utara Jurassic Metamorphic Basement underlain by very thick Oligocene shale as a cap rock [1]. PCSB has discovered oil in the basement through an exploration well drilled within the Southern Malay Basin offshore Terengganu, the first such discovery in Malaysia in December 2004. There are four wells have successfully been drilled which are Anding Utara-1 well, sidetrack well, Anding Utara Basement-1 well and Anding Tengah exploration well.

## 1.2 PROBLEM STATEMENT

Anding Utara, a fracture basement discovery in the Peninsular Malay Basin in during December 2004, could not be developed yet due to inconsistent production testing results. Thus, Anding Utara has become an engineering challenge to put it on production. So far PETRONAS have drilled four wells and all the wells started with good production during testing but did not continue after a few days. From the research, the fracture distribution and connectivity plays an important role in hydrocarbon production from the basement reservoirs.

Anding Utara has random density distribution and many relatively short faults suggest a predominantly extensional (origin) setting. Sidetrack well has significant higher fracture density compare to Anding Utara-1 well. However, the fracture density reduces slightly with depth and possible fault(s) identified on Formation Micro Imager (FMI) show no fracture density increase, nor fracture orientation change. Fracture intensity increase close to fault and fold.

## 1.3 OBJECTIVES AND SCOPE OF STUDY

The objectives of this project are to:

- Do comparative study to find an analog based on geology, geochemistry, reservoir characteristics and production behavior.
- Find engineering solution to put Anding Utara on production.

The scopes of study for this project are simplified as follows:

- Study geological structure of fractured basement formations.
- Analyze geochemical data of basement rocks and fluids.
- Determine reservoir characteristics of crystalline basements.
- Analyze production behavior of basement formation.

In this present study, selected basement discoveries around the world will be compared with Anding Utara field based on the geological, geochemical, reservoir characteristics and production behavior to evaluate potential of hydrocarbon production in basement reservoirs. The main objective of this research project is to come up with possible engineering solution for Anding Utara to put it on production.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 DEFINITION OF BASEMENT ROCK

In geology, the terms basement and crystalline basement are used to define the rocks below a sedimentary rocks that are metamorphic or igneous in origin. Basement reservoirs include fractured or weathered granites, fractured quartzite and metamorphic rocks such as fractured schist or argillites [4]. The term basement refers to crystalline formations ranging from intrusive and extrusive magmatic bodies (especially granites) to the family of low to medium grade metamorphic rocks. Hydrocarbons have been under production from these types of rocks around the world for many decades but since around 1990 there had been growing interest and exploration in these formations where storage and production are dominated by the fracture system [18].

## 2.2 CHARACTERIZATION OF BASEMENT RESERVOIRS

All basement reservoirs underlie a regional unconformity and almost all lie on uplift. Structural uplift in the basement is created by fault tectonics. Unconformities can play an important role in basement reservoirs, as they can be the pathway for oil migration. The unconformity surface often provides evidence that the basement rocks have undergone weathering, erosion, solution and leaching for long time that porosity and permeability have increase greatly, facilitating accumulation of petroleum [5]. The usual cap rock for basement accumulations is relatively tight (low permeability) sedimentary rock. However, a tight zone in the basement rock may act as the seal.

Most basement rocks are hard and brittle with very low matrix porosity and permeability. Consequently, reservoir quality depends on the development of secondary porosity. Secondary porosity may be divided into two main kinds y origin: (i) tectonic porosity (joints, faults, fractures, etc) and (ii) dissolution porosity [5]. In basement reservoir, most of the storage capacity and permeability is due to fractures. Fracture data analysis is the key step in the reservoir characterization and modeling workflow. It begins with the determination of the types of fractures or fracture parameters which controls the distribution and quality of flow zones [13].

### 2.2.1 FRACTURE CHARACTERIZATION IN BASEMENT

In the basement reservoir, the fractures have played an important role for storing and transferring oil from reservoir to production well. Therefore, fracture properties are important parameters for studying reservoir characteristics. Mapping and characterization of the open fracture subset in reservoir rocks begins with analysis and integration of well data, especially core, borehole image logs, dipole sonic and dynamic data (mud losses, shows, productions logs, well tests) [14].

These datasets are used to build a conceptual model of the open fracture system and to help generate parameters for use in constraining static fracture models (fracture spacing, orientation, dimension, and aperture). The well-scale dynamic data is used to identify the fractures which are open and dynamically active due to presence of porosity and connected permeability. Extended well tests and cross-hole interference tests are used to identify flow anisotropy and boundaries in the network at a near-well scale.

Crystalline formation seismic techniques often meet with limitations. However, faults at top basement can generally identify and extrapolated to depth. Seismic attributes also contribute to identify reservoirs units. An outcrop analog information and empirical relationship can help to contribute information about fracture distribution, relationship to lithology and scaling. This provides a basis for predictive fracture models to support simulation and well planning [14].

### 2.2.2 CONTROLS ON RESERVOIR QUALITY

The main controls on reservoir quality in basement are:

- Lithology: there is a tendency for fracture height and dimension to be limited in metamorphic formation resulting from layering. In massive or homogeneous formation such as granites the fracture network is blocky and connected.

- Deformation history: high levels of deformation associated with fault propagation generate high fracture densities. Cataclastic and thermo-chemical processes tend to reduce porosity and permeability on the active slip surface (generating fault rocks). Fault zone architecture (Caine *et al* 1996) is key consideration for reservoir quality.

- Fracture reactivation: even where mineralization has acted to seal fractures in the geological past, subsequent stress fields may have caused reactivation of selected fracture orientations, potentially breaking previous seals. Thus it is important to understand the youngest tectonic activity as this may have controlled the open fracture subset.

- Secondary alteration by hydrothermal or meteoric activity: many basements have been affected by fluid migration leading to fracture sealing. However the same processes can create secondary porosity by dissolution of mineral phases in fractures and in the matrix.

All these factors will impact on reservoir quality, together with migration, charging history, structural height, reservoir column and seal integrity. Hydrocarbon distribution in tight fractured reservoirs will be controlled by a combination of charging mechanism, migration routes and timing, and susceptible formation properties which derive form the interplay of factors described above.

In the case of crystalline basement these will be dominantly formed by fracture networks with high densities and good connectivity through a volume large enough to sustain production at economic rates. This of course is not unique to basement reservoirs but other formations with tight matrix porosity such as many carbonates also rely on fractures to control fluid movement [14].

## 2.3 BASEMENT RESERVOIRS DATA ANALYSIS

The most difficult problem after finding basement rock reservoir is to evaluate them particularly their production capacity and reserves. Nelson (1985), North (1990) and Aguilera (1995) describe relatively traditional methods that include core analysis, well tests and log evaluation. New technologies in the fields of seismic-surveying, borehole logging and fluid-flow simulation provide geoscientist with powerful tools to characterize fracture system better than before. In the field of seismic surveying, this happen through improved data acquisition, particularly with multi-component geophones in 3D, and through advanced processing such as seismic attribute analysis and variance cubes that provide information on degree and directionality of fracturing.

In the field of fluid-flow simulation, discrete fracture network simulators can now model realistic fractures [9].Recent geophysical well techniques have significantly improved the analysis of fractured reservoirs. These methods include electrical and ultrasonic scans and, in some cases, optical video images, that provide azimuthal high-resolution images of the borehole wall on which fractures are prominently visible. Fractures produce reflections and attenuations of the Stoneley wave, a borehole mode recorded by the array sonic wireline tool.

A fracture identified with these methods can be individually probed with a new wireline formation tester featuring a dual-packer module that hydraulically isolates it from the surrounding formation. These techniques can provide information on fracture locations, dip, azimuth, aperture, permeability and fluid content. Seismic data can be used to extrapolate this information away from the wells.

In this particular project, Drill Stem Testing (DST) data and geochemical analysis of the fluid are used for accurate evaluation of the formation conditions. DST tools can directly obtain the temperature data from the formation tested and the formation pressure change during testing.

## 2.4 BASEMENT DISCOVERIES AROUND THE WORLD

Basement rock are important oil and gas reserves in a number of countries and serve as a reminder that in area where basement is not too deep, basement should be considered as a valid exploration objective. Countries with hydrocarbon finds in basement reservoirs are as follows:

- South America, basement reservoirs produce oil in Venezuela and Brazil.
- USA, basement in California, Kansas and Texas.
- North Africa, basement reservoirs occurs in Morocco, Libya, Algeria and Egypt.
- Middle East, basement oil in Yemen.
- West Siberia Basin and China occurs basement reservoirs.
- Southeast Asia, very prolific basement reservoir in Vietnam.
- Indonesia, basement reservoirs produce oil in Beruk Northeast Field and Tanjung Field. Discovery of giant-size gas field in pre-Tertiary basement in South Sumatra.

La Paz field the first naturally basement reservoir was discovered before 1950 in Venezuela. For the first time, people produced from Cretaceous limestone. And then oil was incidentally discovered when they drill into basement rock. The exploration of oil reservoirs in the basement rock significantly increased from 1950s until now. Most of those reservoirs had low production rates like 20 bbl/day at Orth field, 55 bbl/day at Beaver in the US and 210-756 bbl/day at Xinlongtai field, China. However, White Tiger in Vietnam had the flow rate of over 3600 bbl/day. Therefore, White Tiger could be considered one of the biggest basement fields of the world.

# CHAPTER 3
# METHODOLOGY

## 3.1 PROJECT WORK

Data collections from internet, Journals, SPE papers and books are required to gather information about basement reservoirs around the world. The purpose is to select four basement reservoirs as case studies for this particular project and analyze their geological structures, geochemical, reservoir characteristics and production behavior.

The initial step is to identify the characteristics of selected basement which allow production of hydrocarbon from fractured basement reservoirs. From the data gathering, the comparative study of the selected basement discoveries around the world will be conducted with special emphasis to Anding Utara of Peninsular Malay Basin to find the possible engineering solution of Anding Utara to put it on production.

The step involves problem identification of Anding Utara Field. For this particular project, analog data for Anding Utara Field is required to analyze the issues. Collaboration with PETRONAS Carigali will help to access and retrieve the data. The next step is to interpret each different field behavior and compare the finding with analytical data of Anding Utara Field. Finally is to identify the key problems and find out the possible engineering solution of Anding Utara. The overall project work follows the flow chart (Figure 1) as below.

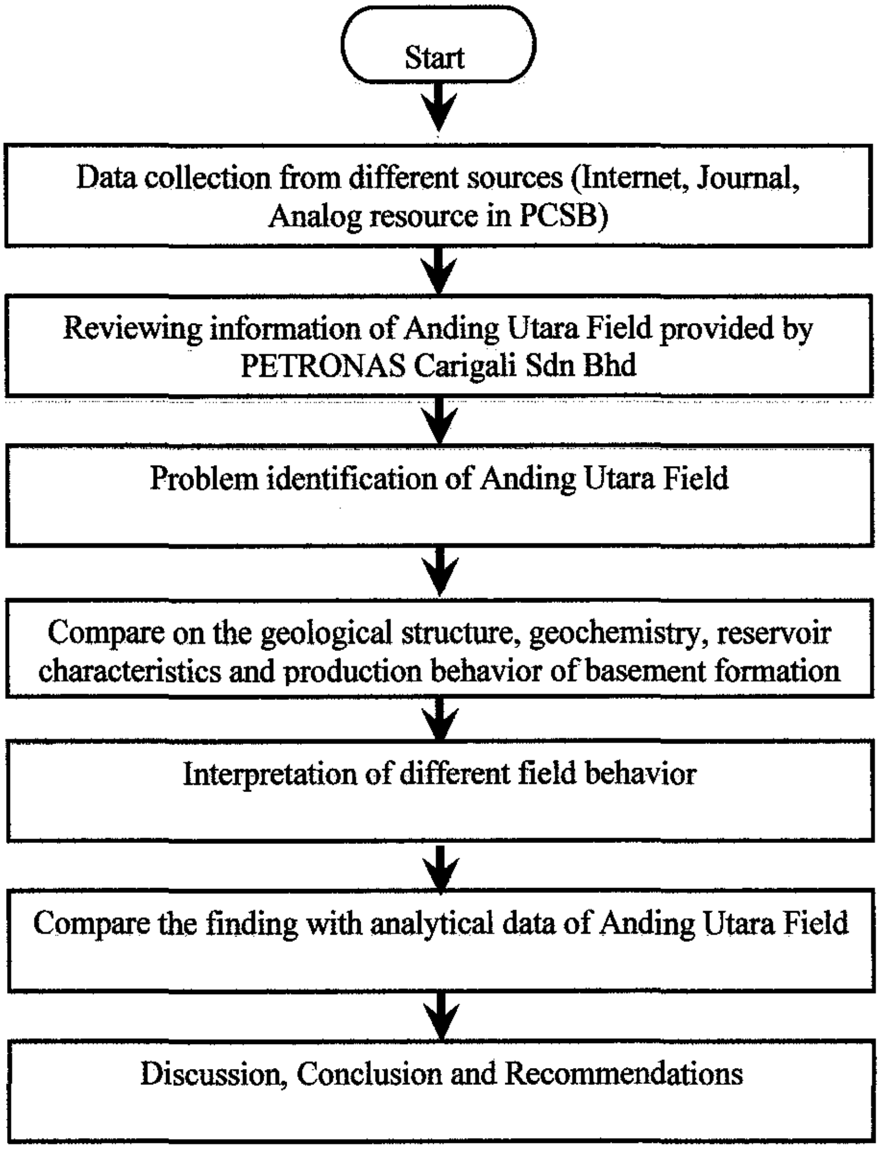

Figure 1: Flow chart for Project Work

### 3.2 PROJECT PLANNING

| Task | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Data gathering | ■ | ■ | ■ | ■ | | | | | | | | | | | | |
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| Reviewing information of Anding Utara Field | | | ■ | ■ | ■ | ■ | ■ | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| Progress Report Submission | | | | | ■ | ■ | ■ | ■ | | | | | | | | |
| | | | | | | | | ✸ | | | | | | | | |
| Problem Identification of Anding Utara Field | | | | | | | ■ | ■ | ■ | | | | | | | |
| | | | | | | | 🟩 | | | | | | | | | |
| Analysis and Interpretation of the study | | | | | | | | ■ | ■ | ■ | | | | | | |
| | | | | | | | | | | | | | | | | |
| Compare the finding with analytical data | | | | | | | | ■ | ■ | ■ | | | | | | |
| | | | | | | | | | | | | | | | | |
| Discussion and Conclusion | | | | | | | | | | ■ | ■ | | | | | |
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| PRE-EDX seminar / Poster Exhibition | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | ✸ | | | | | |
| Final Report Submission / Dissertation | | | | | | | | | | | | | | | | |
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| EDX | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | ✸ | | | | |
| Final Oral presentation | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | ✸ | | | |
| Delivering Final Report to External Examiner | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | ✸ | | |
| Hardbound Report Submission | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | ✸ |

| Legend | |
|---|---|
| Completed task | ■ |
| Dateline | ✸ |
| Future Progress | 🟩 |

Figure 2: Gantt chart for FYP 2

# CHAPTER 4

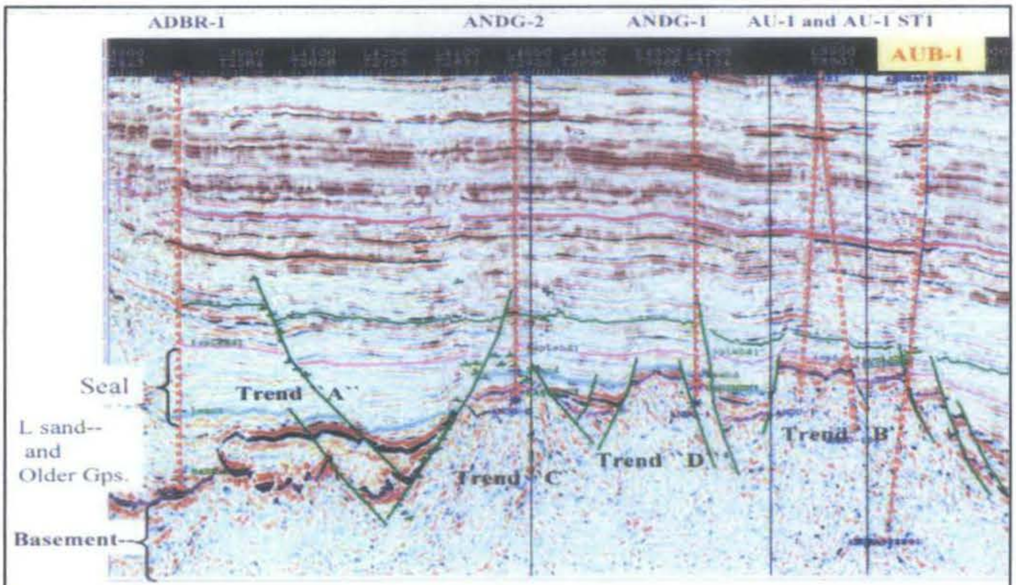
# RESULT AND DISCUSSION

## 4.1 SELECTED BASEMENT RESERVOIRS

Although oil production from basement rocks is not a common occurrence worldwide, there is significant oil production from such reservoirs in a number of countries. Two fields in Indonesia, Beruk Northeast and Tanjung, serve as examples that commercial volumes of oil can be produced from basement in Indonesia .Oil is produced from basement rocks in a number of countries including China, Vietnam, former USSR (West Siberia), Ukraine, Indonesia, Libya, Algeria, Morocco, Egypt, USA, Brazil and Venezuela. In this particular project, four selected basements have been chosen for case studies which are typically the basement reservoirs around the world.

## 4.2 ANDING UTARA FIELD, MALAYSIA

PETRONAS Carigali Sdn. Bhd. (PCSB) has discovered oil in the basement through an exploration well drilled within the Southern Malay Basin offshore Terengganu, the first such discovery in Malaysia in December 2004. The Anding Utara-1 well was drilled to a total depth of 2610 m, including 120 m TVD into the basement, tested oil. The sidetrack well reached a total depth of 2740 m, including 250 m TVD into the basement, tested oil. In Nov 2005 and Nov 2006, PCSB has drilled respectively to further explore the basement, AUB-1 (suspended) 968 m MD into basement, tested oil. And Anding Tengah-1 exploration well 300 m MD, tested oil. All the wells started with good production during testing but did not continue after a few days.



- Thickening of L Shale to the NNE ( Trend ``A``)
- Pinch of Lsand and Older groups ( M and N to the NNE – Tend ``B``
- Basemnt High Tested in Trend ``E`` and proposed to be tested in ``C and D`` Trends

Figure 3: Regional cross section, Anding Utara field (well completion report, PCSB)

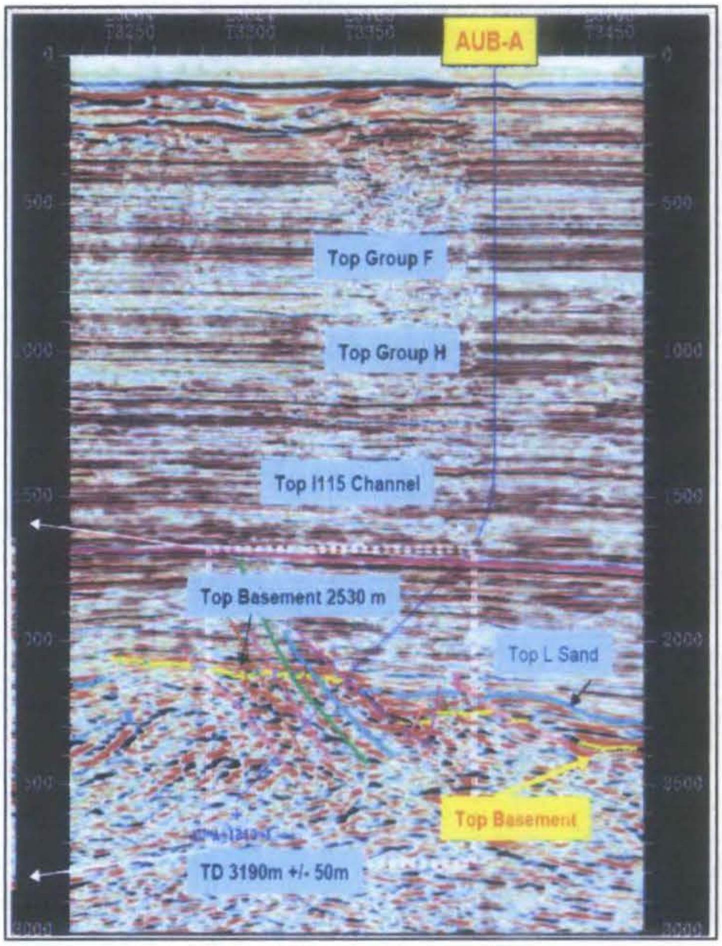


Figure 4: Regional cross section of AUB-A, (well completion report, PCSB)

Figure 3 shows regional cross section of Anding Utara field indicates well correlation and fault trends. Two major distinct fault trends can be recognised in the cross section view are WNW-ESE to E-W, NW-SE locally combined with, NE-SW and 4N-S. Faults probably acting as "tear" or "transform" faults which form random density distribution and many relatively short faults suggest a predominantly extensional (origin) setting. As shown, there are sealing rocks rest on top of the L reservoirs and the Oligocene/Miocene Groups J, K and metamorphous basement. The AUB-A was drilled to further explore the basement (Figure 4). The well reached a total depth of 3190 m.

On December 2004, wireline logs were run in Anding Utara-1ST1 well. The primary objectives are to test the hydrocarbon potential of the Oligocene/Miocene Groups J, K and L reservoirs and investigate the hydrocarbon find in the metamorphous basement. The secondary objectives are to test the hydrocarbon potential of Group H, I-35 and I-155 fluvial sand reservoirs in combine structural and stratigraphic closures (Figure 4). Table 1 below shows Drill Stem Test (DST), the preliminary results summary from well test operations for Anding Utara-1ST1 (December 2004).

Table 1: Preliminary results summary (log report, PCSB)

| Period<br>Time start<br>Tome stop | Main Flow<br>10:20 PM<br>11:00 AM |
|---|---|
| Duration (hours) | 12:30 |
| Choke ( /64) | 32" |
| WHP, psia | 536 |
| WHT, ° F | 167 |
| Separator gas temp, ° F | 267 |
| Gas rate, MMscf/d | 127 |
| Oil rate, stb/d | 0.740 |
| Water rate, stb/d | 977 |
| GOR. scf/stb | n/a |
| Gas gravity, Air =1 | 768 |

| | |
|---|---|
| Oil gravity, API 60 | 49.2 |
| $H_2S$, ppm | 0 |
| $CO_2$, % | 7 |
| BS&W, % | 2 |
| Chloride, mg/I | n/a |
| Ca, mg/I | n/a |
| pH | n/a |

## 4.3 CASE STUDIES

### 4.3.1 CASE STUDY 1: VIETNAM, WHITE TIGER FIELD

**FIELD BACKGROUND**

Ongoing exploration activities have proved the existence of oil and gas in basement reservoirs in the offshore area of South Vietnam. This has resulted in the discovery of several oil and gas fields including White Tiger (Bach Ho), Dragon (Rong) and Rang Dong fields. Wells in the White Tiger field were completed either as open-hole or with a perforated casing and typically down to 5000 m TVD. Formation thickness open to wellbore varied from 100 to 800 m [24]. Figure 5 & 6 shows the distribution of basins in the Vietnam continental shelf and field location of Cuu Long basin.

Figure 5: Vietnam continental shelf of Cuu Long basin (modified from Nguyen V.T. et al, 2008)

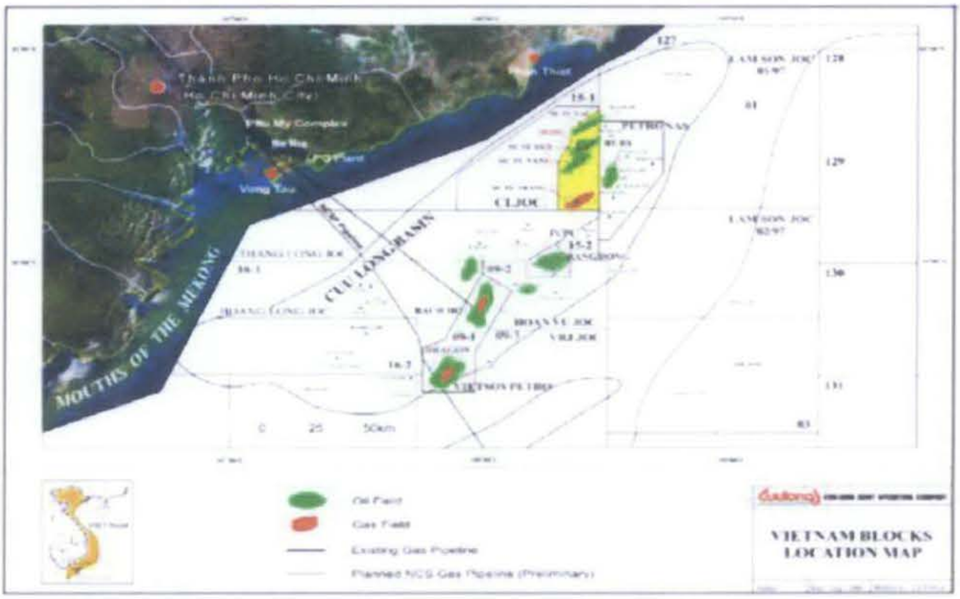


Figure 6: White Tiger oil field location in Cuu Long basin (modified from Nguyen V.T. et al, 2008)

## GEOLOGICAL STRUCTURE

White Tiger Field in Offshore Vietnam is producing from a highly fissured granite basement formation. Basement consists of igneous crystalline rocks characterized by petrography heterogeneity because they were formed in different tectonic activities in their geological evolution. This reservoir has a complicated geological structure, very high heterogeneity, high temperature (more than 275°F) and closure stress (more than 8000 psi) [23].Since being formed to recent, the basement rocks of the Cuu Long basin have been strongly affected by different alteration processes. These processes changed not only the composition, petrophysical characteristics, but also were principal causes creating good reservoir properties of some granitoid basement bodies [24].

Some main alteration processes are volume shrinkage due to the crystallization of magma lavas, alteration due to the tectonic activities, alteration due to the hydrothermal activities, and alteration due to the weathering activities. The inside volume of magma bodies is often shrank when the magma lavas crystallized and solidified. This volume shrinkage caused by sudden change of temperature as well as by viscosity increase during the times that these magma lavas crystallized and resulting in the formation of individual micro fractures and micro-vugs granitoid rocks.

The tectonic activities are principally factors making strong and widespread alteration of basement rocks. The basement rocks have been fractured, broken and catalazited at various degrees, developing different fracturing systems with different directions. The fracturing and breaking did not change the rock composition, but they strongly altered the structure, texture and particularly the petrophysical characteristics of the basement rocks. Fractured granite basement rocks of White Tiger field characterized as high heterogenic and much more complicated than those traditional oil and gas bearing rocks.

The most of basement rocks are hard and brittle. Fractures, faults and vugs contributed to the porosity. There are no pores in the matrix. In the continental shelf of Vietnam, the basement reservoirs are located under the unconformities and on the highs of uplifted block which were weathered and eroded. These basement reservoirs were covered by younger sediments that played an important role such as source rocks and cap rocks (Figure 7).

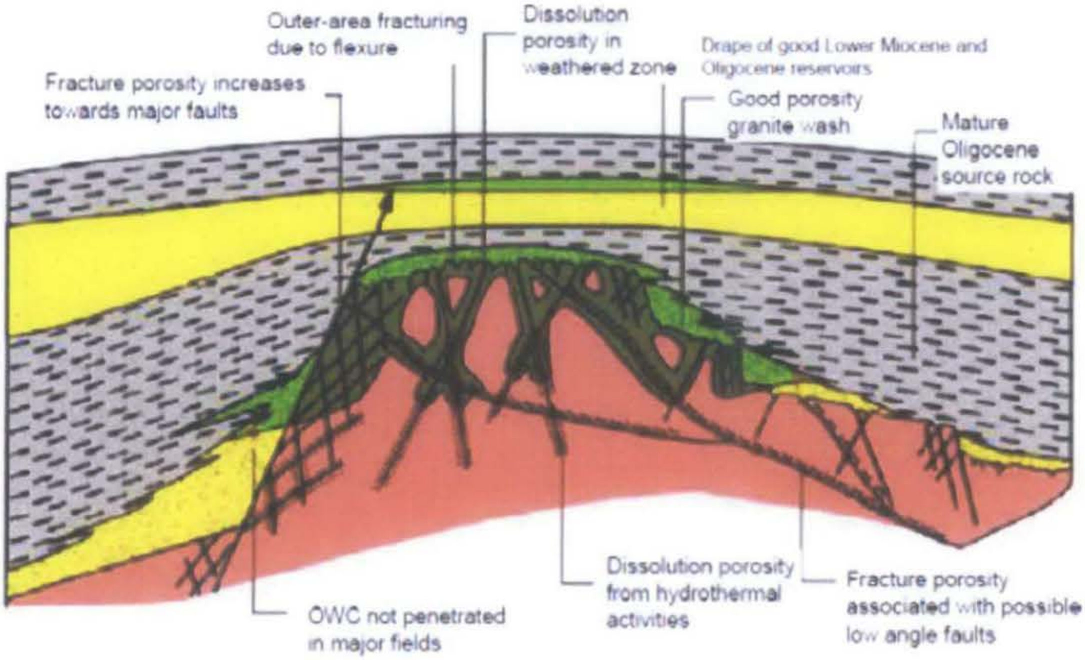


Figure 7: Petroleum play concept in Cuu Long basin and fracture porosity (after Phan T.C and Pham V.T., 2008)

## GEOCHEMICAL ANALYSIS

These Vietnam basement reservoirs are located on the continental shelf of Southern Vietnam. The water depth reaches 120 m. These basement reservoirs correspond to type I reservoirs (Nelson, 2001) where the matrix has little porosity or permeability, the fractures providing the essential storage capacity and permeability [13]. The basement rocks are predominantly granodiorites to granites and diorites and they range in age from Late Jurassic to Early Cretaceous [5]. The basement rocks of Cuu Long basin are characterized by two types of rocks (metamorphic and igneous rocks). The igneous rocks consist of diorite and quartz diorite (granite), which were formed in the active continental margin arc setting. Metamorphic rocks are gneiss. Those rocks were found in White Tiger oil field.

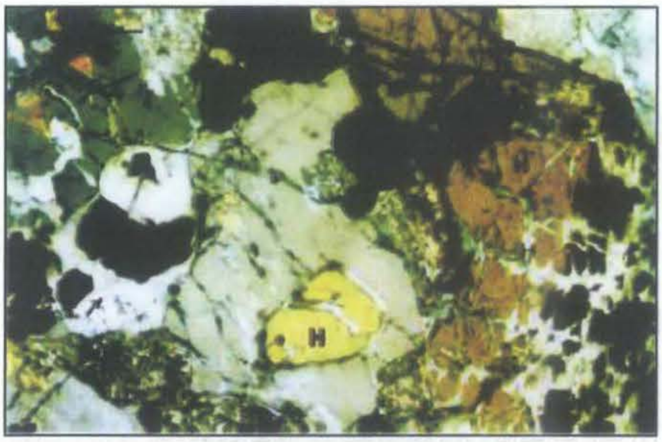


Figure 8: Granite rock from Cuu Long basin (after Trinh, 2006)

## RESERVOIR CHARACTERISTICS

The main porosity types in the White Tiger Field are fractures, caverns, leaching pore and possibly contraction voids. The effective porosity was due to three components which are fractures of tectonic origin, vugs of hydrothermal origin and pores caused by near surface weathering. The porosity distribution is very irregular. Two principal porosity types that are fractured and cavernous pores can always be observed in the altered granitoid rocks (Figure 9).

Figure 9: Natural fractures in basement rock of White Tiger Field (SPE 103329, 2006)

The fracture size is 5-10cm long and 0.5-1.5mm wide even to centimeters in some places. Micro-fracture pore are only observed by microscope with predominant size of 5-15mm long and 0.05-0.2mm wide [24]. Fracture distribution is very heterogeneous with 0-2 fractures/cm$^2$ in weakly fractured rocks and up to 20-25 fractures/cm$^2$ in strongly fractured rock. The cavernous and micro-cavernous porosity has value ranging largely from 0% to 10%. Most of the cavernous pore sizes are from 0.3-0.65mm, sometimes up to 7mm. The caverns and fractures can be observed visually in slightly magnifying core pictures (Figure 10).

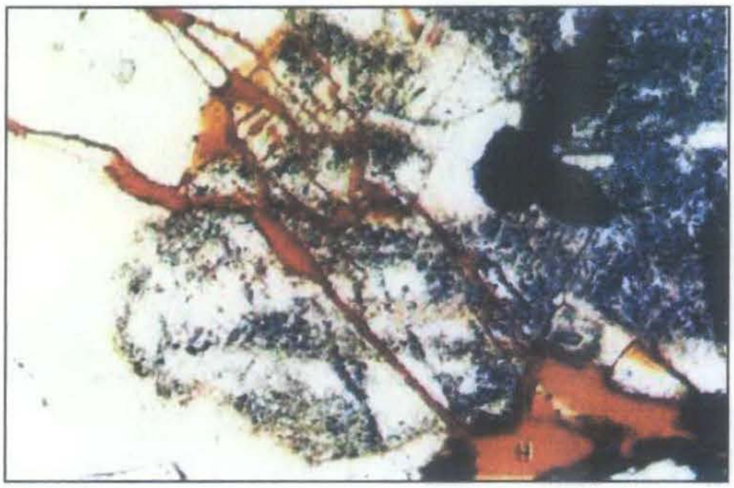


Figure 10: Large caverns in slightly magnified picture of a dyed core (SPE 103329, 2006)

Key reservoir and fluid properties are listed in the Table 2. Note that the permeability contrast is as drastic as the permeability distribution can be varying from 4 mD to 450 mD. Earlier petrographic study on the basement reservoir in Cuu Long basin showed that this wide range of permeability distribution can be due to presence of primary and secondary fissure systems and also due to wide variation of fissure gaps [24].

Table 2: General Basement reservoir properties (SPE 103329, 2006)

| | |
|---|---|
| Effective Permeability, mD | 4 to 464 |
| Reservoir Temperature, °C | 140 to 155 |
| Reservoir Pressure @ 3650 m TVD, psi | 20 to 32 |
| Formation Thickness, m | 100 to 800 |
| In-situ Oil Viscosity, MPas | 0.43 |
| In-situ Oil Density, Kg/m$^3$ | 642 |
| Paraffins, Resins, Asphaltenes Content, % | Up to 24 |

Reservoir quality depends on the development of secondary porosity. Two main types of porosity are tectonic porosity (fracture) and dissoluble porosity (cavern). The fractured zoned are mainly concentrated at the top of the basement. This was observed in many wells of White Tiger oil fields [23]. However, the thickness of basement reservoirs is very thick. The White Tiger basement reservoir has the oil-bearing thickness of nearly 2000 meters in length and a width of 30 km. (Hoang Q.V., 2008). With the characteristics of basement reservoir such as White Tiger oil field, all wells were drilled in vertical direction.

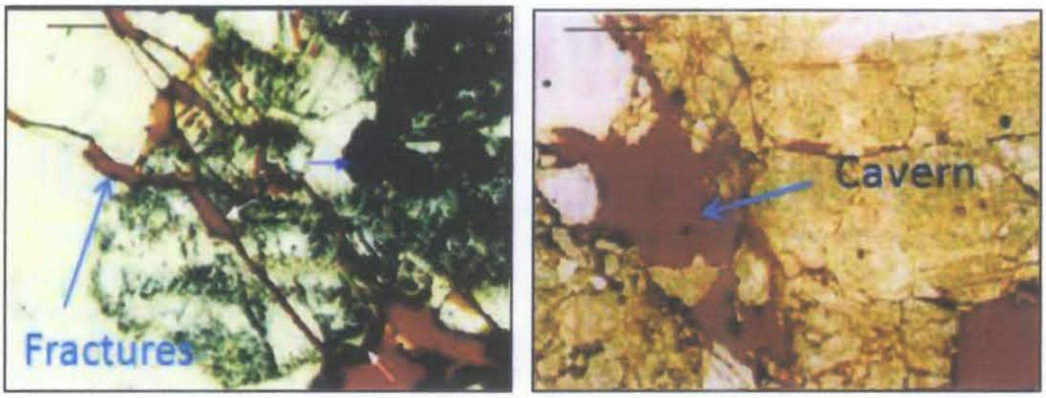


Figure 11: Fractures and caverns in basement reservoir of Cuu Long basin (after Trinh, 2006)

The basement granite rock reservoir of White Tiger oil field can present a good reservoir because of the high fracture in the uplifted block. The oil was generated in the younger sedimentary rock, then migrated and accumulated in the basement rock during the post Oligocene tectonic movements [21].

Figure 12: Macro-fracture and micro-pore in the basement reservoir (after Trinh, 2006 and Phan and Pham, 2008)

The igneous rock reservoirs contain small amount of porosity, which was formed by cooling magma (primary porosity), and a large amount of porosity (secondary porosity), which was formed by tectonic activities (fracture, joint and fault) and solution (vugs). The pore structures of the granite basement rock in the Cuu Long basin are characterized by high heterogeneity and complexity. Those pores are the result of various processes such as heat shrinkage and expansion of magmatic bodies, tectonic movements, hydrothermal impacts and weathering.

The studies of permeability distribution of the White Tiger basement reservoirs showed that the high permeable zones with high production rate relative to reverse faults. That mean zones near the normal faults have permeability lower than one near reverse faults [20]. The whole reservoir is characterized by the united hydrodynamic system. There is no bottom water in this reservoir. To maintain the reservoir pressure and increase oil recovery, water injection was applied in the basement White Tiger reservoir. That was a successful application in where more than 100 millions tons of oil and 10 of billions cubic meters of gas were recorded.

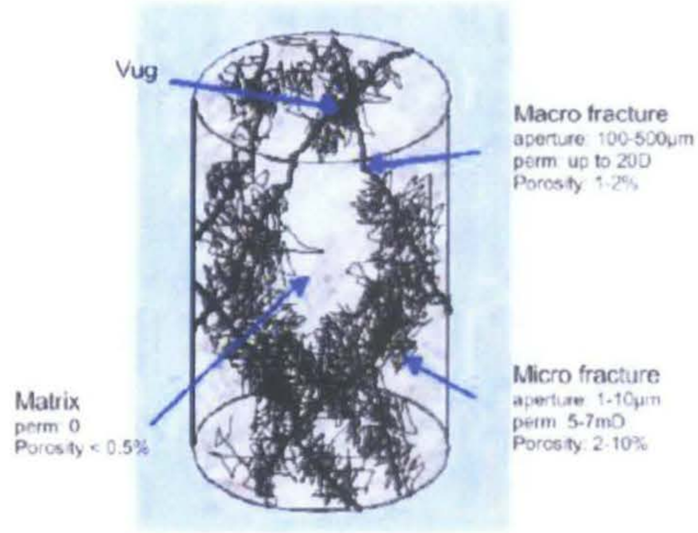


Figure 13: Pore space structure in White Tiger basement reservoir (Hong V.Q. et al, 2008)

## PRODUCTION BEHAVIOR

Hydrocarbon bearing zones in fractured granite basement is the main oil production source in Cuu Long basin. In the White Tiger field, the oil column exceeds one kilometers and production is in excess of 10,000 barrels per day. The total OIIP of this field reached nearly 4 billions barrels with 2000 meters of the oil bearing thickness and has been produced by more than 100 wells, ten of which flow at the rate of approximately one thousands barrels per day. The basement was then identified as an oil reservoir of significant importance. The White Tiger oil field is at a depth of 5,000 m, of which 4,000 m is fractured basement granite with a pay zone interval of 1,000 m.

The oil bearing zone of White Tiger is of massive type with thickness of over 1,500m, closed and has no water in bottom. So, water injection is essential for maintaining the reservoir pressure. After a couple years of water flooding, fluid flow though natural fractures in oil bearing reservoir of White Tiger has started adversely impact economic efficiency as hydrocarbons in the fissures are replaced by injected water and lead to high water cut in production wells [15].

Despite of major incentives for controlling unproductive water flow through fractures, there are insurmountable difficulties in caring mechanical intervention in the production wells in granite basement reservoir. Other chemico-physical action methods such as gas injection, injection of alkali solutions, surfactants including polymer injection are not suitable with the high temperature and heterogeneous reservoir rock of the White Tiger field. These methods require relatively high cost of chemicals and considerable changes in the injection production systems.

Therefore, for the basement oil bearing zone of this field, increasing the sweep efficiency is the most important issue in improvement oil recovery. For these causes, there has been significant effort to selectively place plugging agents into fractures by pumping gels without zone isolation. But due to the specific structure of granite rocks and high temperature in basement reservoir, the selection of the right compounds to get the selective and thermal stable gels is an essentially important task [15].

### 4.3.2 CASE STUDY 2: EGYPT, ZEIT BAY FIELD

#### FIELD BACKGROUND

The Zeit Bay field is situated in the SW part of the Gulf of Suez, Egypt, extending offshore into water depths up to 65 ft. It was discovered in 1981 and brought onstream in December 1983. The field has a STOIIP of 597 MMBO and GIIP of 205 BCF with an oil recovery factor of 54%. The best productivity from the basement reservoir is associated with the fractured and altered (brecciated) intervals which are exploited by wells deviated to maximize fracture intersections. Figure 14 shows the location of Zeit Bay field.

Figure 14: Field location, Gulf of Suez, Egypt (EGPC, 1996).

## GEOLOGICAL STRUCTURE

The structure is a NW-SE tilted fault-block dissected by faults and complicated by pinch-out of pre-Miocene strata and non-deposition of Miocene units towards the crest. Light oil with a gas-cap occur in one pool in reservoirs comprising fractured Precambrian/ Cambrian Basement, Paleozoic/Mesozoic continental Nubian Sandstone and shallow marine Basal Miocene Sand and Kareem/Rudeis Formation carbonates. Figure 15 shows cross section of Zeit Bay field where on the north-east and south-west flanks of the field, eroded Nubian and Basal Miocene sandstones and Kareem carbonates are on lapping onto the basement body. The thick anhydrite of the South Gharib formation serves as cap rock.

Approximately two-thirds of STOIIP is localised over the western flank of the field where the pre-Miocene sandstones and Miocene carbonates onlap the basement whereas the remaining STOIIP is contained in the fractured basement reservoir that provides most of the gross rock volume in the centre of the field. All the reservoirs are in complete hydraulic and pressure communication.

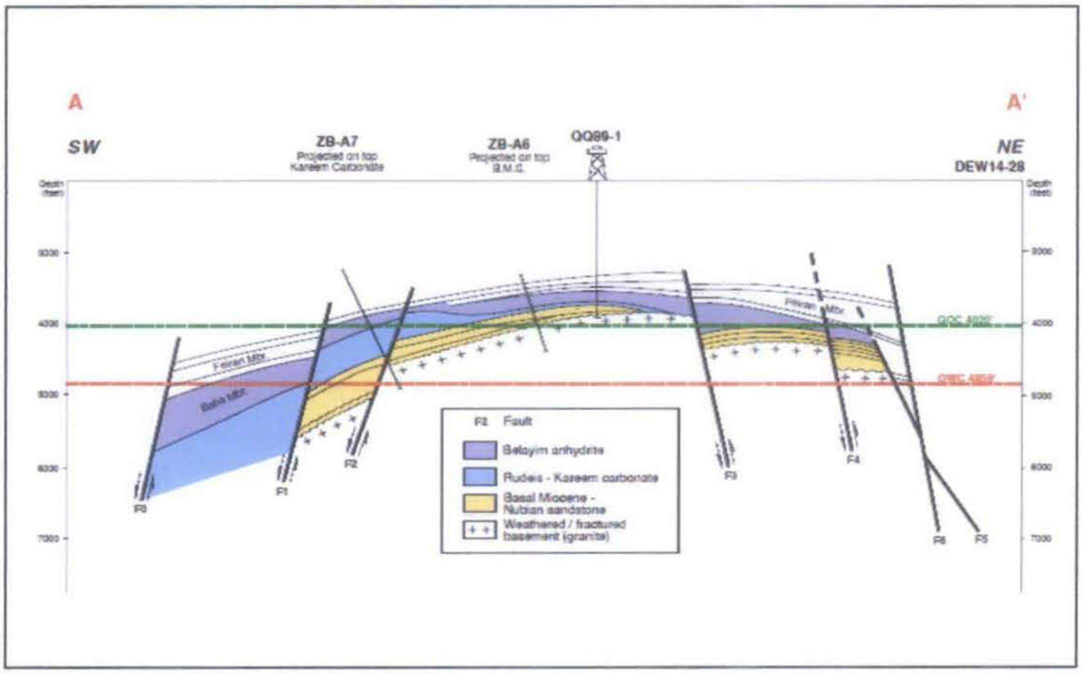


Figure 15: NE-SW structural cross-section through the Zeit Bay Field showing the fluid contacts (El-Hamalawy et. al., 1993).

## GEOCHEMICAL ANALYSIS

The basement reservoir contains several different lithotypes. Granites cover the largest area of the field, in the east and south which consist of feldspar, quartz and mixed clays. Metavolcanics are present in the northern and western areas of the field and comprise meta-andesite (sericitised plagioclase, green hornblende, magnetite, apatite and chlorite) and amphiboles. Dykes are present containing a variety of minerals such as quartz, calcite, feldspars, pyroxenes, amphiboles and clays. Overlying these lithologies, particularly at the crest of the structure, there is a basement wash composed of quartz, feldspars, chlorite and clays. The thickness of the granitic basement is 47-534 ft. Petrographic studies of basement rocks in Zeit Bay field identified different rock types with the associated minerals as listed below:

- Granite rock

- Metavolcanics
- Dykes
- Basement wash

## RESERVOIR CHARACTERISTICS

The Zeit Bay Field has experienced a complex tectonic and stratigraphic history that has generated a succession of interconnected sedimentary reservoir layers. All the reservoirs are in complete vertical and lateral hydraulic and pressure communication (Hiekal et al., 1997; El Hamalawy et al., 1993). The faults across the main field are therefore likely to be non-sealing (Kamal et al., 1998). The basement reservoir contains both fracture porosity and secondary porosity associated with the partial dissolution of the primary igneous minerals (feldspars). The fractures in the basement are tectonic in origin. Petrographic studies identified three porosity types in the fractured basement which are fracture porosity, inter-crystalline porosity and vuggy porosity. It is believed that most of these porosity types are connected with each other by the extensive fracture network.

## PRODUCTION BEHAVIOR

The reservoirs in the Zeit Bay Field have a STOIIP of 597 MMBO and GIIP of 205 BCF (El Hamalawy et al., 1993) with ultimate recoverable reserves of 320 MMBO and 145 BCF, respectively. The oils in the field are light, with API gravities of 32-36o, with a viscosity of 0.84 cp, an initial solution GOR of 680 SCF/STB, and a sulphur content of 1.6 wt%. The initial reservoir pressure was 2235 psia at 4450 ft TVDSS (De Grisogono and Khalil, 1988) and the initial saturation pressure was 2095 psia at a datum of 4020 ft TVDSS (Kamal et al., 1998) and the reservoir temperature was 152 °F. The primary drive mechanism is a solution-gas drive supported by gas-cap expansion, gravity drainage and moderate aquifer support.

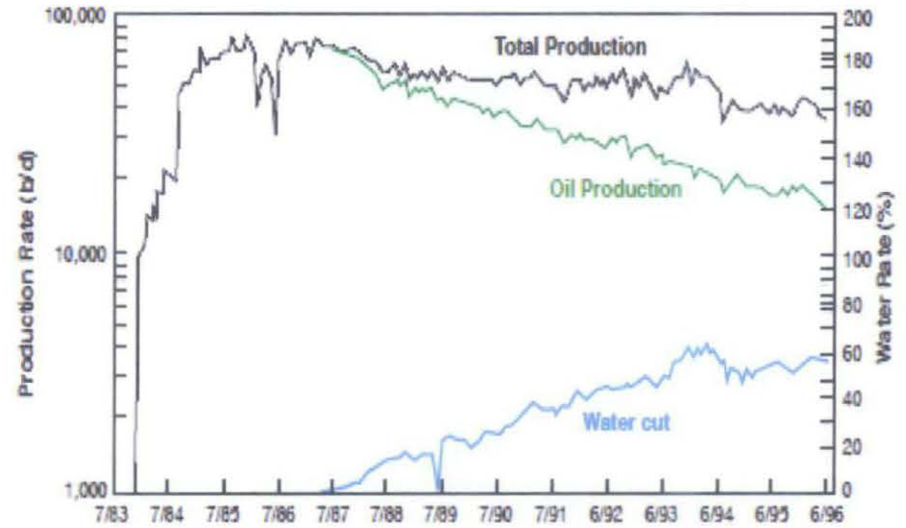


Figure 16: Total production 1983-1996, showing oil production and water-cut (Hamada and Al-Awad, 1998).

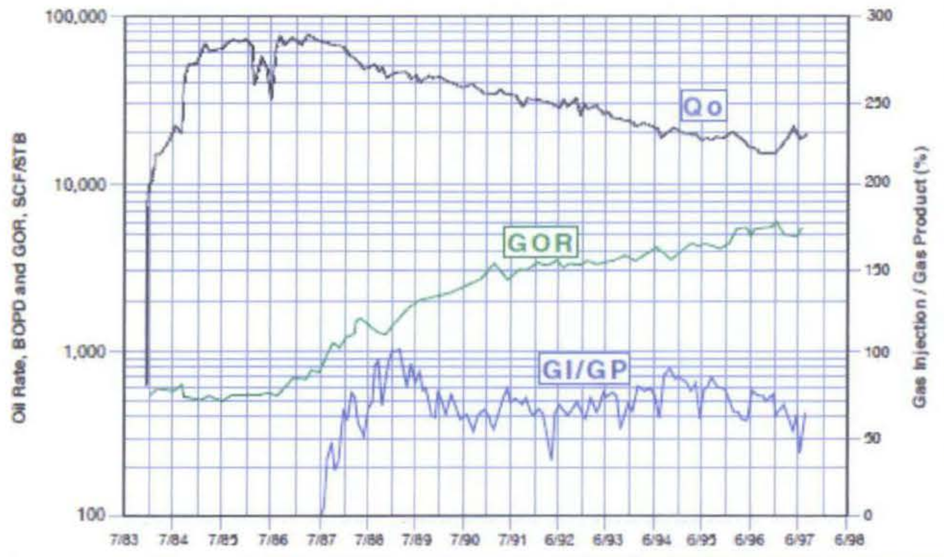


Figure 17: Total oil production 1983-1997, showing GOR and gas injection (GI) to gas production (GP) ratio (Hiekal et al., 1998b).

### 4.3.3 CASE STUDY 3: INDONESIA, JATIBARANG FIELD

#### FIELD BACKGROUND

The Jatibarang Field is situated in the NW Java Basin in the onshore, eastern part of the Jatibarang Sub-basin, Indonesia. It was discovered in 1969 and began production in 1970. The oilfield contains several minor oil and gas pools but the bulk of the oil is contained in a broad tilted fault-block in which folded and fractured volcanic of the Eocene-Oligocene Jatibarang Formation form the main reservoir. The reservoir comprises two productive layers of subaerial and fluvial reworked tuffs separated by a layer of non-productive, highly weathered basaltic/andesitic lava. Fractures are essential for commercial production.

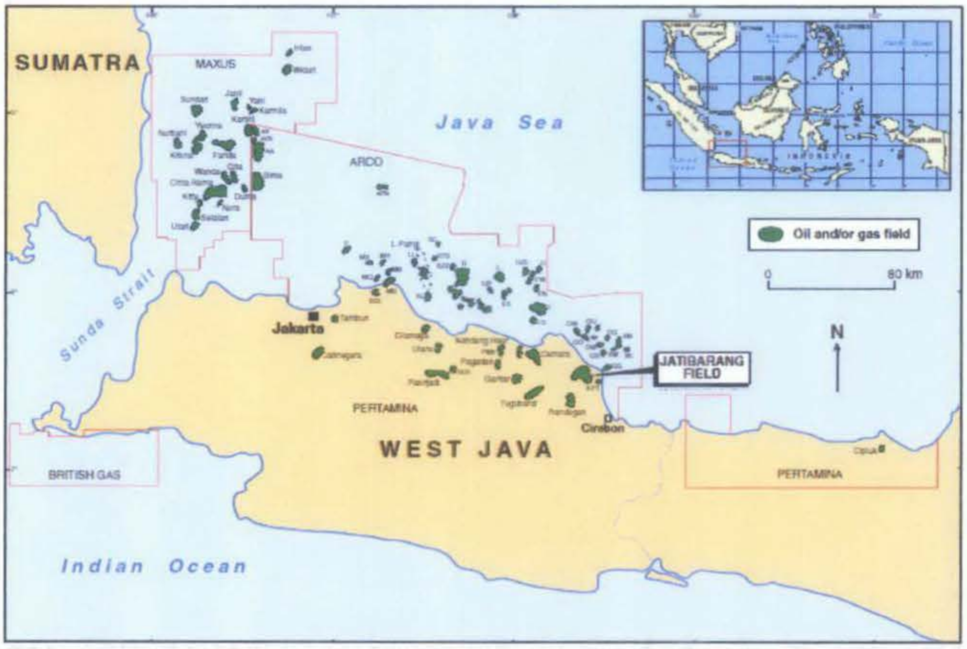


Figure 18: Hydrocarbon occurrences of the NW Java Basin and the location of the Jatibarang Field, onshore Java (Noble et al., 1997).

#### GEOLOGICAL STRUCTURE

Jatibarang field has rather complex geologic structure. Productive formation of oil and gas in the field is found in volcanic rock. In the Jatibarang field, most of the reserves occur in fractured volcanic of the Jatibarang Formation but hydrocarbons are also found in shallower reservoirs, including the (gas) sands of the Plio-Pleistocene Cisubuh formation, the limestone of the Upper Miocene Parigi formation, and reefal limestone and lenticular, shallow-marine sandstones of the Middle-Lower Miocene Cibulakan formation (Courteney et al., 1989).

Regional information indicates that the formation is likely to rest unconformably on block-faulted Mesozoic metamorphic and plutonic rocks (Nutt and Sirait, 1985). An angular unconformity at the top of the Jatibarang Formation is overlain by the transgressive Upper Oligocene-Lower Miocene Talang Akar formation (Figure 19).

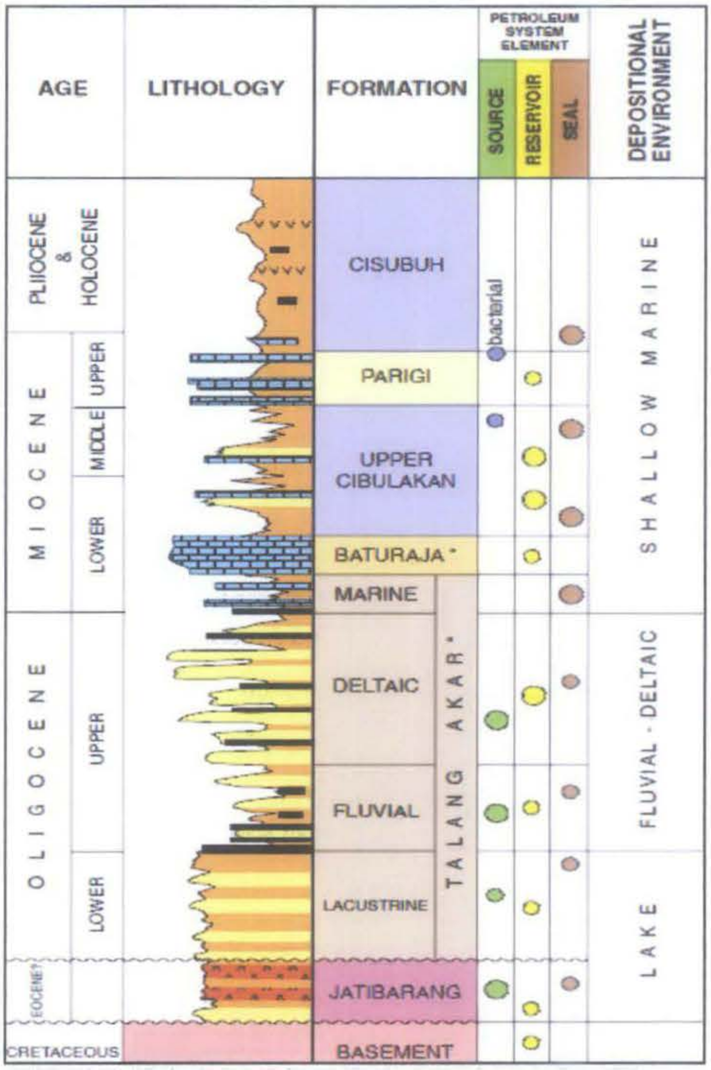


Figure 19: Generalised stratigraphy, depositional environments and petroleum systems of the NW Java Basin (Noble et al., 1997).

## GEOCHEMICAL ANALYSIS

The Jatibarang Formation consists of andesitic lavas at the base and dacite basaltic lavas interbedded with clays, sandstones, conglomerates and felsic tuffs in the upper parts (Nutt and Sirait, 1985). Sandstones at the top of the formation are only productive in a few wells in the Western Block (Kalan et al., 1994). There are two producing tuff layers separated over most of the field area by a generally non-productive dark grey/black basaltic/andesitic lava layer. The tuffs are thought to be subaerial deposits, which have been partly subjected to fluvial reworking.

## RESERVOIR CHARACTERISTICS

The Jatibarang volcanic formation consists of lava flows (andesite/basalt), tuff and agglomerate / volcanic breccia which are volcanic reservoirs. The basaltic/andesitic lavas in the Jatibarang field are normally dark grey to black, have phenocrysts of plagioclase feldspar and a porphyritic texture with localised vugs and vesicles filled with zeolites formed during a late hydrothermal stage. The lavas are generally very heavily weathered and are dominated by greenish and reddish clays, such as chlorite and sericite, with iron oxides.

Compared to clastic reservoirs, volcanic reservoirs exhibit higher heterogeneity. Due to fractures, the tuffs have regional porosity and permeability of 16% to 25% and 10 D, respectively. The 30 °API oil had an initial GOR of 1100 SCF/STB and is probably produced by solution-gas drive. The fractures are detected by mud losses and drilling breaks (Sembodo, 1973). They are more common and more likely to be open in the more compact tuffs than in the weathered clay-dominated lavas.

The volcanic rocks of the Jatibarang formation are mainly felsic tuffs composed of alkali feldspars and quartz. Both rock types contain secondary minerals such as calcite and chlorite and are fractured to varying degrees. Beds of an agglomerate and volcanic breccia with intergranular porosity also occur and contain fragments of acidic and mafic composition. They are locally interbedded with mudstone.

## PRODUCTION BEHAVIOR

Reserve figures for the Jatibarang Field are unavailable but cumulative production at end-1982 was 72 MMBO and 93 BCFG (Courteney et al., 1989). The 30 °API oil is probably produced by solution-gas drive. The development was with its problems and the first 74 development wells drilled had a success ratio of only 59-62% probably due to a lack of fractures in the boreholes (Nutt and Sirait, 1985). By 1989, a total of 154 wells had been drilled on the field (Courteney et al., 1989).

The wells frequently experienced drilling problems such as hole instability, excessive reaming, stuck pipe and lost circulation. Initial production from one well was 3176 BOPD and peak production of 43,570 BOPD which 95% was from the Jatibarang Formation volcanic reached in 1973 from 23 wells (Courteney et al., 1989). Despite the drilling of more development wells and the introduction of gas lift, oil production fell to 7622 BOPD (from 66 wells) in 1984 and was producing 3200 BOPD by 1995 (Figure 1) (Courteney et al., 1989). A pilot horizontal well was drilled into the Eastern Block in the early 1990s but the results were disappointing due to the absence of significant fracturing (Kalan et al., 1994).

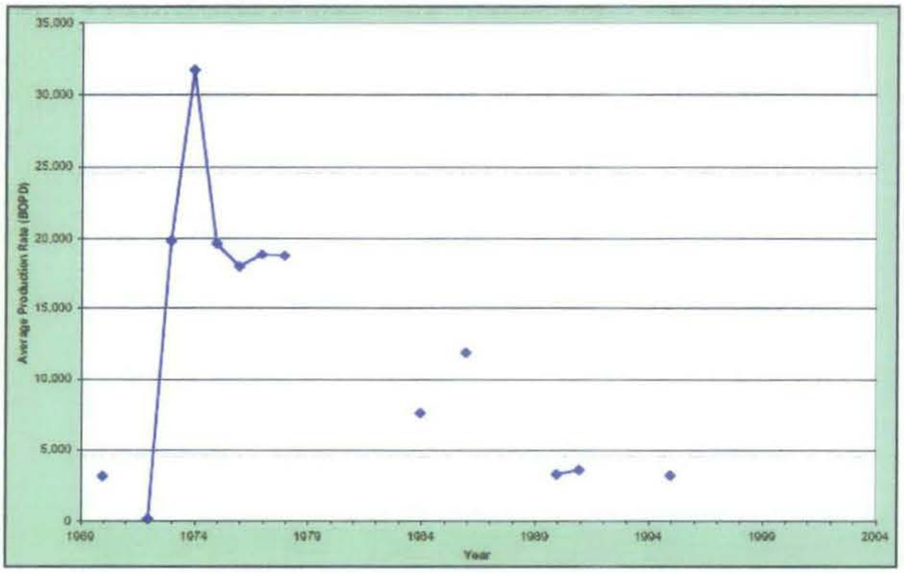


Figure 20: Production history of the Jatibarang Field, 1970-95 (from Reservoir Evaluation Report, 2004)

### 4.3.4 CASE STUDY 4: CHINA, YAERXIA FIELD

#### FIELD BACKGROUND

The Yaerxia field is located in the Laojunmiao Anticlinal Belt along the southern boundary of the Jiuxi (West Jiuquan) Basin, NW China (Figure 21). The field was discovered in 1957 and put on production in 1958 from the Oligocene L-reservoir, followed by the Silurian basement reservoir in 1959 and the Lower Cretaceous Xiagou formation in 1975. The Yaerxia field was discovered by surface mapping and step-out drilling down dip from the Laojunmiao Field. The Silurian reservoir, which contains a STOIIP of 74 MMBO with URR of 13.4 MMBO, is trapped in a sub-unconformity fault-block, with a hydrocarbon column of 550 m. It consists of metamorphic basement with matrix porosity <2.5% and permeability approaching nil, and fractures provide both storage space and pathways for fluid flow.

Figure 21: Map showing location of the Yaerxia and other fields in the Jiuxi Basin (Huo et al., 1997 Chen et al., 2001).

## GEOLOGICAL STRUCTURE

The structure of the Yaerxia field varies from one reservoir to another. The Silurian basement reservoir occupies an approximately NE-trending buried-hill block, which remained uplifted during the Devonian-Jurassic (Pan, 1982). At the beginning of the Early Cretaceous, the Yaerxia area was a faulted horst block 1650 m higher than the surrounding areas. During the Early Cretaceous, the field area subsided gradually, becoming onlapped by the alluvial fan to lacustrine deposits, and was submerged completely during the mid- Early Cretaceous Xiagou period at the time of maximum lacustrine expansion.

The structure at top of Silurian Quannaogou formation is a faulted asymmetric anticline with a gentle south limb (6- 10°), a steep north limb (30-60°) and a flat top (Huo et al., 1997). The reservoir is capped by an unconformity, overlain by muddy conglomerates of the Lower Cretaceous Xiagou formation (Qiu and Gong, 1999). The reservoir is limited to the east by fault and to the west by depositional pinch out. The top of the reservoir lies at 2892 m below ground, the oil column height is 550 m and the productive area is 8.9 $km^2$ (Huo, 1989; Xie et al., 2001).

## GEOCHEMICAL ANALYSIS

The oldest reservoir in the field is the Silurian Quannaogou formation, which consists of low grade metamorphic rocks including slate, phyllite, metamorphosed sandstone and recrystalline dolomite (Xie et al., 2001). The original lithology includes marl, limestone, shale and sandstone deposited in shallow-marine to tidal-flat environments (Du et al., 2004). The Quannaogou formation is divided into three sections. The purplish lower section consists of moderately to thickly bedded, purplish red slate, phyllite and metamorphosed sandstone. The variegated middle section consists of thin and interbedded purple, greyish brown and greyish green phyllite, metamorphosed sandstone and recrystalline dolomite. The greenish upper section consists of thickly bedded greyish green phyllite (Xie et al., 2001). Oil is mainly stored in the thinly bedded middle section where fractures are best developed.

## RESERVOIR CHARACTERISTICS

The penetrated thickness of the Silurian reservoir ranges from ~10 m to 500 m (Qiu and Gong, 1999). Due to the complex fracture systems, the reservoir displays an overall tank-like geometry. The Silurian metamorphic reservoir has low matrix porosity (<2.5%) and virtually no matrix permeability (Huo, 1989). Fractures provide both space for oil storage and pathways for fluid flow. They are predominantly tectonic fractures, and most occur as oblique shearing fractures and vertical extensional fractures. The average fracture density is 39 counts/m and the average aperture is 0.38 mm (Dun, 1995). Fracture density tends to increase with increasing proximity to a major fault.

Lithology and bed thickness also affect development of fractures. Both the fracture length and the frequency of long fractures decrease from coarser grained metamorphosed sandstone through slate to fine-grained phyllite (Table 3). Fracture density is highest in phyllite, lower in slate and lowest in metamorphic sandstone as shown in Table 4. The less brittle limestone has fewer but longer fractures. In terms of stratigraphic thickness, higher fracture density occurs in thinner beds, which explains why most fractures occur in the variegated middle section of the Quannaogou Formation, the main oil bearing unit of the reservoir.

Table 3: Relationship between grain-size and development of long fractures (Dun, 1995)

| Lithology | Fracture density (count/m) | Average length of fracture (mm) | Density of long fracture (count/m) |
|---|---|---|---|
| Limestone | 66 | 130 | 61 |
| Sandstone | 180 | 20 | 40 |
| Muddy sandstone | 171 | 16 | 28 |
| Sandy mudstone | 257 | 5 | 24 |

Table 4: Relationship between fracture density and lithology (Dun, 1995)

| Well | Phyllite | Slate | Metamorphosed sandstone |
|---|---|---|---|
| 311 | 91.3 | 25.8 | 10.6 |
| 315 | | 65.5 | 45.8 |
| 134 | | 62.3 | 17.2 |

## PRODUCTION BEHAVIOR

The Yaerxia Field has a STOIIP of 198 MMBO and URR of 46 MMBO (RF=23%) (CNPC, 2003). The latest STOIIP estimate is more than double that of the 1980s (85 MMBO), probably as a result of continued step-out drilling and reservoir re-evaluation. The Silurian basement reservoir has a STOIIP of 74 MMBO and a URR of 13.4 MMBO (RF of 18%) (Xie et al., 2001).

Oil quality is similar in the Silurian, Cretaceous and the Tertiary reservoirs. Oil gravity is 30°API in Silurian reservoir, 32 °API in Cretaceous Xiagou reservoir and 33°API in the Oligocene L-reservoir. Oil viscosity is 9.5 cp in the Silurian, 4.4 cp in the Cretaceous and 0.75 cp in the L-reservoir at reservoir conditions. Wax content is 16.5-17.0% in all three reservoirs (Huo, 1989). Original GOR is 320-584 SCF/STB (Li and Zhou, 1990). Natural drive is by solution-gas expansion in all reservoirs.

The stable production is likely to have also benefited from contribution from other reservoirs. The Silurian basement reservoir was put on production in 1959 from the Ya-114 well. With more wells put onstream, production from the reservoir increased steadily. Production was 1430 BOPD in 1990 before falling to 1077 BOPD in 1999 (Figure 23). By August 2000, the reservoir had produced 10.5 MMBO (78% of URR) when 38 production wells were producing at average rate of 1072 BOPD with 32.7% water-cut (Xie et al., 2001). The best well, Ya-114, has been on production for >40 years and reached cumulative production of 2.9 MMBO by 1998 (Qiu and Gong, 1999). The production is by solution-gas drive without EOR technique

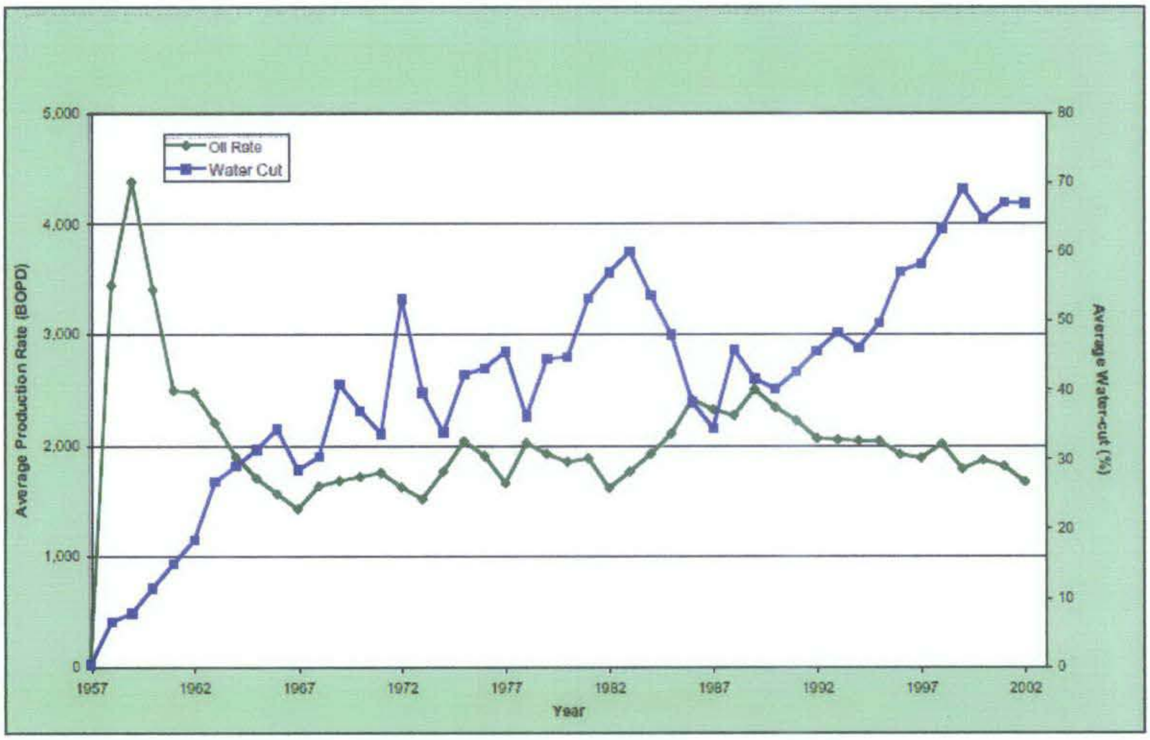


Figure 22: Production history of the Yaerxia Field (compiled from various sources).

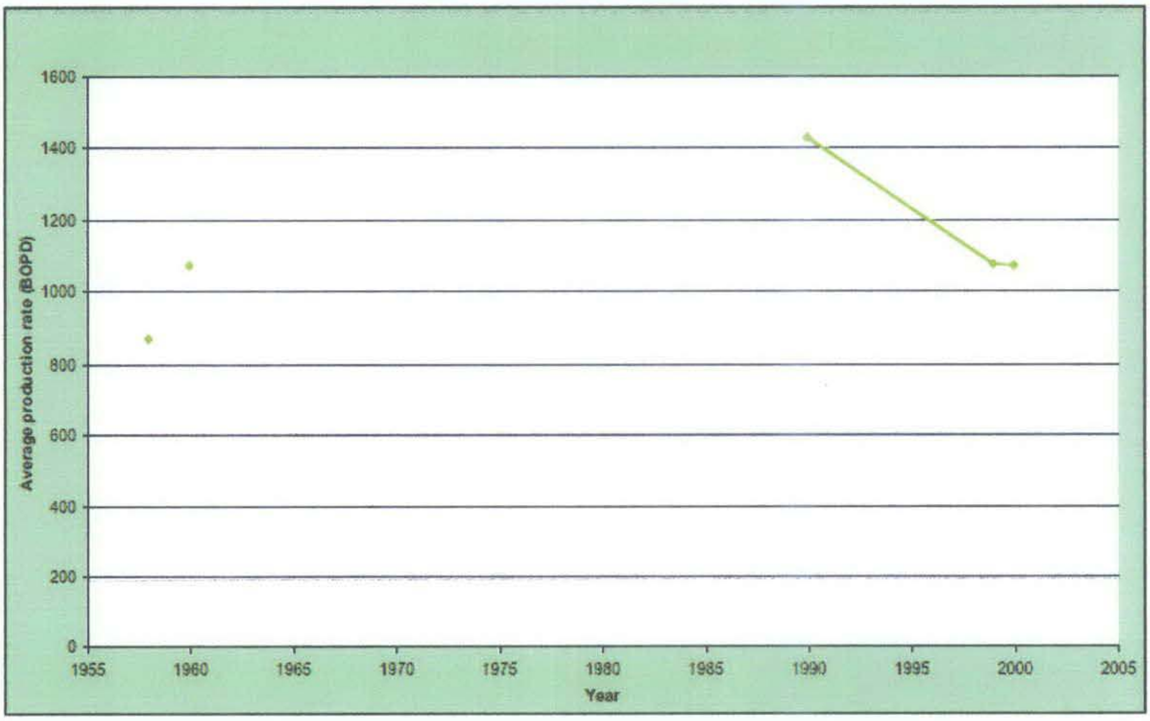


Figure 23: Production history of the Silurian reservoir in the Yaerxia Field (compiled from Huo, 1989; Huo et al., 1997; Xie et al., 2001).

## 4.4 DATA GATHERING AND ANALYSIS

In this project, four selected basement reservoirs are compared with Anding Utara in term of different field characters which are geology, geochemistry, reservoir characteristics and production behavior. All interpreted data are tabulated in the tables as following below:

Table 5: Comparison base on geology

| Fields | White Tiger Field, Vietnam | Zeit Bay Field, Egypt | Jatibarang Field, Indonesia | Yaerxia Field, China | Anding Utara Field, Malaysia |
|---|---|---|---|---|---|
| Age | Middle Jurassic – Early Cretaceous basement | Precambrian / Cambrian basement | Eocene to Oligocene | Silurian basement reservoir | Pre-tertiary |
| Lithology | • Heterogeneous reservoir<br>• Granitic basement formation<br>• Fluvio – lacustrine sandstone | • Heterogeneous reservoir<br>• Granitic basement formation<br>• Basement wash (Paleozoic) | • Jatibarang formation<br>• Andesite lava with volcanic tuff | • Metamorphic reservoir<br>• Phyllite<br>• Slate &<br>• Meta-Sst<br>• Recrystalline dolomite | • Meta-reservoir<br>• Phyllite<br>• Slate &<br>• Meta-Sst |
| Fracture Intensity | • Fracture size varies from 2 µm to mm | • High intensity fracture (5-15 fracture per foot)<br>• Open fracture | • Fracture more effective in compact tuff | • Fracture density is 39 counts/m (highest in phyllite) | • 0.1 – 1.0 fracture / meter |
| Regional stress | • Fault, with dip-closure to the S and NE | • NW-SE trending structure (2.5 km by 4.5 km) | • Fault & dip-closed | • NE trending buried-hill block | • Open fracture<br>• NE-SW trending structure |

Table 6: Comparison base on geochemistry

| Fields | White Tiger Field, Vietnam | Zeit Bay Field, Egypt | Jatibarang Field, Indonesia | Yaerxia Field, China | Anding Utara Field, Malaysia |
|---|---|---|---|---|---|
| Biomarkers | • Tracu & Tratan formation as source rocks<br>• Lithology: shales | • Brown limestone (marine source rock, carbonates)<br>• Lithology: limestone | • Talang Akar formation as source rock<br>• Lithology: Carbonaceous shale and coal | • Quannouqou formation<br>• Lithology: Interbedded purple, greyish brown and greyish green phyllite, meta-morphosed sandstone and recrystalline dolomite. | • Presence of both algal and terrigenous higher plant organic matter being deposited and preserved in a mixed fluvial-lacustrine setting |
| Paraffin, aromatic, resins & asphaltenes, (%) | Sulfur: 0.035%<br>Wax : 27% | Sulfur: 1.6 wt%<br>Wax: 5.0 wt%<br>Asphaltenes: 3.26 % | Paraffin: 39%<br>Wax: 26.95%<br>Asphaltenes:28% | Sulfur: 0.12%<br>Wax: 16.5 % | Very waxy |

Table 7: Comparison base on reservoir characteristics

| Fields | White Tiger Field, Vietnam | Zeit Bay Field, Egypt | Jatibarang Field, Indonesia | Yaerxia Field, China | Anding Utara Field, Malaysia |
|---|---|---|---|---|---|
| Production derived Permeability | 15 to 20 mD | 20 to 300 mD | 10 D | 32 to 614mD | 0.0151 mD |
| Porosity | 2.5 to 3.8 % | 6 to 11% | 16 to 25% | >2.5% | 2-6 % |
| Reservoir Temperature, °F | 230 °F | 152 °F | 246 °F | 187 °F | 270 °F |
| Reservoir Pressure, psi | 4060 psi @ 2800m TVDSS | 2235 psi @ 1356 m TVDSS | 3187 psi @ 2882 m TVDSS | 4849 psi @ 2892 m TVDSS | 5143 psi @ 2606 TVDRT |
| Bubble Point, $P_b$ | 2538 psi | 2095 psia | 2150 psia | NA | 4680 psia |
| FVF@$P_b$ | 1.385 | 1.28 | NA | NA | 1.7257 |
| API Gravity | 40.5 °API | 33 °API | 30 °API | 30 °API | 41.3 ° API |
| GOR, scf/stb | 584 | 680 | 1100 | 350-584 | 4210 |
| Wax Content (%) | 27 % | 5.0 % | 26.95% | 16.5-17.0% | Very waxy |
| Formation Thickness, m | > 1500 m | 14 - 163 m | > 1124 m | 550 m | 278 m |
| $\mu$@$P_b$ and $T_{\downarrow}$ cp | 1.20 cp | 0.84 cp | N/A | 9.5 cp | 0.159 cp |

Table 8: Comparison base on production behavior

| Fields | White Tiger Field, Vietnam | Zeit Bay Field, Egypt | Jatibarang Field, Indonesia | Yaerxia Field, China | Anding Utara Field, Malaysia |
|---|---|---|---|---|---|
| Water depth | 50 m | 20 m | 9 m | 2500 m | N/A |
| Ultimate recoverable (year) | • 900 MMBO, 1 TCFG (2000) | • 320 MMBO, 145 BCFG | • N/A | • 13.4 MMBO (2001) | • N/A |
| Cumulative production (year) | • 550 MMBO, 190 TCFG (1999) | • 210 MMBO (mid-1997) | • 72 MMBO, 93 BCFG (1982) | • 10.5 MMBO (2002) | • N/A |
| Initial production rate (year) | • 800 BOPD, 4 MMCFGPD (1986) | • 22000 BOPD (1984) | • 3176 BOPD (1970) | • 1072 BOPD (1960) | • 160 BOPD (from testing data) |
| Maximum Production rate (year) | • Oil: NA<br>• Gas: 75 MMCFGPD (1994-95) | • Oil: 72000 BOPD (1987) | • Oil: 43570 BOPD (1973)<br>• Gas: 66.5 MMCFGPD (1983) | • 4380 BOPD (1959) | • 182 BOPD (from testing data) |
| No. of production well (year) | • 140 wells (including Rong Field) (1996) | • 45 wells (1998) | • 154 wells (pre-1989) | • 38 wells | • N/A |

# CHAPTER 5

# RECOMMENDATION

## 5.1 DEVELOPMENT STRATEGY

The study of the fractured reservoir should begin with a detailed analysis of the geometry, origin, morphology, density of the fractures and the development of the porosity and storage capacity system of the reservoir rocks. These parameters control the borehole diameter and the trajectory of the boreholes. From the research, a rationale for successful exploration and development of basement reservoirs would consist of the following:

- Identify basement highs with adjacent kitchen area. Gravity mapping may be a useful tool for this when basement is below significant cover rocks.

- Determine migration and tectonic history with particular emphasis on the youngest phase of tectonics and the fracture properties and distributions associated with it.

- Determine the associated mineralization history in order to establish which fracture trends have remained unsealed.

- Determine the present-day in-situ stress condition (magnitudes and orientation of the principal stress axes) and evaluate which fault and fracture trends may be most susceptible to dilation at the present day. Target fault structure in the more homogeneous lithologies, especially granitic formation.

- Target exploration and development wells at the damage zones of major fault, especially those which may be in critical shear. Also target steps and jog zones along the fault structure where strain will have concentrated during deformation leading to potentially higher fracture densities.

Due to the fractured nature of the basement rock very limited amount of core material is available, mostly from the tighter parts of the basement. Petrophysical reservoir description has therefore to be based on the following sources:

- Petrographic reports
- Mud log information
- Cuttings description
- Open-hole logs
- Formation Micro Scanner log results (FMS)

## 5.2 IMPROVED OIL RECOVERY OF BASEMENT RESERVOIR

A large number of EOR research proposals in naturally basement reservoir. Field projects showed the technological capability to increase oil recovery and the estimated long run costs for their operation. This increase in oil recovery would directly result in additional reserves extending the productive life of the different assets. When the maximum oil production in the basement reservoir was reached, after a few years it is gone to declining period. Many solutions can be proposed to increase oil production including acid injection and bottom cleaning, hydraulic fracturing in combination with injection of substance for filling fractures and chemical flooding such as surfactant flooding, polymer flooding and periodical water injection.

### 5.2.1 HYDRAULIC FRACTURING

This method was proposed by some researchers in the Research and Design Institute of Vietsovpetro including S. Jain et al., 2007 and Duong D. L et al., 2008. Many previous researches reported an application of hydraulic fracturing treatments and acid fracturing treatments in naturally fractured carbonate reservoirs or sandstones formation. However, there is a limitation successful hydraulic or acid propped fracturing in deep, high temperature or vuggy-fractured basement reservoir.

The main reasons could be explained due to excessive fluid leak-off nature into vuggy-fracture network, availability with fracture geometry model for design and analysis and a well lack of research and development in relation to economics. Technical inadequacy on fracturing fluid requirements such as compatibility of fluids and rock formation, controlled viscosity requirement, friction pressure and non damaging fluid loss control also one of the limitations.

An example as case study is Vietsovpetro applied hydraulic first time for one well which was produced in basement reservoir in 1995 (White Tiger field). The result is the well's productivity increased 2.5 times to pre-treatment production record. The temperature in basement reservoir is usually more than 140°C, so one of the most common methods is matrix acidizing using acid oil emulsion. However, after many repeated acid treatments in every well and high temperature, this method is no longer effective.

In additional, most of fractures and micro-fractures near wellbore had tended to closed with decreasing of average reservoir pressure. It makes more difficult for stimulation jobs and hydraulic fracturing becomes the most promising method to increase oil recovery [23]. This is one of successful case of improved oil recovery in the basement reservoirs by hydraulic fracturing (Figure 24).

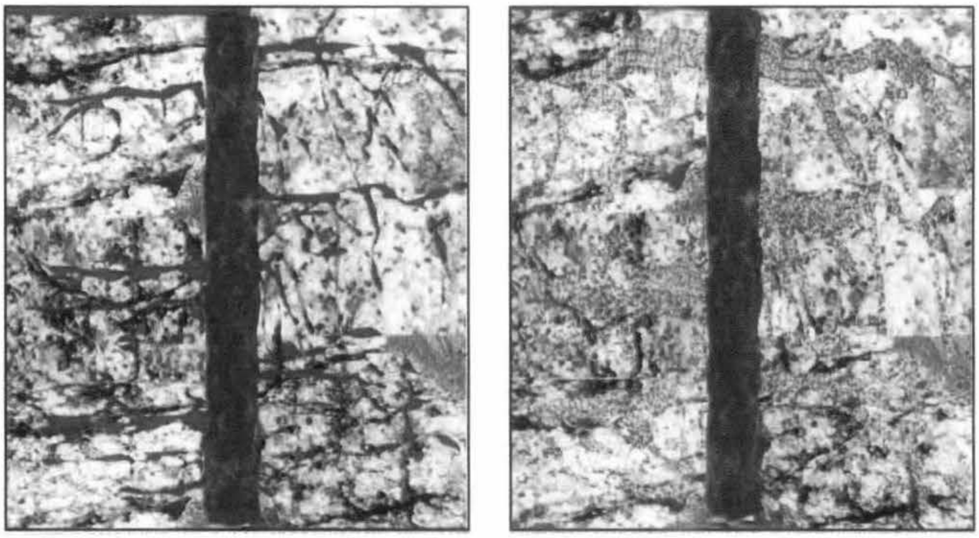


Figure 24: Hydraulic fracturing in basement reservoir (from Duong D.L et al, 2008)

### 5.2.2 SURFACTANT FLOODING

Surfactant plays an important role in oil recovery by reducing the interfacial tension between the injection brine and the residual oil. It can also alter the wettability of the formation in order to increase the oil recovery. However, high temperature and high salinity are big challenges in applying surfactant flooding in basement reservoirs.

### 5.2.3 WATER SHUT-OFF IN BASEMENT RESERVOIR

Many cases happen after a long production time, the greatest difficulty to control well is the high water level in the production well. Oil production from some wells in particular fields is always impaired by excessive water production. Excess water not only reduced the artificial lift efficiency but also imposed a great deal of damage to the oil zones. An example as case study, in 2002, Keng Seng Chan et al proposed a method to improve production water shut-off. The potential of a high temperature polymer base water shut-off fluid is evaluated for deep penetration of the fissure formation and micro-fine cement system for sealing off the entire water.

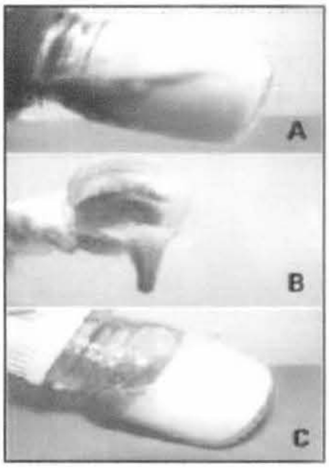


Figure 25: Polymer-gel preparation for water shut-off (from Keng Seng Chan. et al, 2006)

In 2005, the treatments were performed in 2 wells in the White Tiger basement reservoirs. The water cut was 95% in one well and 98% in other well. From the investigation, they have found a new micro-fine particle system was the proposed for the near wellbore seal right after the placement of the flowing gel in the formation. This system is a cementitious material specifically designed to more efficiently penetrate narrow gaps without bridging or dehydrating during placement.

From the research, other chemico-physical action methods such as gas injection, alkaline injection and surfactant injection are not suitable with the high temperature and extremely heterogeneous reservoir. So, it is necessary to study a special chemical to tolerate with reservoir condition for optimum production. In the naturally fractured basement reservoir, it is a challenge to apply enhanced oil recovery due to the complexity of geological characterization. However, some EOR applications were successfully performed for both lab and field scales. This is really a worthwhile lesson to the improvement of the efficiency of the EOR process for basement reservoirs around the world.

### 5.2.4 HORIZONTAL WELLS

Horizontal wells may produce at 3-5 times the rate of vertical wells in the same area (as much as 20 times higher in special cases). However, horizontal wells typically cost 1.5-3 times as much as vertical wells in the same area. Horizontal wells are often very attractive in formations with extensive vertical fractures. The use of horizontal wells has been growing worldwide for conventional reservoirs. It has increased our recoverable reserves. In U.S one rig in ten is drilling horizontal wells (1994-1998) and today, one rig in fifteen is drilling horizontal wells (2001).

The advantages generally include higher productivity indices, the possibility of draining relatively thin layers, decreased water and gas coning, increased exposure to natural fracture systems, better sweep efficiencies and specific EOR applications such as steam-assisted gravity drainage. Horizontal wells may be applicable in fractured basement reservoirs to connect the extensive vertical fractures and increase permeability.

### 5.2.5 Matrix Acidizing

Matrix treatment, an acidizing in particular, aims to remove the excess flowing pressure drop created by the presence of volume rock which has suffered formation damage in the near wellbore area. Damaged zone has lower permeability than original. The removal of this formation damage will restore the 'natural' well productivity. Matrix stimulation treatments increase well productivity by pumping a special formulated treatment fluid normally acid. The fluid is designed to dissolve the formation damage near the wellbore in all types of wells. There are two type of acidizing which are matrix acidizing and acid fracturing. In carbonate formations, acid may be used to create linear flow systems by acid fracturing. However, acid fracturing is not applicable to sandstone. The two basic types of acidizing are characterized through injection rates and pressures. Injection rates below fracture pressure are termed matrix acidizing, while those above fracture pressure are termed acid fracturing.

It is applied to remove skin damage caused by drilling, completion, workover or well-killing fluids and by precipitation of deposits from produced water. Due to the extremely large surface area contacted by acid in a matrix treatment, spending time is very short. Therefore, it is difficult to affect formation more than a few feet from the wellbore. Removal of severe plugging in sandstone, limestone, or dolomite can result in a very large increase in well productivity. If there is no skin damage, a matrix treatment in limestone or dolomite could stimulate natural production no more than one and one-half times. In matrix acidizing, acid flow is confined to the formations, natural pores and flow channels at a bottom pressures less than the fracturing pressures (Figure 26).

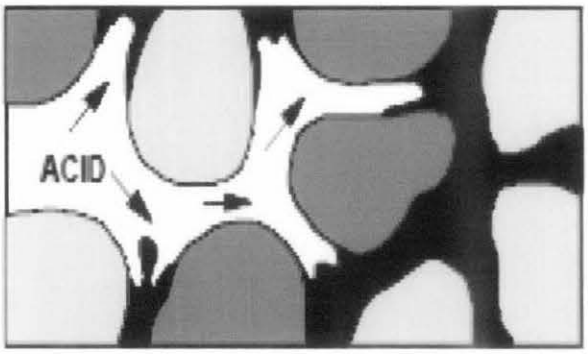


Figure 26: Matrix Acidizing

The purpose is to increase the permeability and porosity of the producing formation. During the matrix acidizing job, the contact area between the acid and the formation is very large. Therefore, friction pressure increases rapidly with increased pumping rates. Due to high friction pressures, matrix acidizing must be conducted at low injection rates. A matrix acidizing treatment consists of slowly injecting acid into the formation so that it penetrates into the pore spaces of the rock without fracturing the formation. Matrix acidizing is used primarily in sandstone formations to dissolve unwanted materials that have invaded the rock pores during drilling, cementing and completions operations.

# CHAPTER 6

# CONCLUSION

From the study, four basements discoveries, White Tiger field of Vietnam, Zeit Bay field of Egypt, Jatibarang field of Indonesia and Yaerxia field of China have been compared of which the Yaerxia field is seen as similar behavior with Anding Utara field. These two fields have same lithology (phyllite), nearly equal reservoir pressure and also both have high wax content (exact value of Anding Utara is not known). However, Anding Utara field has higher reservoir temperature (270 °F) and higher GOR (4210 scf/stb) compared to the Yaerxia field but, the fracture density is comparatively low. The Yaerxia field, with lower temperature (187 °F) and lower GOR (350-584 scf/stb), shows stable production for almost nine years because of its high fracture density (39 counts/m). The Anding Utara on the contrary shows inconsistent production even with high temperature and high GOR only because of low fracture density (0.1-1 fractures/m). From the study, it confirms that the fracture distribution and connectivity plays an important role in hydrocarbon production from the basement reservoirs. Artificial fracturing by hydraulic fracturing and matrix acidizing to increase the permeability, and horizontal wells to connect extensive vertical fractures are suggested here as possible engineering solutions for the Anding Utara to put it back on production.

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