Chiang Mai J. Sci. 2016; 43(6) : 1237-1248
http://epg.science.cmu.ac.th/ejournal/
Contributed Paper

Overview of the Past and Future G&G Activities in the Pattani Trough, Gulf of Thailand

Masashi Fujiwara [a] and Neil Smith [b]
[a] Mitsui Oil Exploration Co., Ltd. (MOECO), Tokyo, Japan.
[b] formerly Mitsui Oil Exploration Co., Ltd. (MOECO) now Consultant.
* Author for correspondence; e-mail: nlewiss@fastmail.fm

Received: 29 June 2016
Accepted: 8 September 2016

ABSTRACT

Oil and gas exploration in the Pattani Trough, Gulf of Thailand was initiated in 1968 and since then more than 20 oil and gas fields have been discovered. As of the end of October, 2015 daily production was 1.7 BCF of gas, 140,000 barrel of condensate and oil, totally 430,000 barrels of oil equivalent. The Pattani Trough is a rift type-sedimentary basin of Cenozoic age and the maximum thickness of sediments is more than 10 km. Oil and gas are mainly trapped in fluvial to deltaic sandstones located between depths of 5,000 to 9,000 feet. Structure is characterized by many normal faults. ConocoPhillips and MOECO drilled the first exploratory well, Surat-1 in the Gulf of Thailand in 1971. The first successful exploratory well, 12-1 (Erawan-1), was drilled in 1972 by Union Oil (presently Chevron) and SEAPEC (presently MOECO). The first gas from the Erawan field was put on stream in 1981 and shortly after the commencement of production a shortfall issue occurred due to the smaller reserves per well than anticipated. This crisis was rescued through the reduction in the cost of drilling and facilities and the reduced geologic risk by using 3D seismic data to plan complex well paths to penetrate multiple gas reservoirs. The 3D seismic acquisition in the Erawan field was completed in 1980 only three years after the first 3D acquisition of the Bongkot field in the Gulf of Thailand. Since then more than 30 additional 3D seismic surveys have been carried out in the Chevron operated Blocks 10,11,12,13 totaling approximately 12,000 square kilometers. The most advanced interactive interpretation systems at the time, *SDS and *SIDIS were introduced in the early 1980s and although these were proto-type workstations they were used for both structural interpretation and for reservoir prediction. The first test for reservoir prediction was made by the Erawan E-4 well in 1982, however, it was unsuccessful. In general, it is understood that high amplitudes are directly related to the presence of sands but not necessarily the volume of gas and, direct hydrocarbon prediction has had mixed results. This paper will briefly review the historical perspectives of seismic technology with some old-fashioned "hand-drawn" maps and the future exploration potential including shallow hydrocarbons related to the Middle Miocene Unconformity (MMU) and Basement traps.

Remark : *Trade mark of GSI

Keywords: Pattani trough, oil and gas, G&G, 3D seismic, Q survey

1. INTRODUCTION

Oil and gas exploration in the Pattani Trough, Gulf of Thailand was initiated in 1968 and since then more than 20 oil and gas fields such as Erawan, Pailin, Benchamas and Jasmine have been discovered (Figure 1) (Fujiwara, 2011 [1]).

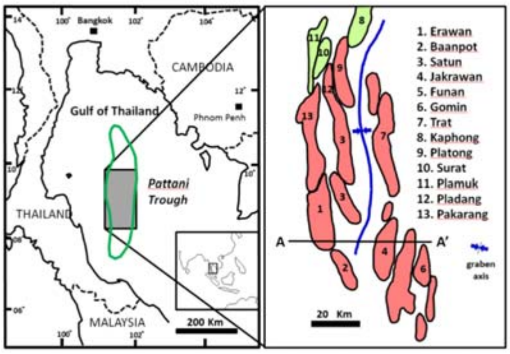

Figure 1. Location map of study area and oil and gas fields in the Gulf of Thailand (modified from Fujiwara, 2011 [1]).

As of the end of October 2015 daily production was 1.7 BCF (billion cubic feet) of gas, 140,000 barrels of condensate and oil, totally 430,000 barrels of oil equivalent. The natural gas is piped onshore and used for the generation of electricity where it counts for approximately 70% of Thailand's need for power. Confidence in the future production for gas is essential for the long term economic and energy planning for the Kingdom.

The Thai offshore area in the Gulf of Thailand was originally divided into 18 offshore blocks that were internationally tendered before the Petroleum Law and Petroleum Tax Laws were ratified in 1971.

The only company that made a successful bid at that time and is still operating is Chevron (formerly Union Oil/Unocal). In 1970 MOECO (Mitsui Oil Exploration Co., Ltd.) farmed into the Blocks 10 and 11 which Conoco (ConocoPhillips) acquired in the first round with the earning obligation of two exploratory wells.

The first exploratory well, Surat-1 was drilled on 2D seismic data by Conoco (ConocoPhillips) and MOECO in 1971. The well failed to encounter hydrocarbons, heweve, this struture was found to contain a commercial oil field 25 years later. The Erawan gas field was discovered in 1972 by the exploratory well, 12-1 and the first gas was produced in 1981 with a CPP (Central Processing Platform) and four production platforms (about 40 wells) with an expected production life of 20 years. However, due to the highly faulted small gas reservoirs and the unexpected seal failure of production packers due to high temperatures encountered, the gas supply was insufficient resulting in Contractual shortfall. An expert evaluation concluded Erawan's reserves to be less than half of the original estimate.

This crisis was rescued through the reduction in the cost of drilling and facilities and reduction in geologic risk through using three-dimensional seismic data to plan complex well paths to penetrate the multiple gas reservoirs. Details of the Erawan gas field will be discussed.

After almost 50 years of oil and gas exploration and production in the Pattani Trough it is unlikely that any further large exploration potential remains in the mature developed trends although there are some new ideas. We will review the previous G&G work in the Gulf of Thailand and will discuss future potential.

2. GEOLOGICAL BACKGROUND OF THE PATTANI TROUGH

The Pattani Trough, approximately 100 km wide and 250 km long, is a rift type-sedimentary basin of the Cenozoic age and the maximum thickness of sediments is more than 10 km. In general, oil fields are common in the north and gas (plus condensate) fields are dominant in the south. The geological column is divided into five sedimentary units from Sequence 1 to 5 in ascending order (Figure 2). Two major unconformities are identified: one is called the Middle Cenozoic Unconformity (MCU) and the other one is the Middle Miocene Unconformity (MMU). The latter unconformity is located between Sequence 4 and Sequence 5. Oil and gas are mainly trapped in fluvial to deltaic sandstones of Sequence 3 and Sequence 4 located between 1,500 to 2,700 m. Structure is characterized by many normal faults as shown in Figure 3. Oil and gas are mainly trapped in sandstones in Sequence 3 and 4 with a depth of ranging from 1,200 (3,940') to 2,750 m (9,020') of the Lower to Middle Miocene age.

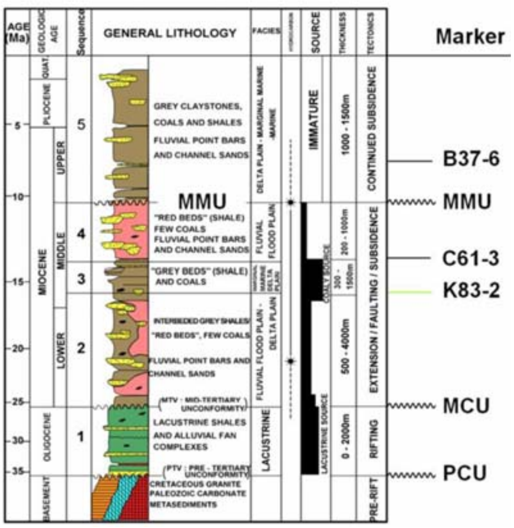

Figure 2. Generalized stratigraphy of the Pattani Trough.

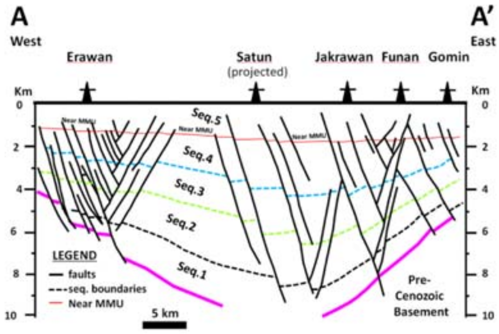

Figure 3. Geologic cross section through the Erawan - Satun - Jakrawan - Funan - Gomin fields which is highly faulted (Fujiwara, 2011 [1]). Location is shown in Figure 1.

3. G&G OPERATIONS IN THE PATTANI TROUGH

3.1 Geological Operations

Geological operations in the Pattani Trough are not on the same scale when compared to seismic operations but basic and steady. As this is well documented by Racey (2011) [2] only some additional points will be mentioned.

3.1.1. Diagenesis of reservoir sandstones

The main reservoirs in the Pattani Trough are the Lower to Middle Miocene fluvial channel and over-bank sandstones which predominantly occur at depths between 1,500 m to 2,400 m, although hydrocarbon bearing sandstones have been encountered from 1,200 m to 3,000 m (Racey, 2011 [2]).

Lundegard and Trevena (1990) [3] chemically and isotopically analyzed 20 samples of formation water and cements in the reservoirs from the Erawan and Platong fields. It is concluded that porosity decreases rapidly with depth due to mineralogical alteration under high geothermal gradient, high CO_2 content and low salinity formation water when compared to the Gulf of Mexico reservoirs that are approximately the same geologic age.

3.1.2 Distribution of CO_2 and its origins

Main inert gases in the Pattani Trough are carbon-dioxide (CO_2) and nitrogen (N_2). Total CO_2 content generally increases with depth from 10% at 1,500 m (4,500') to 20% at 2,700 m (9,000') as shown in Figure 4 (Minezaki and Moriyama, 2002 [4]). Some reservoirs have a CO_2 content over 90%. In the center of the basin N_2 is generally less than 1% but in some areas, such as western part of the Erawan field is greater than 2%.

The vertical distribution of CO_2 is expressed as "General Trend" in Figure 4. The origin of the CO_2 is thermogenic derived from kerogen. However, the abnormally high CO_2 in the western part of the Platong field may have a different origin. Sasaki (1986) [5] studied the distribution and origin using geological phenomenon such as abundance of pyrite and chlorite in the cuttings and samples of fresh water taken in the tests and concluded it to be of hydrothermal origin (Figure 5). Also following the idea from Minezaki (personal communication), Fujiwara, Yamada and Sasaki (2009) [6] proposed to predict high CO_2 zone using E-log as shown in Figure 6 because of high shale resistivity of hydrothermal effected shales. Minezaki, Jagerman and Lin (2002) [7] stated that the anomalously high CO_2 gases were generated by the thermal decomposition and/or dissolution of the pre-Tertiary basement carbonates based on the carbon isotopic analysis and geological and geophysical data.

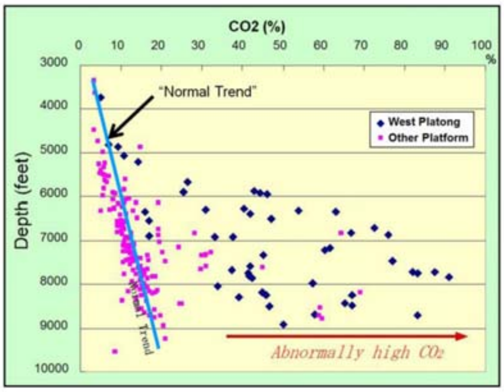

Figure 4. Vertical distribution of CO_2 in the Platong field (modified from Minezaki and Moriyama, 2002 [9]).

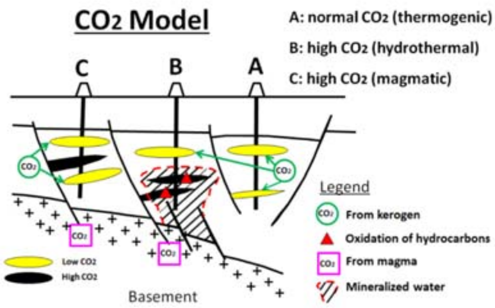

Figure 5. CO_2 model for the Platong field (Sasaki, 1986 [4]).

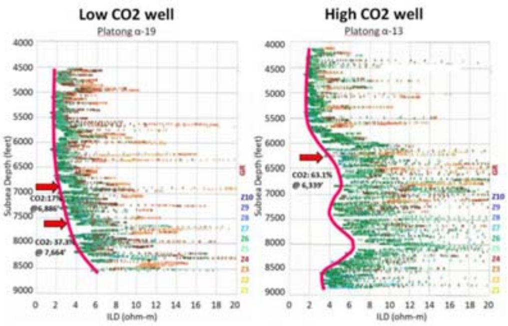

Figure 6. Formation resistivity v.s. depth plot (after T. Minezaki).

The origin of high CO_2 in the western part of Erawan field is interpreted by Fujiwara and Sasaki (1988) [8] to be of inorganic origin based on the study on isotopic data and geological evidence as shown in Figures 7 and 8.

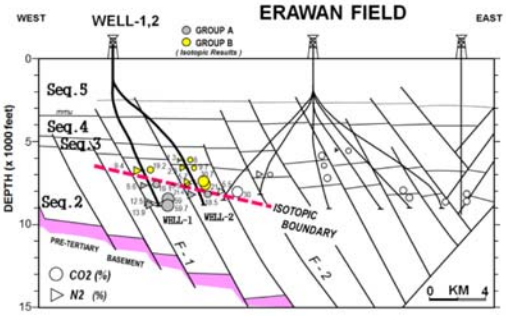

Figure 7. Geologic cross section and CO_2 & N_2 distribution in the Erawan field (modified from Fujiwara and Sasaki, 1988 [8]).

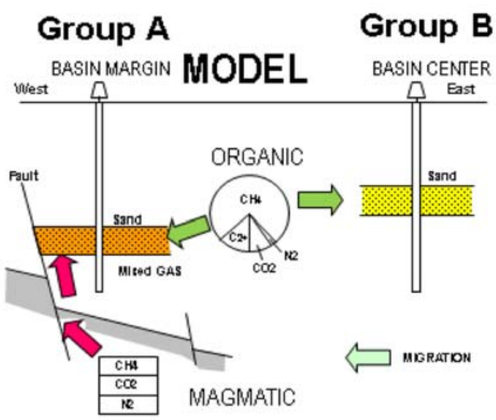

Figure 8. Hydrocarbon accumulation model in the Erawan field (Fujiwara and Sasaki, 1988 [8]).

The Gas Sales Agreements have a CO_2 cut-off for sales of 23% and this is achieved through blending of high and low CO_2 content gases at the CPPs or through partial removal of CO_2 as at the Pailin Field.

3.1.3 Nature of gas and crude oil

3.1.3.1 Nature of gas

Although the data are limited, three groups (1, 2, 3) can be seen in the δ13 °C methane and δ13 °C ethane in the Pattani Trough (Figure 9) (Fujiwara, 2012 [9]. Group 1 is gas generated from Type III kerogen in Sequence 3 although maturation is not determined because its kerogen type is unknown. Group 3 is associated gas with oil generated from lacustrine source rock in Sequence 1. Group 2 is characterized with higher maturation gas probably cracked from oil. Differentiation between Group 1 and Group 2 (and Group 3) can be made by the plot of C1 / (C2 + C3) ratio vs δ13 °C methane as shown in Figure 10. There are two groups between the line on δ13 °C methane = - 34.6%.

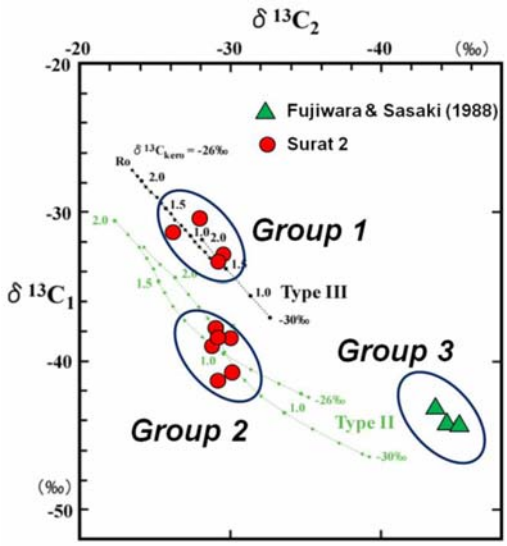

Figure 9. δ13 °C methane and wetness (C1/(C2+C3)) (Fujiwara, 2012 [7]).

As mentioned above, it is not easy to estimate maturation levels based on only measured isotopic data. Maturation is variable based on the type of source rock. Therefore, estimated maturation directly from δ13 °C methane may not be accurate. More data should be collected and careful interpretation is needed.

According to Figure 10, most gases in the Pattani Trough may be cracked gas from oil derived from the deeper areas and generated from lacustrine shale in Sequence 1 if Group 2 gas is located on Type II maturation trend where δ13 °C methane is about - 40%. This is in agreement with the results of the basin modeling by Minezaki and Moriyama (2002) [4].

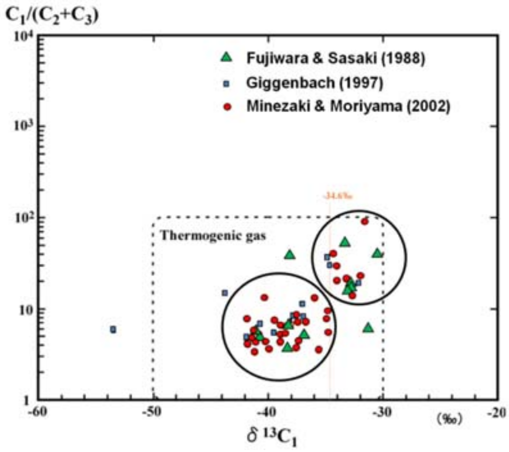

Figure 10. δ13 °C methane and wetness (C1/(C2+C3) (Fujiwara, 2012 [7]).

3.1.3.2 Nature of crude oil

Based on the Pr / Ph (Pristane / Phytane) ratio vs. δ13 °C plot of oil from the southern Pattani Trough (excluding Benchamas) as shown in Figure 11 (Jardine 1997 [10], Minezaki and Moriyama 2002 [4]), two types of source rock, lacustrine shale in Sequence 1 and coaly shale in Sequence 3, are identified. However, since δ13 °C of oil is widely ranging from - 21 % to - 34 %, it is possible that δ13 °C of kerogen may be more variable. For example, it is clearly identified that these two type of groups, such as from Dara/Surat fields and Ubon/Yala fields are generated from different kitchens. Therefore, if source rock type is known, it is possible to estimate the maturation level of the associated oil and gas.

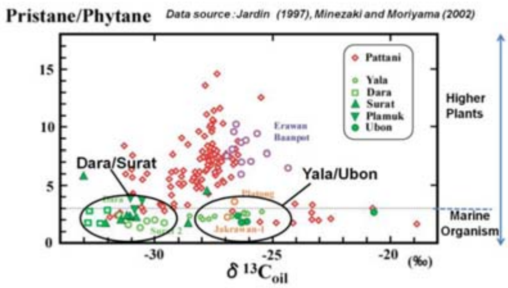

Figure 11. Pristane / Phytane ratio vs. δ13 °C plot of oil in the Pattani Trough (Fujiwara, 2012 [7]).

3.2 Seismic Operations

3.2. General history of seismic operations

The history of seismic is summarized below according to Smith (2004) [11]. Seismic activity was initiated in late 1960s in the Gulf of Thailand and its timing was almost coincident with the coming of the digital revolution in seismic and gave us tremendous bonus to the Gulf of Thailand considering the difficulties encountered in its initial production.

1960-1975 Digital revolution. Modern seismic sections & potential field mapping

1975-1985 Stratigraphic Geophysics, Bright-spot technology, Sequence Stratigraphy

1985-1995 3D Seismic, 2D PSDM, AVO, Advanced Workstations

1995-2004 3D Pre-Stack Depth Migration, Reservoir Geophysics

Since 2004 many new innovations in seismic acquisition and processing have occurred including:

i) Increase bandwidth and resolution through the removal of the frequency notched caused by the water leg "ghost". This has been achieved using a variety of techniques including streamers containing both geophones and hydrophones or use of two streamers at different depths or one streamer towed at an angle.

ii) Time lapse acquisition where a second (or third) survey is recorded later in the production life of a producing field. With the right conditions it is possible to see how the hydrocarbons have moved during production and indicate areas of possible by-passed production for future drilling.

iii) Multi-azimuth or wide-azimuth acquisition where a range of shot-to-receiver azimuths is recorded using either multiple shooting vessels or a single vessel in circular or spiral shooting pattern. The latter technique has the advantage of continuous acquisition and deployment of fewer vessels thereby saving costs and time.

Another improvement in technology that should be mentioned for improving the quality of seismic data and its interpretation are the increased accuracy of navigation and location both external to the seismic vessel (location on the Earth) and internally between the seismic vessel and the various components of the guns and streamers. Modern systems use GPS receivers on the tail-buoys and sonar systems on the streamers and guns. As the locations of all elements of the system are known in real time the vessels and can be geo-steered to counteract currents or tides, avoid obstructions or infill areas of poor or incomplete subsurface coverage.

3.2.2 Seismic activities in the Gulf of Thailand

3.2.2.1 Pre- 3D seismic survey

In the first years of exploration activities more than ten 2D seismic surveys were carried out in the Blocks 10 to 14 and many favorable drillable structures were identified. Based on the 2D seismic survey data, exploratory wells such as Surat-1 well in 1971 and 12-1 (Erawan-1) well in 1972 were drilled as pioneer exploration in the Gulf of Thailand.

3.2.2.2 3D seismic survey

In 1977, the first 3D seismic survey in the Gulf of Thailand was carried out at the Bongkot field located in the Malay Basin. Three years later the Erawan 3D seismic survey in the Pattani Trough was completed. Figure 12 shows a comparison of the Erawan structure based on 2D and 3D seismic data. To date more than 30 different 3D surveys were acquired creating a patchwork pattern as shown in Figure 13.

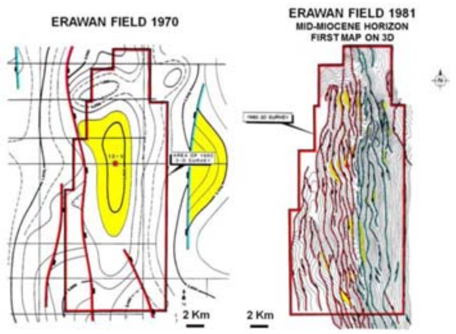

Figure 12. Comparison of the 2D and 3D data based structure of the Erawan field (Smith, 2004 [11].

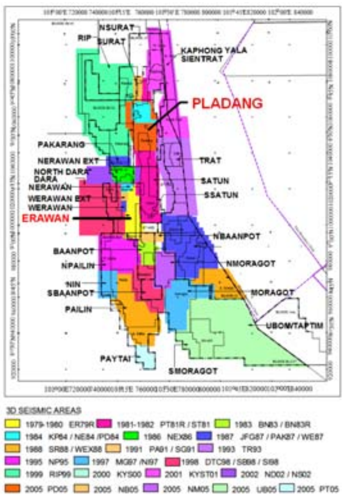

Figure 13. Patchy 3D vintages in Blocks 10 to 14 (Smith, 2004 [11]).

Interpretation of the 3D seismic data was made initially by hand, the so-called "jump correlation" where only every fifth line is picked for quick interpretation. A few years later, the Operator (Unocal Thailand, presently Chevron Thailand) introduced the prototype of workstation, SDS and SIDIS (GSI's trademark) to help map the complex structures and to predict reservoirs. The Operator also studied how seismic waves can predict reservoirs as shown in Figure 14. According to the wedge model, it says if thickness of reservoir is more than 20-30 feet, amplitude will be enhanced due to the tuning effect of both reflected waves from top and bottom of reservoir sandstone constructively interfere. Figure 15 shows the first attempt to predict reservoir at the Erawan E-2 well; however, it was not successful (Fujiwara, 2007 [12]). Figure 16 shows and older vintage had drawn map in which there is good agreement between the seismic anomaly interpreted manually and the anomaly identified by the SDS (Fujiwara, Maeda and Yasuhara, 1986 [13]). In Figure 14 it is noted that a thickness of 20 feet of the Sand D is in general agreement with the theoretical wedge model described above.

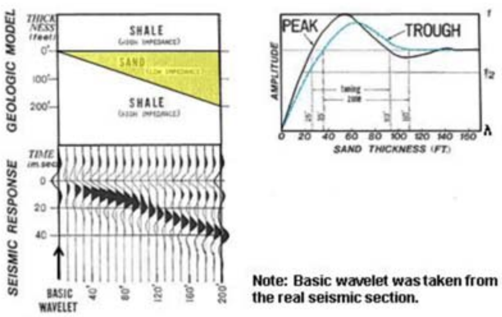

Figure 14. Sand wedge model vs. seismic wave (Fujiwara, Maeda and Yusahara, 1986 [13]).

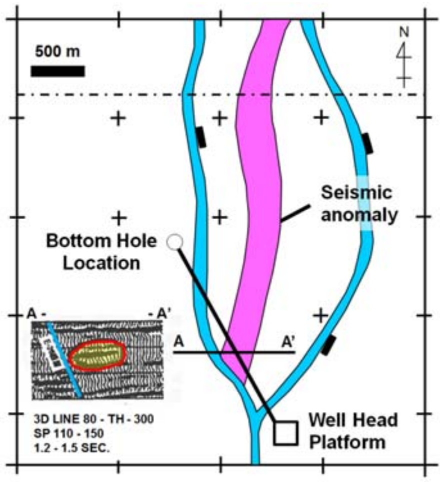

Figure 15. First predicted reservoir sandstone at the Erawan E-2 well in 1982 (Fujiwara, 2007 [12]).

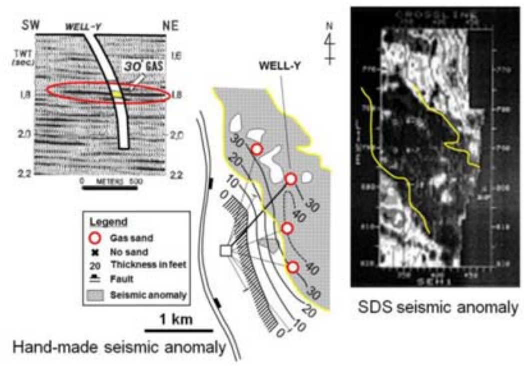

Figure 16. Comparison of the hand-made and SDS.

Figure 17 shows a meandering channel at the Erawan Field. Two development wells were drilled in this channel sandstone and found 16 feet and 35 feet of gas pay, respectively.

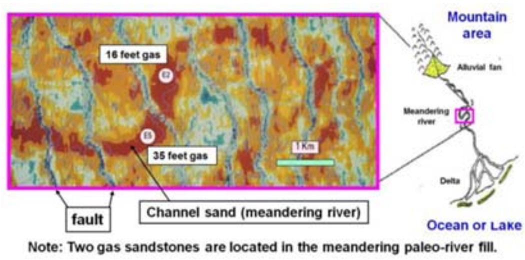

Figure 17. Meandering paleo-river at 1,900 m subsea depth in the Erawan field (Fujiwara, 2007 [12]).

The seismic response in the Gulf of Thailand shows many changes in the amplitude response at all depths (Smith and Brunsvold, 2007 [14]). Over the past 30 years there have been many attempts to use Amplitude vs Offset (AVO) as a Direct Indicator of Hydrocarbons (DHI). Unfortunately there are some physical constraints in the geology that have led to in general inconclusive results.

- Low gas saturation produces a similar effect as high gas saturation

- Sands are laterally very discontinuous and generally thin less than 10 feet (3m)

However, during the selection of well locations amplitudes are used to high-grade locations and targets.

The geological column can be split into two broad halves namely above 1.6sec TWT (approximately 6000ft) and below 1.6 sec.

Above 1.6 sec the observed AVO response is Class III (Increase in Amplitude with Offset) for blocky, clean sands and increased magnitude of the amplitude differentiates oil and gas from water.

Below 1.6 sec increases in AVO are not always indicative of pay. There are positive AVO gradients at the bases of blocky but wet sands. Owing to consolidation of the sands at greater depths and the thin bed nature of the deposits, inter-beds of shale, silt, coals and sands, the fluid effects of AVO are masked but AVO attributes could potentially be used as lithology indicators.

3.2.2.3 Q-survey (3D seismic survey)

Owing to the difficulty of acquiring new surveys in operational areas with existing production facilities such as CPPs, wellhead platforms and FSOs most of the areas in the Pattani Trough operational areas have not been re-shot despite significant improvements in seismic technology over the past decades. There are some exceptions such as one area where the original water-gun source produced poor data quality and it was subsequently reshot using an air-gun source.

One area that was reshot was in the Pladang 3D operating area where a Q-survey was carried out in 2005 by WesternGECO. At that time this area only had two existing wellhead platforms that could be undershot using a second air-gun boat. The survey outline is shown in Figure 18. Figures 19 (vertical section) and 20 (horizontal section) show very high quality seismic resolution that led to the precise interpretation of this complex operating area. However, since then no further areas have been reshot partly due to the operational difficulty created by the large numbers of wellhead platforms, CPPs and other production equipment.

In 2011 Chevron Thailand finished a major reprocessing project so that all of the surveys are now merged and standardized.

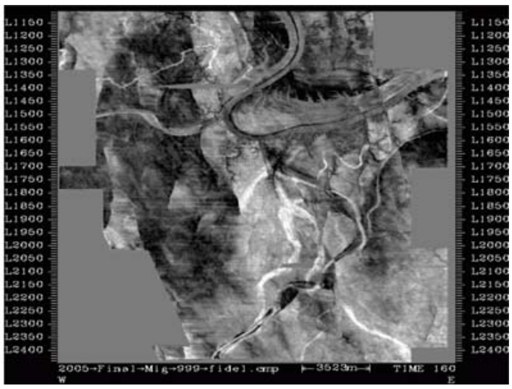

Figure 18. Complex stratigraphy in shallow section 160 msec at Pladang field (Smith and Brunsvold, 2007 [14]).

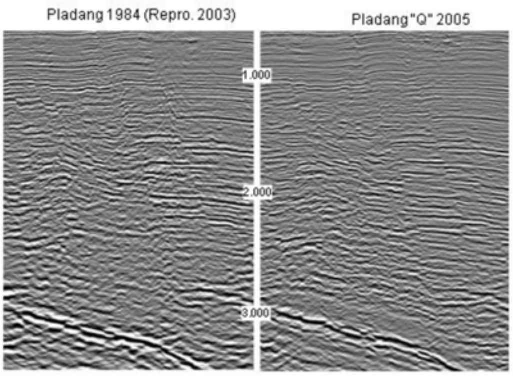

Figure 19. Comparison of the conventional and Pladang Q 3D survey (Smith and Brunsvold, 2007 [14]).

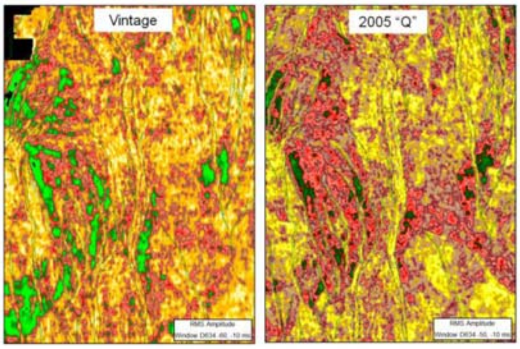

Figure 20. Data comparison, mapped horizon at approximately 1875 msec (Smith and Brunsvold, 2007 [14]).

4. FUTURE G&G ACTIVITIES IN THE PATTANI TROUGH

Exploration with the conventional play is almost completed in the developed Pattani Trough and future plays will have to exploit new geological ideas different from the conventional ones. Candidates for the new plays are:

- High pressure deep play
- Shallow hydrocarbon play
- Basin margin play
- Basement play

For example, there are still remaining undeveloped reservoirs at Baanpot and Satun field in the deeper section where formation pressure is more than 14-15 PPG. Lian and Bradley (1986) [15] reported 7,400 psi at 2,740 m (8,990 feet) in the Baanpot field.

The shallow hydrocarbon play proposed by Fujiwara, Takaoka and Fukuda (2015) [16] is shown in Figures 21 and 22. This play could be applicable not only for the Pattani Trough but also the nearby Malay and the Nam Con Son Basins.

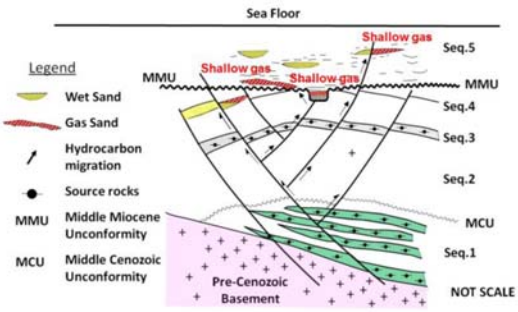

Figure 21. Hydrocarbon accumulation model for shallow hydrocarbons (Fujiwara, 2011 [1]).

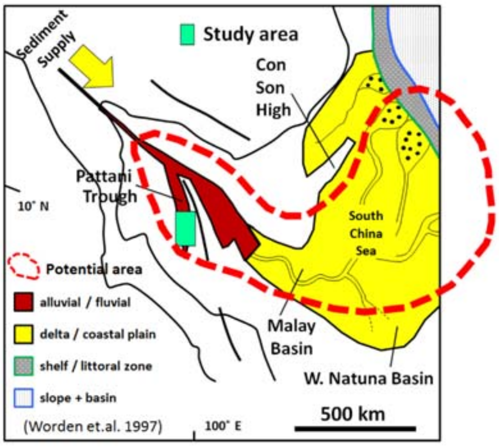

Figure 22. Potential area for the incised valley-fill play in the Sunda Shelf (Fujiwara, Takaoka and Fukuda, 2015 [16].

For the Basement play several wells have penetrated basement but very few have had basement as a specific primary target. The rock types found to date are carbonates, metamorphic rocks and granites and all were generally tight with little effective porosity. High areas that remained exposed to erosion for a long period such as in the West Pakarang area may have had enhanced porosity through karstification or similar processes. Although high risk, the large size of the basement structures would be worth a few deep wells to test the concept

5. Conclusion

Oil and gas fields in the Pattani Trough are characterized by multiple thin-bedded reservoirs broken into multiple fault blocks. G&G studies, primarily the use of 3D seismic data, have overcome the difficulty of identifying and drilling these small targets. The economics have also been enhanced through reduced drilling and completion costs including a simplified completion and casing design and the introduction of PDC drilling bits, oil base mud, top drive amongst others. Excellent teamwork and continuous challenge to overcome difficulties will break through future difficulties.

The geological conditions encountered in the Pattani Trough are unique for offshore oil and gas production. Geoscientists and engineers have, through applied science and experimentation, learned the method for commercial success from more than 40 years of E&P history.

6. Acknowledgements

We would like to thank Chevron Thailand, PTTEP and Mitsui Oil Exploration Co., Ltd. for permission to publish this paper.

Dr. Fujiwara orally presented this paper at GEOPHYSICS 2016 held in Bangkok on January 14-15, 2016.

Note: During the preparation of this written paper Dr Fujiwara passed away on 23rd April, 2016 after a short illness. This paper contains a summary of some of the many geological studies that he carried out in the Gulf of Thailand for MOECO over a period of more than 30 years and was recognised by the award of a PhD in September, 2012. He will be sadly missed as a colleague, mentor and friend.

References

[1] Fujiwara M., *J. Jap. Assoc. Petroleum Technol.*, 2011; **76**: 545-555. (in Japanese with English abstract).

[2] Racey A., Petroleum Geology; in Ridd M.F., Barber A.J. and Crow M.J., eds., *The Geology of Thailand*, The Geological Society, London, Special Publications, 2011: 351-366.

[3] Lundegard P.D. and Trevena A.S., *Appl. Geochem.*, 1990; **5**: 669-685.

[4] Minezaki T. and Moriyama K., *J. Jap. Assoc. Petroleum Technol.*, 2002; **67**: 16-29. (in Japanese with English abstract).

[5] Sasaki A., *J. Jap. Assoc. Petroleum Technol.*, 1986; **51(3)**: 218-227. (in Japanese).

[6] Fujiwara M., Yamada M. and Sasaki A., *A.A.P.G. Hedberg Conference* in Jakarta on April 29-May 2, 2009.

[7] Minezaki T., Jagerman R. and Lin R., *American Association of Petroleum Geologists, 86, Annual Convention* (abstract), 10-13 March, 2002. Houston Texas.

[8] Fujiwara M., *Significance of the Middle Miocene Unconformity on Petroleum Geology in the Pattani Trough, Gulf of Thailand*, PhD Thesis, Chiba University, Japan, 2012.

[9] Fujiwara M. and Sasaki A., *J. Jap. Assoc. Petroleum Technol.*, 1988; **53**: 119-130. (in Japanese with English abstract)

[10] Jardine E., *Proceedings of the Petroleum Systems of SE Asia and Australasia Conference*, 1997; **351**: 363.

[11] Smith N., *International Conference on Applied Geophysics*, 26-27 November 2004, Chiang Mai, Thailand.

[12] Fujiwara M., Lessons learned from the 35 years E & P activities in the Pattani Trough, Gulf of Thailand, Asia Oceania Geoscience Society (AOGS), Bangkok. 2007.

[13] Fujiwara M., Maeda J. and Yasuhara K., *J. Jap. Assoc. Petroleum Technol.*, 1986; **53**: 119-130. (in Japanese with English abstract).

[14] Smith N. and Brunsvold L., *Asia Oceania Geoscience Society (AOGS) 2007*, Bangkok, Thailand, 2nd. August, 2007.

[15] Lian H.M. and Bradley K., Exploration and Development of Natural Gas, Pattani Basin, Gulf of Thailand; in Horn M.K., ed., *Transactions of the Fourth Circum-Pacific Energy and Mineral Resources Conference*, Singapore, 1986: 171-181.

[16] Fujiwara M., Takaoka S. and Fukuda K., *The 21st Japan Formation Evaluation Society (JFES), a Chapter of the SPWLA, JOGMEC Technical Research Center, Chiba, Japan*, October 13-14, 2015; U (1-10).