Bulletin of Earth Sciences of Thailand

Fractured Basement Reservoirs in South Pattani Basin: Seismic Recognition and Integrated Multi-attributes Analysis

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Abstract

The South Pattani Basin Fractured Basement Reservoir (SPB FBR) potential covers an area of at least 166 km^2. It is composed of a horst-graben structure with a high vertical offset. The SPB FBR differs from other explored FBR due to the trigger mechanism which is poly-phase deformation of a rift and transform tectonic. Integration of 3D seismic attributes was used to identify potential basement high areas and fault features. There was a combination of structural and amplitude attributes used in this study such as variance, RMS amplitude, structural filtering, sweetness, energy amplitude and distance to faults attributes. The potential basement high area influenced by north-south striking normal faults and divided into three basement crest areas with one of them in a northeast-southwest direction. The three-basement high potential areas are north FBR zone, west FBR zone and east FBR zone. The faults have high angle dipping on Tertiary strata and transformed into low angle faults in Pre-Tertiary basement area. Intra-basement area showed low angle dipping seismic reflection and strong amplitudes. Multi attributes analysis identified the potential FBR area located at near major fault and its synthetic faults. Variance and ant-track attributes delineated the possible fault corridor alongside the major faults. The western basement high zone exhibited cross-cutting fracture pattern in the western side of the major fault and became the high porous and permeable zone. The FBR zone consisted of north-south trending fractures while eastern FBR zone had northeast-southwest trending fractures.

Keywords: Pattani Basin, Pre-Tertiary Basement, Reservoir, Seismic Attributes

1. Introduction

Pattani Basin is one of the most prolific basins in the Gulf of Thailand (Fig. 1). Most of the hydrocarbon is produced from tertiary petroleum system. Recently, the exploration trends move to the deeper area where fractured basement reservoir lies. The development of fractures pattern in the Pattani Basin had a complex geological history which is related to poly-phase deformation (Charusiri and Pum-Im, 2009; Morley and Westaway, 2006).

The study objectives are mapping the extent of basement structure, interpreting faults at basement horizon and understanding seismic attributes character of basement highs. This study focused on 3D seismic data and basement high area below the Tertiary sediments.

2. Regional Geology

The Pattani Basin consists of a Tertiary sedimentary section with approximately as much as 8500 m thick sediments and lies above Pre-Tertiary rocks as the basement is related to Pre-Tertiary basement highs (Watcharanantakul and Morley, 2000). The basement in Pattani Basin is divided into five elements based on onshore geology: 1) Precambrian crystalline basement, 2) highly folded and foliated rocks consisting of greenschist grade meta-sediments has Lower Palaeozoic age, 3) during Perm-Triassic, there is a collision between the Shan-Thai and Indochina continental blocks which create suture belt, 4) The Indosinian orogeny as a product of subduction of oceanic crust beneath the Indosinian craton and closure of one arm of the neo-Tethys, and 5) Late Cretaceous – Early Tertiary granite intrusion along Burmese border and peninsula Thailand as the result of subduction beneath western Burma which become the source of sediments in the Pattani Basin (Morley and Racey, 2011; Watcharanantakul and Morley, 2000). The Pre-Existing (Pre-Tertiary) rocks fabrics lie beneath the Tertiary sedimentary sequences in South Pattani Basin (Morley et al., 2004).

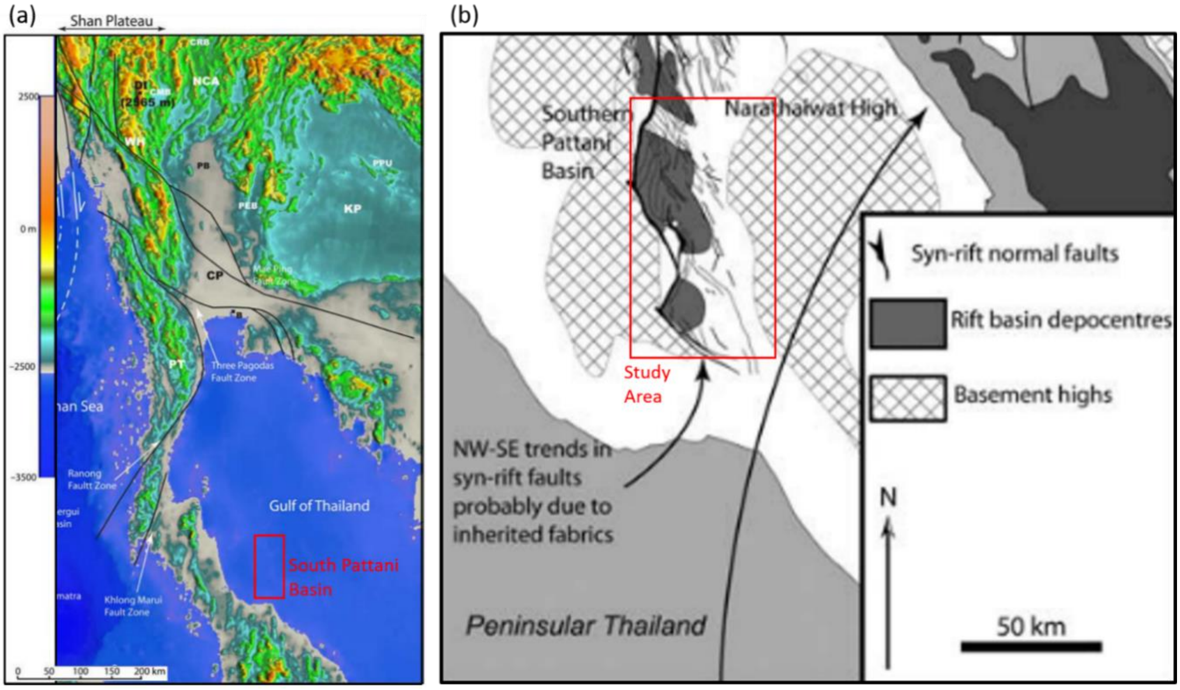

Figure 1. Location of Study Area. (a) topography and bathymetry of Thailand and Surrounding regions and (b) regional syn-rift fault map of the Pattani basin based on 2D and 3D seismic reflection data (modified from Morley and Charusiri, 2011).

The Tertiary sedimentary sequences in Pattani Basin consists of 5 sequences based on the integration between well-log, seismic and core description (Fig 2) (Morley and Racey, 2011). The five Tertiary sequences in South Pattani Basin has a typical rift basin character which has multiple sources from the north, east and west (Morley and Racey, 2011).

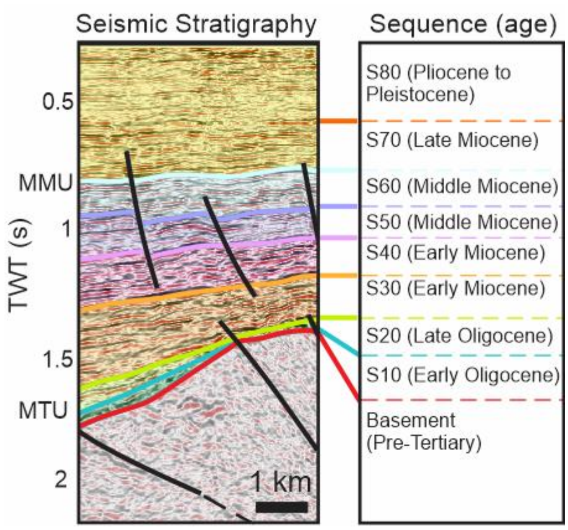

Figure 2. Stratigraphy of Study area from the interpreted basement and Tertiary overlying sequences.

3. Methodology

This study focuses on 3D seismic interpretation and seismic attributes analysis over top of Pre-Tertiary basement horizon. Seismically, top of the basement was picked at trough seismic reflector as a decrease in acoustic impedance. Top of basement horizon picked within interval 40 in crossline and more detailed 20 intervals in complex basement zone. The inline section was only used to control the picking in crossline due to parallel to the basin strike. Five chosen seismic attributes (RMS amplitude, average energy, mean amplitude, sweetness, and variance) used to delineate and characterize basement high areas. Horizon probe and time slicing also used to display the 3D geometry of the seismic attributes at the top and intra basement high areas.

Two structural attributes used to identify the open fractured zone in basement highs. Those two attributes were ant-track (Petrel) and automatic fault extraction (Paleoscan). The outputs compared and the high values of ant-track (near 1) are extracted as potential open fractured (Gaafar and Najm, 2014; Kee et al., 2017; Schlumberger, 2015)(Fig 3).

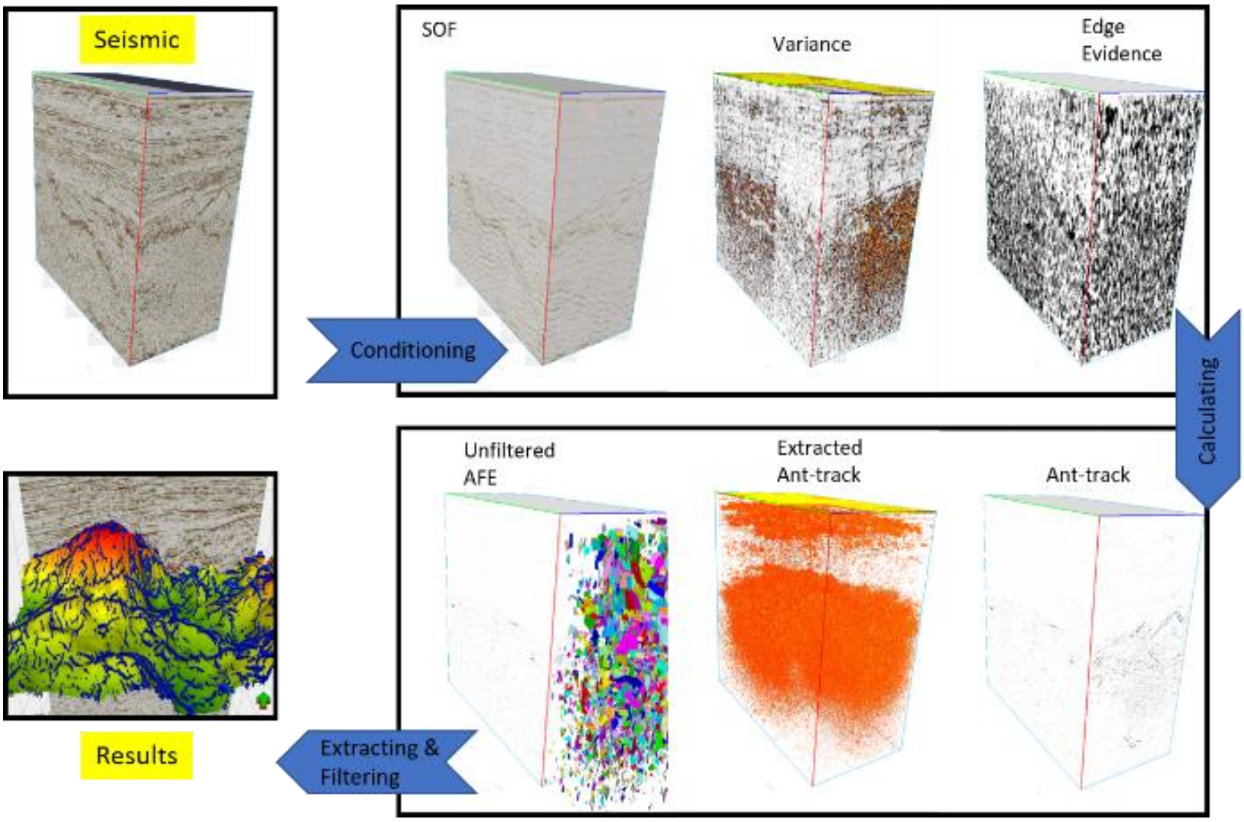

Figure 3. Structural attributes generation workflow

4. Results

Top of Basement horizon was picked at trough seismic reflector (blue colour in Petrel and Red in the TKS Kingdom) and has an angular unconformity from the overlying Tertiary strata (Fig 4). Top of Basement was picked within intervals 40 in crossline and more detailed interval 20 in crossline as it was used in the complex basement zone. The methods for picking basement horizon was primarily done only in the crossline section due to the reflector continuity and the geometry was not shown obviously in inline section because it was cutting parallel to the basin strike.

The top of the basement horizon was remarked by unconformity between Pre-Tertiary and Tertiary strata. In the western side of well B-1, the low dipping Tertiary strata overlie steeply dipping reflector of basement horizon. The steeply dipping reflector are caused by pre-Tertiary fabrics. On the eastern side of well B-1, there are two types of unconformities; 1) disconformity between Early Oligocene and Late Oligocene sequences as Mid Tertiary Unconformity (MTU), and 2) non-conformity between basement high and syn-rift sequences due to normal faulting.

Structural map of the top basement horizon shows that there are at least three basement highs in the research area (Fig 3.10). Those three basement highs are named as Area A (FBR north), Area B (FBR west) which align north-west trending and the other one is Area C (FBR east). Area A is bounded by two normal faults where both faults are eastward dipping. Area B is bounded by a major fault at its eastern side and it continued to the western side of Area A. Area B exhibit a series of normal faults in the basement high crest.

Ant-track attributes were chosen to identify fractures related to faults in the study area, especially in the basement section. Two methods identify fractures; automatic fault extraction and ant-tracking (Fig 3). Ant-track attributes were extracted and filtered to see the fracture zonation. Based on the extraction, the

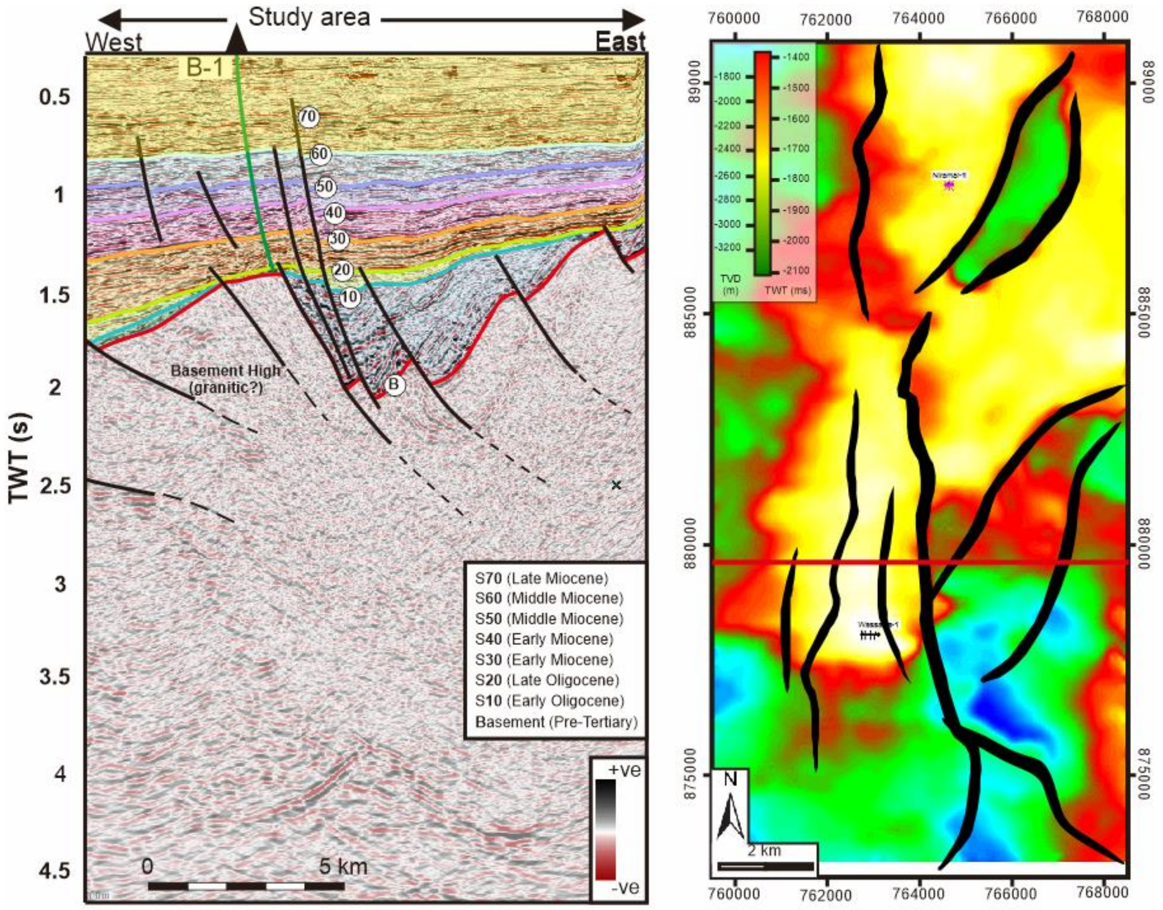

Figure 4. Structural Map of Pre-Tertiary Basement in South Pattani Basin.

fracture domination assembly in the basement high area (orange volume) (Fig 5) is where there are flexural fractures associated together with extensional faulting. In the unfiltered Automatic Fault Extraction (AFE) volume fault patches showed noisy and complex patterns. The result from the extracted and filtered ant-track volume showed that possibly open fractures dominated in basement high area and as shown by blue lines.

Based on seismic attributes observation, three basement highs have different characteristics (Fig 5). In north FBR Zone, it has high RMS amplitude value which indicates they might be open fractures which filled up by hydrocarbon while in west FRB Zone the RMS amplitude is low to moderately high in several areas nearby the major fault (Figure 6b). RMS amplitude in east FBR Zone has NE-SW trending which parallels to the open fracture orientation in this zone.

High mean amplitude attributes value showed in north FBR Zone specifically at the highest area near the northern border of the study scope (Figure 6c). No significant mean amplitude attributes value exhibited in West FBR Zone while in East FBR Zone there is a sign of potential open-fractures features trending NE-SW in the basement high crest. The anomalies only occur in North FBR Zone and East FBR Zone crest of basement high.

Sweetness attributes indicate the presence of fluids stored in the rock pores. In the western side of North FBR Zone where the basement high overlaid by onlapping syn-rift sequences, bright amplitudes are showing the possibly filled-up open fractures (Figure 6d). West FBR Zone has the same characteristics as North FBR Zone in the western and eastern side respectively while in East FBR Zone the distribution of bright amplitudes is distributed parallel to the fault direction (NE-SW).

Average energy attributes represented a hydrocarbon occurrence for direct hydrocarbon indicator in the zone of interest. The red colour represents the highest score found in North FBR Zone at the basement high crest and distributed around flanks (Figure 6e). West FBR Zone showed moderately high average energy at the basement high crest nearby the major fault. At the western down-dip of the West FBR Zone high, the distribution of average energy is relatively low where noted by red colour. East FBR Zone basement high characterized by moderate average energy score in the NE-SE crest and showed a relatively low score in the NW flank. Another anomaly of high average energy exhibited at the southern side of West FBR Zone basement high area as the downthrown area of a series of normal faults.

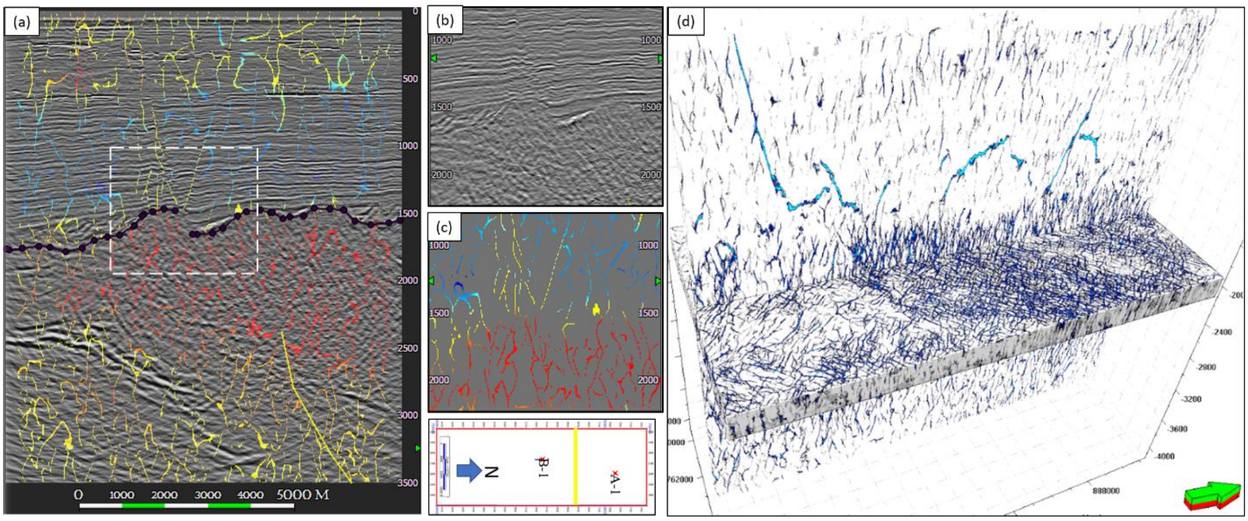

Figure 5. (a) showing west-east seismic cross-section of basement area in red, (b) initial seismic volume, (c) automatic fault extraction (Paleoscan), and (d) ant-track (Petrel) result showing incoherent zone as the fractured zone in blue and the ant-track result shows structural features in the intra-basement horizon (time slice) and vertical section shows high angle faults.

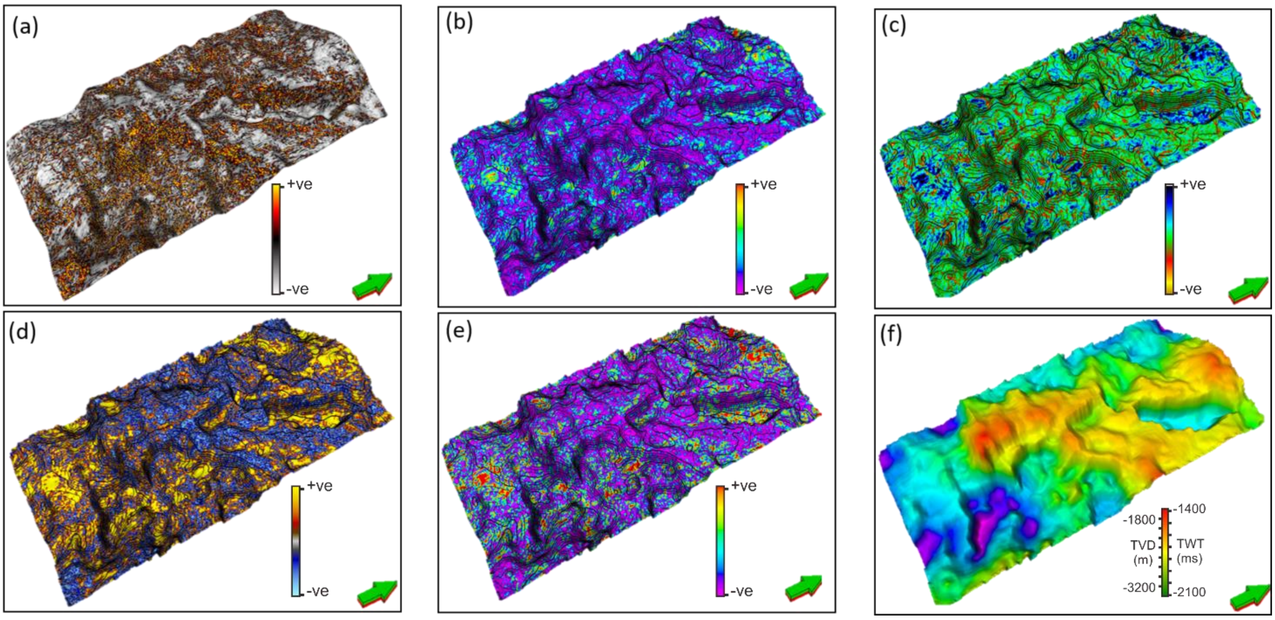

Figure 6. Integration between quantitative and qualitative analysis of seismic attributes to delineate and identify the fractured potential area in basement high section; a) variance, b) RMS amplitude, c) mean amplitude, d) sweetness, e) average energy and f) top basement surface.

Horizon probe of the ant-track attribute on the top basement horizon showed fractures distribution and accumulation (Fig 7a). The fractures accumulated at the eastern side of the basement high at west FBR where the major fault drag the east block down and created down-thrown area. The ant-track results filtered with north-south direction by using north-south major fault (in the centre study area) as structural constraints. The major fault is a normal fault with dip-slip dominant and has maximum horizontal stress north-south direction. The maximum horizontal stress inferred as the main trigger for open fractures generation.

Ant-track attributes showed a possibly open fracture (in blue) that might become a potential fractured basement reservoir. The ant-track attributes filtered with values more than 8 to maximum 1 to extract fractures. Potential open fractures extracted (in blue) and overlaid to top basement structural map (Fig 7b). In the basement structural map, the fractures accumulated at the crest were shown in orange to red.

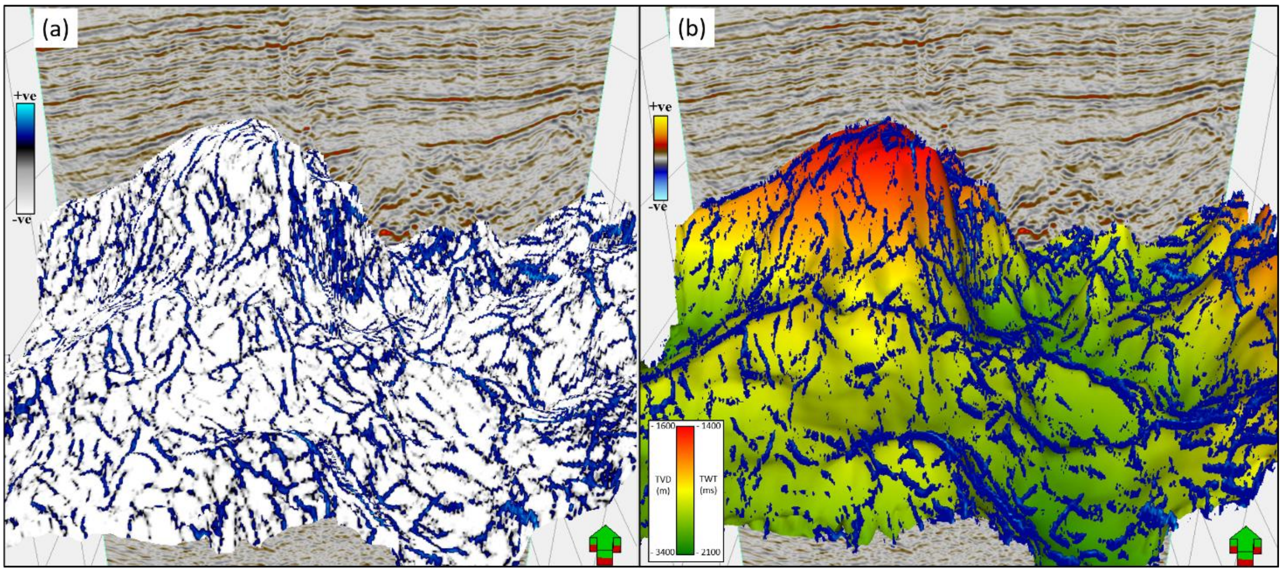

Figure 7. shows zoom in seismic attributes from horizon probe in three-zone respectively.

5. Discussion

In this paper we examine the fractures characterize in three basement high areas. The seismic character in the study area shows the different seismic response in those three areas. The top of the basement horizon marked by onlapping of syn-rift deposit as an unconformity.

Fractured Basement Reservoir Play concept idea in South Pattani Basin is challenging due to no well has reached the basement section. As an analogue, Malay Basin has successfully found hydrocarbon accumulation in the fractured basement rocks in their secondary drilling objectives (Madon and Council, 2018). The pre-Tertiary basement in Malay Basin and South Pattani Basin is similar where it consists of Narathiwat high rocks. The potential play might come from charging of lacustrine shale of Sequence I into the Fractured basement reservoir where the primary migration is through the onlap direction.

Potential of fractured basement characteristics in South Pattani Basin might be closely related to the pre-existing fabrics and the overprint Tertiary tectonic activity (Charusiri and Pum-Im, 2009; Morley et al., 2004). In the White Tiger Field in Cuu Long Basin, the major mechanism is multi-phase (extension, compression, shear and wrenches) (Cuong and Warren, 2009; Huy et al., 2012). The difference between tectonic transport and mechanism causes different fracture styles. South Pattani Basin has open fractures parallel to the maximum horizontal stress wherein the Cuu Long Basin, multi-regimes create complex overprinted fractures.

A similar Fracture style example for South Pattani Basin might be North Sea especially UK and Norwegian rift margin fractured basement. The fractures generated from upfaulting by rifting and later exhumed (Trice et al., 2019). The fractured style in South Pattani Basin was quite surprising and suggests that it controlled by the distribution of pre-existing fabrics.

The north FBR area shows the high value of amplitude attributes (RMS amplitude, mean amplitude, sweetness and average energy). In contrast, the structural attributes show fractured areas. The anomaly might be because of the fractures had been filled as they marked in the amplitude attributes.

Western FBR area exhibits a similar result of the structural attributes where fractures accumulated in the crest of basement high. The amplitude attributes play a crucial role in the open fracture's potential. The amplitude attributes are low which might indicate areas of open fractures.

The NE-SW trending effects the potential open fractures occurrence. East FBR area is controlled by a deflection of local stress that caused the open fractures that are not N-S direction but NE-SW direction. The ant-track result shows the fractures align parallel to the nearby normal faults. The amplitude attributes marked the fractures are open.

Structural evolution of South Pattani Basin controlled by rifting tectonic that caused the development of normal faults (Charusiri and Pum-Im, 2009; Morley and Charusiri, 2011). Amplitude based seismic attributes showed different behaviour of fractured, non-fractured and non-potential fractured zones. Using ant-track and variance attributes a high probability of open fractures occurrence is located nearby the major faults and at the basement highs crest (Fig 8). The eastern side of west FBR area, coloured by dominantly purple, promises a high potential fractures area. The eastern FBR area dominated by blue color as closed fractures.

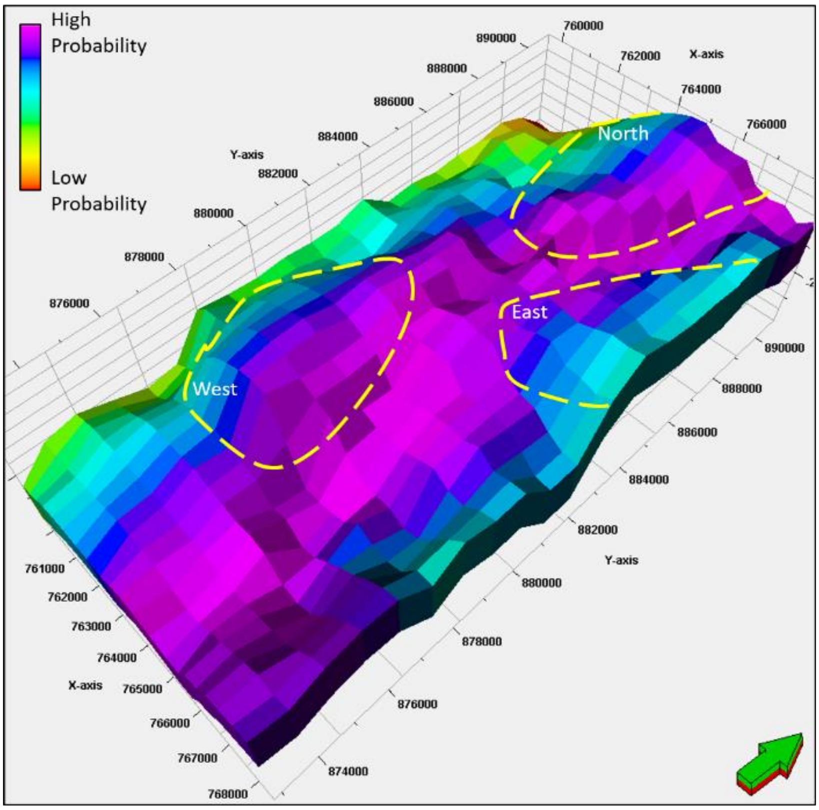

Figure 8. Fault damage zone and the probability of open fractures occurrence of north, west and east FBR areas.

6. Conclusion

Naturally fractured basement rocks have been identified and mapped in the South Pattani Basin by detailed seismic interpretation and their structural evolution to fracture development had been analyzed. The study area exhibit three basement highs where north FBR Zone and west FBR Zone are located just below the producing conventional reservoir while east FBR Zone with NE-SW direction has no well penetration in the area. The seismic interpretation confirms that top of the basement horizon was marked by an unconformity to a syn-rift onlap towards the basement high. The extent of these three basement high areas are bounded by north-south extensional faults.

One major normal fault exhibited in the centre of the study area that controls the distribution of the possible fracture. The interpreted faults are normal dip dominated slip with north-south direction. The faults have high vertical separation and show a series of normal faulting. Strong seismic reflections at intra-basement area interpreted as faults. The intra-basement seismic reflections showed low-angle eastward dipping.

Five seismic attributes analysis tested and used to delineate and characterize potential fractured basement reservoir. High amplitude attributes indicate filled fractures as shown in north FBR area. Low amplitude attributes interpreted as potentially open fractures area where it shows at west FBR area.

7. Acknowledgements

Deeply grateful to Chulalongkorn University and PTTEP for sponsoring my study. Many thanks to Kris Energy for allowing me to allow me to use their data and involved in their project. My very sincere gratitude to my supervisor Pak Angus Ferguson for your invaluable guidance, feedback, support and introducing me to this challenging topic and warm encouragement, thank you, Pak. I also would like to thank the Petroleum Geoscience lecturers: Professor John Warren, Professor Punya Charusiri, Professor Thasinee Charoentitirat, Professor Piyaphong Chenrait and Dr Sukonmeth Jitmahantakul. Thank you for all my friends for your warm welcome and endless support in our one-year learning journey in Petroleum Geoscience Program.

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