CHARACTERIZATION OF THE PLEISTOCENE FLUVIAL SYSTEM IN SEPAT FIELD, MALAY BASIN USING SEISMIC ATTRIBUTES ANALYSIS

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ABSTRACT

This study is focusing on the characterisation of Pleistocene to present day fluvial system found in Sepat Field in the offshore of Terengganu. It aims to characterise the fluvial system in Sepat Field and correlate the fluvial systems found in Sepat Field with the larger scale fluvial system of the Malay Basin. The methodological approach used for this subsurface study includes geological interpretation of 3-dimensional seismic data and wireline logs interpretation. Frequency spectral decomposition combined with variance and relative acoustic impedance attributes had provided a precise prediction on the dimensions, flow orientation and type of the fluvial systems in this field. This study shows that the fluvial system in this field is dominated by meandering channels that flow from northwest to southeast. Points bars, straight channels, channels boundaries and the evolution of the channels can be imaged and interpreted in this study through frequency spectral decomposition technique. A "hook" shape point bar stands out clearly in the data with depth up to 1.5km and is interpreted to be related to the Malay basin fluvial system. The fluvial system in Sepat Field is interpreted to deposit in the midstream river system and highly associated with the Chao Phraya-Johore River, with sediment sources come through this drainage basin and distributed to the tributaries fluvial channels including those in Sepat Field.

Keywords: seismic attributes, fluvial characterisation, Malay Basin, spectral decomposition, meandering river

INTRODUCTION

Sepat Field is in Malay Basin in the offshore of Terengganu (Figure 1). It is a prolific gas field that sits on east-west elongated anticline with a four-way dip closure and related to transgressional movements of NW trending dextral shear along the basement faults in Malay Basin [1] [2]. The primary exploration focus in this field is within Lower Miocene to Middle Miocene units which fall in Group J, I and H. However, this study is focusing on the younger stratigraphic units of Group A and B which is equivalent to Pliocene to recent sections.

The deposition of sediments in Malay Basin is very much influenced by the channels and rivers [3] which made up as a fluvial system. The climate, tectonic of an area, sediment types and the hydrology plays a vital role in determining the characteristics and features of the channels [4]. Rivers and channels usually deposited and evolve through time and this can be viewed through 3-dimensional seismic data, especially on the time-slices. Still, detection of the fluvial environment becomes tricky below the seismic temporal resolution with the natural rivers behave by either meandering, branching out or showing dendritic flow patterns [4]. The fluvial detection in

Sepat Field is made even difficult by the existence of gas clouds that degraded the seismic data quality [5]. With that, this study was conducted to utilise the seismic attributes in characterising the fluvial system of Sepat Field and correlate it the larger scale fluvial system of the Malay Basin.

Malay Basin has gone through three major tectonic events that form the observed structure in the basin today (Figure 2). The first tectonic event was extension phase started during Late Cretaceous to Early Miocene followed by the second event, the thermal subsidence which took place from Early Miocene to Middle Miocene

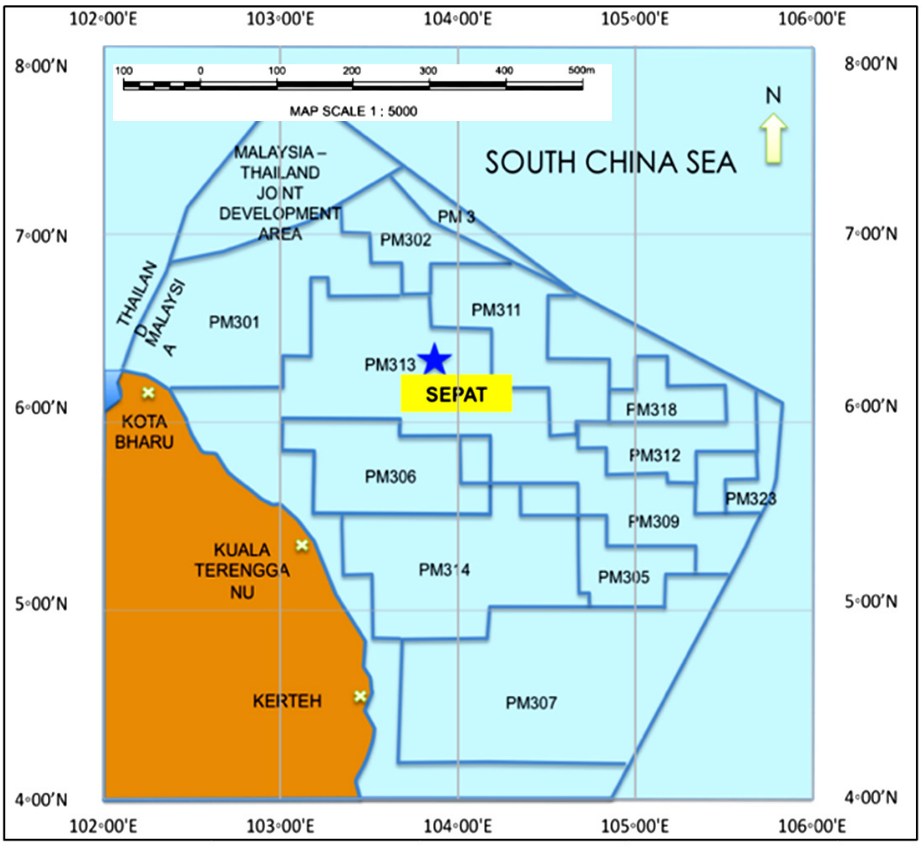

Figure 1 The location map is showing Sepat Field within the Malay Basin, in offshore of Terengganu

GEOLOGICAL SETTING OF THE STUDY AREA

The Malay Basin is situated at the centre of Sundaland, the cratonic core of Southeast Asia. It elongates from NW – SE and spreads a zone of around 500km long and 250km wide [6]. It is found seaward in the South China Sea, east of Peninsular Malaysia with the latitude of 4 – 8 N and longitude of 102 – 106 E [7]. It is one of the deepest continental extensional basins in the region and the biggest among the hydrocarbon-bearing Tertiary basin of the Sunda Shelf. The Tenggol Arch isolates the Malay Basin from Penyu Basin [9], while the Narathiwat High separates the Malay Basin from Thailand's Pattani Basin [8], [3].

and the last tectonic event was compression stage which happened from Late Miocene to Pliocene [9]. The Malay basin experienced inversion during the Middle to Late Miocene, which took place during the 3rd tectonic event, the compression stage [8],[6],[9].

The Malay Basin strata are subdivided informally into seismo-stratigraphic units [10] refer as "Group", derived exclusively from the oil companies working in this region. The "Group" is named according to alphabetical orders, starting from Group A as the youngest (Pliocene-recent) and Group M as the oldest (Lower Oligocene). Figure 2 summarises the stratigraphic units used in the Malay Basin, in relation to the structural history of this basin.

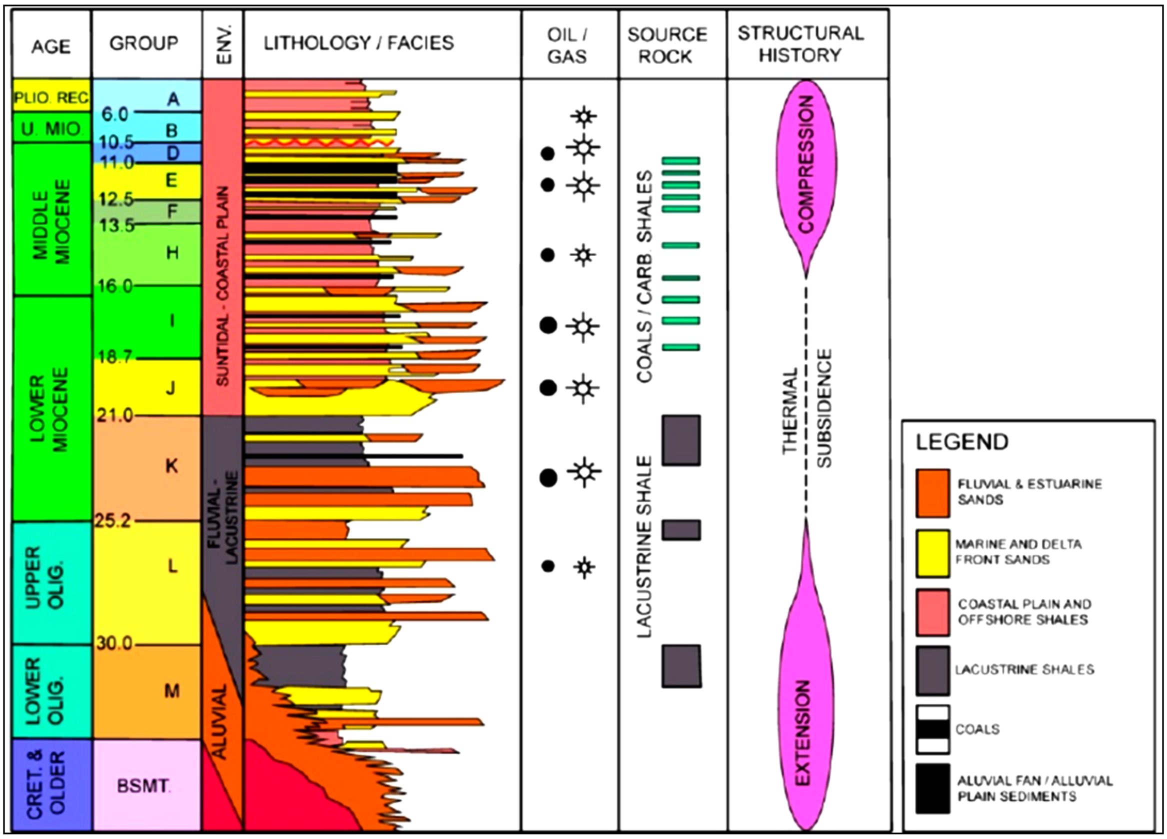

Figure 2 Stratigraphy of Malay Basin from Group A-M showing the dominant lithofacies in fluvial, estuary sand and marine with delta front sands. The right-most column is displaying the major tectonic events that had affected this basin, modified after [3]

DATA AND METHODOLOGY

A 3D seismic volume and three sets of wireline logs from Sepat Field in offshore Malaysia were used throughout this study. The data was provided by Malaysia Petroleum Management (MPM), PETRONAS for this study. The data was acquired in the year 2002 with a seismic grid of 12.5m inline spacing and 25.0m crossline spacing. The seismic data quality ranges from poor to good, with the poor quality is mainly caused by the shallow gas clouds effect. The minimum bed resolution is estimated at 17m with a dominant frequency of 43Hz. Since this study is focusing on the younger stratigraphic units of Group A and Group B, the seismic data was cropped only to the interest section. Well, data from Sepat-3, Sepat-8, Sepat Barat-1 and Sepat Deep-1 were used to tie the geological interpretation across the Sepat Field area.

Seismic to well tie

The first step taken in the interpretation of the data is establishing the seismic to tie well. Data acquired in the geophysics exploration is in the two-way-time domain while the data from the good logs is an in-depth domain. Seismic to well tie enables the comparison of the data quality in depth and time domain. Sonic and density logs from Sepat Deep-1 well the seismic to well tie was performed with a dominant frequency of 30Hz to 40Hz. A moderate to good well to seismic tie with minor bulk shift was generated in this study.

Seismic Attributes Interpretation

Horizons are picked within Group A and Group B sections from -100ms to -1250ms in a two-way time domain. The time slices at a time -100ms to -500ms clearly show the traces of rivers and channels. Nonetheless, the rivers and channels become more difficult to trace after -500ms due to chaotic and disruption on the reflections of the seismic data due to gas seepages. Application of True Amplitude, Relative Acoustic Impedance and Coherence-Variance seismic attributes on the seismic data that is affected by shallow gas seepages have been proven to improve the quality of seismic images as presented on the paper by [5]. In this study, we had emphasis the application of Frequency Spectral Decomposition and Red-Green-Blue (RGB) and Cyan-Magenta-Yellow (CMY) colours blending, along with the application of the Variance and Relative Acoustic Impedance attributes.

Variance Attribute

Variance is the measurement of differences between waveforms and traces. It operates on a spatial window based on the adjacent traces [11]. Variance detects discontinuities that produce trace- to- trace variability over a vertical analysis window of a certain number of waveforms samples which was later normalised by the average energy traces obtain from the seismic [12], [11]. A high value of variance indicates heterogeneity which is usually caused by faults and rivers. Variance is a suitable seismic attribute to be used in this study.

Relative Acoustic Impedance Attribute

Relative Acoustic Impedance works based on the physical properties of the rocks, computed by taking the density and interval velocity of the strata. It is usually used in the inversion to get the correct value to acoustic impedance [11]. The application of this attribute usually beneficial for thin beds, but in this study, it is applied to show the better boundary of the channels. Relative acoustic impedance measures the running sum of the trace to which a low-cut filter is used where is it applied to remove the shift which is typical in impedance data [11]. The calculated trace is composed of the simple integration of the complex trace and represents the approximation of the high-frequency component of the relative acoustic impedance. Therefore, relative acoustic impedance helped in the detection of thin channels beds at a minimum area.

Frequency Spectral Decomposition & RGB Blending

Frequency decomposition replaces the single input trace with a gather of traces corresponding to the spectral decomposition of the input attribute. The raw seismic volume is used as an input, and the output is a few volumes with different frequency band as the

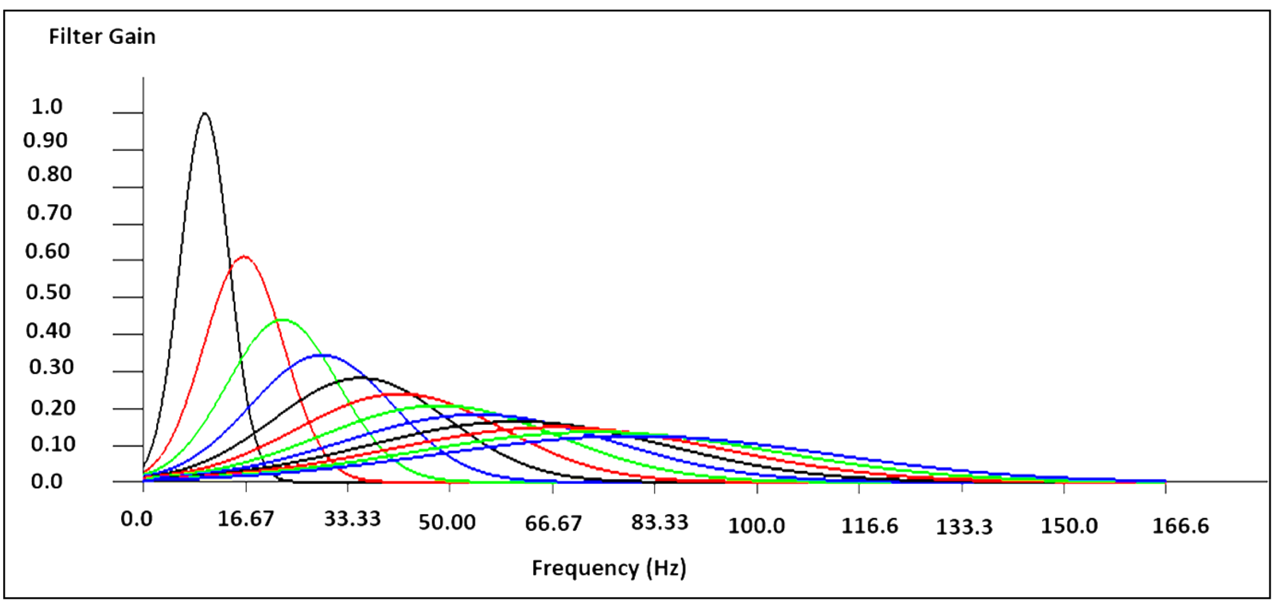

Figure 3 Bandwidth of 10Hz to 80Hz set for frequency spectral decomposition attribute in this study

user defined. Spectral decomposition allows discrete frequency responses to be isolated and combined with red, green and blue (RGB) blending that enables detection of structures which have different frequency bands as resolution thickness depends on the wavelength. Lower frequency has a longer wavelength that produces thicker tuning thickness, and higher frequency has a shorter wavelength that produces thinner tuning thickness. Therefore, it is necessary for the presence of both low and high frequency to ensure thick beds and thin beds are detected respectively.

volumes. The decomposition is achieved through the application of a set of bandpass filters to the seismic traces. Figure 3 shows the frequency coverage from 10Hz to 80Hz to ensure the seismic bandwidth of both low and high-frequency amplitude. Figure 4 shows the workflow for spectral decomposition using GeoTeric ® 2017 software that was applied in this study. This technique used was uniform constant Q which is analogous to wavelet transform. Using this method, the frequency modulation is kept constant, and the bandwidth scale is varied.

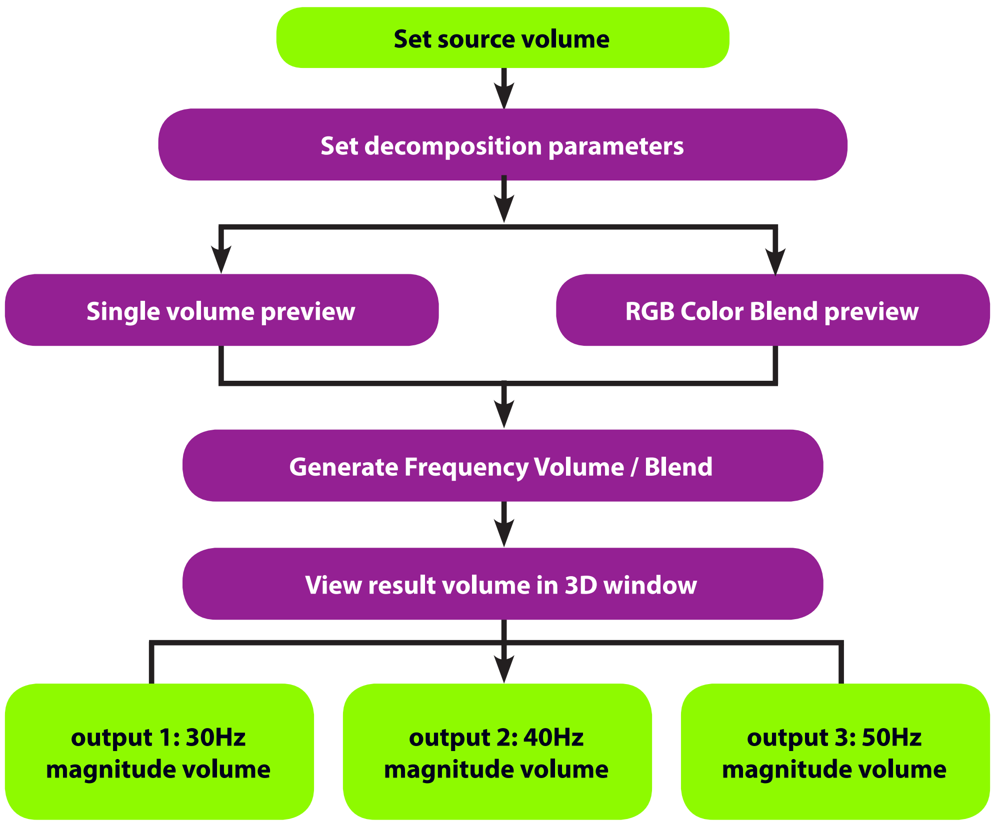

Figure 4 Flowchart is highlighting the workflow for frequency spectral decomposition analysis using GeoTeric ® 2017

The band-limited volumes created in this study consists of 30Hz, 40Hz and 50Hz of red (R) green (G) and blue (B) (RGB) respectively. RGB Color blending tool was used to combine the three magnitude volumes to analyse the interplay between the different frequency information contained in those

RESULTS

Horizon (Stratigraphic) Interpretation

The stratigraphic interpretation of seismic data was performed based on the horizon interpretation. Well, tops from Sepat-3 Well was used as a reference to pick the horizons. The focus group of this study starts from 100ms to 1250ms consisting of Group A (Pleistocene to Recent) and Group B (Upper Miocene). However, due to poor seismic data at the upper section, which is caused by the gas seepage, only four horizons were picked that falls in Group A and B. Group A is divided into A1 and A2 since it is a thick bed. Another four seismic horizons were selected below time 1250s to represent the structure of the Sepat field.

The frequency and amplitude are low with chaotic reflectors in the middle section due to gas seepage effect. Normal faults are commonly observed in this section. The reflectors within Horizon B have sub-parallel to chaotic reflections, and the presence of Direct Hydrocarbon Indicator (DHI) is frequent in this group due to gas seepage. Anticlinal domal structure is also observed in this group.

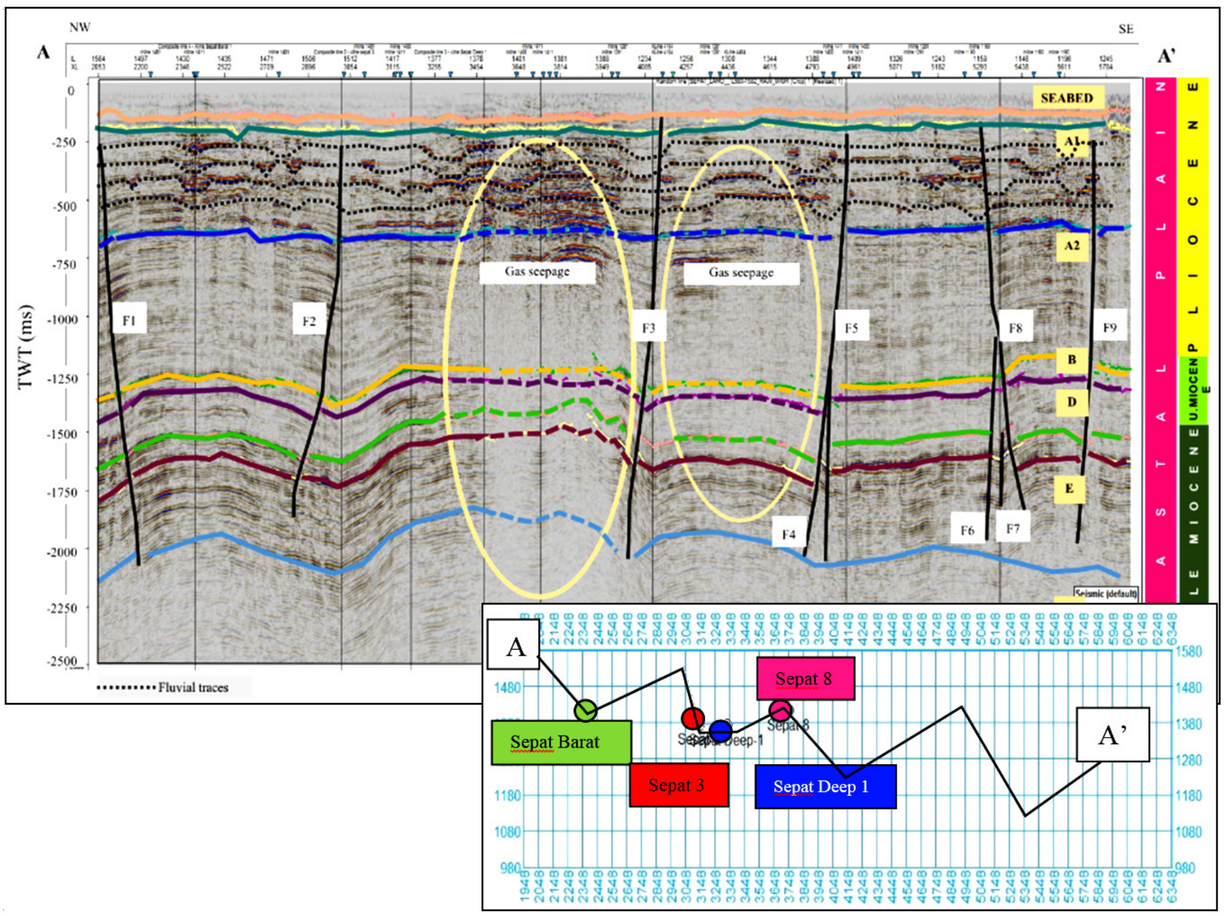

Figure 5 Map view of the arbitrary line A-A' showing all the stratigraphic horizons picked in this study. The dashed lines are representing the fluvial traces in Group A and Group B

Figure 5 is showing the interpreted seismic cross section A-A' that crossed all the four wells available for this study. Horizons A1, A2 and B belongs to Group A and B while Horizon D and E belong to Group D and E. The seismic characteristics for reflectors within A1 and A2 show discontinuous bed at the top followed by a more continuous, parallel reflectors.

Fluvial Characterization through Relative Acoustic Impedance & Variance Attributes

Detection of fluvial features including river and channels is compared using Relative Acoustic Impedance and Variance attributes. As the depth of the data goes more in-depth, the usage of both

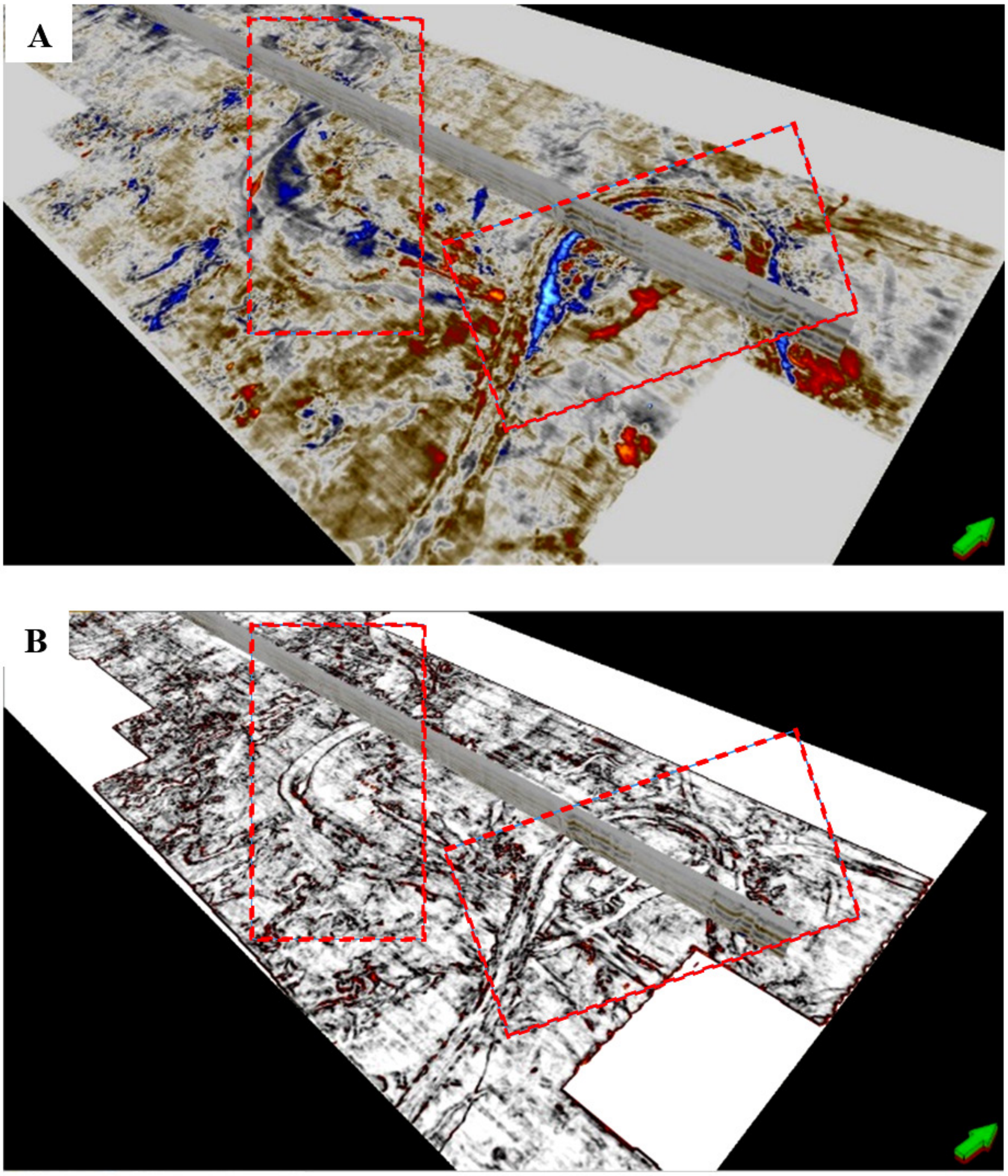

Figure 6 Time slice at -225ms using (a) Relative Acoustic Impedance attribute and (b) Variance attribute. Red boxes are highlighting the point bars and older channel cross-cutting the younger channel. The channels' boundaries are precisely detected using Variance attribute while the sand body distribution within the point bar is better determined using Relative Acoustic Impedance attribute

attributes is more difficult, because it also delineates some noise from the gas seepage. In general, both seismic attributes can show the body of channels, point bars and cross-cutting tributary channels. Relative Acoustic Impedance attribute acts as a more powerful tool to give a better interpretation of the distribution of sand bars within the point bars since it works relatively with the amplitude values (Figure 6a). At the same time, Variance attribute provides a reliable set of data for the interpretation of the boundaries between the rivers and channels (Figure 6b).

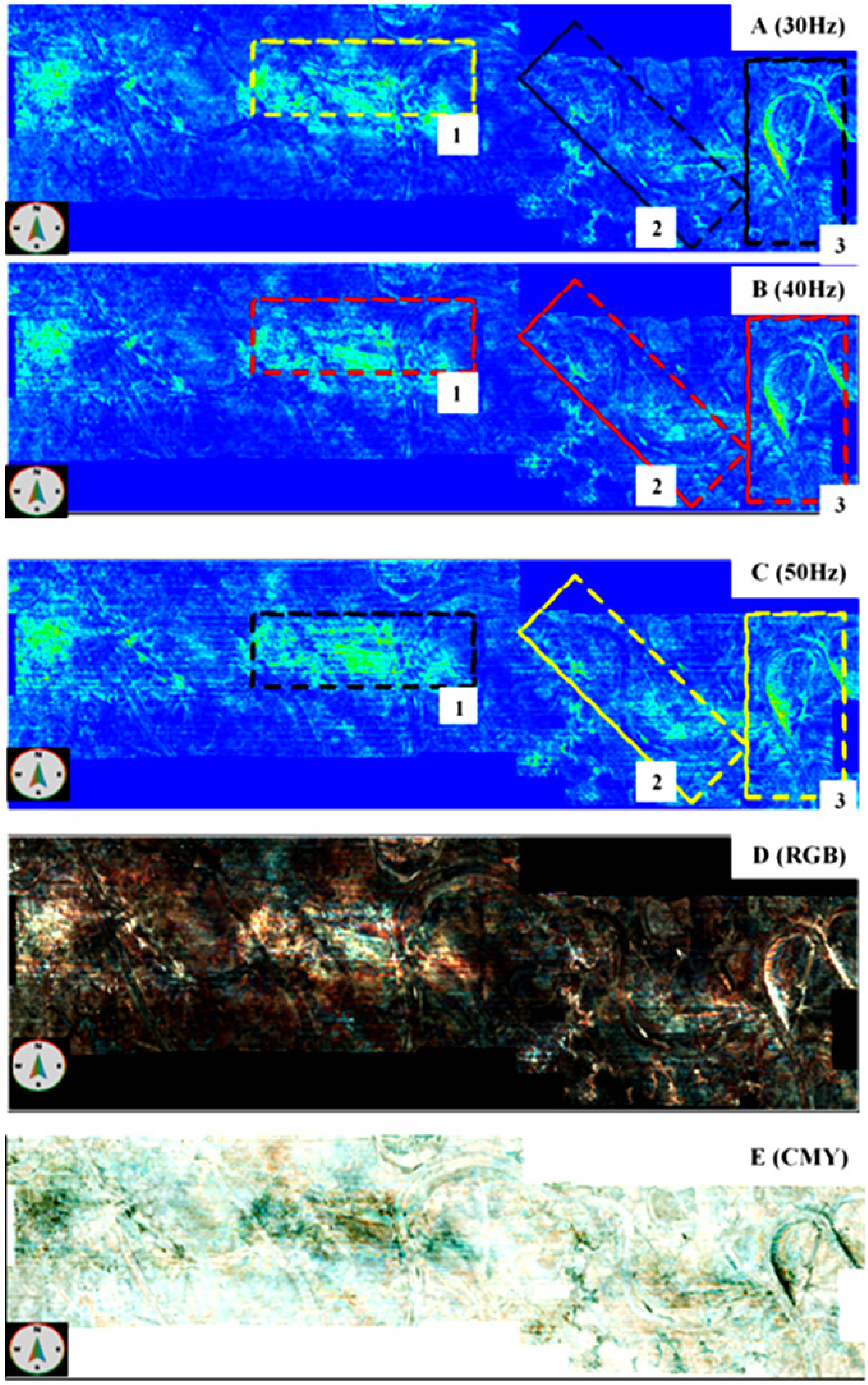

Figure 7 Spectral decomposition analysis on time 225ms. (A), (B) and (C) shows frequency at 30Hz, 40Hz and 50Hz respectively that was produced as the output from spectral decomposition. (D) shows red – green – blue (RGB) blend volume that is a combination of (A), (B) and (C). RGB channels of different frequency in one volume. (E) shows Cyan Magenta Yellow (CMY) blending that is more frequently used for structural analysis. The yellow, red and black box represents clear, medium and smeared image respectively

Fluvial Characterization through Frequency Spectral Decomposition & Colors Blending

Frequency bands of 30Hz, 40Hz and 50Hz were used respectively to separate the seismic characters within these bands. Figure 7a-7c represent the differences in channels enhancement at time slice -225ms with a yellow, red and black box representing the good, medium and smeared image quality respectively. Figure 7a, representing 30Hz bandwidth shows wider channel (central section of the image) is at a good, satisfactory quality, while the smaller meandering channels (east side) produce poor, smeared quality image at this frequency band. Figure 7b, representing the 40Hz bandwidth shows a medium quality image of the time slices on all channels' detection. At bandwidth of 50Hz, the imaging of smaller channels (east side) is improved compared to within bandwidth of 30Hz and 40Hz. The frequency spectral decomposition technique shows that lower frequency value gives a better result for wider channel while higher frequency value is more suitable to delineate the smaller channels.

Figure 7d and 7e show two different colours blending, which are Red-Green-Blue (RGB) and Cyan-Magenta-Yellow (CMY), respectively. Colours blending reveal the geological features in seismic data more clearly compared to single attribute viewing. RGB colours blend highlights the variations, heterogeneity and differences in the seismic data. It allows detection with similar amplitude characteristic, while CMY colours blend focuses more on the structural features such as faulting. In this study, RGB colours blending produced a better time slice image for rivers and channels interpretation compared to CMY colours blend.

Type and lithology of the fluvial in Sepat Field'

Channels that are observed from Sepat Field are mainly meandering river with different sinuosity level. Few straight channels are also observed. Meandering channels are mostly found in lower coastal plain and have fining sequence upwards. Point bars are tracked in the seismic attributes and were form when a meandering river eroded due to moving water in the stream and created outer banks and widens the valley [13]. The inner section of the point bar contains less energy where silt will deposit and the exterior part exhibit higher energy where sand is stored. The analysis from Sepat-3, Sepat-8 and Sepat Deep-1 wells shows that the fluvial system in Sepat Field is dominated by silty sand and sandy lithologies.

DISCUSSION

Dimension of the fluvial in Sepat Field

Most of the channels detected on the shallow surface of Group A and Group B are elongated, a long river with shallow depth.

At the time of -225ms, the observation from RGB colours blending had imaged five river systems (annotated as no 1-5 in Figure 8a) flowing in several directions, channel cross-cutting each other and a "hook" channel at the edge of the map (annotated as no.1 in Figure 8). As we go deeper to time -402ms (Figure 8b), the map view of the river system in Sepat Field shows rivers labelled as 3, 4 and 5 were not deposited yet at this time. One wide river labelled as no 6 is observed at this time -402ms and it is related A wider river appears at this time range, and seismic images become harder to interpret due to gas seepages, but the "hook" shaped meandering river (labelled as 1) is still clearly visible. It is interpreted as an incised valley was tracked at the northeast section of Sepat Field (Figure 8a-8d). This "hook" shaped incise valley is detected from time 90ms to 1400ms, which is approximately 1.5km deep and 0.65km width (Figure 9). At the time -606ms, the only river labelled as no 1, and no 2 appears, which means these two rivers were deposited much earlier compared to the other rivers (no 3, 4, 5 and 6). At this time, we can also observe a fault that cuts through river 2 (Figure 8c). As we go deeper (time -729ms (Figure 8d)) only "hook" shape incise valley can be seen, proving that it is a deep valley.

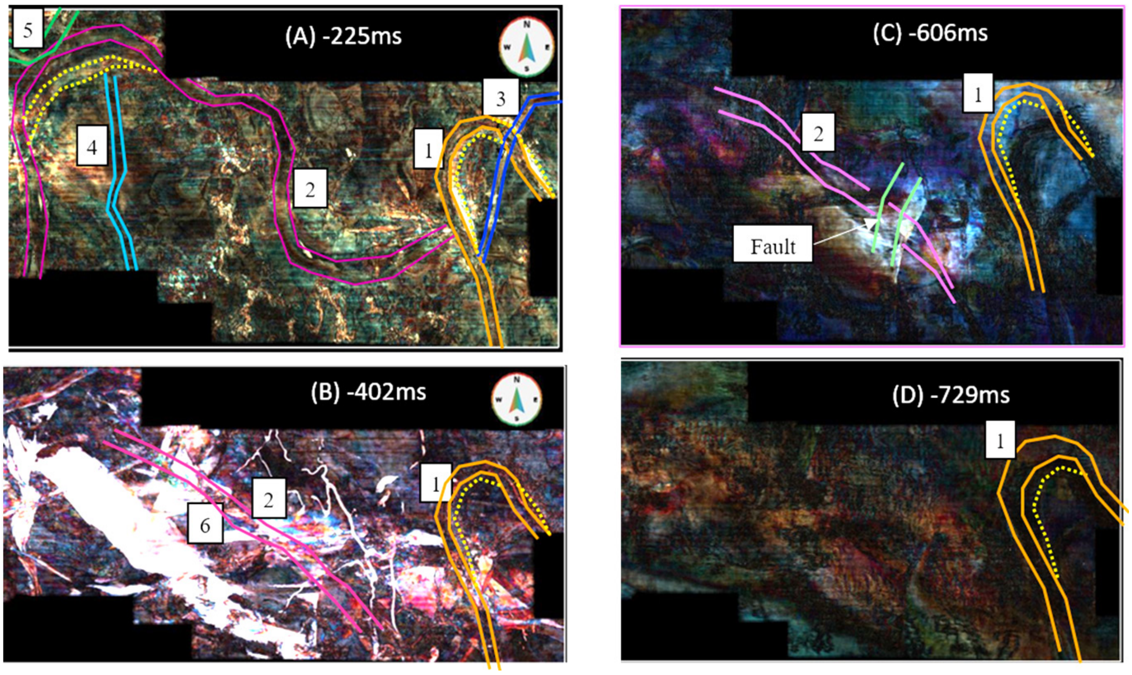

Figure 8 Different depth of time slices showing the orientation of the rivers found at the depths. The shallowest section in (A) at -225ms shows five different rivers flow, but as the time goes deeper to (B) – 402ms, the rivers labelled as no 3, 4 and 5 cannot be seen on the time slices. This means these rivers form only after the deposition of sediments at -402ms. Fault dividing the river can be seen at the time (C) -606ms and just point bar (meandering river) no 1 can be observed in the deeper section at (D) -729ms

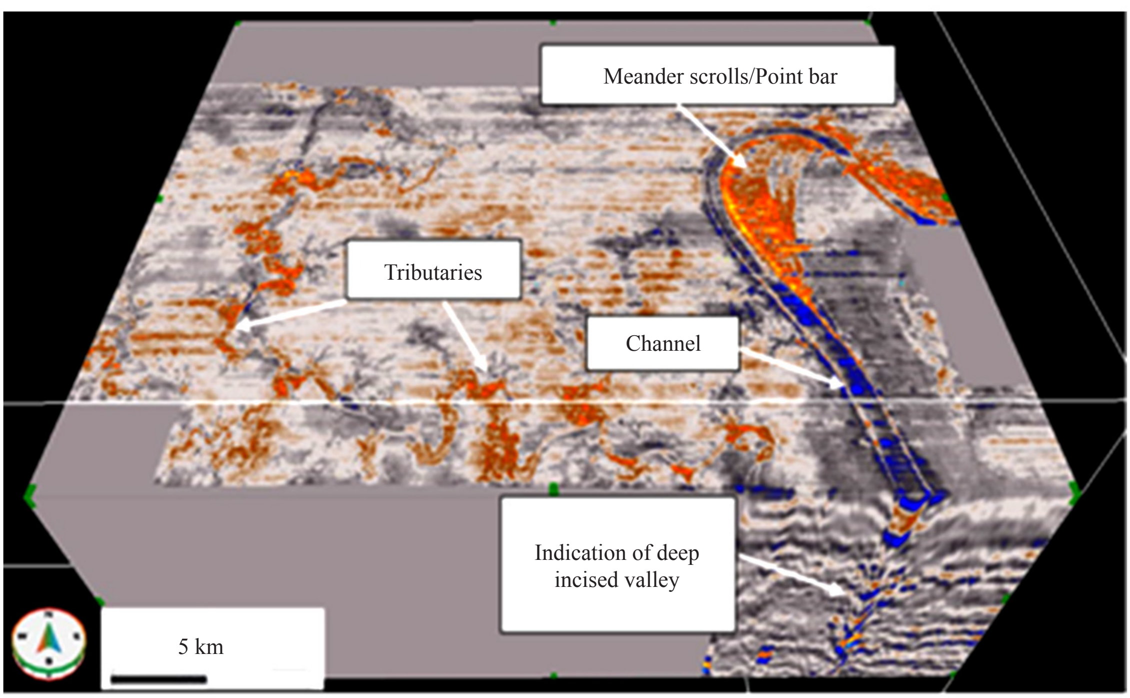

Figure 9 Time slice at -108ms twt shows a highly sinuous channel, which is flowing from north to south. It shows the characteristic of a deeply incised valley and can be tracked up till time slice -1400 twt. Point bars are well developed that gives bright amplitudes

Fluvial System of Sepat Field in relation to Malay Basin Fluvial System

The main orientation of the channels observed in Sepat Field in from northwest to southeast and west to east. This direction is relatively similar to the flow direction of the Chao Phraya-Johore River that flows from high ground in Thailand, which then passes through the axial of the Malay Basin [7]. Our interpretation relates this major "hook" (Figure 8a-8c) to be a part of the significant trunk channel of the Late Pleistocene rivers [7]. However, since it is located at the edge of the seismic cube, the continuation of the valley could not be tracked further.

With the access to the map of river system of Malay Basin produced from the study of [7] and [6], the position of Sepat Field is located next to the Noring Oil Field (Figure 10). Since the major trunk river flows from the northwest to southeast, the "hook" features found in the meandering river of Sepat Field is has high possibility to be part of the developed point bars along the major river system of the South China Sea (Figure 10). The fluvial system in Sepat Field is noted to be part of the larger fluvial system of Malay Basin and falls in the midstream. It is located within the transitional zone between the high grounds (upstream) in the north (Thailand) and the marine environment in the downstream (South China Sea) as presented in Figure 11.

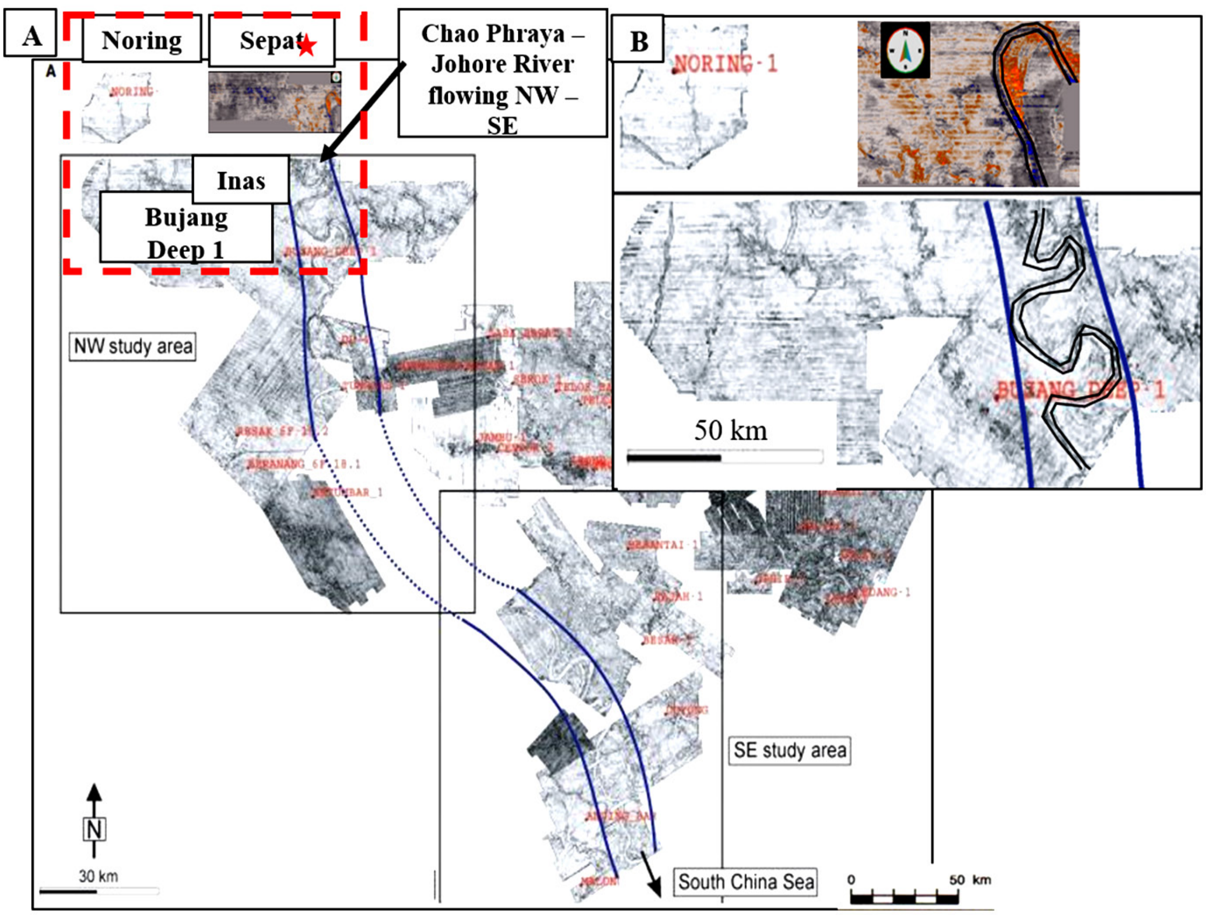

Figure 10 (A) shows the merged 3D dataset of the Malay Basin with the location of Sepat Field from the study of [7]. The two blue lines in (A) represent the valley margins that bound the large meandering channel observed in research conducted by [7]. The red box in (A) is later interpreted as shown in (B) that focuses the connectivity of the trunk "hook" channel from Sepat field to the rest of the data, and it shows good continuity of the Chao Phraya – Johore River

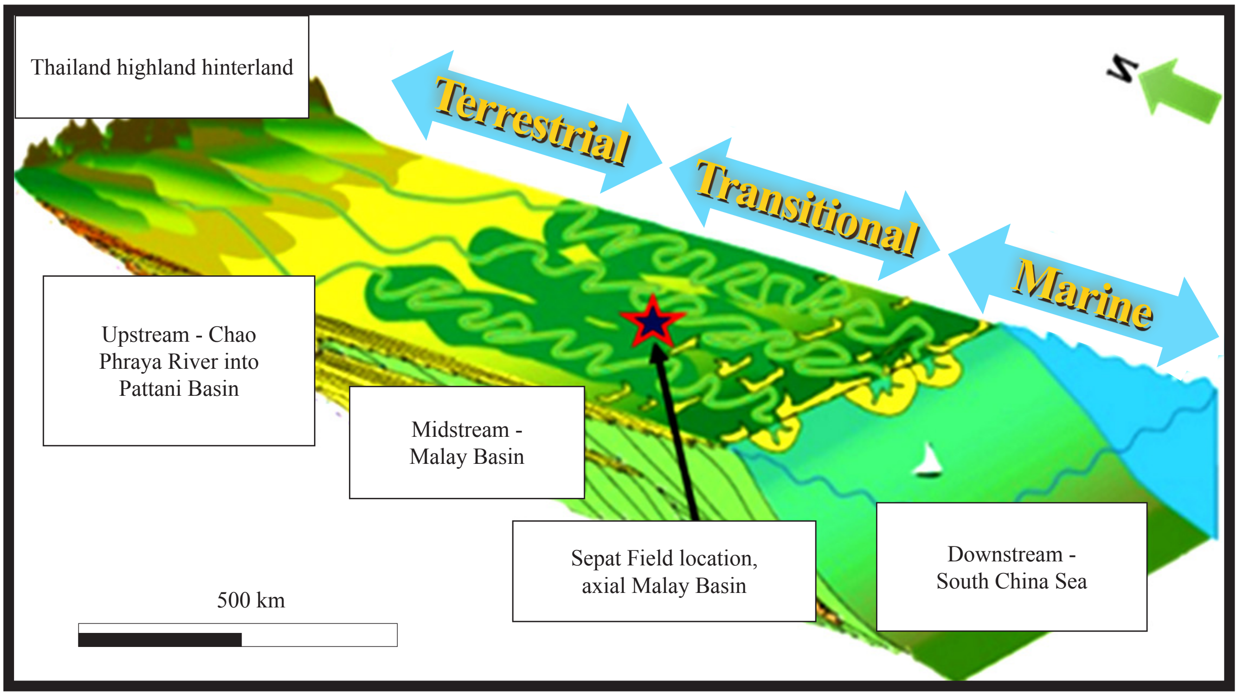

Figure 11 Position of Sepat Field within the Malay Basin fluvial system, relative to the interpretation by [7]

CONCLUSION

The characterisation of the fluvial channel in Sepat Field was achieved by applying geophysical technique mainly focusing on attributes application. The application of seismic attributes in characterising stratigraphic features has shown its effectivity following the presence of the gas cloud. If seismic attributes were not applied, the characterisation of channels would have been tough and incomplete. The interpretation that was done using variance attributes was compared with frequency spectral decomposition that enhanced the interpretation. The utilisation of colours blending also improved the interpretation in time-slices.

The fluvial channel in Sepat Field has two major dominant flow of direction which is from northwest to southeast and west to south. The channels in Sepat Field can be classified to two types i) deep incised valley or meandering channels with high sinuosity and ii) weakly incised valley or straight channels with low sinuosity. The meandering channels in Sepat Field have well – developed point bars that are observed in the time slices. Sepat Field and the whole Malay Basin fluvial system developed as midstream rivers in the context the upper stream is in the northern side and the downstream is the marine system of the South China Sea.

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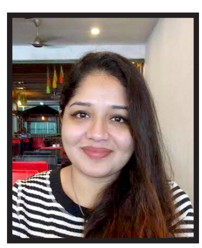

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