Seismic Facies and Geological Structure Interpretation of the A-Field, Malay Basin, Malaysia

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Abstract. This study aims to interpret the seismic facies and geological structures of the Miocene-Pleistocene succession based on the 3-D seismic dataset. The seismic data was interpreted by using Kingdom 8.8 version software. The dimension of study area is approximately 187 km² (14.8 km long by 12.6 km wide). The variable types of seismic facies and geological structures were determined from the horizontal (inline) and vertical (crossline) lines in 2D seismic section of study area. The seismic facies can be classified into major seismic facies such as parallel and sub-parallel, wavy, facies that reach out to south-east and chaotic reflector. Parallel and semi-parallel facies consist from high amplitude to low amplitude and moderate to high continuity. The mounded discontinuous seismic facies also can be seen in the seismic section and can be interpreted as turbidities depositional environment at the two-way time (TWT) ranges from 1.4 to 1.5 ms. The chaotic facies contain natural gas as it display due to an error to a wave at the two-way time ranges from 1.0 to 1.1 ms. The geological structures were determined at the study area consists of anticlines, syncline and faults that can be interpreted as structural and stratigraphic trap for potential hydrocarbon.

1. Introduction

Seismic facies are mappable, three dimensional seismic units composed of groups of reflections where parameters differ from those adjacent facies units. Seismic facies analysis is the interpretation of seismic reflection parameters, such as amplitude, configuration, continuity, and frequency within the stratigraphic framework of a depositional sequence. Geophysicists use seismic attribute as a method to analyze seismic facies. Seismic facies analysis has broad applications in subsurface interpretation and reservoir characterization from 3-D seismic surveys, which aims at delineating structural and depositional features by quantifying seismic signals using various algorithms [1]. Structure interpretation and fault/fracture characterization can be analyzed by extracting the seismic geometric attributes. A few attributes measure the lateral changes in certain properties of the signal in a reflection seismic section/ volume, including waveform/amplitude and two-way time/depth and they can be further categorized as coherence and its derivatives [2,3]. Seismic reflection pattern geometries are perhaps the most useful for calibration with lithofacies interpreted from well logs, cores and cuttings. The amplitude analysis of 3D seismic horizon slices is the best technique that directly yielding to the width of channel belts and channel pattern image (channel splitting, sinuosity) of subsurface sandstone bodies [4,5,6,7]. It can predict the spatial distribution of channel-belt thickness and lithofacies.
However, this method depends on the resolution of the seismic data relative to the thickness of the sandstone body image. It is also need to calibrate to the cores and the wireline-logs [8]. The seismic facies are interpreted by using the horizon or sequence boundaries. In order to choose the most prominent seismic reflectors as sequence boundaries, all possible sequence boundaries were initially identified in a high quality seismic reflection section [9]. This study aims to classify the types of seismic facies in the study area using 3-D seismic dataset and to determine the geological structures as types structural and stratigraphic trap for hydrocarbon potential.

2. Literature review

2.1 Study area
Terengganu offshore is located at the southwestern part of Malay basin which is in between Vietnam and Peninsular Malaysia. This basin covers an area of about 80,000 km² and is filled with Tertiary sediments up to 14 km [10]. The Malay Basin was set up northwest and joined the Natuna West Basin, Indonesia. The Malay Basin is a northwest basin with a dimension of about 500 km long and 200 km wide. The Malay Basin is located at the central part of the Sunda Plate which is the core of Southeast Asia, formed in the early Tertiary. The basement of this basin consists of approximately 12 km thick of alluvial, fluvial, and eastuarine sedimentary deposits aged Cretaceous and older. Generally, this Oligocene sediment is a land deposit with a small marine influence the Oligocene deposits, while the Miocene to Recent sediment is a coastal deposit up to shallower sea. The oldest graben may contain sediment from the Late Eocene period to the Early Oligocene [11]. The sump rocks which from Lower Miocene to Oligocene age contain rough granular to moderate fluvial. Lacustrine shale depositional was spotted at the graben structure. The earliest sediment formed comes from the boundaries of the half graben basin. This Oligocene to Lower Miocene lacustrine shale are the source rock for oil and gas. Lacustrine shale since to accumulated at the remote graben [11]. The basement sediment originates locally from the side of the graben part of the basin. The source rocks are from fluvial-delta depositional environments are generally best found in Group 1 and E [12]

In general, the transgressive deposition in Malay Basin continues in late Miocene to Pleistocene [13]. Most of these regions are exposed to erosion during the Pleistocene period and river channels are cut along the basin [14]. [11] said that based on seismic data, it shows sediment thickness up to some kilometres below the Upper Oligocene strata and suggested the beginning of the Malay Basin before the Oligocene. Oligocene age reservoirs and early Miocene reserves include coarse-grained sandstone in between an estuary deposition to an average of alluvium deposition [11,15].

The structural evolution of the Malay Basin had been described in terms of syn-rift phase and a post-rift phase [16]. The syn-rift phase within the age of Eocene-Oligocene involved an active faulting and extension events meanwhile the post-rift phase within the Miocene to recent came to half the extensional faulting event. This will ensure the basin continued to subsidence the load under the sediment and it is continually happened at the present-day. However, early to middle Miocene age, there was an interrupted event from the major phase of basin inversion [14]. The post-rift subsidence produced a huge sagging of the basin because of the activation of the Malay Basin axial shear zone from left-lateral to right-lateral inversion [17]. The depositional of the post-rift phase had been concluded as the coastal to shallow marine deposits. Besides, the alternating sand-dominated and shale-dominated fluvio-lacustrine sequences within a series of isolated half graben were the characters of their sedimentation. The trans-tensional shear and crustal extension affected the basin due to the extrusion of Malaya and Indochina continental blocks [18]. The extension event developed the syn-rift half-grabens while the northeastern flank is gentler and more structured than southwestern flank.

3. Materials and Methodology
This study uses 3-D seismic dataset that covering approximately 187 km² located at the southwest Malay Basin (Figure 1). The bin spacing of inline and crossline for these surveys are 12.5 m and 12.5
m, respectively. The vertical length used in this study ranges from 0 ms to 6500 ms two-way time. The seismic data provided by the Petroleum Management Unit is secondary data covering basic maps and seismic templates. This data needs to be reworked for processing and interpretation by using the computer version of Kingdom version 2018.

![Figure 1](image)

**Figure 1.** Study area located at the southwest of Malay Basin

The SEG-Y data format was imported into seismic computer software. The seismic reflection can be divided into three levels i.e.; data acquisition, data processing and data interpretation. Sequence boundaries were determined and interpreted to recognize and correlate a seismic sequence boundary accurately. Sequence boundary was determined by the occurrence of unconformity. The geological age of layers at the top and below of unconformity being determined for provided the size of hiatus at the certain area. The two-way time of sequence boundaries being detected by lateral that may become parallel but the hiatus being an evidence for continued to determine the unconformity. The seismic facies analysis was used to determine sedimentary sequence units generally through polar and patterns indicated in the seismic cross section. The interpretations may reflect the geometry of the geological bodies, the type of stratification, the geological environment, the deposition process, the direction of sedimentation and etc. Interpretation of seismic cross section for geological structures certainly requires detailed analysis, especially in fault interpretation and fold. However, the interpretation of geological structure will only discuss the brief structure of the study area along the seismic survey lines.

4. Results and Discussion

4.1 Seismic Sequence and Seismic Facies

Four sequence boundaries (seismic units) have been identified from the observation of the seismic facies from 2-D seismic section. The amplitude attribute was used in this study. In general, the seismic facies were described for the basin area can be classified into several series of facies such as parallel and sub-parallel, wavy, facies that reach out to south-east and chaotic seismic facies.

4.1.1 Inline (IL) 25827

Four sequence boundaries/horizons were identified in this seismic inline as shown in Figure 2. This seismic line was found at two-way time ranges from 0.1 s to 7.65 s. The sequence boundary SB 1 with presence of toplap terminates to the younger strata. It is as a result of sedimentary rocks by passing with perhaps only minor erosion [20]. This boundary was found at two-way time ranges from 0.02 s until 0.19 s. At the 1.15 s of two-way time (TWT) another boundary which is SB 2 is found. Figure 3 shows the sequence boundary SB 2 with presence of onlap at the boundary which it terminates to the oldest strata. It terminates progressively against an initial incline surface. Toplap seismic termination also can be seen at the southeastern part of the seismic line. The seismic facies that can be found in this sequence boundary is subparallel continuous with high amplitude. This area can be interpreted as turbidite depositional environment. Meanwhile there is also mounded discontinuous with low
amplitude and can be interpreted as hyper concentrated density flows depositional environment setting.

SB 3 boundary can be seen at TWT 1.85 s. Figure 4 shows the sequence boundary SB 3 with presence of onlap at the boundary which it terminates to oldest strata which is SB 2. As mentioned above it terminates progressively against an initial incline surface. Subparallel continuous and low amplitude seismic facies is clearly showed in this sequence. This can be interpreted as debris flow environmental deposition setting. Another sequence boundary was found which at the 4.5 s TWT till the bottom which is 7.65 s two-way time (TWT) is label as SB 4. SB 4 with presence of downlap at the southwestern part of the boundary (Figure 4). It terminates down dip against an initially horizontal surface. The presence of toplap can be seen at the southeastern part of the line. It is believed that it undergoes transgressive system tract. As the rate of relative sea-level rise increases, it eventually outpaces the supply of sediment, leading to retrogradational stacking in the transgressive systems tract (TST). The rapid relative rise in sea level leads to the formation well-developed estuaries, and their trapping of sediment hinders the dispersal of sediment to the shelf. This starvation of sediment also promotes the formation of features that indicate stratigraphic condensation, such as the formation of authigenic minerals, accumulations of marine fossils, unusually bioturbated horizons, and the formation of firm and hard grounds.

Figure 2. Seismic line IL 25827 shows the four sequence boundaries which is labelled as SB1-SB4.

Figure 3. 2-D seismic section shows the sequence boundary SB 2 consists of onlap and toplap seismic reflection termination and seismic facies such as subparallel continuous, mounded continuous, high and low amplitude.
4.1.2 Crossline (XL) 13994

On the seismic line crossline (XL) 13994 as shown in Figure 5, the total four sequence boundaries were seen. In this point the obvious of toplap at SB 1 at two-way time (TWT) ranges from 0.1 to 0.5 s (Figure 6). It terminates at the youngest strata. It seen terminates towards to the eastern part of the line. The seismic facies were interpreted in this seismic section are consists of parallel continuous, mounded discontinuous, high and low amplitude. Figure 7 shows the SB 2 boundary, at TWT 1.32 ms, nearby the boundary seen an onlap termination reflection and interpreted as marine onlap. SB 3 boundary is interpreted at TWT 2.2 ms, present nearby the boundary is toplap, it is believed to represent a marine condensed unit. The toplap shows the clinoforms against an overlying lower angle surface. The seismic facies that can be clearly seen consists of subparallel continuous, mounded discontinuous, low and high amplitude. Figure 8 shows the SB 4 boundary, at TWT 3.6 ms. Present nearby the boundary are downlap from TWT 3.5 ms towards the SB 4 boundary. The chaotic seismic facies pattern is clearly seen in this seismic section.

Figure 4. 2-D seismic section shows the sequence boundary SB 3 and SB 4 consists of onlap seismic reflection termination and seismic facies such as subparallel continuous, mounded semicontinuous, high and low amplitude.

Figure 5. Seismic line XL 13994 shows the four sequence boundaries which is labelled as SB1-SB4.
Figure 6. 2-D seismic section shows the sequence boundary SB 1 consists of toplap and onlap seismic reflection termination and seismic facies such as parallel continuous, mounded discontinuous, high and low amplitude.

Figure 7. 2-D seismic section shows the sequence boundary consists of onlap seismic reflection termination and seismic facies such as subparallel continuous, mounded discontinuous, high and low amplitude.

Figure 8. 2-D seismic section shows the toplap and downlap seismic reflection termination and chaotic seismic facies.
Figure 9 shows the four seismic facies at the study area. Besides that, there are possibility that study area has a presence of gas because it has chaotic facies due to the gas gave an error to a wave. Amplitude analysis is particularly important in hydrocarbon exploration which can be indicative of the existence of hydrocarbon by looking at bright-spot or flat-spot amplitude anomalies. The direct interpretation aimed at predicting lithology, types of reflector and its geologic setting [21]. Seismic facies can be seen prominently in every sequence. Parallel and semi-parallel facies consist from high amplitude to low amplitude. It also has moderate to high continuity. Moved to the bottom part of seismic section, the frequency decreasing and amplitude decreased from high to moderate and finally low amplitude. Wavy facies can be seen at the middle of the line survey, where it has high amplitude, high continuity and regularly spaced reflectors. In addition, it shows an asymmetrical in cross section. Furthermore, polar pattern of the reflection at the southeastern part of study area has high amplitude. Some of the reflector polar looks chaotic with variable amplitude.

![Figure 9](image-url)

**Figure 9.** Four (4) types of seismic facies in the study area; a) Seismic Facies A: Parallel reflector, i. untraced ii. traced, b) Seismic Facies B: Chaotic, i. untraced ii. traced, c) Seismic Facies C: Oblique reflector, i. untraced ii. traced, iv) Seismic Facies D: Wavy reflector, i. traced ii. untraced.

4.2 Geological structure

The interpretation of this geological structure will only discuss the brief structure of the study area along the seismic survey line. The selected seismic line is located at a distance of less than 2 km between a seismic survey which usually gives the same fault plane along the parallel line. The geological structure of the study area is very complex as there are some structure of aggregation and fault that are difficult to interpret. The fault plane orientation around this study is complex but the normal fault usually dominates the fault trend in this A-Field from various directions. The structure that involved at the A-Field area is very significant with the presence of anticlines, syncline and fault. Figure 10 shows the occurrence of geological structure and it can be one indicators of the hydrocarbon presence at the study area.
5. Conclusion

Four sequence boundaries are recorded (0-7 s two-way time (TWT)) from two seismic sections obtained in the southwestern part of Malay Basin. SB1 is in the Pleistocene age. Meanwhile SB 4 is interpreted as basement rock which is located in two-way time (TWT) ranges from 4.5 to 7.5 s and consists of potential hydrocarbon such as natural gas. According to the facies analysis that had been done and geological structure that presence at the field, this field have a potential hydrocarbon. This can be look through the indicators of the hydrocarbon such as anticline and syncline structure. The seismic facies analysis show that the variety of seismic facies pattern associated with the polar pattern in this seismic survey. In addition, according the presence of chaotic reflectors it maybe also associated with gas at the field.

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Figure 10. 2-D seismic section shows the geological structure occurred in study area consists of faults, anticline and syncline.
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