Seismic Geomorphology of Fluvial Systems from Pleistocene to Recent in Southern Pattani Basin, Gulf of Thailand

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Abstract

The purpose of this study is to document the distribution and architecture of fluvial systems within the Pleistocene to Recent section in the southern margin of Pattani Basin, Gulf of Thailand, by integrating time slices and vertical seismic sections. The study interval is from 111 to 271 ms TWTT. Conventional seismic amplitude attribute maps show meaningful channel patterns for analysis. Key channel parameters were measured. Eustacy and climate fluctuations, which in turn affects sedimentation and fluvial discharge, are the most likely controlling factors in the development of fluvial systems in the study area. Moreover, the study interval represents the post-rift section; hence, tectonics has no significant effect on sedimentation. Unincised fluvial systems include low sinuosity (1.1-1.20), medium sinuosity (1.21-1.50), and high sinuosity channels (>1.50), with meander-belt widths ranging between 0.3 and 1.4 km, abandoned channel widths of 20 to 650 m, and channel depths of 4 to 19 m. These channels do not have tributaries associated with them. Incised valleys tend to be deeper (up to 50 meters) and wider systems (up to 1.3 kilometers). Tributaries provide the most significant evidence for the existence of incised valleys. Three depositional periods were identified based on fluvial styles. Period 1 (271-239 ms) begins with high to moderate sinuosity channels, and eventually shifts to low sinuosity channel, which indicates a depositional environment that is fluvial-dominated with estuarine influence in the upper part. The onset of Period 2 (239-191 ms) is marked by a sequence boundary, as evidenced by the presence of an incised valley. Low to moderate sinuosity channels dominate this period, which suggest low to modest accommodation generation, consistent with either slow transgression or highstand. The depositional environment of Period 2 is dominantly of estuarine influence. A second sequence boundary, that is marked by the presence of another incised valley, indicates the onset of Period 3 (191-111 ms). High to moderate sinuosity channels dominate the lower part and eventually shifts to low sinuosity channels in the upper part.

Keywords: Pattani Basin, conventional seismic amplitude, incised valleys, unincised channels

1. Introduction

During the last decade, major advancements in three-dimensional (3D) seismic acquisition, processing, and data analysis for hydrocarbon exploration have made seismic geomorphology an important tool for the analysis of a wide variety of depositional environments from fluvial to deep-water settings (Reijenstein, 2011). 3D seismic data also enable us to image the stratigraphic record at selected time slices or along interpreted horizons.

The study area is located in Block G10/48 which lies within the southern margin of the Pattani Basin, Gulf of Thailand (Figure 1). It covers an area of approximately 330 square kilometers. The water is approximately 60 meters deep, with a reasonably flat seabed. The study interval comprises the uppermost 300 meters below the seabed.

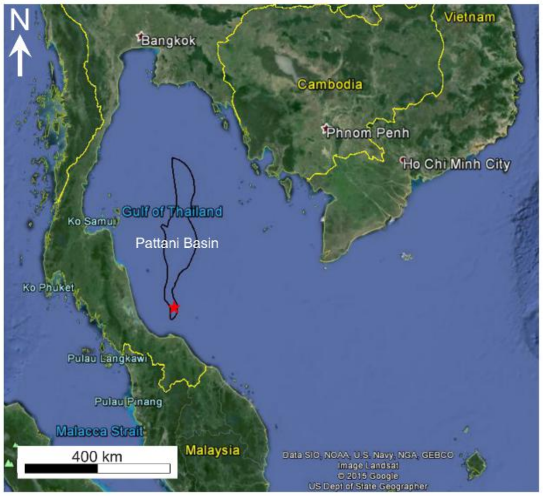

Figure 1. The location map of the study area (red star) Pattani Basin, Gulf of Thailand

The main objective of this study is to conduct a shallow seismic interpretation in the study area using time slice and seismic attribute analysis of the Pleistocene to Recent section, specifically to (i) document the distribution and architecture of the different fluvial systems in the study interval, (ii) to investigate the sedimentology of complex depositional systems, and (iii) to produce a sequence-stratigraphic model of the depositional systems in the southern margin of the Pattani Basin.

2. Methods

The study interval is from 111 to 271 ms TWTT on the available 3D seismic data. The data set covers an area of approximately 300 square kilometers, with frequencies between 15 and 60 Hz. For the shallow section in the Gulf of Thailand, seismic velocities are estimated at 1,600 m/s (Miall, 2002). The dominant frequency is 35 Hz which gives a vertical resolution or tuning thickness of 12 m. The general workflow is summarized and illustrated in Figure 3. The approach to the shallow seismic interpretation in this study emphasized the careful integration of time slices and vertical seismic sections. First, time slices were produced starting from 111 ms to 271 ms using a 16 ms interval. Next, horizons were picked and interpreted. Using both time slices and horizon slices, maps were then generated by extracting several seismic attributes, such as (1) Conventional Seismic Amplitude, (2) RMS (Root Mean Square) Amplitude, (3) Semblance and (4) Spectral Decomposition.

3. Results and Interpretation

A total of 11 time slices proved to show sufficient detail for useful analysis. These are the slices at 111, 127, 143, 159, 175, 191, 207, 223, 239, 255, 271 ms TWTT (Figure 2). There are no prominent channel features above 111 msec. Slices deeper than 271 msec show, for the most part, a confusing pattern of crossing channel fragments. It is important to note that some channels with significant relief can be imaged by more than one slice. And, channels formed at different times could appear at the same time slice.

Stratigraphy from the seabed down to approximately 300 ms in the study interval is substantially flat or horizontal. Channel features can readily be seen on the conventional seismic amplitude time slices. The time slices are plotted in gray scale (or in an appropriate color bar) which corresponds to variable amplitude, and which in turn, probably reflects varying lithology and/or compaction characteristics. In the deeper section, below 271 ms, the structural configuration is rather complex. There was an attempt to pick horizons in the lower section. However, the horizon slices did not show for the most part, any meaningful channel patterns. This can be partly due to the low reflective seismic packages in this section (a muddy interval characterized by nearly transparent reflections). This section is interpreted as a marine section. Three seismic attributes were also extracted from the available 3D seismic data, such as RMS amplitude, semblance or coherence, and spectral decompositon.

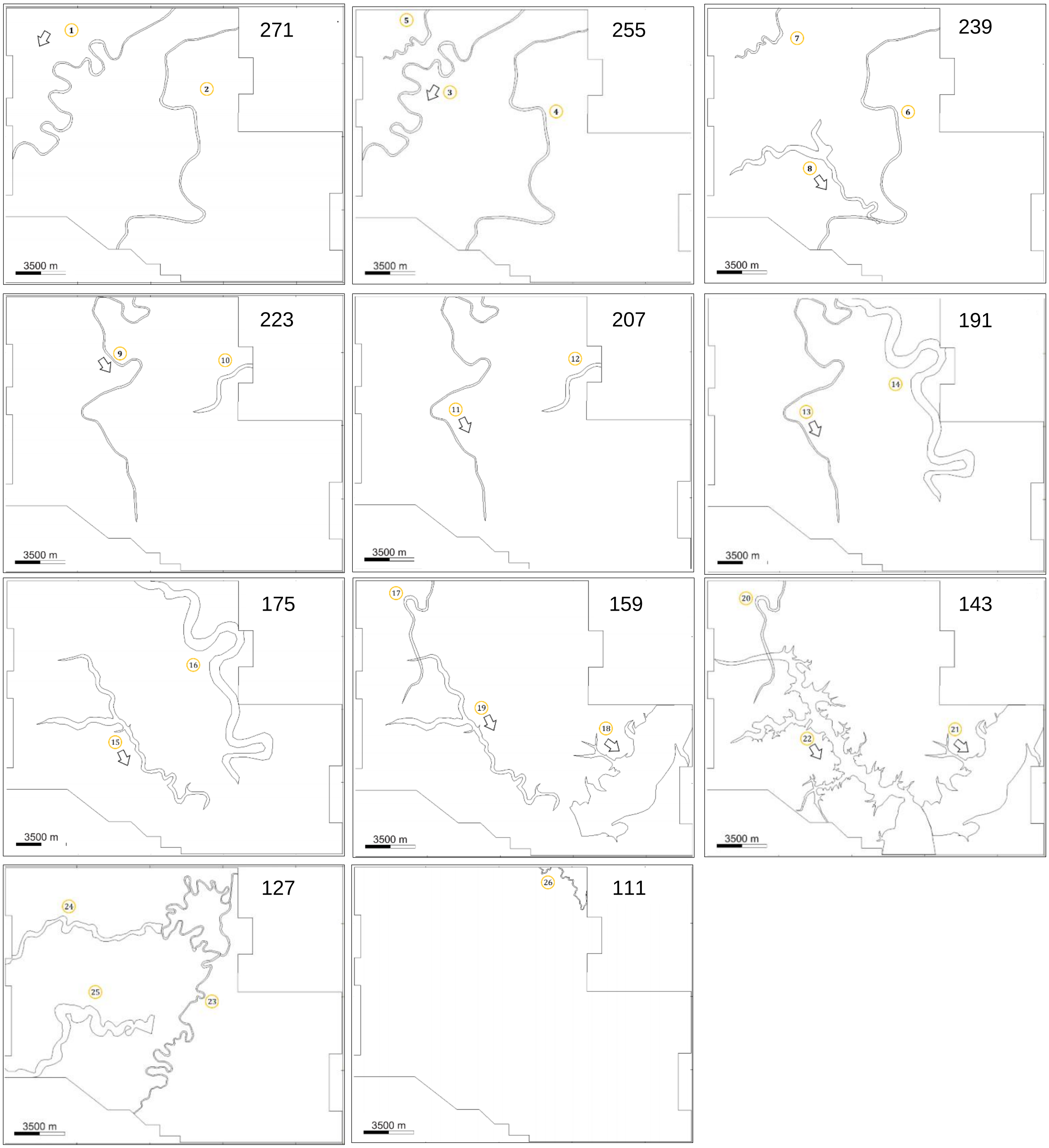

Figure 2. Eleven interpreted time slices drawn from conventional seismic amplitude maps.

In addition, several attribute combinations and/or overlays were also generated to get the best images of the different fuvial systems. However in most cases, these individual seismic attributes and attribute combinations pale in comparison to the conventional seismic amplitude attribute. Hence, all of the results presented in this paper are images produced from several time slices displayed in conventional seismic amplitude.

271 ms Time Slice

A prominent meander belt (Feature 1) with a meander-belt width of between 0.7 and 1.4 km, and meander wavelength ranging from 2.0 to 2.5 km, present on the northwestern part of the study area. Meander scrolls are clearly visible. The accretion direction (on the central meander is toward the south, suggesting a southerly flow for this river. Another channel (Feature 2) with a slightly larger meander-belt width of between 2.0 and 2.7 km, and a meander wavelength of 7.0 km, is present on the east side of the area. However, no meander scrolls are clearly visible. The accretion direction on the northern meander is toward the south, suggesting a southerly flow for this river.

255 ms Time Slice

Features 1 and 2 described in the 271 ms slice are also present in this time slice as Features 3 and 4. Hence, these features are then grouped as channels A and B respectively. Another feature (Feature 5) with a meander-belt width of between 0.5 and 0.9 km, and a meander wavelength of about 2.0 to 2.5 km, is present near the northwestern corner of the area. The meander scroll bars are not clearly visible.

239 ms Time Slice

Features 4 and 5 observed in the 255 ms slice are also present in this slice as Feature 6 and 7. These two are then grouped into Channels B and C respectively. An incised valley (Feature 8), with a main valley width of 1.3 km, runs from the central part of the area and drains to the southeast direction. The flow direction is indicated by the presence of an incised tributary channel feeding the valley that is located near its northern tip. This feature is labeled Channel D.

223 ms Time Slice

A prominent meandering channel (Feature 9) that runs the full length of the map area in the 223 ms slice. It has a meander-belt width of between 1.0 and 1.1 km, and a meander wavelength of 2.0 to 2.5 km. Meander scrolls are most clearly visible on the northern and central part of the area. Another meandering channel (Feature 10) is present near the eastern edge of the map area. It has a meander-belt width of between 0.3 and 0.9 km, and a meander wavelength of 2.7 km. Meander scrolls are not visible.

207 ms Time Slice

Features 9 and 10 described in the 223 ms slice are also present in this time slice as Features 11 and 12. These channels are then grouped as channels E and F respectively.

191 ms Time Slice

Feature 13 clearly resembles Features 9 and 11 in the 223 ms and 207 ms slices respectively, and thus grouped as Channel E. The accretion direction on the northern meander is towards the south, suggesting a southerly flow for this river. Another prominent meandering channel (Feature 14) with a meander-belt width of 0.9 to 2.4 km, and a meander wavelength of 5.5 km, is present near the northeastern edge of the map area. No meander scrolls are visible.

175 ms Time Slice

Feature 15 clearly resembles Feature 8 in this 239 ms slice. They are labeled separately as Channels D and H respectively.

159 ms Time Slice

Near the northern corner of the map area, a meandering channel (Feature 17) with a meander-belt width of 1.0 to 1.2 km, and a meander wavelength of about 2.0 km, is present. Meander scrolls are not visible. Feature 18 is observed as a plethora of crossing channels and channel fragments within a high amplitude complex. The main channel has a meander-belt width of 0.4 to 0.6 km, and a meander wavelength of 0.8 to 1.1 km.

143 ms Time Slice

Features 17 an 18 described in the previous slice (159 ms) are also present in this time slice as Features 20 and 21. These channels are then grouped as channels I and J respectively. Feature 22 is a major incised valley with a main valley width of 1.6 km. It is fed with incised tributary channels from the western and eastern margins. If compared with the incised valleys observed in the 175 ms and 239 ms slices, this feature suggests a more developed incised valley system. This feature is noted separately as Channel K.

127 ms Time Slice

A prominent meandering channel (Feature 23) runs the full length of the map area from north to south in the 127 ms slice. It has a meander-belt width of between 0.4 and 1.5 km, and a meander wavelength of 1.4 km. Meander scrolls are not visible. Two large meandering channels trend east-west. Feature 24 has a meander-belt width of 0.9 to 1.4 km, and a meander wavelength of 1.2 to 1.8 km, while Feature 24 has a meander- belt width of 0.5 to 0.6 km, and meander wavelength of 1.5 km. Both channels do not clearly have meander scrolls along its span, and thus, the accretion direction cannot be determined.

111 ms Time Slice

Feature 26 is the only observable channel feature in the uppermost slice, located near the northeastern corner of the map area. It is an incised tributary, that is clearly filled with a high amplitude anomaly. Probably, this tributary drains to an incised valley outside the extent of the seismic coverage.

4. Discussion

As suggested by Miall (2002), the major control on the development of fluvial systems is the change in the accommodation space by means of changes in rate of subsidence and/or changes in eustatic sea level. Late Pleistocene to Recent sea level curve indicates several periods of large scale eustatic sea level fall (Bard et al., 1990). However, the role of eustacy diminishes upstream while local factors (e.g. climate/subsidence) become dominant (Posamentier and Allen, 1999).

The study interval represents the post-rift section, and since the Gulf of Thailand sits on a relatively stable platform during the Pleistocene to Recent, tectonics becomes an unlikely key factor in the development of these fluvial systems. Nevertheless, the role of sea level change could not be ignored, provided that the Pleistocene is characterized by large scale sea level changes.

Blum (1993) has demonstrated that changes in climate also cause major changes in fluvial style through their effects on sediment yield, discharge, and vegetation cover. It is only reasonable to assume that the fluvial styles in the Pleistocene-Recent section could be controlled by both eustatic and climatic changes.

Cross sections of channels have been made through the studied interval. These sections illustrate the internal architecture of both incised and unincised fluvial channel (Figure 3).

A sequence-stratigraphic model for the study interval is proposed and illustrated in Figure 4. Two sequence boundaries at the 239 and 191 ms level were interpreted in this study interval, based on the presence of incised valleys at two levels. In conjunction to the time slices, tributaries provide an important evidence of incised valley formation. Three units, and the most likely depositional environment were interpreted and shown in Figure 5.

Unit 1 (271-239 ms)

In the lower part, Channels A and C of high to moderate sinuosity appear in the 271 and 255 ms slices. Meandering systems characterized by well-developed meander belts commonly represent periods of modest accommodation, but factors such as fluvial discharge and local slope are also important in determining local fluvial style (Miall, 2002). The fluvial style eventually changes to a low sinuosity channel (Channels C and D in the 239 ms slice) towards the upper part. Such low

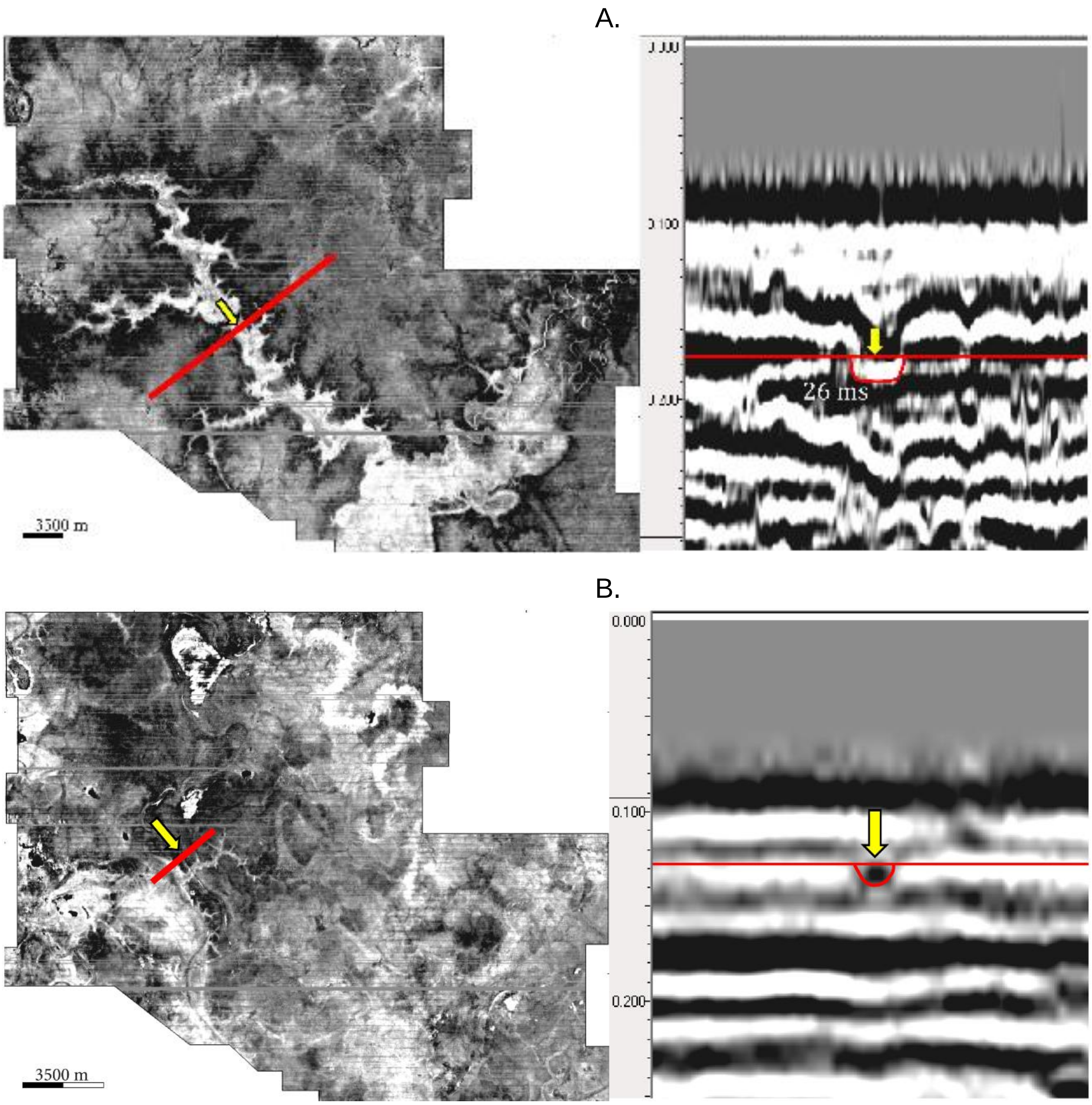

Figure 3. Cross section along an arbritary line (red line) showing the internal architecture of (A) an incised valley at 175 ms, and (B) an unincised valley at 127 ms.

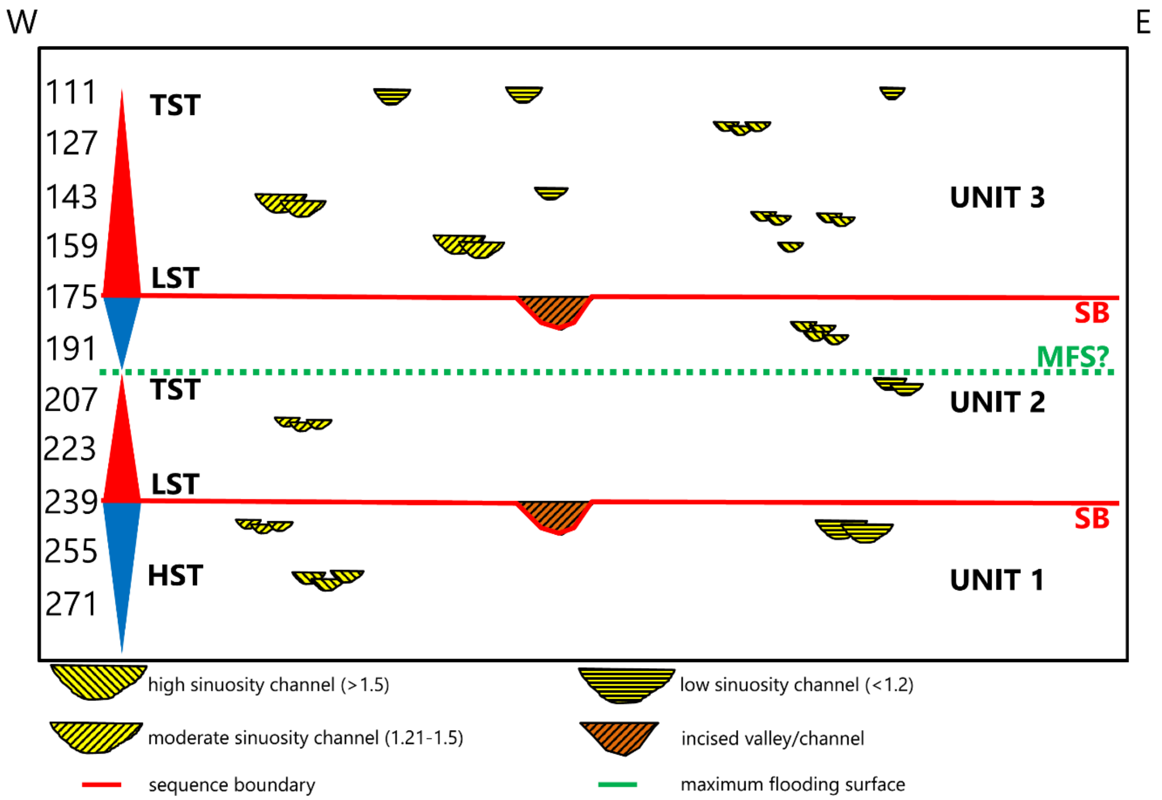

Figure 4. Sequence-stratigraphic model showing two sequence boundaries that were identified based on the presence of incised valleys. Three units were identified based on fluvial styles. Sinuosity index after Rosgen Stream Classification, 1994.

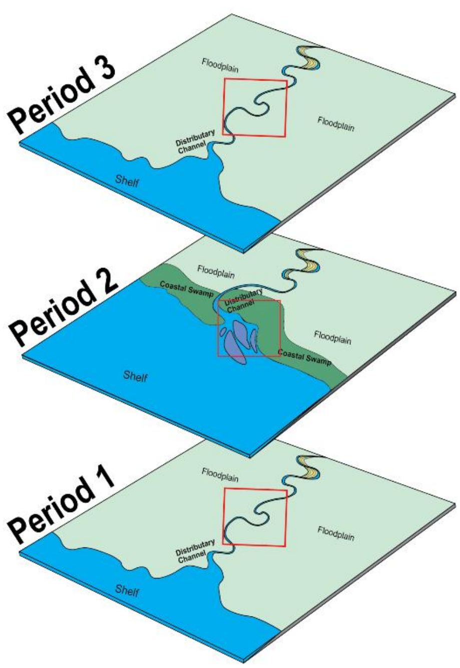

Figure 5. Simplified paleo-environment model for the three major depositional periods in the study area (modified after Imranuzzaman, 2014).

sinuousity channel with no clear evidence of meander scroll migration indicates areas of very low slope and low accommodation such as lower delta plains (Miall, 2002). This period is interpreted as a fluvial- dominated environment with estuarine influence near the top of the unit.

Unit 2 (239-191 ms)

Low to moderate sinuosity channels (Channels E and F) appear between the 239 and 191 ms slices. Their fluvial styles suggest periods of low to modest accomodation generation, consistent with either slow transgression or highstand (Miall, 2002). This period is interpreted as an environment of mostly estuarine influence.

Unit 3 (175-111 ms)

In the lower part, Channels G, H, I , J and L of high to moderate sinuosity appear between 175 and 143 ms slices. These channels extend the full length of the map area. Anastamosing channels (particularly Channels L and J in this study), are commonly associated with rapid accommodation generation, such as during transgression (Miall, 2002). The fluvial style eventually shifts to low sinuosity channels (Channels K, M, N and O between 143 the 111 ms slice) towards the upper part. Such low sinuousity channel with no clear evidence of meander scroll migration indicates areas of very low slope and low accommodation such as lower delta plains (Miall, 2002).

5. Conclusions

The main objective of this study is to conduct a shallow seismic interpretation of a 3D seismic data set from the Gulf of Thailand, specifically to document the distribution and architecture of fluvial systems in the study area. This study quantifies channel widths, channel-belt widths, channel length, half-meander wavelength, meander-belt width, sinuosities, channel depth and channel width.

The conclusions drawn from this study are as follows: 1) Time slice images in the conventional seismic amplitude attribute, in comparison to several other seismic attributes and attribute combinations, proved to provide useful information for geomorphological interpretation of fluvial systems within the Pleistocene to Recent section.; 2) Eustacy and climate fluctuations are the most likely controlling factors (which in turn affects sedimentation and fluvial discharge) in the development of the fluvial systems in the study area. In addition, the study interval represents the post-rift section, and thus, tectonics has no significant effect on sedimentation; 3) Two incised valleys were observed in the study area. In comparison to unincised channels, incised valleys tend to be deeper (up to 50 meters) and wider (up to 1.3 kilometers) systems. Tributaries provide the most clearly defined evidence for the existence of incised valleys; 4) Unincised fluvial systems include low sinuosity channels (1.1 -1.20 sinuosity), medium sinuosity channels (1.21 - 1.50 sinuosity), and high sinuosity channels (>1.50), with meander-belt width ranging between 0.3 to 1.4 km, meander wavelength of 0.4 to 2.3 km, abandoned channel width of 20 to 650 m, and channel depth of 4 to 19 m. Particularly in this study, it is quite difficult to describe the internal architecture of the fluvial systems in the vertical sections given the seismic resolution; 5) Two sequence boundaries were interpreted in this study interval based on the presence of incised valleys at two levels; 6) Three depositional periods were identified based on the fluvial styles: a) Period 1 (271-239 ms) begins with high to moderate sinuosity channels and eventually shifts to low sinuosity channel. This probably indicate a depositional environment that is fluvial-dominated with estuarine influence in the upper part; b) The onset of Period 2 (239-191 ms) is marked by a sequence boundary, as evidenced by the presence of an incised valley. This period is comprised of low to moderate sinuosity channels. Their fluvial styles suggest periods of low to modest accommodation generation, consistent with either slow transgression or highstand. The inferred depositional environment is dominantly of estuarine influence; c) A second sequence boundary, that is marked by the presence of another incised valley, indicates the onset of Period 3 (191-111 ms).This period, similar to Period 1, begins with high to moderate sinuosity channels, and eventually shifts to low sinuosity channel.

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