

## Seismic geomorphology of fluvial systems, Pattani Basin, Gulf of Thailand

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### ABSTRACT

During the last decade seismic geomorphology has become a key tool for the analysis of a wide spectrum of depositional settings from fluvial to deepwater environments. This study uses seismic geomorphology interpretation of a 3-D seismic data set in the southern Pattani Basin, Gulf of Thailand to analyse the fluvial dominant Upper Miocene to Holocene succession deposited in this basin during this time. This succession contains fluvial features which are well imaged in this seismic data set and the objective of this study was to document the distribution and internal architecture of these fluvial systems in order to better understand the controlling factors on their distribution and geometry. Wide varieties of fluvial styles were found over the short stratigraphic interval from Upper Miocene to Pleistocene section ranging from distributary channel and estuarine deposits in marginal marine environments in the Upper Miocene to lowstand incised valley dominant systems in the Pleistocene. In the later period, large meandering river systems develop in the incised valleys during lowstand with well developed point bars and associated tributary valleys. The controls on channel style in these systems are predominantly related to changes in fluvial discharge associated with climate change in the Pleistocene which in turn is related to high frequency, high amplitude sea level changes during this time. In contrast, sea level changes in the deeper section during the Upper Miocene were relatively stable and marginal marine fluvial features are well preserved. During this time, relative sea level is the main control on fluvial accommodation space in this area. The fluvial systems in the shallow section of this study are not good analogues for deeper prospective fluvial systems in the Pattani Basin as previously suggested.

**Keywords:** Seismic Geomorphology, Fluvial systems, Pattani Basin, Gulf of Thailand

### INTRODUCTION

The 3-D seismic data provides the opportunity to image the stratigraphic record at selected time slices or along interpreted stratigraphic markers which are

called horizon slices. These slices provide detailed images of the plan view geometry of ancient depositional systems and environments.

This study uses seismic geomorphology interpretation of a 3-D

seismic data set in the southern part of the Pattani Basin, Gulf of Thailand to analyze the fluvial dominant Upper Miocene to Holocene succession deposited in this basin during this time.

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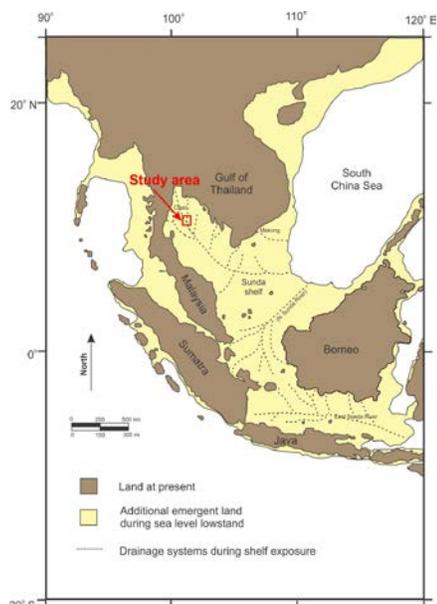


Figure 1. The paleogeography and fluvial drainage systems of the Gulf of Thailand during the last glacial maximum (Modified from Reijenstein et al, 2011).

## METHODS

The general work flow designed to derive stratigraphic insight from 3D seismic data involves analysis which is derived from

1. Horizon picking
2. Amplitude extraction tied to specific horizons
3. Horizon slicing, whereby the volume is flattened on a key horizon and then amplitude extractions are made from time

slices parallel to that key horizon

4. Proportional horizon slicing, where an interval is bound between two mapped horizons and then is proportionally sliced between those two horizons
5. Extraction of volume-based attributes such as phase, coherence, and impedance.

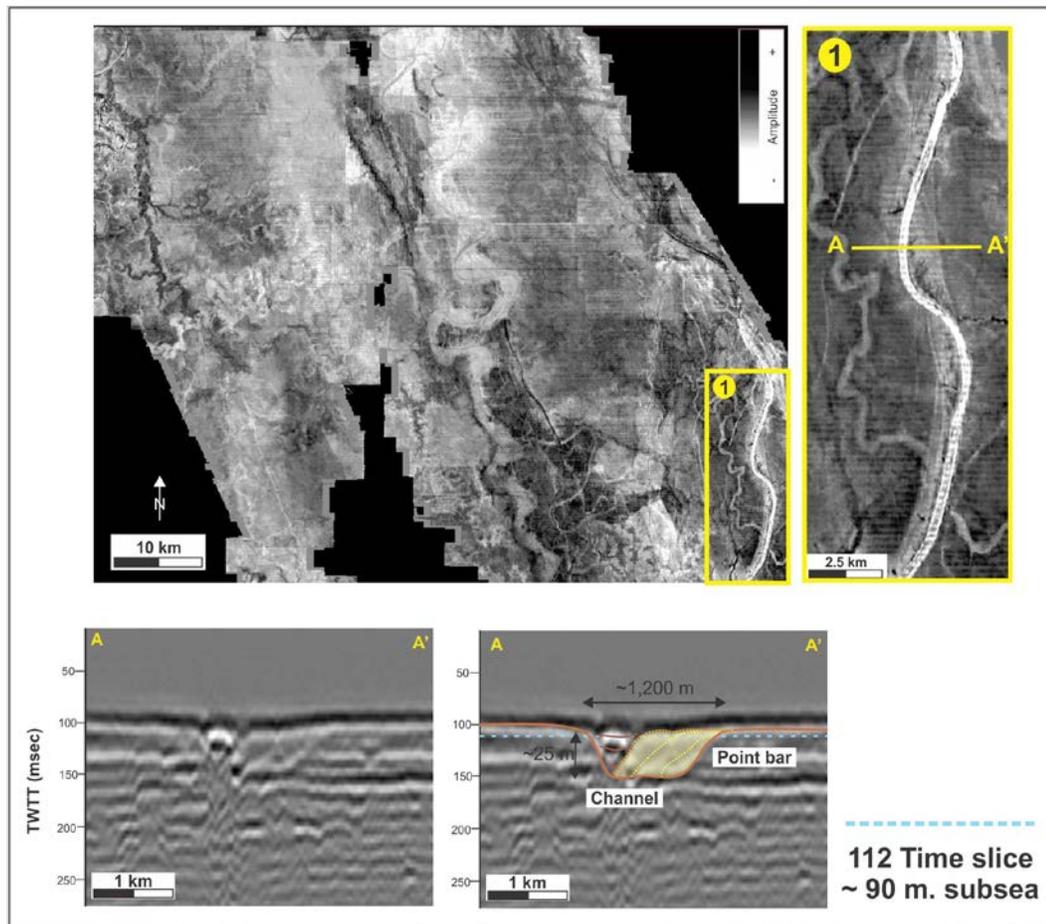
The key step of these analyses is to look for and recognize geologically and geomorphologically meaningful patterns in plan view as well as in section view which represents a geological feature in multiple dimensions.

## SEISMIC GEOMORPHOLOGY

Fifteen depositional features were examined in the time and horizon slices in the seafloor to 1200 msec interval for the analysis in terms of the variation of dimension, geometry and internal architecture of the fluvial systems. Note that all the estimates of thickness and depths are based on the regional average seismic interval velocities of 1600 m/s for the shallow section in the Pattani Basin. Representative feature from shallow and deeper section are shown in this paper.

### *112 msec TIME SLICE*

This slice is approximately 30 msec below the sea floor, and shows a distinct fluvial system geometry (Figure 2) characterized as **Feature 1** in the southeast with dimension up to 54 km long, 400 m wide, and approximately 25 m thick. It shows a low to moderate sinuosity meandering channel associated with point bar development. Integrating



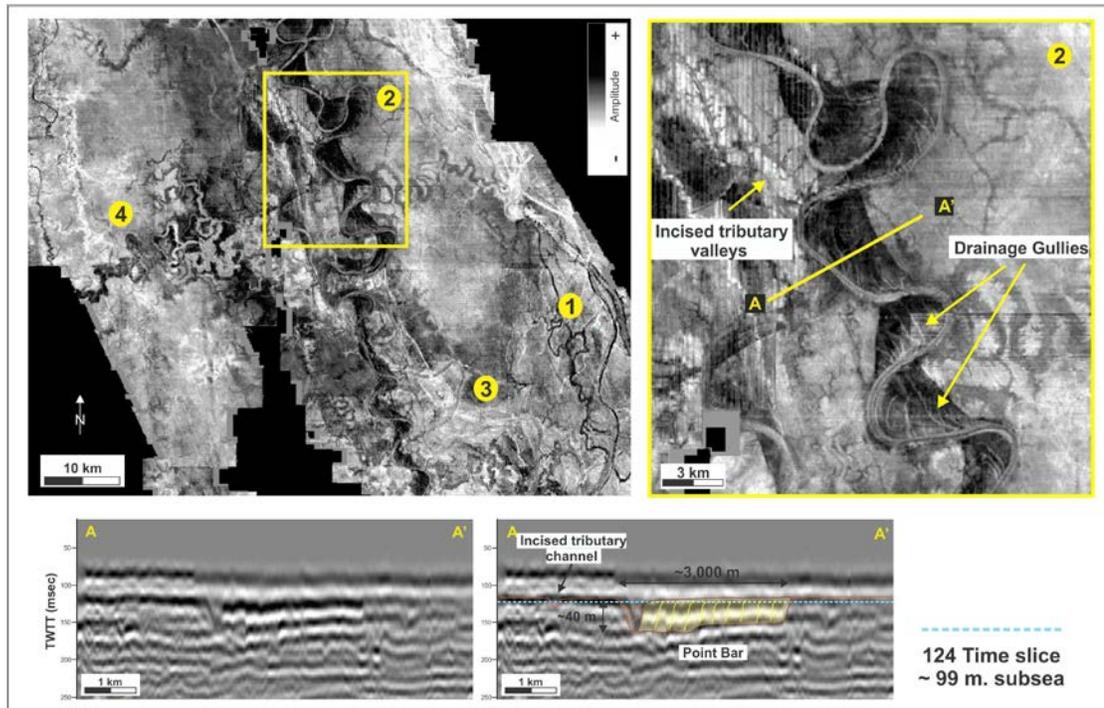
**Figure 2.** The 112 msec (~90 m subsea) time slice showing **Feature 1** which is characterized as a meandering river style with low sinuosity and deep incision.

this plan view observation with the section view shows the seismic character of channel cut and lateral accretion of the point bar to the west direction. Compared with the deeper time slices, this time slice has a lack of the landscape features suggesting that the deposition is probably largely mud dominated at this time.

#### ***124 msec TIME SLICE***

The 124 msec time slice shows three distinctive features. **Feature 2** has significant thickness as it originated in the 148 msec time slice in the northern part and developed through to the south (Figure 3). Its dimensions are up to 145

km long, about 350-400 m wide and approximately 40 m thick. This is a high to moderately sinuous fluvial system with point bars and meander scroll bars clearly visible. Along the edge of the meander belt, incised tributary valleys develop which are used in this study as one of the criteria to define an incised valley system. In the top of some of the point bars several smaller channels can be seen which are less than 100 m wide and several meters deep. These small channels are interpreted as drainage gullies which develop on top of point bars and form due to the seasonal changes from high to low water influx in the dry season. Based on



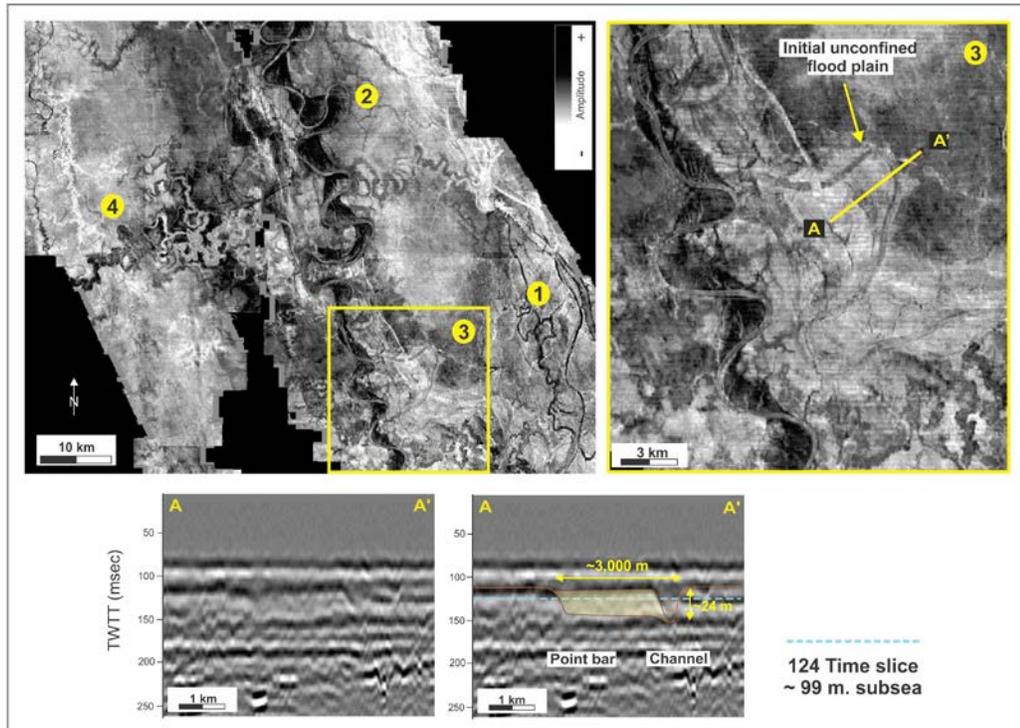
**Figure 3.** The 124 msec (~99 m subsea) time slice showing **Feature 2** in plan view and section view.

the evidence of incised tributary valleys observed in the interfluvial areas, this feature is interpreted as a broad incised valley system with locally unconfined channel dimensions because this meandering river shows high to moderate sinuosity.

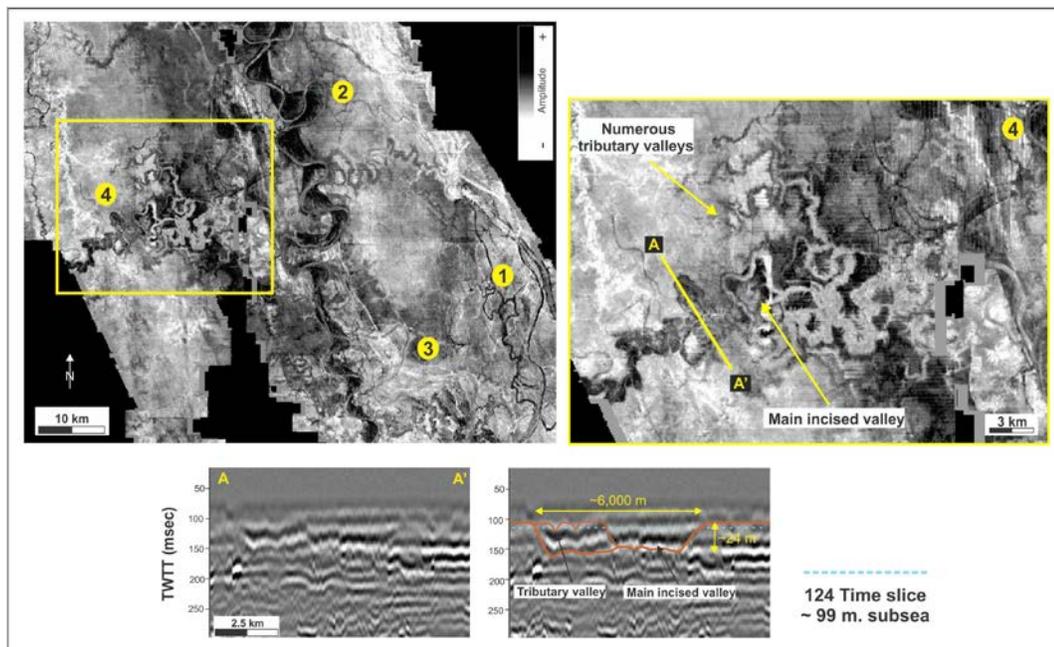
**Feature 3**, as shown in Figure 4 is also present in this time slice. The feature is a channel without tributaries and meanders across the broad interfluvial area. This channel is an unincised valley system and is imaged on only a few successive slices, suggesting that the depth and fill thickness is significantly less than in the incised valley system of feature 2. It is cut through by feature 2 in places.

**Features 2 and 3** have good morphological patterns to show the contrast between incised and unincised valley systems.

**Feature 4** (Figure 5) shows the characteristics of a very high sinuosity channel. Point bars are not clearly visible in this system. Tributary valleys develop in the interfluvial areas which is good evidence to support the interpretation of a confined incised valley system or underfit stream. The cross-section of this feature shows the vertical section across a broad unincised valley with tributary valleys. Paleo-flow direction is from the west side of the study area as represented by a change from low to high sinuosity eastward to the center of the basin. Also the valley broadens significantly in this direction.



**Figure 4.** The 124 msec (~99 m subsea) time slice showing **Feature 3** (uncised valley system) in plan view and section view.



**Figure 5.** Time slice and sections showing **Feature 4** which is characterized to be confined valley system. Cross-section shows incised valley with small associated tributary valleys and very high sinuosity channel associated in this system.

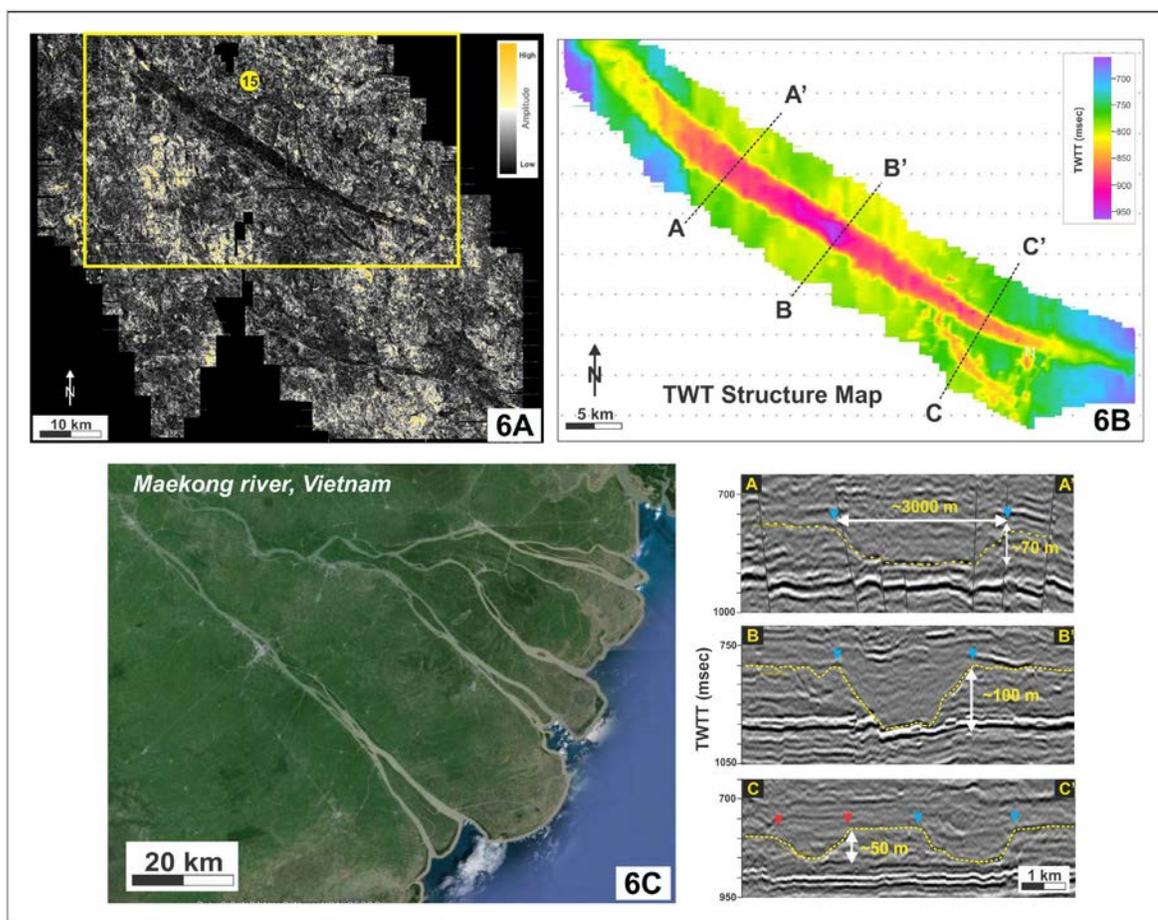
### *H+60 HORIZONS SLICE (~850 msec)*

This horizon slice penetrated down to 800 to 900 msec of the succession and shows a large feature of a fluvial system (Figure 6). This feature is up to 70 kilometers long and 2-3.5 kilometers in channel width and over a hundred meters thick in the deepest part of the channel. The geomorphology of this feature is very straight and it narrows toward the southeast.

A time structure map was generated for the base of this feature and it can be noticed that in the center part of this

feature is the deepest down cutting. Another observation from the time structure map is a small branch channel associated with this channel in the downstream direction. No evidence supports structural control of this feature because faults are located along N-S trend in this study area.

The probable interpretation of this feature (Figure 6) is a largely shale-filled, flood estuary, shale filled because of the largely reflection free character. The straightness is associated with it likely being a distributary channel; distributary channels, especially towards the mouth of



**Figure 6.** A H+60 horizon slice (6A), time structure map with cross-section (6B) and modern analogue from MaeKong river distributary channel (6C)

ivers tend to be relatively straight. Also distributary channels tend to get shallower as one approaches the mouth.

The RMS amplitude extraction from horizon slices show no possible sands which supports the interpretation of nearby marine influence.

Note that this unique feature can be compared to modern distributary channel from Maekong river, Vietnam in terms of plan view morphology but it is difficult to explain in thickness. The flow direction is definitely to the southeast based on regional geology and a certain conclusion is that it indicates nearby marine influence.

## SUMMARY OF OBSERVATIONS

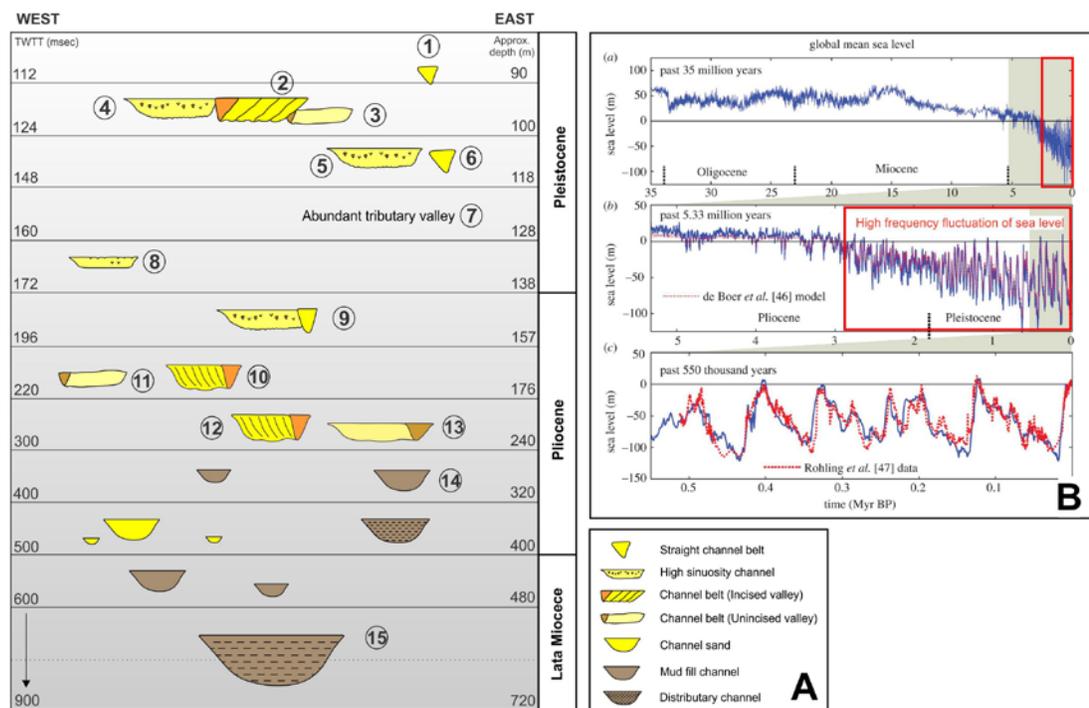
The stratigraphic observations summarized in Figure 7A was constructed based on the features that have been identified from the plan view integrated with cross-section views (**Features 1-15**). Many more features have been observed at different levels, particularly in the deeper section, but these were not documented here. This is a representative sample of the range of fluvial styles in this depositional system. A broad range of channel styles, channel size and seismic characteristics can be seen. Global mean sea level curve is considered to support this interpretation.

The variety of fluvial styles can be separated into three categories starting from the base of the interval of study to the sea floor. The interpretation of distributary channels observed in the time interval from 900 to 500 msec TWT indicates a near coastal estuarine environment which implies significant marine influence. Marine transgression is documented basin wide during this time

which is about late Miocene age (Jardine, 1997). It impacts on the channel character by the establishment of relatively straight mud or shale-filled channels. Channels filled with sand are also found in this time section but are not as dominant as mud filled channels. During this time sea level was relative high with low magnitude of high frequency fluctuations (Figure 7B) which helped to preserve the marginal marine depositional architecture. This is in contrast to the shallower section where large fluctuations in sea level did not allow preservation of coastal deposits in this shallow, very low relief basin.

The stratigraphic interval from 500 to about 200 msec TWT is time equivalent to the Pliocene. Mud filled channels are coeval with channel belts with well developed point bars in this interval and incised and unincised valley fills are evident. The sea level curve shows that this is a transition period from stable sea level to the higher frequency higher amplitude fluctuations of the Pleistocene. Sandy channel belt systems are dominant.

The section above 200 msec TWT is equivalent to the Pleistocene age and is dominated by channel belts in incised valley systems with associated tributary valleys. Occasional small unincised valley systems were found. Tributary valley systems are abundant in this section, particularly at the 160 msec time slice where large area of erosional surfaces are observed. At this time incision and drainage patterns indicate a long standing lowstand period in the study area. Previous studies from high resolution 2D seismic data in this area (Reijnenstein et al, 2011; Samorn, 2006) reveal that short lived marine transgressions are evident in between fluvial dominated lowstand



**Figure 7(A).** A chronostratigraphic summary of the observations from seismic sections and horizon slices in this study. **(B)** Global sea level focused on the late Miocene to present (Modified from Hansen J et al, 2013)

periods. The high frequency, high amplitude fluctuations of sea level curve during this time (Figure 7B) produced variations of depositional environment from marine to fluvial dominant in relatively short periods of time. Significant changes in climate, which affect discharge rates in the fluvial systems, is interpreted to be a factor in controlling fluvial styles during this time.

### INCISED VS. UNINCISED FLUVIAL SYSTEMS

An incised valley system occurs when a river has cut into its own floodplain or underlying strata. It cuts deep enough to control the river flow within the channel even when it is flood stage. The formerly active floodplain is left abandoned to serve as interfluvies

(Posamentier, 2001). Incised valley formation can occur in at least three ways as a result of;

1. Base level fall
2. Tectonic tilting
3. Significant decrease in fluvial discharge to form underfit streams

The criteria used in this study to interpret incised valley systems was;

1. Cross-section evidence (3D seismic data) : Incised tributary valleys cutting into their own floodplain
2. Plan view evidence (3D seismic data) : Presence of incised tributary valleys that extend away from the trunk channel

In this study area were observed both incised and unincised valley systems. Incised valley systems are dominant in the shallow section with the characteristics of incised tributary valleys present in the time slices and also supported with V and U-shape cutting into base level interfluvial which constrains the channel even in the flooding time. High to low sinuosity and relatively straight channels are all observed forming these incised valley systems.

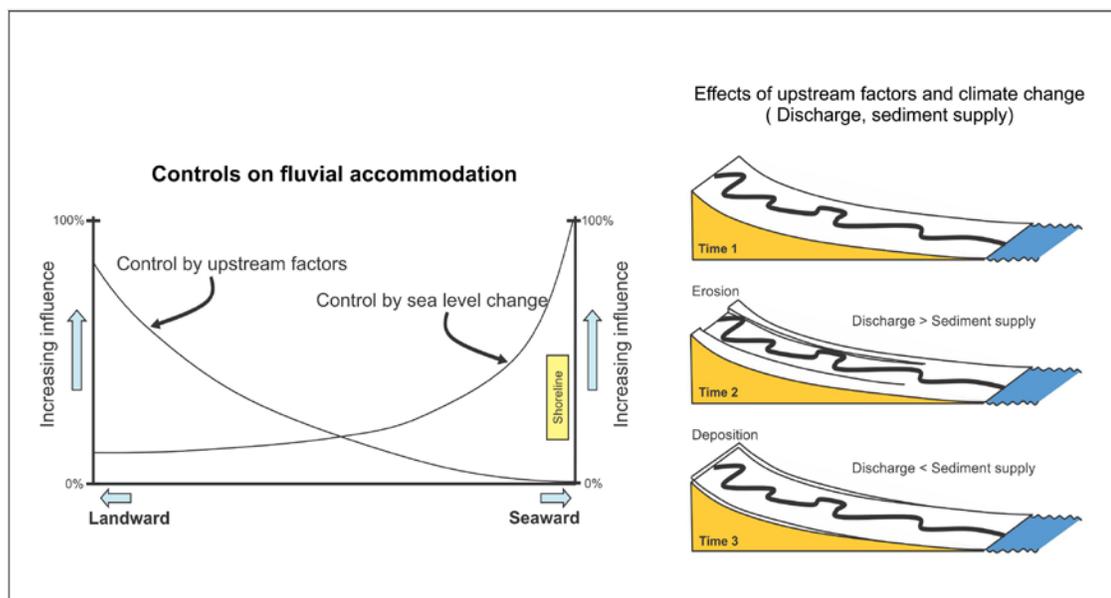
### CONTROLS ON CHANNEL STYLE

The controls on fluvial style are well documented in the literature and are considered to be dependent on subsidence, tectonic setting, eustacy or relative sea level change and climate change which controls the balance between fluvial discharge and sediment

supply.

Previous studies in Southeast Asia emphasize the importance of controls on fluvial accommodation space by climate and fluvial discharge instead of eustatic sea level falls (Wellner and Bartek, 2003; Clift, 2006). On the other hand, a study in the Java Sea (Posamentier, 2001) suggests that only in the lowest lowstands can incised valleys form, and that unconfined fluvial systems are the dominant fluvial style. So, what does the majority of evidence suggest as to what controls fluvial accommodation space in this study area?

As Posamentier and Allen (1999) suggested, the controls on fluvial accommodation are dependent on which part of the system you are in (Figure 9). The schematic diagram shows the control on fluvial accommodation and the role of relative sea level, fluvial discharge and sediment supply.



**Figure 8.** Diagram showing the controls on fluvial accommodation and the effect of downstream and upstream factors (Modified from Posamentier and Allen, 1999)

The study area is interpreted to be in an upstream environment during the extended lowstand periods in the Pleistocene. The coastline can be as much as 1,000 km. away downstream (Figure 1) during these times and discharge versus sediment supply controlled by climate changes dominates fluvial style. The high meandering system developed first in an area of low gradient (**Time 1**, on the right of Figure 30) and then, due to a climate change, fluvial discharge became greater than sediment supply (**Time 2**) and fluvial incision was established. When discharge diminished because of climate change such as a dry season, an underfit fluvial system was created. The interfluvial areas were exposed during the lowstand time, and tributary valleys were well developed.

On the other hand, the section below 500 msec TWT indicates the preservation of more near coastal estuarine environments as mentioned earlier. The controls on fluvial accommodation for this downstream section changes as fluctuations in sea level become less in amplitude in the lower Pliocene and Upper Miocene (Figure 8B). The coastline is in a more stable position with transgressions and regressions less severe so that preservation of estuarine and distributary channel geomorphology is more likely. The effect of relative sea level rise and fall are more dominant on fluvial accommodation space.

## CONCLUSIONS

Important outcomes from this study are:

- A broad range of channel styles and channel size were observed.
- In the Upper Miocene section distributary channels were observed implying a near coastal estuarine environment which continued through to Pliocene. Mud-filled channels are dominant. Sea level was relatively high with low magnitude fluctuations which helped to preserve these deposits.
- The Pleistocene section is dominated by channel belts in incised valley systems. The high frequency, high amplitude fluctuations of sea level during this time produced variations of depositional environment from marine to fluvial dominant in relatively short periods of time.
- Formation of incised valley systems in this area results from significant fluctuations in fluvial discharge due to climate changes in the Pleistocene which helps to create underfit fluvial systems. Tributary valleys were the criteria used to determine incised valleys systems. High to low sinuosity and relatively straight channels are present in these valley systems.
- Unincised valley systems tend to have a simple stratigraphic architecture and are smaller and less common in the shallow study area.
- High sinuosity meander belts with well developed point bars provide the best reservoir potential in these fluvial systems and these can be found in both the shallow incised valley systems and the deeper unincised fluvial systems.
- The dominant controls on fluvial style in this system vary from fluvial discharge fluctuations associated with climate change in the shallow Pleistocene section to

sea level change in the deeper marginal marine Upper Miocene section.

- The shallow Pleistocene section is not regarded to be a good analogue for the deeper prospective fluvial systems in this basin as previously published in several studies.

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