Seismic Facies Interpretation of Fluvial/Marginal Marine Sand Architecture in Kra Basin, Gulf of Thailand

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Abstract

The study area lies in the Kra basin, Gulf of Thailand covering an area of approximately 990 sq.kms. The goal of this study is to understand the distribution and architecture of fluvial sand systems by analyzing the seismic facies based on 3D seismic images in the interval of interest from the Middle Miocene to Recent. Three wells are located in this area but only one has a good well to seismic tie. The seismic facies interpretation used the stratal slicing method based on several key horizons which is able to handle the non-flat lying deeper formations and time slices in the very shallow section. The seismic images from stratal slices and time slices illustrate the complex fluvial systems for the whole interval with minor marine influence in the shallow section. Nine distinct fluvial styles were interpreted which are single small channels, small to medium channel meander belts, tidal creeks, incised valley fills, high-sinuosity channels with large point bars, moderate to high-sinuosity channels with moderate point bars, high-sinuosity small channels with narrow point bars, low to moderate-sinuosity small channels with narrow point bars, and low-sinuosity large channels with no point bar. The results show that the variety of fluvial styles deposit sand within point bars with a dramatic range of sand body dimensions. The fluvial styles are dominantly influenced by variations in discharge rate, sediment load, climate and basin topography. Relative sea-level changes have an effect mainly in the shallow section. In term of reservoir implication, the high-sinuosity channels with large point bars associated with large channels give the greatest volume of porous reservoir facies whereas small channels deposit thin sands with limited areal extent and volume.

Keywords: **Kra Basin, Fluvial Sand Architecture, Stratal Slices**

1. Introduction

The area of interest straddles the Western and Kra Basins, Gulf of Thailand and contains the Bualuang Oilfield which produces oil from Middle Miocene sands (Figure 1). This field represents the main hydrocarbon play in these basins, and understanding the distribution and architecture of the Miocene reservoirs is a key to unlocking further resources in this area. The purpose of this research is to evaluate sand architecture and characteristics using shallow sub-surface data from a new 3D survey acquired in the Kra Basin. This seismic data set can be calibrated to exploration and development wells in the Western and Kra Basins via existing 2D and 3D data. The goal is to build analogues for Miocene sand development within the Western and Kra Basins in order to better understand reservoir geometries.

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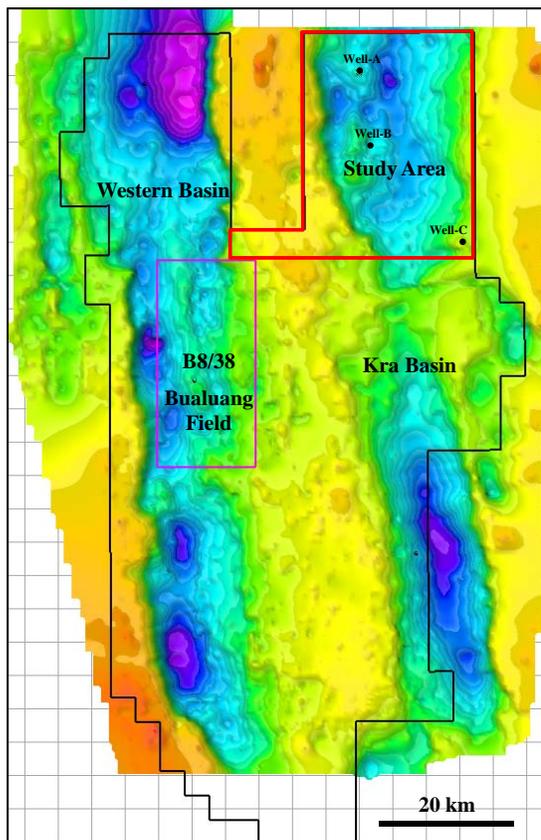
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Figure 1. Basement structural map of the area of interest showing outline of new 3D, the study area in Kra Basin, and block B8/38 which contains the Bualuang field.

2. Methodology

2.1 Well log Analysis

There are three wells in this area including Well-A, Well-B and Well-C (Figure 1) . Only Well-C had a full set of logs so it was used to determine sand and shale characterization. The log plots were used to identify key horizons in Well-C which was divided into three zones by the T4, T6 and T8 markers based on gamma ray, sonic and resistivity log characterization (Figure 2).
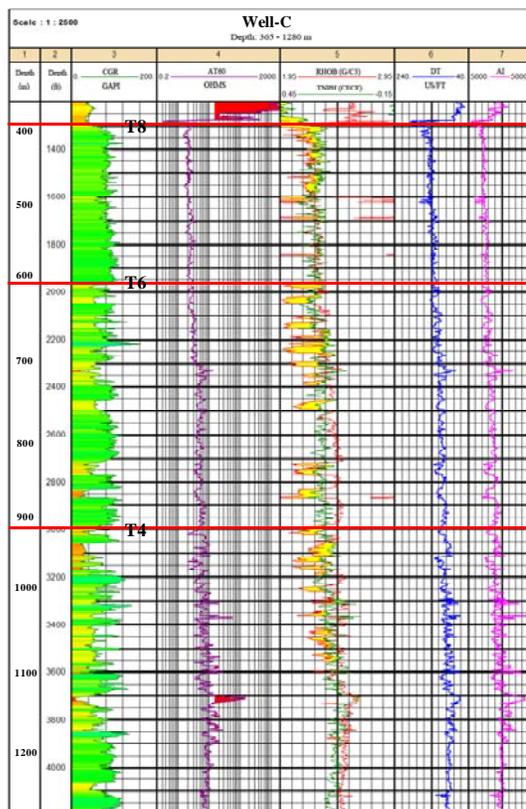

Figure 2. WELL-C log characterization and zonation showing three different intervals based on gamma ray, resistivity and sonic logs.

2.2 Well to seismic tie

In this study sonic and density logs from the Well-C were used to generate a synthetic seismic trace with initial calibration from a time-depth chart from Bualuang Field wells. The synthetic was displayed on the seismic data and showed a very good tie of seismic character, with tops of sands represented by trough events. Key horizons identified in the well were correlated to distinct seismic horizons for mapping (Figure 3).
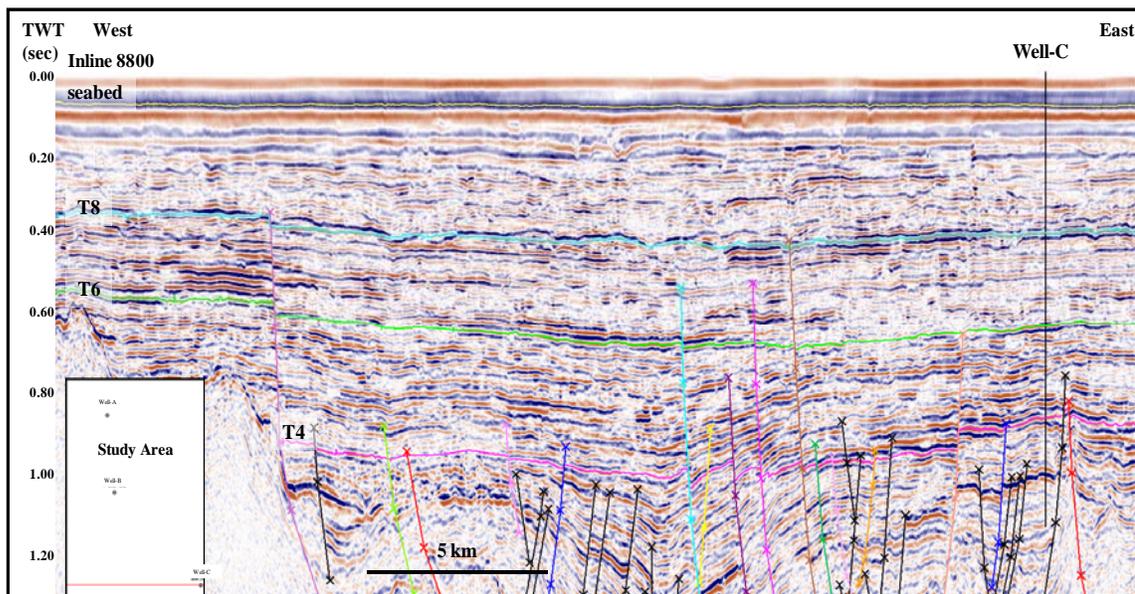
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Figure 3. Seismic cross section Inline 8800 showing picked key horizons, seabed, T8, T6 and T4 tied to WELL-C.

2.3 Faults and horizons interpretation

The seismic interpretation was based on a newly acquired 3D survey covering 990 sq. kms. Based on the well tie, horizons were picked starting from the seabed and followed by T6 and T4 horizons which were correlated from the 2D seismic data over the Bualuang Field in the Western Basin. The T8 horizon was picked as an infill horizon between the seabed and T6 and faults were also picked. The horizon interpretation started from Well-C location focusing on the strong and continuous reflectors that separated each sequence (Figure 3).

2.4 Stratal slicing

Stratal Slicing is a method to create near horizontal seismic displays with chronostratigraphic significance using horizon based interpretations (Figure 4). In this study volume attributes were generated from horizons created by stratal slicing using

root mean square (rms) amplitude. It is a useful attribute to display data such that modern and ancient depositional systems can be imaged more clearly.
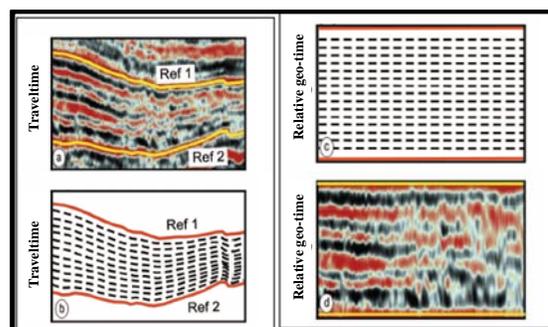

Figure 4. The concept of Stratal Slicing. (a) Data cube with geologic time-parallel reference events picked (Ref1 and Ref2). (b) Stratal time cube created by linearly slicing between reference events. (c) Flattened strata time volume labeled with relative geologic-time scale. (d) Amplitude strata slice cube (Zeng, 2010).

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3. Petrophysical analysis

Each interval can be characterized by the nature of the gamma ray, resistivity and sonic logs from the log plot. Cross plotting of the gamma ray, acoustic impedance and density logs can be used to differentiate the character of sands and shales in each zone (Figure 5).
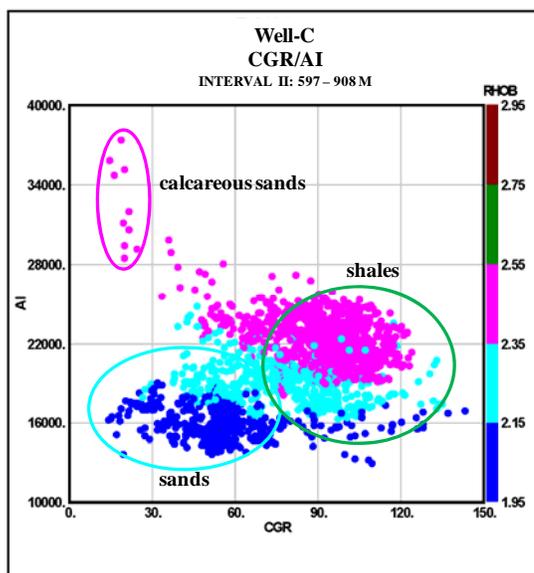

Figure 5. Example AI versus GR crossplot of T4 to T6 interval.

These crossplots suggest that sands are low impedance and show good contrast with the shales at least down to the T4 horizon. This means that sand-prone depositional systems should be well imaged on the seismic stratal slices.

4. Seismic Interpretation

4.1 Structural Interpretation

Four horizons were interpreted on 3D seismic including the T4, T6, T8 and seabed from base to top respectively (Figure 3). Three horizons were mapped in order to stratal slice more accurately.

The structural map of T4 horizon shows a highly faulted surface associated

with the late rift stage and shows clear image of half-graben geometry. Faults are oriented north-south.

In contrast, the structural map of T6 horizon shows a partly faulted surface within the early post-rift sequence which is faulted more on the western margin than to the east. The T6 horizon extents over the Ko Pha Ngan Ridge which separates the Kra and Western basins to the west. Faulting is mainly reactivation of earlier rift related faults with a dominant north-south trend.

The structural map of T8 horizon shows a minor faulted surface within the post-rift sequence. Nearly all the faults are seen along the western margin and some faults extend up from the T4 to T8 horizons near the Ko Pha Ngan Ridge.

4.2 Facies Analysis of Time slices and Stratal Slices

A representation of the slices generated is discussed using a series of 8 seismic images from the total of 42 slices generated.
112 ms Time Slice

The seismic image shows a single isolated meandering channel, which flows northwest-southeast cutting across an extensive floodplain (Figure 6). It shows an oxbow lake and very limited point bar development.

192 ms Time Slice

The seismic image shows partially marine influence in an abandoned channel of north-south trending meander belts. Tidal creek geometries are evident in the mud-filled channels.

196 ms Time Slice

The seismic image shows an apparent small to medium channel meander belt with point bars. The meander belt flows north-south and northeast-southwest along the west of the Kra Basin and is up to 10 km wide.

428 ms Time Slice

The seismic image shows multiple complex channel systems cutting across one another. In the west there is an incised valley which are common along the flank of Ko Pha Ngan Ridge near T8 horizon boundary.

T8T6_5 Stratal Slice

The seismic image shows the distinct high-sinuosity large channels with large point bars which flow northwest-southeast and northeast-southwest. The high rms-amplitude likely corresponds to point bar deposits with the character of scroll bars (Figure 7).

T8T6_7 Stratal Slice

The seismic image shows two characters of fluvial styles. One is high-sinuosity medium channels with moderate to thick point bars (~10 m thick) flowing north-south. Another is the low sinuosity large channel with no observed point bar flowing northwest-southeast. The high-sinuosity channel lies along the flank of the high area in the west but the low sinuosity channel is in the middle to east of the basin.

T8T6_8 Stratal Slice

The seismic image shows multiple fluvial systems with variable sizes of channels. The systems of interest are the high-sinuosity small channels with narrow point bars, and the low to moderate-sinuosity channels with small point bars. There are several directions of channel flow ranging from north-south, northeast-southwest, northwest-southeast and east-west.

T6T4_6 Stratal Slice

The seismic image of a typical T6-T4 interval stratal slice shows separate moderate to high-sinuosity medium channels with moderate point bars. These channels are mainly present in the middle to the east of the basin with no presence in the west on the flank of the Ko Pha Ngan Ridge. This is the deepest slice showing clear fluvial geometries.

4.3 Fluvial Styles

Based on analysis of all 42 slices 9 different fluvial styles were characterized and documented.

(1) High-sinuosity single channel with occasional point bars

The time slice at 112ms shows a single meandering channel with high-sinuosity trending northwest-southeast across the extensive floodplain (Figure 6). It also shows occasional point bars and oxbow lake in the southern part of the basin. The channel width is around 150 m and the channel wavelength ranges from 3 to 5 km. The seismic cross section illustrates the thick high-amplitude because it is immediately below the seabed. This kind of fluvial style occurs in low depositional gradient during sea-level rise where the accommodation space is increasing and sediment supply is low (Miall, 2002).
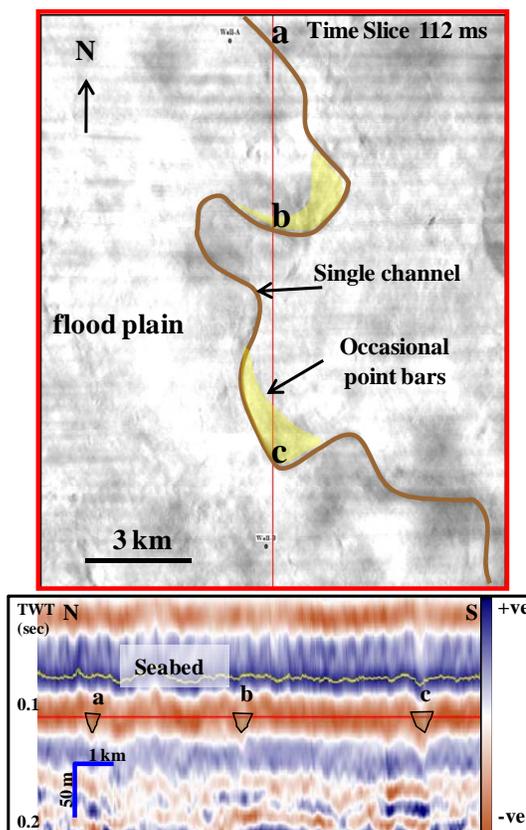
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Figure 6. The 112 ms time slice shows high-sinuosity meandering channel and a representative seismic cross-section.

(2)Tidal Creeks

The time slice at 192ms shows evidence of marine influence within a dominantly non-marine system. The oxbow lake in abandoned channel shows tidal creek patterns, indicating flooding episodes and sea-level rise. The marine influence indicates this part of the system was close to the shoreline affected by a tidal regime at that time. Tidal influence can reach distance of approximately 10 to 15 km inland from the shoreline (Reijenstein et al., 2011). A modern analogue which is similar to this style of river is the Smithburne River, Australia, which shows the fluvial system with strongly associated with tidal currents.

(3) Small to medium channel meander belts

The time slice at 196ms illustrates a meandering system with well-developed meander belts which commonly characterize periods of modest accommodation space generation (Miall, 2002). It shows small point bars along the paleo-meandering river within meander belts extended in north-south flow direction. Meander belts are also seen in other slices and vary in size based on channel width and basin topography.

(4) Incised Valley Fills

The time slice at 424ms shows incised valley fills extended north-south across the Kra Basin. The incised valleys occur during a period of negative accommodation space, such as during regional uplift or falls in base level. Incision can also occur during times of increased discharge or during times of reduced sediment load (Miall, 2002). Most of the incised valleys are observed near the T8 boundary on the flank of the high Ko Pha Ngan Ridge and some are found just above the T8 horizon as well.

(5) High-sinuosity channels with large point bars

The T8T6_5 stratal slice shows very distinct high-sinuosity large channels with well-developed point bars flowing northwest-southeast and northeast-southwest (Figure 7). The expansion of point bars is described where there is low slope, high accommodation space and a high energy fluvial system. The high rms-amplitude (black) refers to sand-prone facies of the point bar deposits. The low rms-amplitudes are associated with the muddy facies (blue & brown) of the abandoned channels which cut through the earlier point bars. A modern analogue river is middle part of the Wabash River, U.S.A.

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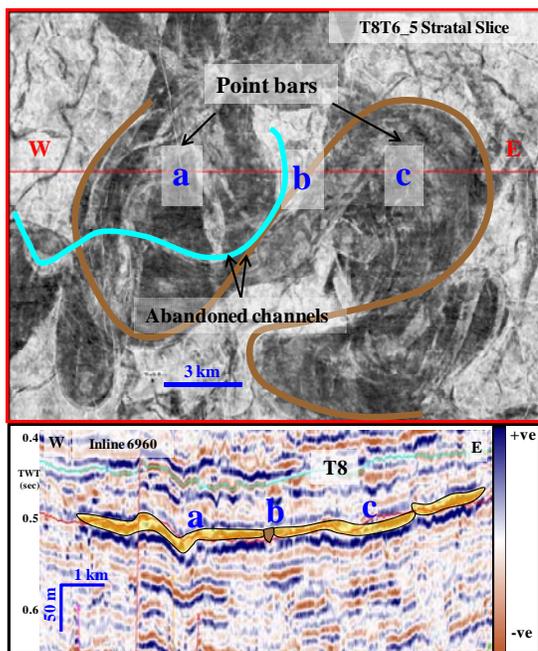
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Figure 7. Stratal slice T8T6_5 shows high-sinuosity large channel with associated point bars and strong amplitude represent point bar in seismic. Blue line represents younger channel cut through the existing point bars.

(6) Moderate to high-sinuosity channels with moderate point bars

The T8T6_2 stratal slice shows moderate to high-sinuosity channels with moderate point bars. As with the larger system, the muddy channels cut through the older point bars of the high-sinuosity channel, resulting in a mud plug facies suggesting the change in accommodation space from high to low.

(7) High-sinuosity small channels with narrow point bars

The T8T6_8 stratal slice shows a number of high-sinuosity small channels with narrow point bars (Figure 8). This fluvial style forms ribbon-shaped sand bodies which commonly are seen in the very low-slope lower delta plain environments and are characteristic of rivers in high-accommodation space settings. Both plan-view and vertical-view show low to moderate amplitude

reflections at the point bars corresponding to low-energy system and reworked sand and mud that caps the point bar (Reijenstein et al., 2011).
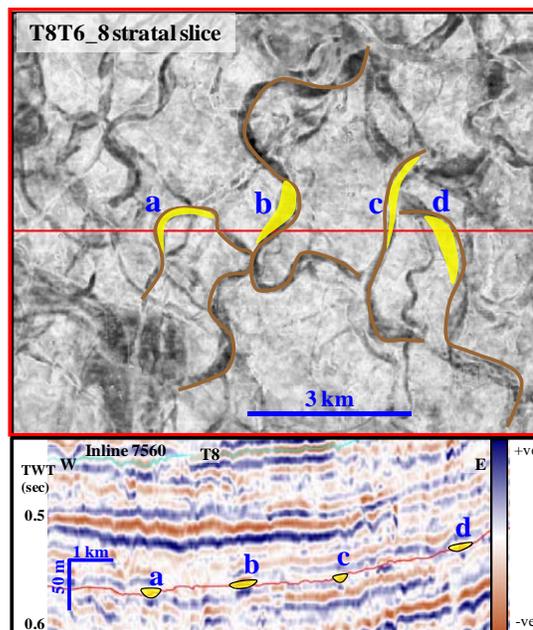

Figure 8. Stratal slice T8T6_8 shows high-sinuosity small channel with narrow point bars and a representative seismic cross-section.

(8) Low to moderate-sinuosity small channels with narrow point bars

Southwestern part of the T8T6_12 stratal slice shows low to moderate-sinuosity channels with narrow point bars. This kind of channel is typical of areas with low slope and low accommodation space appearing over the high of the Ko Pha Ngan Ridge.

(9) Low-sinuosity large channels with no presence of point bar

Low-sinuosity channels show little evidence of lateral migration and are typical of areas of very low slope and low accommodation space, such as in the lower delta plain (Miall, 2002). These channels can be quite large, up to 1.5 km across, but generally lack the typical features of meandering rivers like point bars (Miall, 2002). Silty to muddy deposits are interpreted to infill these broad low energy channel.

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5. Discussion

5.1 Evolution and Controls

In general fluvial systems are dominant in theT4 to T8 interval whereas fluvial systems with marine influence occur in the T8 to seabed interval, based on the observed seismic image architectures. The T6 to T8 interval has the best developed point bar systems which may be due to renewed tectonic activity at this time. (Figure 9). The factors that are likely to be the major controls in this area are the variation in sediment load, climate, tectonism and basin topography whereas changes in relative sea-level affected mainly in the very shallow section.

guide to sand thickness elsewhere in basin.

The variation in fluvial styles with their dimensions highlights the range of potential reservoir volumes associated which each of these fluvial styles and can be ranked from the largest to the smallest point bar volume as follows.

No.1 High-sinuosity large channels with large point bars (470 x 10^6cu.m)

No. 2 High-sinuosity medium channels with moderate size of point bars (26 x 10^6cu.m)

No. 3 Moderate to high-sinuosity channels with narrow point bars (18 x 10^6cu.m)
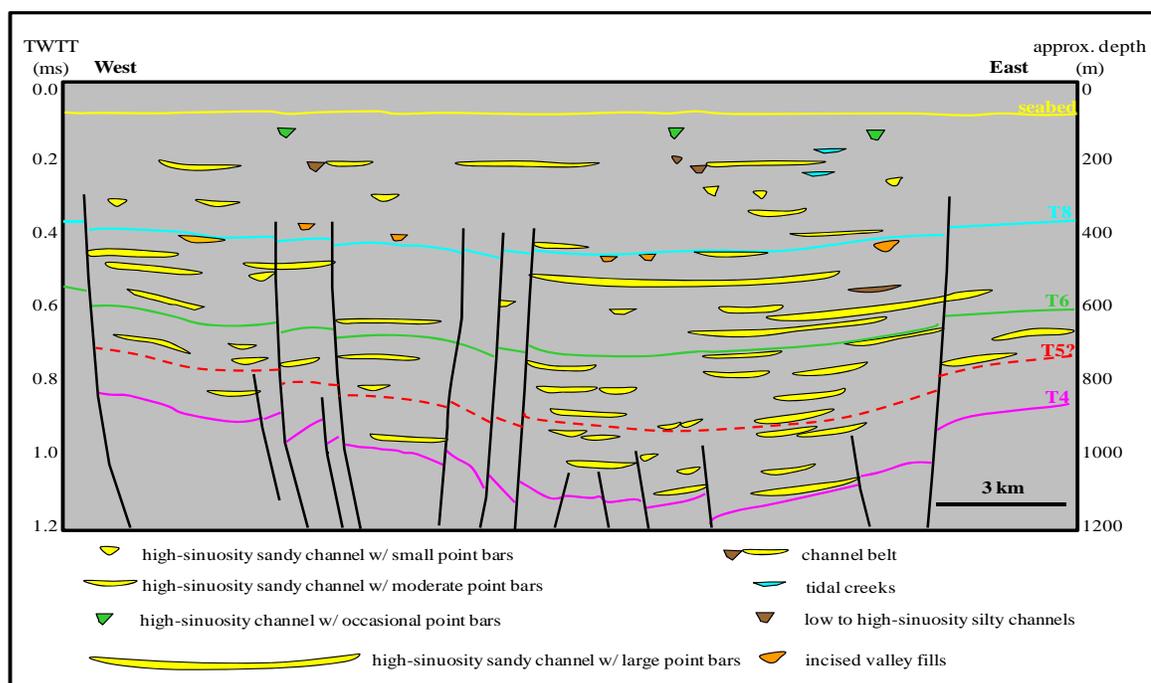
No. 4 Meander belts with small point

Figure 9. Stratigraphic observations of interval seabed to T4 in Kra Basin, Gulf of Thailand.

5.2 Fluvial dimensions and reservoir implications

The dimensions of point bars associated with the nine fluvial styles was determined using the thickness of sand bodies encountered in the Well-C as analogues and correlating to seismically derive acoustic impedance data as a

bars within the meander belt (4 x 10^6cu.m)

No. 5 High-sinuosity small channels with narrow point bars (2 x 10^6cu.m).

The implication for reservoir shows that the high-sinuosity channels with large point bars provide the greatest volume of sand in this area. At the other end of the scale incised valley

fills and tidal creeks have the possible potential reservoirs but scale of sand body is variable.

6. Conclusion

The main objective of this report was to study the reservoir architectures of fluvial systems in the Kra Basin in shallow section using time slices and stratal slices derived from newly acquired 3D seismic. The time slices give the better images than stratal slices in the very shallow section where the formations are flat while the deeper dipping and faulted formations need to be imaged by the stratal slices.

The seismic images provide evidence of dominant fluvial systems with minor marine influence in the shallow section, and complex fluvial styles in the deeper section. Dimensions of the systems are controlled by variations of discharge rate and sediment load, and minor effect of relative sea-level change in the shallow section. The meandering channels have variation in point bar sizes and their sinuosity ranges from low to high. High-sinuosity large channels with large point bars provide the greatest volume of potential porous reservoir facies. Comparing thickness of sand body with well log data, the sands of large point bars have average thickness of 10 m and the thickest is up to 16 m. This study shows that there is a large variation in the potential reservoir volume of a typical fluvial sand. A comparison of seismic images from the Kra and Western Basins shows similar fluvial styles of meandering.

7. Acknowledgement

8. References

Miall, A.D.2002. Architecture and sequence stratigraphy of Pleistocene fluvial systems in the Malay Basin, based on seismic time-slice analysis: AAPG Bulletin, v. 86, no. 7, p. 1201-1216.

Reijenstein, H.M., Posamentier, H.W., and Bhattacharya, J.P. 2011. Seismic geomorphology and high-resolution seismic stratigraphy of inner-shelf fluvial, estuarine, deltaic, and marine sequences, Gulf of Thailand: AAPG Bulletin, v. 95, no. 7, p. 1959-1990.

Zeng, H. 2010. Stratal slicing: Benefits and challenges, Special Section: Seismic Interpretation, p. 1040-1047.

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