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SEQUENCE STRATIGRAPHIC INTERPRETATION OF CHANNEL SAND DISTRIBUTION USING WELL LOGS FROM THE BUALUANG FIELD, GULF OF THAILAND

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ABSTRACT

The most important reservoir sandstones in the Bualaung Field, Gulf of Thailand, are fluvial channel sands with a complex stratigraphy that has resulted in uncertainties in reservoir prediction and reserve estimation. The distribution, geometry and stacking pattern of the sands within the late syn-rift to post-rift succession was determined from sequence stratigraphic interpretation of wireline log data from twelve wells. The study interval includes two stratigraphic units: aggradationally-stacked thin channel sands with thin interbedded floodplain mudstones that underlie isolated thick channel sands interbedded with thick floodplain mudstone. The stacking pattern reflects a decrease in stream gradient with time that was caused by a relative sea level rise and/or waning of fault activity during the transition from syn-rift to post-rift. The variable sand geometry and connectivity has significant implications for field development and reserve estimation, with the well-connected, thicker sands having better reservoir potential than the stacked thinner sands. The results of this study are applicable to other areas in the Gulf of Thailand, or wherever there is a gradual syn-rift to post-rift transition.

Keywords: Bualaung Field, Western Basin, Fluvial Channel Sands, Stream gradient, Sea Level Rise, Faulting

INTRODUCTION

Middle Miocene fluvial sandstones are the most important reservoir type in Bualaung Field, which is located in the central western part of the Gulf of Thailand in the Western Basin (Figure 1). However, the reservoir distribution and geometry in the Bualuang Field is not well understood because the stratigraphy within the field is complex. This results in uncertainties in reservoir prediction and reserve estimation. The purpose of this study is to investigate sand body geometry and distribution at the field scale using sequence stratigraphy from well log data.

GEOLOGICAL SETTING

Salamander Energy (2013) classified the Western Basin based on 3D seismic data, wells drilled, core data, and biostratigraphy. The post-rift section is defined as Middle Miocene to Recent and the section of syn-rift is defined as Late Oligocene to Middle Miocene (Figure 2). The seismic cross section also shows the

Pre-Tertiary Basement. The basin is dominated by east-dipping normal faults that terminate near the top of the Middle Miocene. The study interval which is located in the red block (Figure 2) is also dominated by east-dipping normal faults It is clear that faulting continued into the post-rift and the transition was slow as there are normal faults cutting through the early post-rift section. The study interval comprises approximately 250 m from a depth of 900 to 1150 m (TVDSS) in the early post-rift Middle Miocene succession that was deposited in a fluvial environment.

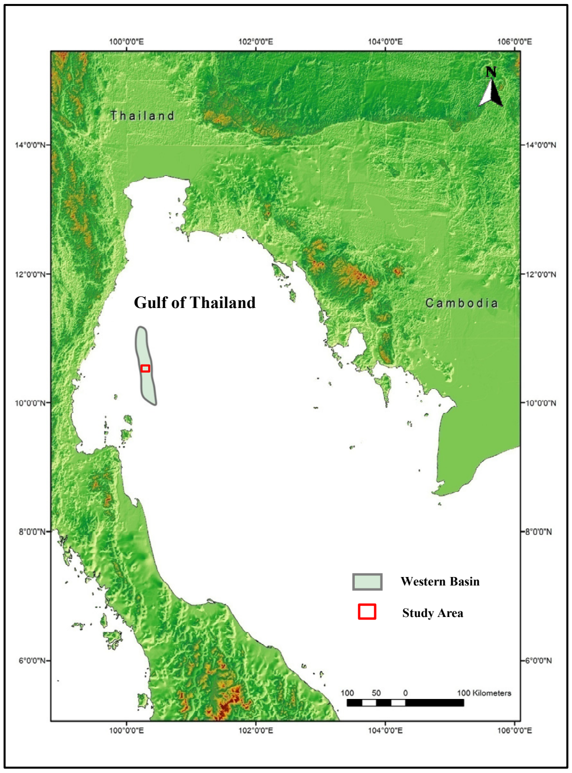


Figure 1. Location map of Western Basin within the Gulf of Thailand.

DATABASE

The database comprises 12 wells (Figure 3). The analysis in this study is based on Gamma Ray, Density, Resistivity and Neutron logs.

RESULTS

There are two main stratigraphic units: Unit A and B and two main correlations: a west-east correlation and a north-south correlation (Figures 3, 4, 5).

Unit A

Observations

The thickness of Unit A varies from around 50 to 90 m. The west-east correlation crosses all 3 Fault Blocks and the north-south correlation lies entirely within Fault Block 1 (Figures 4, 5). In Fault Block 1, there are stacked, thin blocky log shapes and thin fining-upward, serrated bell shapes separated by thin serrated high gamma ray log values. The same location also has slightly higher resistivity and lower neutron and density values and a crossover of neutron and density indicates high porosity, further supporting the assumption of sand layers. The average thickness of sand layers in Fault Block 1 is approximately 3 - 5 m. The upper part of the block has a highly serrated gamma ray log, which indicates mud that is approximately 20 - 30 m thick (Figures 4, 5). Fault Block 3 is very similar to the Fault Block 1 however, Fault Block 2 has significantly fewer sand layers (Figure 4).

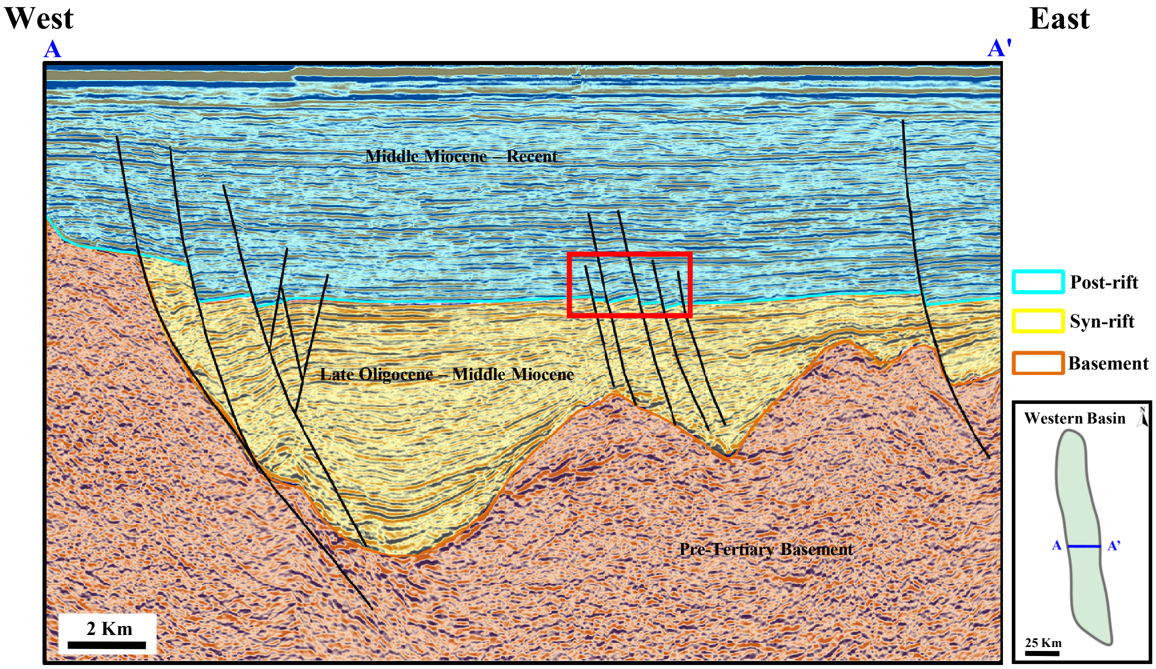


Figure 2. A W-E seismic cross section showing the structural style and stratigraphy of the Western Basin, faults, Pre-Tertiary basement, Late Oligocene to Middle Miocene (Syn-rift), and Middle Miocene to Recent (Post-rift). The study interval is outlined with a red block.

Interpretation

A regional palynology study by Salamander Energy (2013) based on 161 ditch cuttings in an area about 17 km north of the study area in Western Basin indicates exclusively fresh water species in the same stratigraphic interval. So, there is no evidence of marine influence anywhere in the stratigraphic interval included in the present study. Therefore, the thin blocky and fining upward serrated bell shaped responses are interpreted as small fluvial channel sands while the thick serrated high gamma ray response is interpreted as floodplain mud. Because the channel sands are very thin and do not extend from well to well, this section is interpreted as aggradational stacking of isolated small channel sands. The depositional environment is interpreted as a meandering river system because many of the sands fine upward and there is a relatively high proportion of interbedded mud.

Posamentier et al. (2014) concluded that channel width is about 17 times the point bar thickness. If this ratio is applied to the Unit A channel sands, the channels have an estimated width of only 50 to 100 m, which supports the observation that the individual channels sands do not extend from well to well (Figures 4, 5).

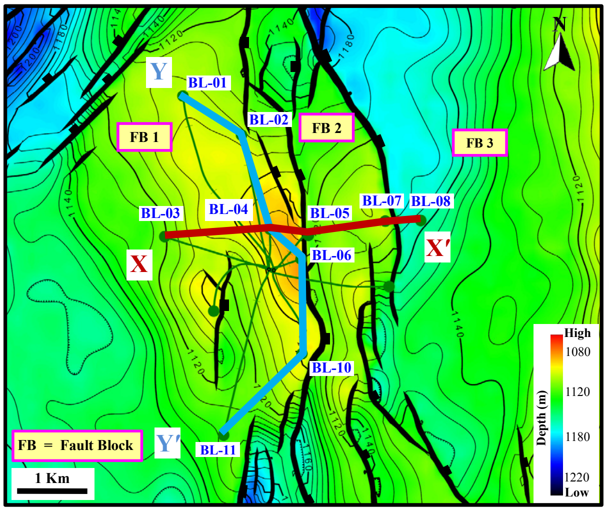


Figure 3. Well locations, Fault Blocks, and the correlations west-east (red) and north-south (blue).

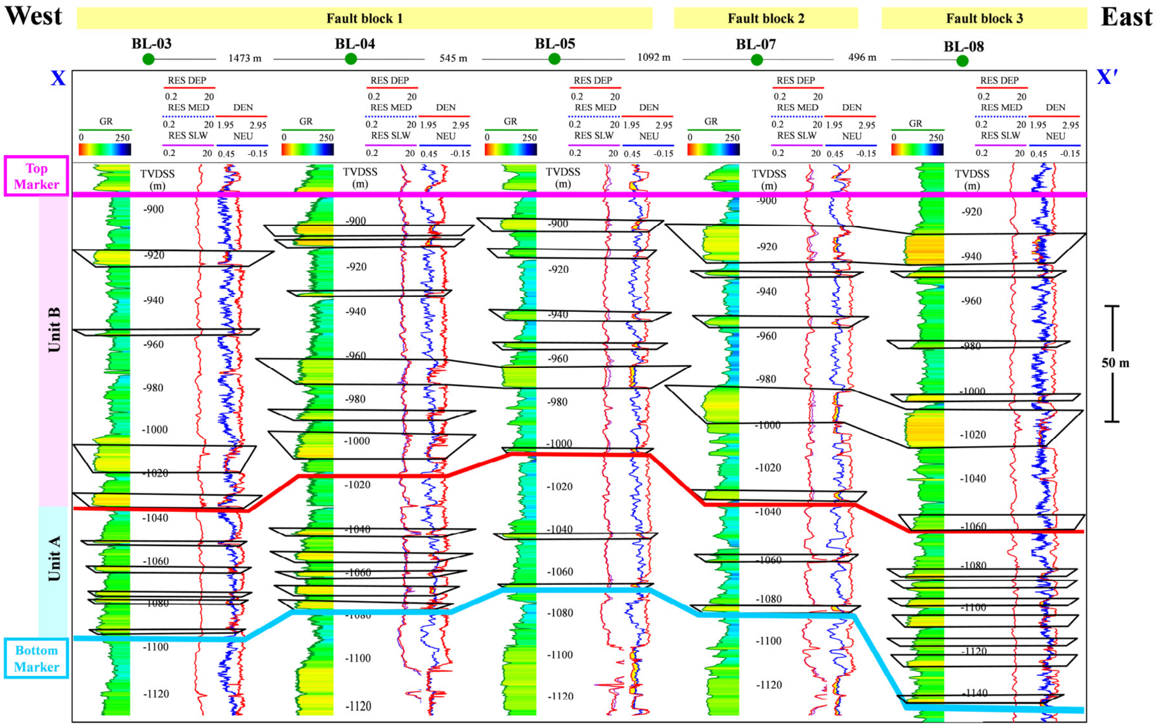


Figure 4. A west - east well correlation (Flattened on the top marker) across the Fault Blocks with individual channel sands outlined in black.

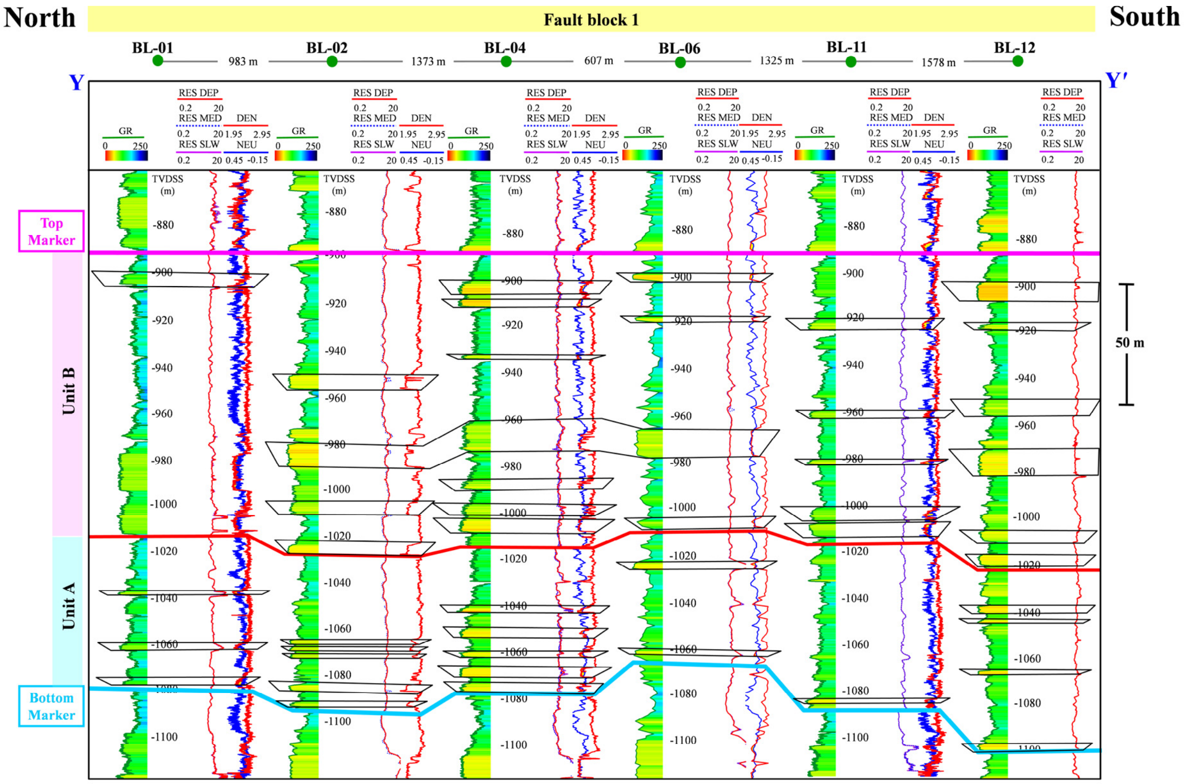


Figure 5. A north to south well correlation (Flattened on the top marker) along Fault Block 1 with individual channel sands outlined in black.

Unit B

Observations

The thickness of Unit B is approximately 120 to 150 m with little variation over the study area. Most of the sands are around 15 - 20 m thick which is thicker than the sands in Unit A. The log characteristics of Unit B consist of fining-upward serrated bell-shapes and blocky-shaped sands. The sands in this unit also have slightly higher resistivity and lower neutron and density values, plus there is a neutron and density crossover similar to that in Unit A. The well logs indicate there is proportionately more mud in Unit B than in Unit A, as indicated by thick serrated high gamma ray packages.

A well correlation across the fault blocks indicates that the Unit B sands in Fault Block 1 are thinner than those in Fault Blocks 2 and 3 and that some sands in this unit connect from well to well (Figure 4). Some Unit B sands also can be correlated from well to well from north to south (Figure 5).

Interpretation

The thick fining upward and bell-shaped sands in Unit B are interpreted as an aggradational succession of isolated large channel sands. The thick interbedded, serrated high gamma ray intervals are interpreted as thick floodplain or overbank muds; Unit B has a higher proportion of mud than Unit A.

The depositional environment of Unit B is interpreted as a meandering fluvial system with larger channels and proportionately more floodplain deposits than the Unit A system.

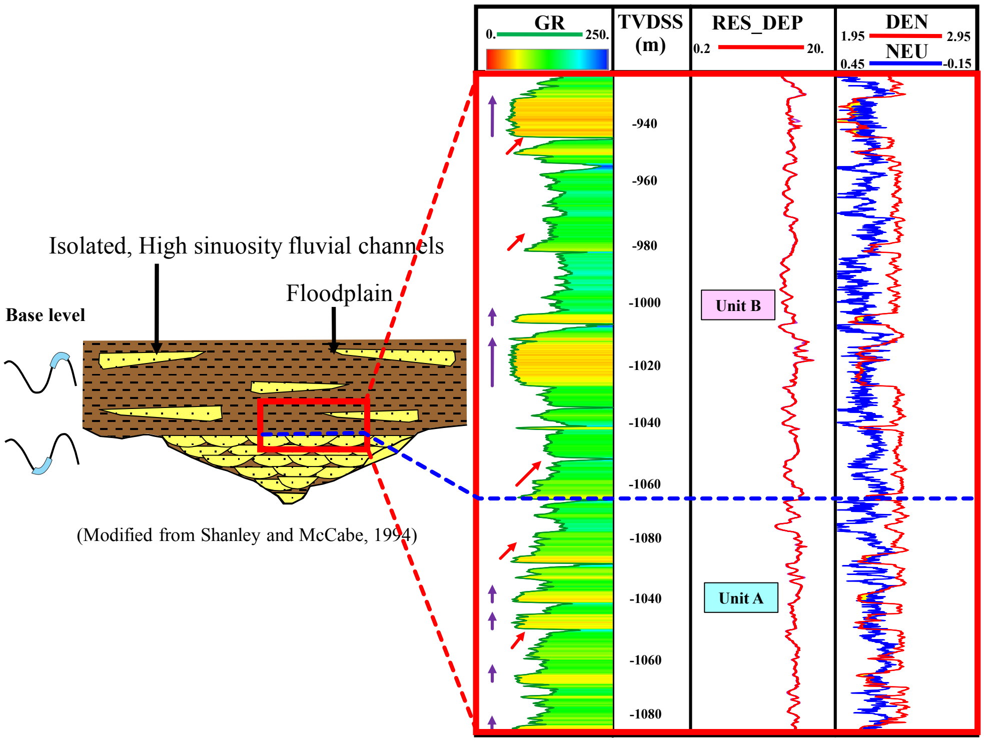
Posamentier et al.'s (2014) width to thickness ratio supports this interpretation. It estimates that the 15 to 20 m thick sands were deposited in approximately 250 to 400 m wide channels, which is compatible with channels that extend across more than one well (Figures 4, 5). A seismic amplitude study indicates that they have a north - south orientation similar to those in Unit A (Salamander Energy, 2013).

Study Interval Development

The well log correlations in Figures 4 and 5 indicate that there is a change from stacked, thin sands in Unit A to isolated thicker sands in Unit B, plus an increase in the proportion of mud from Unit A to Unit B. This represents a change from the aggradationally stacked small fluvial channel sands in Unit A to the isolated larger fluvial channel sands in Unit B, suggesting a decrease in stream gradient from Unit A to Unit B. Two potential causes for a decrease in stream gradient are a relative sea level rise or waning fault activity at the syn-rift to post-rift transition.

The stacking pattern and size of the channels in Units A and B corresponds closely to the model of Shanley and McCabe (1994) for deposition of an incised valley fill succession during transgression. The stratigraphic interval in the present study represents part of that succession, with the stacked small channel sands in Unit A and the isolated large channels with proportionately more mud in unit B (Figure 6)

Faulting is the other potential control on channel sand size and shape in the study interval. A seismic line flattened on the top marker of the study interval demonstrates that faulting continued into the early post-rift and that it was waning in Unit B time relative to Unit A time (Figure 7). This suggests that stream gradient may have decreased with time as fault-rejuvenated topography became less pronounced, which is compatible with the observed trend of larger channels and proportionately more mud in Unit B than in Unit A.



(Modified from Shanley and McCabe, 1994)

Figure 6. A comparison between (A) the Shanley and McCabe (1994) model and (B) the well log characteristics of Units A and B.

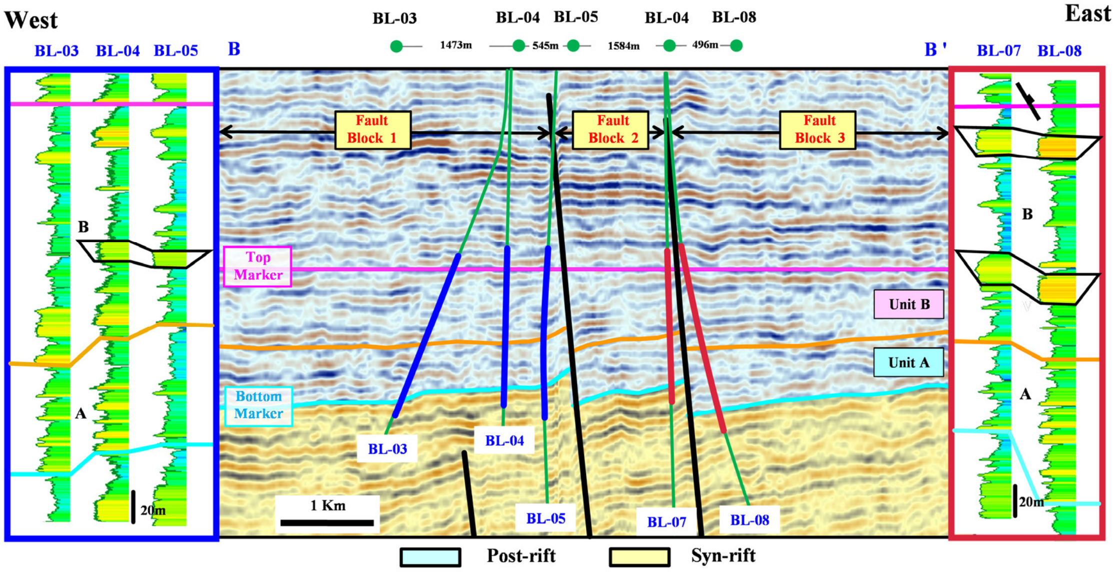


Figure 7. A west-east seismic section flattened on the top of the study interval (within a red block as shown in Figure 2). Gamma ray logs through Units A and B in the various wells come from the part of the respective well path outlined in blue and red.

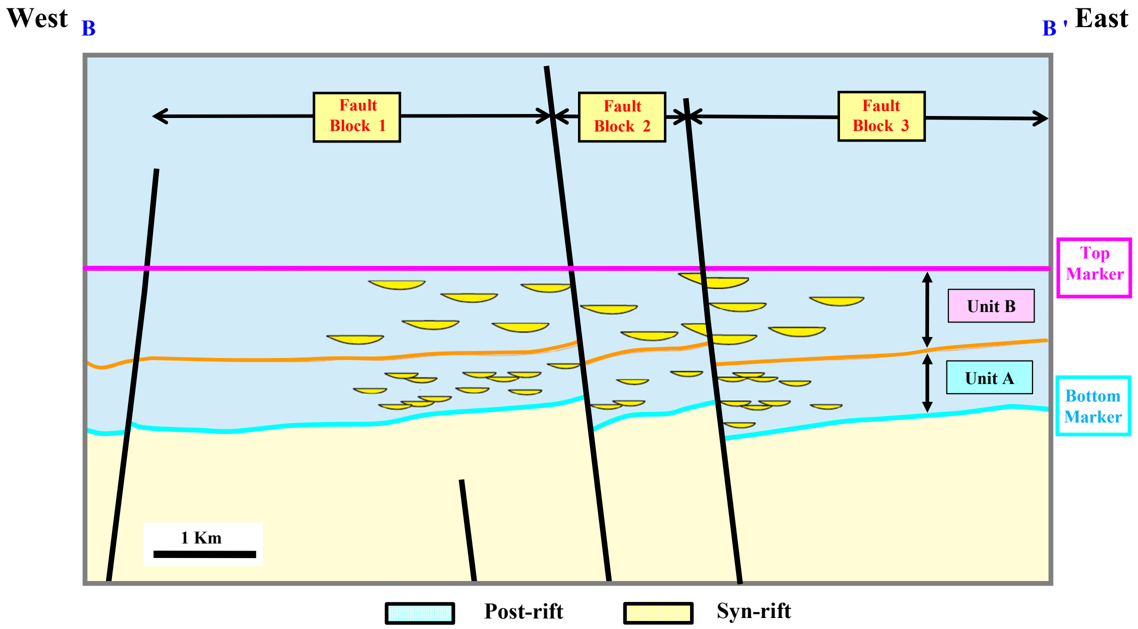


Figure 8. A cartoon of the channel sand distribution and geometry along the seismic line in Figure 7.

DISCUSSION

It is impossible to determine whether faulting or sea level is the main control on channel size and stacking pattern in the study area. Faulting appears to control channel size and location in Unit A and less so in Unit B, as expected in the late syn-rift and early post-rift, respectively. However, the overall stacking pattern is transgressive, suggesting that relative sea level also is important. Much of the ambiguity may be because the syn-rift to post-rift transition is gradual, not abrupt, so that both controls are operative for a considerable time period, with relative sea level eventually replacing faulting as the more important.

Unit B probably has more reservoir potential than Unit A because Unit B sands body generally are thicker and better connected than Unit A sands (Figure 8). While sands in both units are connected along the north-south channel orientation, many Unit B sands appear to connect in the east-west direction as well. Some of the stacked Unit A sands almost certainly have sufficient volume to be viable reservoirs.

The observed variation in sand body geometry and connectivity within the late syn-rift to early post-rift stratigraphic interval also has significant implications for field development and reserve estimation. Reserve estimates for Unit A sands should discount lateral (east - west) connectivity and account for stacking, while estimates for Unit B sands should include significant lateral connectivity, but little or no vertical connectivity. The locations and spacing of development wells must reflect the different sand body geometries in the two stratigraphic units and allow for permeability barriers between isolated Unit B sands and vertical permeability baffles within stacked Unit A sands.

The results of this study are applicable to other areas in the Gulf of Thailand because it is generally recognized that the syn-rift to post-rift is gradual throughout the Gulf (J. Lambiase, 2014 pers. comm.). Although the exact stratigraphic architecture may differ considerably from area to area, it is expected that the distribution, size and geometry of channel sands in the late syn-rift and early post-rift will be controlled by both faulting and relative sea level, with the latter becoming more important with time.

CONCLUSIONS

A sequence stratigraphic analysis based on well logs in one stratigraphic interval of the Bualuang Field concludes that:

1. The study interval represents the late syn-rift to early post-rift.

2. There are two stratigraphic units, including aggradationally-stacked small channel sands (Unit A) underlying isolated large channel sands (Unit B).

3. The sands are fluvial channel sands related to meandering rivers and are interbedded with fine-grained floodplain deposits.

4. The increase in channel size from Unit A to Unit B reflects decreasing stream gradient caused by either a relative sea level rise or a decrease in fault activity, with faulting becoming less important with time.

5. The thicker, better connected sands in Unit B have more reservoir potential than the thinner, less well-connected Unit A sands, except where Unit A sands are sufficiently stacked.

6. A similar stratigraphic response is expected throughout the Gulf of Thailand and wherever there is a gradual syn-rift to post-rift transition.

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