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RESEARCH ARTICLE

SEISMIC GEOMORPHOLOGY AS A TOOL FOR RESERVOIR CHARACTERIZATION: A CASE STUDY FROM MORAGOT FIELD OF PATTANI BASIN, GULF OF THAILAND

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ARTICLE DETAILS

ABSTRACT

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Pattani Basin hosts the greatest number of hydrocarbons producing fields in the Gulf of Thailand. Early to Middle Miocene fluvial channel and overbank sands are the main reservoirs in this basin. Due to their nature of very limited vertical and horizontal distribution it is not always easy to predict the geometry and distribution of these sands based on the conventional seismic interpretation. This study aims to study seismic geomorphology at different stratigraphic intervals to predict sand distribution by applying advanced imaging techniques such as RMS amplitude analysis, spectral decomposition, semblance and dip steered similarity. For this purpose, the study interval is divided into three periods. In period 1, RMS and semblance successfully identified sand bodies and mud filled channels associated with channel belts. On the other hand, deeper stratigraphic levels (period 2 & 3) can be imaged more effectively by using spectral decomposition and dip steered similarity volumes. Horizon slices from these attribute volumes show the distribution of sands and mud filled channels at different stratigraphic level. The width of channel belts varies from 200 m to 3 km. These channel belts are N-S and NW-SE oriented. The findings from seismic geomorphology analysis in these three (3) periods were then validated by well log analysis and correlation. Broad channel belts in horizon slices in period 3 correspond to stacked channel sands in well log. Whereas narrow channel belts correspond to thin sand units in well log in period 2. Widespread occurrence of coals has also been noticed in this interval. Very well-developed meander belts in horizon slices are transpired as fining upward succession in well logs in period 1. Mud filled channels identified in the horizon slices might act as a barrier and compartmentalize the reservoir. The proposed workflow of predicting sand distribution in this study might help to reduce exploration risk as well as in planning infill development wells.

KEYWORDS

Seismic Geomorphology, Semblance, RMS, Fluvial, Well log.

1. INTRODUCTION

The Pattani Basin in the Gulf of Thailand is an important hydrocarbon producing basin with up to 10km of thick non-marine to marginal marine clastic strata of Cenozoic age [1-3]. The study area is located in the western flank of south Pattani Basin of the Gulf of Thailand. Fluvial and deltaic sands comprise the main reservoirs in the basin and they exhibit complex stratigraphic architectures in terms of geometries and continuity of reservoirs. The fluvial depositional systems developed as an extensive fluvial/delta plain and rapidly avulsing meander belts. These sands are mostly thin and laterally limited, occasionally are in the form of thick point-bar accretions. Although many of the reservoirs are laterally discontinuous, the adjacent occurrence of source rock combined with abundant structural and stratigraphic traps make the Pattani Basin a prolific gas and condensate producing basin [4]. It is not always possible to predict the sand distribution based on conventional seismic data because of their rapid vertical and horizontal changes. This results in high uncertainties in reserve estimation in the basin as well as in planning development wells. Conventional seismic interpretation and well log analysis are not very helpful in delineating the spatial distribution of these reservoir sands effectively. Most of the gas sands fall below the tuning thickness hence seismic cannot detect them. They can be identified in well logs but then again wells only give a point estimation. Identification of their lateral extent is not possible as they do not have any equivalent seismic reflector. This problem can be overcome by studying seismic geomorphology in horizon slices with small time shifts. The idea is

identifying depositional systems in seismic data is easier because of their higher lateral and vertical extent compared to their resultant deposits. Since most of the depositional systems have predictable depositional pattern it will be possible to determine the extent of reservoirs once the depositional setting in the reservoir interval is known. The main endeavor of this research work is to better understand the inherent uncertainties in reservoir distribution hence the aim of this study is to map the sand distribution by using different seismic attributes and observing seismic geomorphology along stratigraphic horizon slices in the study area. Seismic geomorphology has lately become an essential tool for the analysis of depositional settings of a wide range of environments. It has proven to serve as an excellent tool for the identification of key architectural elements of fluvial deposits. Understanding the fluvial system is essential in the hydrocarbon exploration [5]. Seismic attribute analysis is key to the identification of seismic geomorphology [6].

In this study, a 3D seismic dataset has been used for detailed documentation of the distribution of fluvial systems and related deposits in the reservoir interval that ranges from 1200 to 2100 ms. I have used semblance, spectral decomposition both Discrete Fourier Transformation (DFT) and Continuous Wavelet Transformation (CWT), dip steered similarity and RMS amplitude extraction techniques to map fluvial styles at different stratigraphic levels in the zone of interest.

Specific objectives of this work are following:

- Evaluate the effectiveness of different seismic attributes to image fluvial styles in the study area.

- Define sand bodies and observe changes in channel size and geometries of the main reservoirs of the Miocene fluvial system. Identification of the reservoir characteristics in different study intervals by integrating seismic geomorphology and well log data.

1.1 Study area and Data Set

The study area is located in the Moragot field which is next to south Pailin field in Pattani basin of the Gulf of Thailand (Figure 1). Water depth is about 31 m. The area is 550 km south of Bangkok and covers approximately 463 km². Chevron Thailand Exploration and Production, Ltd provided the data set. The seismic 3D volume consists of about 1800 cross-lines and 1650 in-lines with 25 and 12.5 meters spacing respectively.

The wireline log data consists of Gamma ray, resistivity, and neutron-density logs from 96 wells. Three of these 96 wells have sonic logs. Therefore, these data may be more appropriate to study the seismic attributes and spectral decomposition for sand prediction.

Figure 1: Location map of the study area

2. METHODOLOGY

This section shows the methods applied to detect and map the reservoir sand-bodies. These methods consist of well log correlation, amplitude-based attributes and spectral decomposition (frequency attributes). The workflow adopted to image the sand is shown in (Figure 2).

Figure 2: Adopted methodology for reservoir characterization using seismic geomorphology

3. RESULTS

3.1 Well to Seismic Tie

Well to seismic ties were performed by establishing a reasonable correlation between the seismic and synthetic seismograms by adjusting T-D functions through stretch and squeeze. From the synthetic seismogram it can be seen that the synthetic trace is matching quite well with the seismic. Lithology wise sand is represented by trough in seismic and shale is represented by peak (Figure 3).

Figure 3: Well to seismic tie shows troughs correspond to sand and peaks correspond to shale

3.2 Seismic Geomorphology Analysis

An examination of the illustrated eleven horizon slices (Figure 8) reveal a landscape of channels apparently superimposed on each other (Figure 6, 10). It is a result of the different channel belts being closely spaced in vertical space. I tried to map the sands and associated channels by combining different techniques. The sand bodies represented by bright negative amplitudes within the study interval. The study interval is divided into three period based on the interpreted markers. Then seismic geomorphology has been studied in those intervals of interest from the horizon slices (Figure 4).

Period 1 (B to D horizon)

Period 2 (D to K horizon)

Period 3 (K to O horizon)

Figure 4: Seismic section showing the interpreted and calculated horizons

3.2.1 Period 1

The horizon slices of this period show the most prominent and well-defined images of fluvial systems as compared to horizon slices of other periods. Horizon B+250 is selected as the representative of period 1. The slice of RMS attribute shows very well-developed meander belt running across NW-SE direction. Two major meander belts are easily identifiable in this horizon slice. There are plenty of small channel fragments superimposed on each other in random directions. The width of the meander belt is in the range of 3 km (Figure 5). The dominant channel belt width is in comparison with the shallow seismic study of high-resolution seismic data that indicates the width of meander belts of Gulf Thailand in the range of 5 to 10 km [7].

Figure 5: Dip steered similarity (a) and RMS amplitude (b) in Horizon slice B+250. The seismic section along A-B shows strong amplitude at the sand position confirmed by log data. Red ellipse indicates well location.

The associated channel width is around 147m. This is in comparison with modern Chao Phraya River near Bangkok, which width ranges from 150-220 m. Very conspicuous scroll bars and overbank splays are easily identifiable. One well drilled in the point bar of one channel belt shows blocky pattern on gamma ray log. The thickness of the sand in this stratigraphic level is 23 m. Wells drilled in this interval show similar sand thickness. From the scroll bars accretion direction, the dominant flow direction is interpreted (Figure 6). It shows the paleo flow direction was in NW-SE direction.

Figure 6: High RMS value has been interpreted as sands associated with meander belts in Horizon slice B+80 (a). The interpretation shows various meander belts (b). Flow directions from scroll bar accretion (c).

3.2.2 Period 2

The stratigraphic slices were analyzed between D and K marker for sand distribution. RMS, spectral decomposition 45 Hz slice and RMS overlay

with semblance yield similar result. To better image the fluvial system, RGB blending of 12Hz, 25Hz and 45Hz were used. The RGB blended image reveals some channels (Figure 7) which were not identifiable in other attribute maps. Identified channels are running mostly north-south direction. With the help of RGB blended image meander belt width was calculated along with the channels in the horizon slice of spectral decomposition 45 Hz. The width of the meander belts ranges from 300-800m and the width of the abandoned channels are in the range of 100-270 m. Sands are quite thin compared to the sands in the stratigraphically higher horizon slices. Spectral decomposition CWT 45 Hz slice were used to map the sands in this interval as the sands are thinner in this interval.

Figure 7: RGB blending of 12 Hz, 25Hz and 45Hz (a) and Spectral decomposition 45 slice (b) in Horizon slice D. The interpretation shows the channel pattern identified from RGB blended image. White line indicates meander belt and dashed orange lines indicate channels.

K-30 horizon slice was selected as the representative of this interval. Spectral decomposition CWT 45 Hz frequency slice adequately delineate the distribution of sands in this interval (Figure 8). Two distinct channel belts have been identified in the horizon slice. They are running mostly in the N-S direction. One well drilled in the high amplitudes shows the presence of an 11 m thick sand (Figure 8). Plenty of thin coal layers have been identified around this level. High amplitudes are restricted in the northern part of the study area in this stratigraphic level. The Southern part is comprised of low amplitude materials. RGB blending of 12 Hz, 25 Hz and 45 Hz and dip steered similarity attribute were used to identify channels. The width of the meander belts ranges from 80 to 220 m and the width of abandoned channels are in the range of 60 to 170 m. In comparison with the channels encountered in the shallow stratigraphic level i.e. period 1, channels in this period are narrower.

Figure 8: Dip steered similarity (a) and Spectral decomposition CWT 45 Hz (b) of horizon K-30. The seismic section along A-B shows strong amplitude at the sand position confirmed by log data. Red dot indicates well location.

3.2.3 Period 3

Spectral decomposition slice of 20 Hz and RMS overlay on semblance give better delineation of the sand bodies. Since the sands are thicker in this interval spectral decomposition 20Hz frequency slice has been opted to map sand distribution.

This horizon signifies the lowermost stratigraphic level in the zone of interest. Spectral decomposition 20 Hz frequency slice (Figure 9) has been used to map the sands in this horizon. Large meander belts have been identified in the middle and eastern part of the horizon slice.

Figure 9: Spectral decomposition 20 Hz frequency slice (a). The interpretation shows various meander belts with superimposed pattern (b). The seismic section along A-B shows strong amplitude at the sand position confirmed by log data. Red ellipse indicates well location.

The width of the meander belt is in the range of 1.5 to 3 km which is analogous to the ones found in period 1. The width of abandoned channels identified from dip steered similarity map is around 120 - 330 m. Another interesting feature is the presence of sand filled channel (Figure 10) in period 3.

Figure 10: Semblance map (a) and RMS overlay on semblance map (b) at horizon O-100. The seismic section along A-B shows that channel shape is filled with high amplitude materials

3.3 Well log Analysis

3.3.1 Period 1 (B to D)

This is the uppermost period in the zone of interest. The horizon slices in this interval show well developed (Figure 5 & Figure 7) moderate to high sinuosity fluvial system. The wireline character of this part is represented by fining upward cycles (Figure 11) indicating point bar deposits of the fluvial system. Thus, the depositional environment of this period can be interpreted as fluvial.

Figure 11: Wire line character of depositional sequences of period 1

3.3.2 Period 2 (D to K)

The seismic geomorphology in this period is represented by low sinuosity broad channel systems (Figure 8) as well as some narrow meander belts. Such straight channels with little or no evidence of lateral migration suggest a low slope and low accommodation area similar of delta plains [8]. The interpretation is well supported by the widespread occurrence of coal (Figure 12). The wireline character of this part is represented by coarsening upward cycles (Figure 12). It implies a deltaic progradation sequence in a paralic setting. In the depositional model, this period is broadly interpreted as the marginal marine depositional environment [9-14].

Figure 12: Wire line character of depositional sequences of period 2

3.3.3 Period 3 (K to O)

This period covers the lower part of the zone of interest. The seismic attribute maps show the number of moderate to high sinuosity fluvial systems populating the horizon slices (Figure 9) at that interval in the study area. The fluvial systems are mostly concentrated in the central and eastern part. The wireline character shows the dominance of blocky and fining upward cycles (Figure 13). These can be interpreted as channel sands and point bar deposits associated with the fluvial systems mapped in this interval [9]. The blocky and fining upward log response with high numbers of fluvial systems dominating this interval indicate that the sediments are deposited in a fluvial environment. However, the presence of sand filled channel in this interval (Figure 10) suggests there might have been some occasional marine transgression.

Figure 13: Wire line character of depositional sequences of period 3

4. DISCUSSION

Seismic geomorphology has proved to be very helpful in identifying the lateral distribution of reservoir sands. Horizon slices showed sand distribution of various pattern. From their distribution and regional stratigraphy, it is interpreted these sand bodies are associated with fluvial channel and channel belts. The observed channel belt widths and channel widths are summarized in Table 1 for comparison. Channel belts width in period 1 and 3 are larger as compared to channel belt width in period 2.

Table 1: Summary of the channel belt and abandoned channel width in the zone of interest

Age	Period	Key horizon	Horizon slices	Channel belt width (m)	Channel width (m)
Middle Miocene	Period 1	B	B+80	1000-2500	152-470
			B+180	300-500	50-78
			B+250	2000-3200	147-332
	Period 2	D	K-150	200-800	80-140
			K-80	250-450	110-200
			K-30	230-420	60-170
		K		250-800	152-347
Early Miocene	Period 3	O	O-100	500-2000	170-300
			O-50	800-2500	130-280
		O		1500-3000	120-330

The horizon slices at O-100, O-50 and O typify the fluvial system in the central and eastern part of the area. Drilled wells in that region show the evidence of stacked channel sands. The fluvial system in period 3 interval has multiple channel sands, which are mostly north-south trending. The sands are associated with broad N-S meander belts. Whereas period 2 shows narrow meander belts, and there are also some high amplitude features in the selected horizon slices without any distinctive pattern. The high amplitude features are most likely because of the prevalence of coal. The horizon slices B+80, B+180 and B+250 are characterized by paleo flow towards the south-southeast. B+80 and B+250 have sands associated with large single meander belts, while B+180 shows multiple narrow meander belts. The morphology of meander belts observed in period 1 is similar to the channel belts between period 3.

Figure 14: Summary of the channel evolution from bottom to top in the zone of interest.

Fluvial system size and pattern change rapidly in the area over a short time window of 15 to 20 ms. The sand distribution model for the entire zone of interest has been prepared (Figure 14). Period 1 shows broad channel belts. Stacking of channels is not very common. Period 2 shows narrow channel belts with broad distributary channels whereas period 3 is characterized by well-developed meander belts. Multiple stacked channels have been noticed in this interval in the well logs. The only difference between period 1 and period 3 is that channels are isolated here. Sand bodies are laterally continuous both in period 1 and 3 as evidenced by the widespread occurrences of high amplitudes in horizon slices. This has occurred mostly due to the fact that rivers migrate laterally. Whereas period 2 represents the downstream reach of fluvial system grading into marginal marine setting, hence shows patchy high amplitudes in horizon slices. Reservoir development in period 2 will require much more investment and analysis compared to other periods.

5. CONCLUSIONS

Different geophysical techniques were applied to map the reservoir sands. Key results and conclusions of the present study are summarized below. Spectral decomposition proved to be the most useful technique in mapping thin sands in the deeper intervals. Continuous Wavelet Transform (CWT) works better than the Discrete Fourier Transform (DFT) in identifying sand bodies. The amplitude response of CWT spectral decomposition is different for different thickness of sands. Low frequencies (20Hz) show high amplitudes for thick sands (>15 m), while higher frequencies show bright amplitudes for relatively thinner sand beds. RMS amplitude maps are useful to detect sand distribution associated with meander belts if the sand is sufficiently thick (in this case above 10 m). Dip steered similarity gives more accurate delineation of channel features than semblance calculated from raw seismic volume in period 2. 20 Hz CWT spectral decomposition along with similarity volume successfully mapped sands and mud filled channels in the deeper stratigraphic level. These mud-filled channels may act as barrier between two separate sand bodies and compartmentalize the reservoirs. Meander belts in period 2 are relatively narrow as compared to meander belts above D marker and below K marker. The fluvial channels and channel belt width change both laterally and vertically. In different periods sand distribution pattern were different. These findings need to incorporate in reservoir models for better field development. Exploration in the unexplored part of Gulf of Thailand should also take these into consideration.

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