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Detection of Fluvial Sands Using Spectral Decomposition and Seismic Attributes in North Erawan Field, Pattani Basin, Gulf of Thailand

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Abstract

Pattani Basin is one of the major hydrocarbon producing areas of the Gulf of Thailand. The reservoirs in the Pattani basin are Lower to Middle Miocene fluvial channels and overbank sands. These reservoirs are sometimes thin and have restricted lateral distribution and it is not always possible to predict the distribution of these sands. This study attempts to predict sand distribution by applying advanced imaging techniques. Spectral decomposition out puts through Continuous Wavelet Transform (CWT) reveal that thicker sands (>30m) can be detected by amplitude spectra at 20 Hz, while relatively thin beds can be detected by higher frequencies. Bright amplitudes were observed at 20 Hz for hydrocarbon bearing zones. At shallow stratigraphic levels, RMS and coherency volumes successfully identified sand bodies and mud filled channels associated with meander belts. On the other hand, using 20 Hz CWT and coherency volumes can image deeper stratigraphic levels. These images show distribution of sands and mud filled channels at different stratigraphic level. Mud filled channels may act as barrier and compartmentalize the reservoirs. Some sands are distributed within small area (200-300m) cross cut by low amplitude mud filled channels. Therefore, narrow well spacing is required to drain the hydrocarbons from these sands. Sand distribution model is prepared within the zone of interest. The width of channel belts varies from 200 m to 3 km. These meander belts are N-S or NW-SE oriented. The mapped sands based on seismic data are in match with GR log at drilled wells. This suggested workflow of sand prediction might help to reduce exploration risk.

Keywords: Spectral Decomposition, Continuous Wavelet Transform, RMS and Coherency

1. Introduction

Pattani Basin is located at the centre of the Gulf of Thailand and consists of several structurally complex extensional basins. The study area is located in the northern Erawan gas field of Pattani Basin. Major gas reservoirs are fluvial and deltaic sands. The fluvial depositional systems developed as an extensive fluvial/delta plain and rapidly avulsing meander belts. These sands are mostly thin and of small-scale lateral distribution, occasionally are in form of thick point-bar accretions. It is always not possible to predict the sand distribution based on conventional seismic data because of their rapid vertical and horizontal changes. The aim of this study is to image the sand distribution in the area. I applied attribute analysis and spectral decomposition techniques to detect the fluvial sand reservoirs within the study area.

This study utilizes the well logs and seismic geomorphology to examine the geometry and spatial distribution of sand bodies of Miocene fluvial system in the northern Erawan field of the Pattani basin.

Specific objectives of this research are following.

1) Define sand bodies and observe changes in channel size and geometries of the main reservoirs of the Miocene fluvial system.
2) Study the response of seismic attributes and amplitude spectra of different frequencies of spectral decomposition as a function of different thicknesses of sand bodies within the zone of the interest.

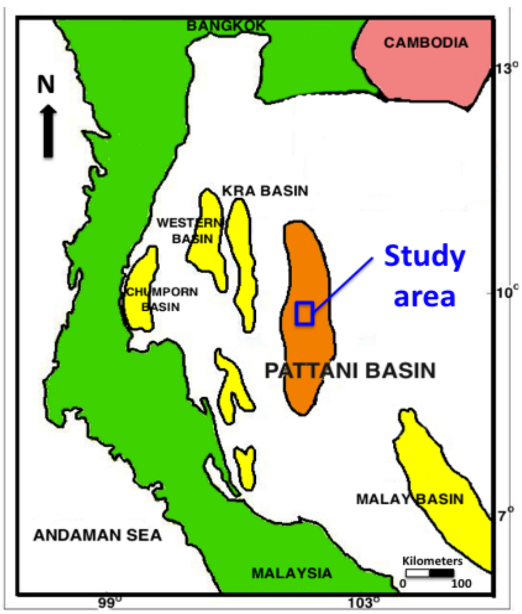

Figure 1. The location map of Erawan field, Gulf of Thailand.

2. Methods

Integration well logs data and seismic based analysis was used to compare well log data to the seismic, synthetic seismograms were generated. Three main C, F and K markers were interpreted as key horizons, and horizon slices within those intervals, which were used to generate seismic attribute, seismic coherence and Continuous Wavelet Transform (CWT) amplitude frequency for sand distribution. Moreover, study the response of CWT spectral decomposition within main zone of interest (C-F interval) and observed corresponding CWT with different thickness from simple synthetic models.

3. Results

3.1. Well log correlation and synthetic seismogram

Well log correlation shows that there are multiple sand bodies within the zone of the interest. The vertical and lateral distribution of these sands shows rapid variations. Some sands are only limited to narrow zones, while others are covering larger area.

The seismic data is of normal polarity as seabed (increase in acoustic impedance) is represented by peak. The synthetic seismograms of all four wells show reasonable cross correlation coefficients (greater than 60%) when compared with seismic data. Acoustic impedance of the sands is comparatively lower than shale. Consequently, the amplitudes are negative for sands on the synthetic and seismic data.

3.2. Seismic interpretation

The seismic character for C, F and K are mentioned markers represent low acoustic impedance and their synthetic response is trough, but on the seismic data, these markers were picked on nearby positive peak to perform the interpretation conveniently.

The two-way-time structural map is shown planar normal faults oriented north-south are common. The normal fault systems are defined as tilted fault blocks that cause gently dipping strata, which create dominant structural highs or three-way dip closures at the upthrown side of west-dipping fault.

3.3. Spectral decomposition analysis

A cross section of the amplitude-tuning cube with a short temporal window (24 ms) in the zone of interest shows that signals are in the range of 10~60 Hz. The spectral decomposition technique (CWT) reveals that amplitude is different for each frequency. The high amplitude anomalies can be observed between C and F marker at 20 Hz of frequency and low amplitude zone is observed for 40 Hz. In order to understand the amplitude variation due to thickness of the sands and hydrocarbon content, two analysis were performed; 1) modeling of different thicknesses sand reservoir to study the amplitudes response for different frequencies, 2) relationship of average amplitude with respect to net to gross and percentage of water wet sands were studied between C & F at low frequencies. As net to gross increases amplitude at low frequency (20 Hz) increases (Figure 2), which means more the sands in the zone of interest, higher the average amplitudes at low frequencies. The amplitude at low frequency also directly proportional to the hydrocarbon bearing sands (Figure 3). The same phenomena also reported by Castagna et al., (2002). Therefore high amplitudes at lower frequencies are important for the identification of lithologies as well as hydrocarbons.

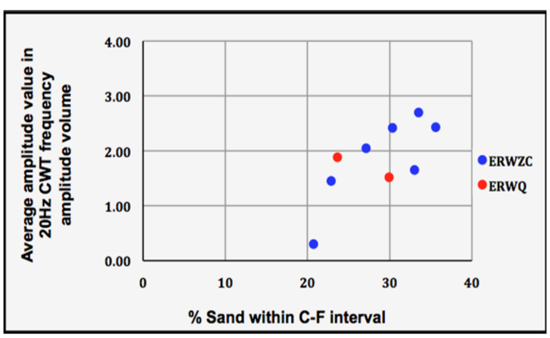

Figure 2. Crossplot of sand percentage and average amplitude at 20 Hz between C and F marker.

Modeling of sand-body response

Using extracted wavelet from one of the wells generated the nine synthetic models of different thicknesses and their synthetic seismograms. The sand models reveal that as thickness of the sand body decreases the maximum amplitude is observed at high frequency amplitude spectra.

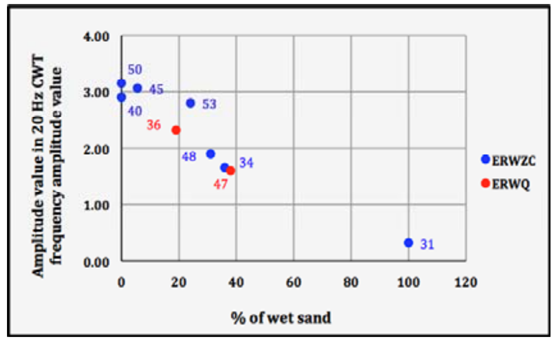

Figure 3. Crossplot of percentage of wet-sand and average amplitude at 20 Hz.

Therefore, the thicker sands can be detected at low frequencies while thinner sands can be observed on high frequencies. The thin sands (less than 10 m) indicate maximum amplitude at 40 Hz. This may be due to the limitation of the frequency bandwidth of the wavelet used (Figure 4).

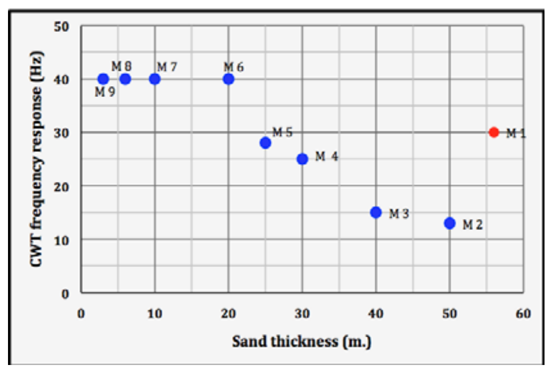

Figure 4. Crossplot of sand thickness and frequency response.

3.4. RMS attribute map analysis

Comparing between above and below F horizon. RMS amplitudes successfully identified thick sands (up to 10 meter), but it is not easy to detect thin sands (less than 10 meters) by using the RMS maps. The sands above F marker are mostly thick as compared to the sands below the F maker. Therefore, RMS amplitudes can efficiently detect the sands up to the F maker.

Seismic coherence analysis

Coherency slices up to F-marker show good quality images and it is easy to interpret channels and sands, but the quality of coherency images below F-marker is not as good as of coherency slices above F-marker. Width of channels and channel belts can be measured by using coherency horizon slices and vertical sections. I measured width of channels and channel belts on various horizon slices, which are mentioned in the next section.

3.5. Mapping of sands

An examination of the illustrated nine horizon slices reveals a landscape of the different channel belts being closely spaced in vertical space. I tried to map the sands and associated channels by combining different techniques. Nine horizon slices were selected to coincide as close as possible with the sand bodies represented by bright negative amplitudes within the study interval.

Horizon slices above C-horizon

The shallowest horizon slice shows most prominent and clear image of fluvial systems as compared to other horizon slices of deeper part. The horizon slice of RMS attribute shows well-developed NW-SE oriented fluvial system of high sinuosity. The paleoflow direction is towards the south-southeast. The channel belt width is very broad. This channel belt width is similar size in comparison with shallow seismic study of high-resolution seismic data that indicates the width of meander belts of Gulf Thailand (Posamentier & Kolla, 2003).

On deeper horizon slices, sands are well detected by amplitude spectrum of spectral decomposition (CWT) at 20 Hz. The sand bodies and low amplitude channels are better resolved at this slice if 20 Hz amplitude spectra are overlain by 50% transparent coherence slice. The features are of low sinuosity as compared to horizon slice at the shallow (C-300) and sands are of less width in the range of channel belt. The general trend of these sand bodies is northwest southeast. The superimposed pattern of multi-channels is observed in the central part of study area with low amplitude channels. The well logs show blocky pattern followed by fining upward and the 3D visualization technique helped to observe the geometry sands from vertical slice of 20Hz spectral decomposition through sand body.

C-F interval

The stratigraphic slices were analyzed between C and F marker for sand distribution. Coherency and 20 Hz spectral decomposition volumes were used to map the sands between C and F marker. The direction of channel belts is north south. The widths of meander belts are narrower than shallower slices (Figure 5). The GR log shows blocky pattern and relate to strong amplitude sand through vertical slice that are indicating high rates of fluvial aggradations of medium to high sinuosity (Norfjord et. al, 2005 & Mail, 1992).

The sand zones between C & F marker are hydrocarbon bearing. These sands are changing rapidly in lateral direction. Therefore, it is critical to know the net to gross within the zone of interest. By using 20 Hz spectral decomposition is useful to detect thick sands in the study area. This map highlights promising zones for hydrocarbon exploration.

F-K interval

The horizon slices were analyzed between F & K marker by using higher frequency volumes, as thickness of the sands is less below F marker. The size of the meander belt is wider in the range of 1-2 Km and main sand system is oriented NW-SE in the eastern part of the area. The thickness of the sands is relatively less at drilled wells and GR well log pattern is fining upward.

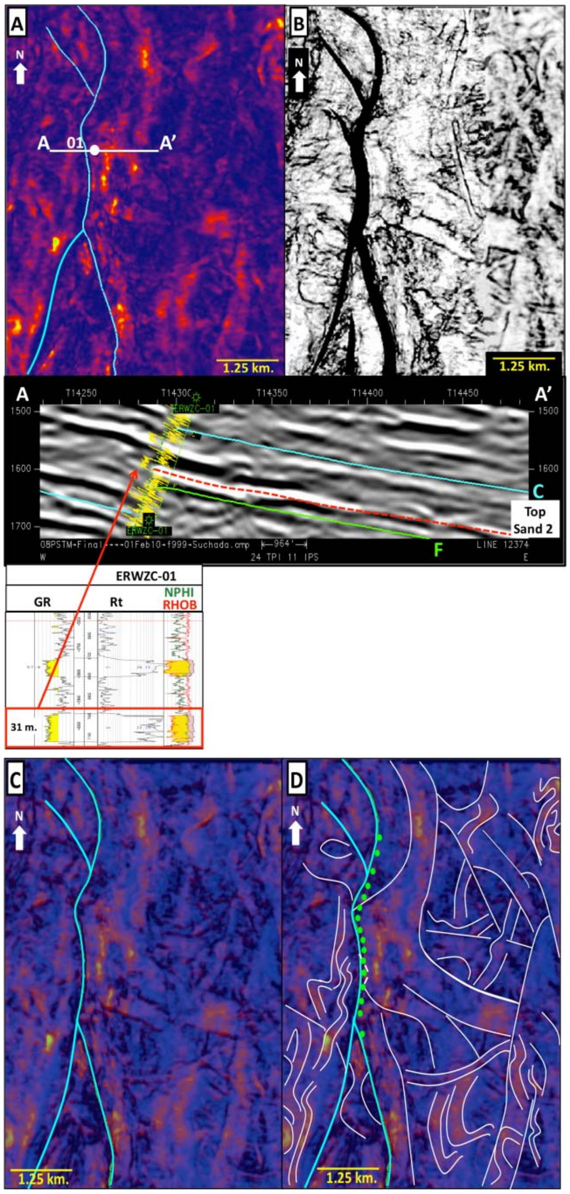

Figure 5. (A) Amplitude spectra of CWT at 20 Hz and (B) Coherency horizon slice of Top sand 2. The seismic section A-A' shows strong amplitude at the sand position confirmed by log data. Lateral migration of sands can be seen on vertical section. (C) Overlay of coherency on 20 Hz CWT spectral decomposition. (D) The interpretation shows meander belt with superimposed pattern in this study area. Green dots are well location and blue lines mark major fault across the area.

4. Discussion

The observed channel belt widths and channel widths are summarized in Table 3 for comparison. Channel belts widths below F marker and above C marker are larger as compared to channel belt width between C&F. Moreover, the channel widths above C marker and below F marker are in comparison with modern Chao Phraya River, while the meander belts between C & F have relatively small size (Table 1).

Key marker	Horizon slices	Channel belt width	channel width
The modern Chao Phraya River		2500-7000 m	150-220 m
	C-300	3200 m	148 m
	C-105	160-300 m	70-90 m
	C-40	1000-2500 m	60-110 m
C			
	Top sand 1	200-800 m	90-200 m
	Btw s1&s2	200-400 m	150-200 m
	Top sand 2	200-500 m	80-350 m
F			
	K-160	1000-2000 m	70-150 m
	K-100	2400 m	70-150 m
	K-60	not clear	100-300 m
K			

Table 1. The size of channel belt and channel width within zone of interest.

The horizon slices F-K interval exhibit the fluvial system of moderate to high sinuosity in the eastern part of the area. None of the drilled wells encountered the sands associated with this sinuous meander system. Therefore, all wells in this interval have thin sands with fining upward GR character inter-bedded with shale. These may be associated with another meander belts.

Fluvial system within C-F interval has multiple channel sands, which are mostly north-south trending. The sands are associated with narrow N-S meander belts and channel belts are superimposed and often nested together which increases their net thickness.

The horizon slices above C-horizon are characterized by paleoflow toward the south-southeast at shallowest and have sands associated with large single meander belts. While below that shows multiple narrow meander belts, which is similar to the mender belts between C and F.

Fluvial system size and pattern change rapidly in the area over short time window of 15 to 20 ms. There are various reasons for change in the fluvial style such as discharge rate from the source, eustatic, climate and tectonic control on sedimentation. Well-developed broad high sinuous meander belts, which were observed below F marker and above C marker, are indicating low slope area (Nordfjord et al., 2005). Whereas narrow meander belts may be formed at higher slopes as relating to high rate of subsidence within Pattani basin in Early Mid Miocene (Morley, et al. 2011).

In summary, the best reservoir target sands along the high structure are within the C-F interval. While above C marker and below F marker, broad single channel fluvial systems associated with broad point bars are way from the high structure. we identified prospect sand zones but also at some places able, to identify the mud filled channels. These mud-filled channels may act as seal and compartmentalized the reservoir sands. This information will be useful for further field development.

5. Key findings and conclusions

Different geophysical techniques were applied to map the reservoir sands. Key findings and conclusions of the present study are summarized below.

1. Amplitude response of CWT spectral decomposition is different for different thickness of sands. Low frequencies (20-25 Hz) show high amplitudes for thick sands (>30m), while higher frequencies show bright amplitudes for relatively thinner sand beds.
2. Net to gross maps can be generated by extracting low frequency amplitudes within the zone of interest.
3. Amplitude values of 20 Hz CWT spectral decomposition are directly proportional to hydrocarbon saturation. Amplitudes are higher for hydrocarbon bearing sands as compared to water-wet sands. Amplitude maps of low frequency can be used to detect prospect zones of hydrocarbon exploration.
4. RMS amplitude maps are useful to detect sand distribution associated with meander belts down to certain depth i.e. down to F marker.
5. 20 Hz CWT spectral decomposition along with coherency volume successfully mapped sands and mud filled channels. These mud-filled channels may act as barrier between two separate sand bodies. This may help to identify different reservoir compartments.
6. Some sands are distributed within restricted area (200-300m) and cross cut by low amplitude mud-filled channels. Therefore, narrow well spacing is required to drain the hydrocarbon from these sands.
7. Meander belts between C and F are relatively narrow as compared to meander belts above C marker and below F marker.

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