



# Application of seismic attribute analysis in fluvial seismic geomorphology

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## Abstract

Seismic attributes can be important predictors, either qualitative or quantitative, of reservoir geometries when they are correctly used in reservoir characterization studies. This paper discusses seismic attribute analyses and their usefulness in seismic geomorphology study of Moragot field of Pattani Basin, Gulf of Thailand. Early to Middle Miocene fluvial channel and overbank sands are the reservoirs in Pattani Basin. Due to their limited horizontal and vertical distribution, it is not always possible to predict the geometry and distribution of these sands based on the conventional seismic interpretation. This study utilized various seismic attributes, e.g., RMS amplitude analysis, spectral decomposition, semblance and dip-steered similarity, RGB blending to image the geometry and the spatial distribution of sand bodies in horizon and stratal slices at different stratigraphic intervals. Attribute analyses reveal, at shallow stratigraphic levels, RMS and semblance can successfully identify channel-shaped sand bodies and mud-filled channels associated with channel belts. On the other hand in deeper stratigraphic intervals, sand distribution can be imaged more effectively by using spectral decomposition and dip-steered similarity volumes. High-frequency spectral decomposition slices can image thin sands, and low-frequency slices can image thick sands quite effectively in deeper intervals. RGB blending of different frequency slices is particularly useful in delineating channel systems of various dimensions at deeper intervals. These images show the distribution of sands and mud-filled channels at various stratigraphic levels. The width of channel belts varies from 200 m to 3 km. These channel belts are N–S or NW–SE oriented. From the channel pattern and their dimensions, depositional environments can be predicted. Mud-filled channels identified in the horizon slices will act as a connectivity barrier between sand bodies at either side of the channel. They can also act as lateral and up-dip seal to form stratigraphic traps. The seismic attribute analyses clearly show the geometry and spatial distribution of sand bodies. Hence, this method for predicting sand body geometry might help in field development planning as well as in reducing exploration risk.

**Keywords** Seismic geomorphology · Seismic attributes · Semblance · Spectral decomposition

## Introduction

Recent development of three-dimensional (3D) seismic datasets enables geologists to visualize and analyze buried lands and seascapes revealed by subsurface geophysical data in a manner resembling surface geomorphology (Miall 2002; Davies et al. 2007). Seismic geomorphology is a useful technique to interpret seismic patterns for formation geomorphology of a formation, which is similar to using satellite and aerial photographs of the Earth's

surface. 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 different depositional systems. Understanding the depositional system is essential in the hydrocarbon exploration (Davies et al. 2007). Seismic geomorphology interpretation is also a primary method in viewing, mapping subsurface geologic features, and making interpretation of structure and stratigraphy possible away from well control in petroleum exploration. Seismic attributes have been increasingly used in petroleum exploration and production and have been integrated in the seismic interpretation process. Since 1990s, the seismic attributes have been developed into many types of them such as

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structural attributes and stratigraphic attributes (Brown 2001; Chopra and Marfurt 2007). The fundamental seismic data type is amplitude data, but seismic attributes can reveal characteristics, which are not easily seen in amplitude data themselves. The seismic attribute technique should allow us to increase ability of geological interpretation of a formation, particularly in the thin-bed reservoir environments (Farfour and Yoon 2014). Seismic attributes typically provide information relating to the amplitude, shape, and position of seismic waveform. Seismic attribute analysis can extract information from seismic data that is otherwise hidden in the data and has been used to identify prospects, ascertain depositional environments (e.g., fluvial or deep-water channels, carbonate buildups), detect and enhance faults and fracture sets to unravel structural history, and even provide direct hydrocarbon indicators (Burnett et al. 2003; Castagna et al. 2003; Chopra and Marfurt 2007; Farfour et al. 2012).

The objectives of this paper are as follows:

- Studying seismic geomorphology by seismic attribute analyses to identify the sand body geometry and distribution at reservoir levels in Moragot field of Pattani Basin.
- To evaluate the efficacy of seismic attributes in delineating geomorphic features at different subsurface intervals.
- Suggesting the best attributes to image sand body geometry and distribution in Pattani Basin and adjacent areas.

## Study area and dataset

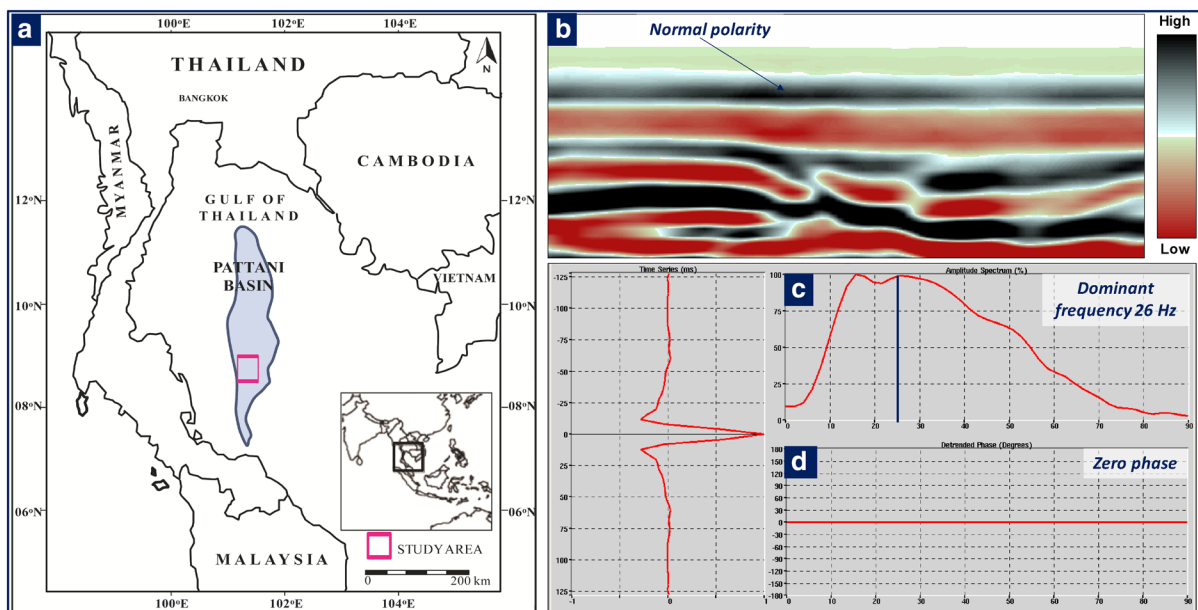
The study area is the Moragot field in Pattani Basin, Gulf of Thailand (Fig. 1a), which is next to south Pailin field (Morley and Racey 2011). Water depth is about 31 m. The area is located 550 km south of Bangkok and covers approximately an area of 463 km<sup>2</sup>. Chevron Thailand Exploration and Production, Ltd., provided the dataset. The seismic 3D volume consists of about 1800 cross-lines and 1650 in-lines with 25 and 12.5 m spacing, respectively (Hossain 2018). The seismic data are of zero phase and normal polarity (Fig. 1b, d). Dominant seismic frequency in the study interval is 26 Hz (Fig. 1c).

The wireline log data consist of gamma ray, resistivity, and neutron–density logs from 96 wells. Three of these 96 wells have sonic log. Therefore, these data may be more appropriate to study the seismic attributes and spectral decomposition for sand body geometry and distribution prediction.

## Methodology

### Seismic interpretation

For seismic interpretation, firstly marker horizons were identified. Then, they were interpreted with the help of seismic to well tie. Based on the interpreted marker horizons, study interval was divided into three periods. To study seismic



**Fig. 1** Location map of the study area (a, b, c, d) is showing polarity, dominant frequency, and phase of the 3D seismic data

geomorphology in each period, several stratal and horizon slices were generated from the interpreted seismic horizons.

### Well-log interpretation

Well-log analysis also performed to identify the variations in sand thickness in different periods. Well data were integrated with seismic attribute analysis through seismic to well tie to identify the seismic amplitude variation with sand thickness. A well-log-based depositional environment analysis was performed to infer the depositional setting in each period. This is very helpful in anticipating and analyzing features in horizon slices of different periods.

### Attribute analysis

#### Root mean square (RMS)

Amplitude maps were generated by using RMS (root mean square) amplitude attributes along the interpreted horizons to map the sand distributions (Brown 2001). Variable small window intervals were selected along each horizon depending upon the thickness of the sands encountered at wells. This window interval ranges from 5 to 20 ms.

#### Semblance

Semblance is a measure of trace-to-trace similarity or continuity of seismic waveform in a specified window. In this study, each point in 3D seismic volume was compared with the waveform of 12 adjacent traces over a short vertical window of 9 ms. Semblance can provide useful information about lateral and vertical stratigraphic changes and may be helpful to detect sands associated with fluvial systems (Peyton et al. 1998). In this study, semblance slices were utilized to image the fluvial reservoir sands.

#### Dip-steered similarity

Dip-steered similarity is also analogous to semblance attribute (Chopra and Marfurt 2005). It measures the trace-to-trace similarity in waveform by considering the dip. For this, a dip-steering volume was calculated, and this volume was used to dictate similarity analysis from the original seismic volume. As it takes structural dip into account, it gives a better picture of structural features in horizon slices.

#### RMS overlay on semblance

RMS overlay on semblance with a transparency of 50% was particularly useful for mapping sands in the shallow stratigraphic level. High-amplitude features are more apparent in

this method as high amplitude conforms to high semblance value.

### Spectral decomposition

Spectral decomposition or time–frequency decomposition is an effective method for seismic interpretation that gives better definition to determine stratigraphic and structural features (Partyka et al. 1999; Castagna and Sun 2003; Farfour et al. 2017). The converted amplitude spectrum (frequency domain) can be used to describe the thickness of thin layers, which cannot be resolved in the time domain due to the low seismic resolution (Castagna and Sun 2006; Loizou et al. 2008; Farfour et al. 2012; Farfour and Yoon 2014). The amplitude spectra can be utilized to indicate the lateral discontinuity of geologic bodies that can help locating prospect areas and delineating facies such as channel sands (Gang et al. 2011). Amplitude spectra at low frequencies are also reported as a direct hydrocarbon indicator (DHI) in some reservoirs (Sinha et al. 2005; Welsh et al. 2008; Zhang et al. 2009). Spectral decomposition was applied to detect sand bodies (Posamentier and Kolla 2003; Suarez et al. 2008)

1. A zone of interest was selected containing the reservoir sand zones from B to O markers. The zone of interest is from 1300 to 2100 ms, from line 5650 to 7500, and from trace 16,000 to 17700 which was used for further spectral decomposition processing. The subset of 3D seismic volume was selected along drilled prospect.
2. A short temporal window (24 ms) within the zone of interest was transformed from the time domain into the frequency domain. The outputs of this process are frequencies slices generated over a time-windowed zone of interest, which is termed as the tuning cube. The vertical axis of this cube is frequency instead of time. Tuning cubes are classified into two types: amplitude and phase tuning cube. In this study, only amplitude tuning cube was used. This workflow is useful to recognize a band-pass filter or a range of frequencies that can be used to create iso-frequency amplitude volumes.
3. Based on the selected frequency range in step 2, iso-frequency volumes were generated through DFT by setting 24 ms window length. Another spectral decomposition technique, continuous wavelet transform (CWT), was also applied in this study area. The output of both methods is time–frequency volume. CWT uses inner products to measure the similarity between signals and provides a different approach to time–frequency analysis. This method provides fine details of the signal both in time and in frequency. By applying this method, I calculated frequency volumes for 12, 20, 38, 45, and 60 Hz. The advantage of CWT is particularly helpful in tackling problems involving signal identification and detection

of hidden transients that are hard to detect, short-lived elements of a signal (Partyka et al. 1999; Chopra and Marfurt 2005).

## Results

### Seismic interpretation

For this study, firstly four marker horizons (B, D, K, and O) have been identified and interpreted. From seismic to well tie, it was found that sand units correspond to trough and shale corresponds to peak. Based on these markers, the study area is then divided into three periods.

To map the vertical changes in sand distribution in detail, some additional horizon slices were generated. Total 36 stratal slices (Fig. 2) were calculated with reference to the interpreted four marker horizons. The ones that show the best geomorphic (Fig. 3) features were then selected for seismic geomorphology study in the three periods (Fig. 3). Period 1 (marker horizon B to D); Period 2 (marker horizon D to K); Period 3 (marker horizon K to O).

### Well-log interpretation

The marker horizons identified in seismic were transferred in the well section. Then, the log character has been studied to interpret the depositional environments (Fig. 4) in the interval of interest. Based on the log motif analyses, three main depositional settings were identified. Fining-upward succession with some coal bed in period 1 is indicating dominantly fluvial depositional setting in the proximity of coast-line (Rider 1996). Period 2 shows thin sand with abundance of coals which is suggestive of marginal marine setting. Finally, period 3 shows thick blocky sands. The depositional environment in this period is most likely fluvial. In general,

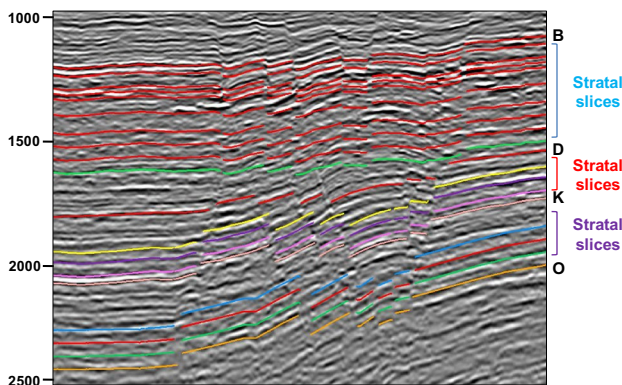


Fig. 2 Interpreted horizons and the calculated horizons

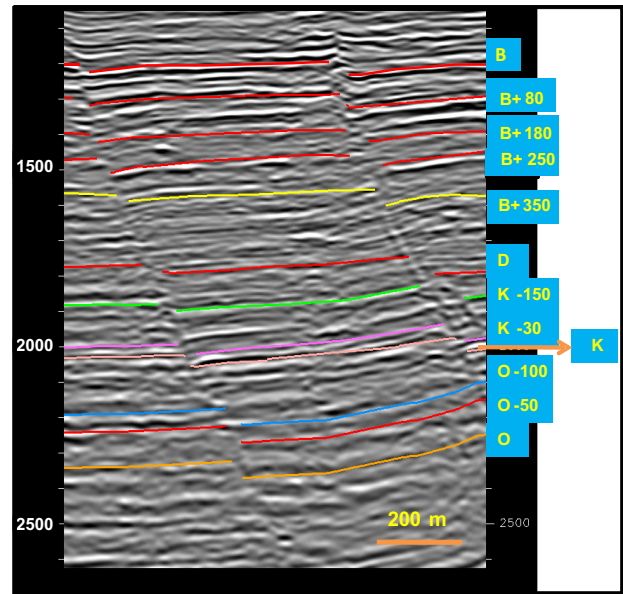


Fig. 3 Selected horizons for seismic geomorphology study

period 3 shows the interval of the thickest sand. Period 1 has similar sand thickness, whereas sands in period 2 are thinner compared to other periods. From seismic attribute analyses, it was found that sand thickness is proportional to seismic amplitude, i.e., higher amplitude in horizon slices corresponds to thick sand and lower amplitude represents thin sands.

### Seismic attribute analysis

#### RMS attribute analysis

The synthetic seismogram confirms that troughs on seismic data represent sands in this area. Therefore, high-amplitude troughs are an indicator of sands or high-energy environments, whereas the low amplitudes represent shale or the homogeneous low-energy environment.

On RMS amplitude maps, high amplitudes are corresponding to sands at well locations (Figs. 5, 6). The RMS attribute maps above D horizon show high-amplitude distribution of distinct pattern that is indicative of meander belts running in NW–SE direction (Fig. 5).

In D–K interval, high amplitude in RMS maps shows diffused pattern. High amplitudes are spread out all over the horizon slices without any distinct pattern. The northern part shows more high-amplitude features as compared to the southern part. Well-log data suggest this interval contains abundant coal.

In K–O interval, RMS can detect sands (Fig. 5) as the sands in this interval are thicker on average than the sands



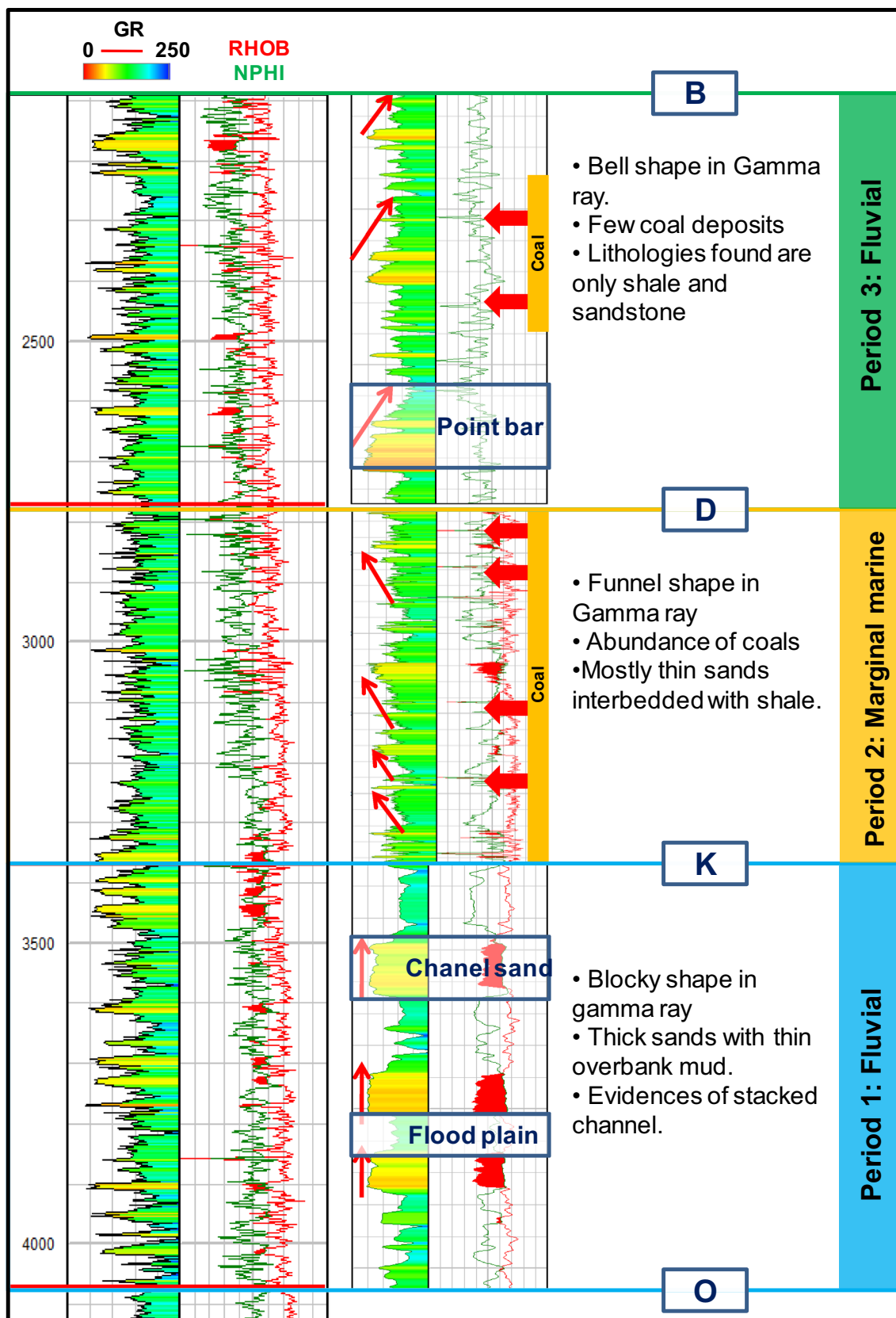
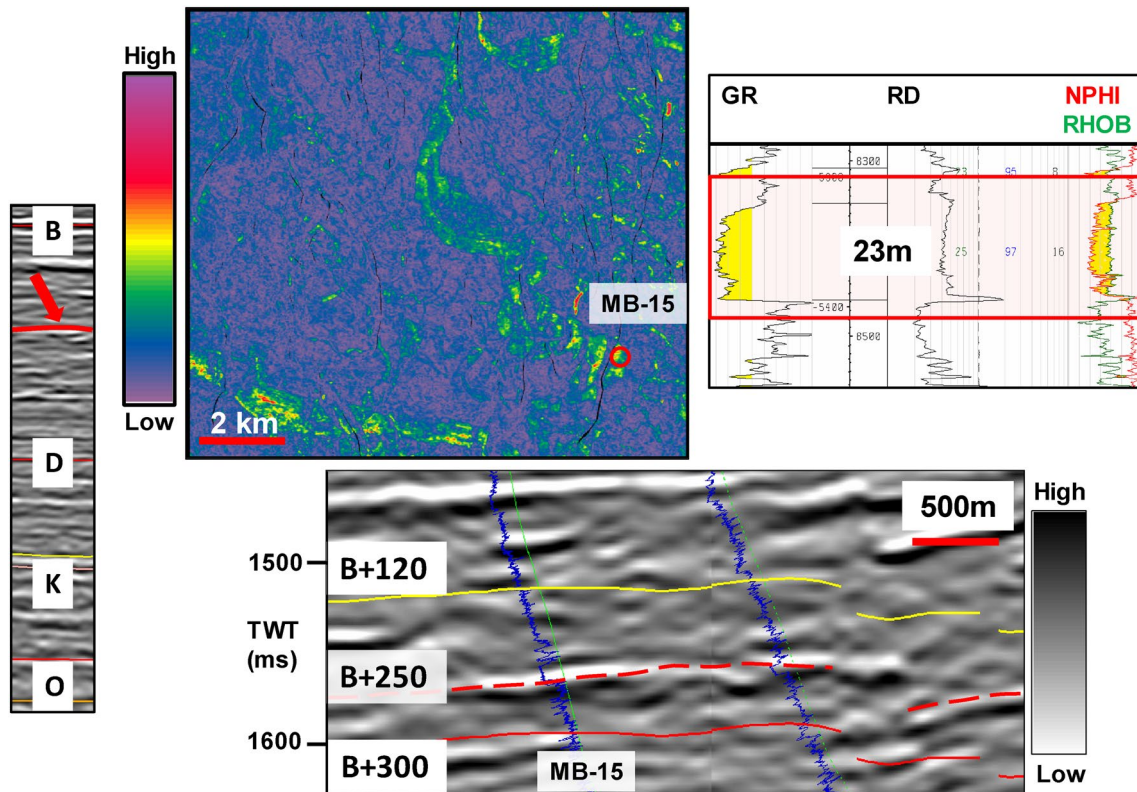


Fig. 4 Interpreted depositional environments at different periods. Three major depositional environments are interpreted based on log motifs



**Fig. 5** The RMS amplitude map of B+250 horizon. The high amplitudes are aligned roughly north–south in the study area. The seismic section along well bore shows B+250 horizon pick. The well log

shows the RMS window range (red zone) covered in well MGWB-15. The extraction window for RMS is 20 ms, which is centered at the horizon

in other zones of interest. However, if the sand thickness is low, RMS cannot detect sand (Fig. 6).

RMS amplitudes successfully identified thick sands (above 10 m), but it is not easy to detect thin sands (less than 10 m) by using the RMS amplitude analysis.

### Semblance analysis

Semblance slices were analyzed to identify channel and any other stratigraphic features. Semblance slices show narrow darker sinuous features associated with broad white belts of high semblance (Fig. 7a, c). The vertical sections across these dark sinuous features reveal that they are channels (Fig. 8). These channel shapes are filled with low positive amplitude material, and in this case, based on the synthetic modeling this is interpreted as mud. On the other hand, the high-coherent brighter broad features on semblance slice (Fig. 7b) represent negative amplitudes on the vertical seismic section. These negative amplitudes are indicating sand. Based on their geometries on semblance slice and vertical section, these are interpreted as sands associated with meander belts. The geometry is not obvious in all the slices specially horizons below K.

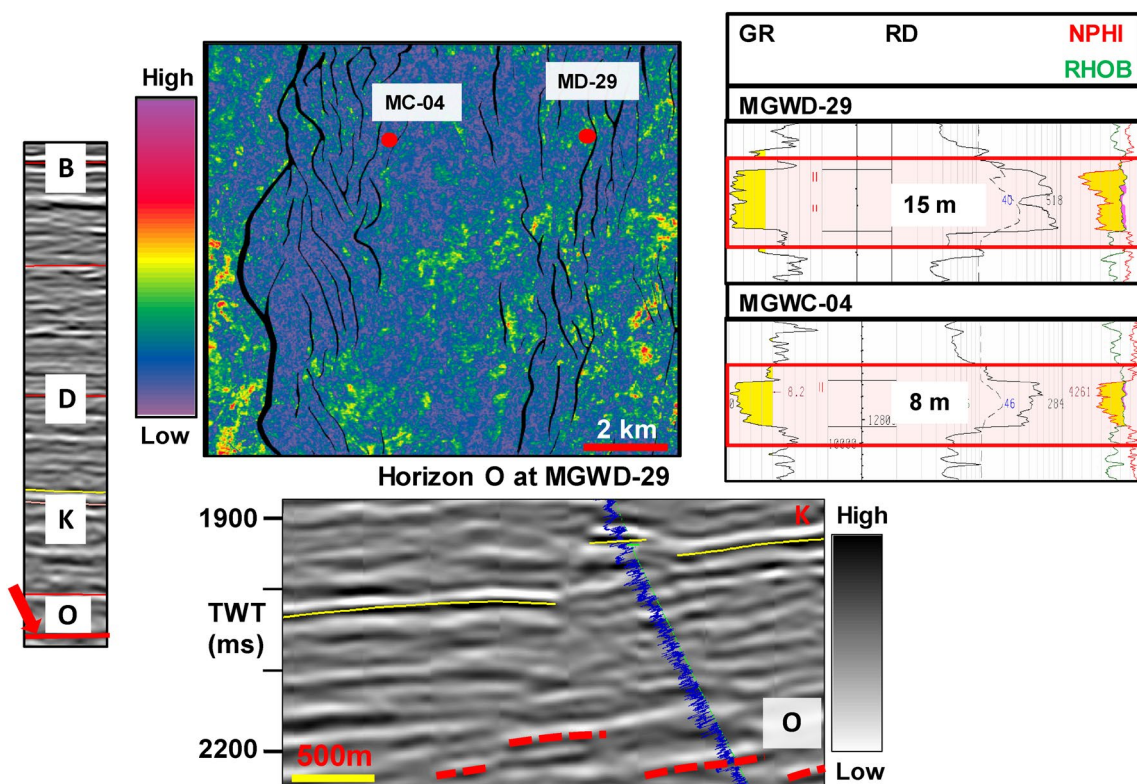
Semblance slices up to K marker show good quality images, and it is easy to interpret channels and sands (Fig. 7a, b), but the quality of semblance images below K marker (Fig. 7d) is not as good as of semblance slices above K marker. Figure 7b depicts an example showing a meandering channel running roughly in the north–south direction. The width of channels and channel belts can be measured by using semblance horizon slices and vertical sections; for example, Fig. 8 shows approximately 470 m wide channel in the southern part and 350 m wide channel in the north.

### Semblance versus dip-steered similarity

Although this attribute is similar with semblance, the only difference is that a dip-steered volume was calculated to dictate the process of coherency measurement of adjacent features. As it takes structural dip into consideration, dip-steered similarity gives better delineation of features (Fig. 9), and in some cases, it provides some additional features.

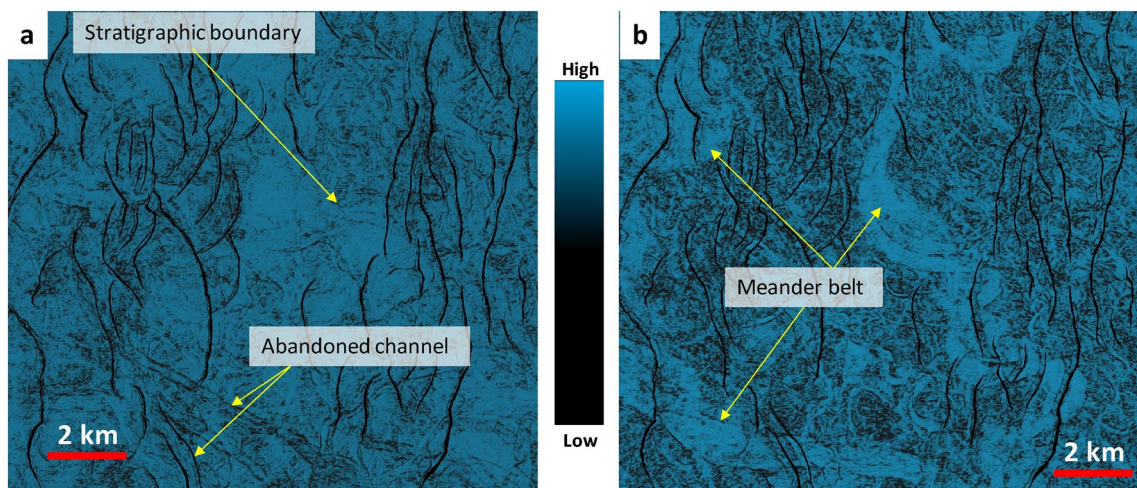
### Spectral decomposition analysis

The horizon slices for different frequencies (10–50 Hz) reveal that amplitude spectra for different frequencies show



**Fig. 6** The RMS amplitude map of O horizon. The high amplitudes show sporadic pattern. High amplitudes have been noticed for 15 m thick sand at well MGWD-29, whereas no high amplitude anomaly

observed for 8 m thick sand at well MGWC-04. The seismic section along well bore shows O horizon pick. The extraction window for RMS is 20 ms, which is centered at the horizon

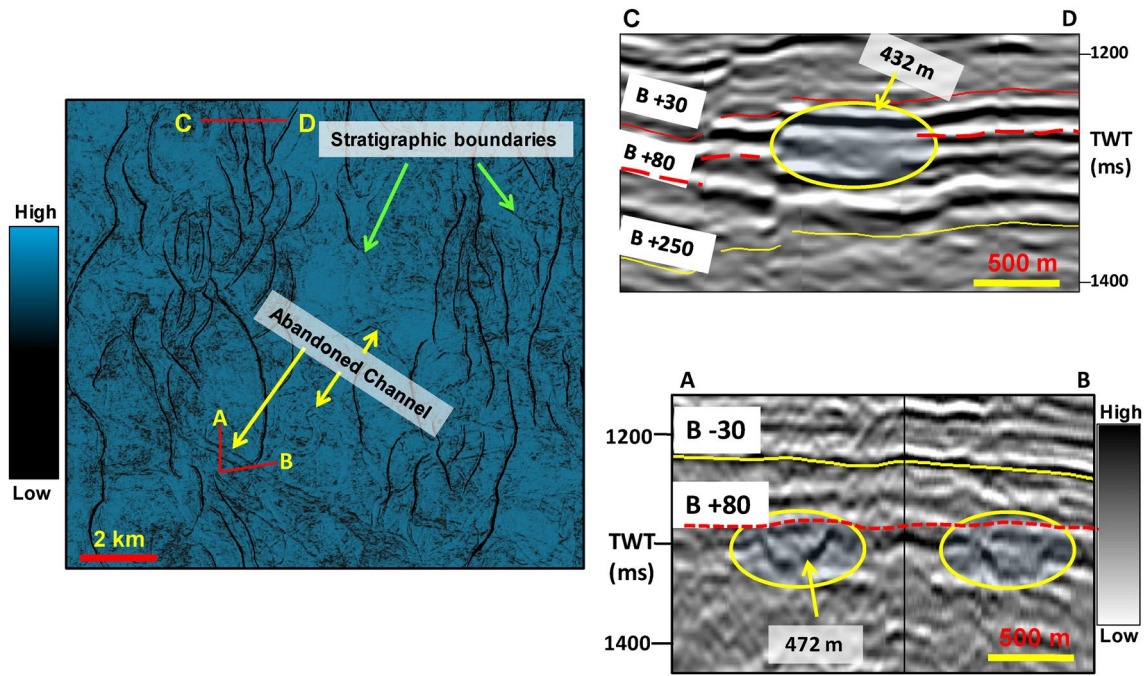


**Fig. 7** The semblance map of horizon B+80 (a) and B+250 (b) (above K horizon). In B+80 slice stratigraphic boundaries and abandoned channels were clearly seen on the semblance slice. In B+250 yellow arrows indicating big meander belts

the same pattern of the anomalies. Figure 10a, b indicates the same pattern of amplitude anomalies for 20 and 45 Hz on horizon slices. Therefore, amplitude spectra of different frequencies cannot resolve different thickness sands in the area. It may be because of the minimum possible window

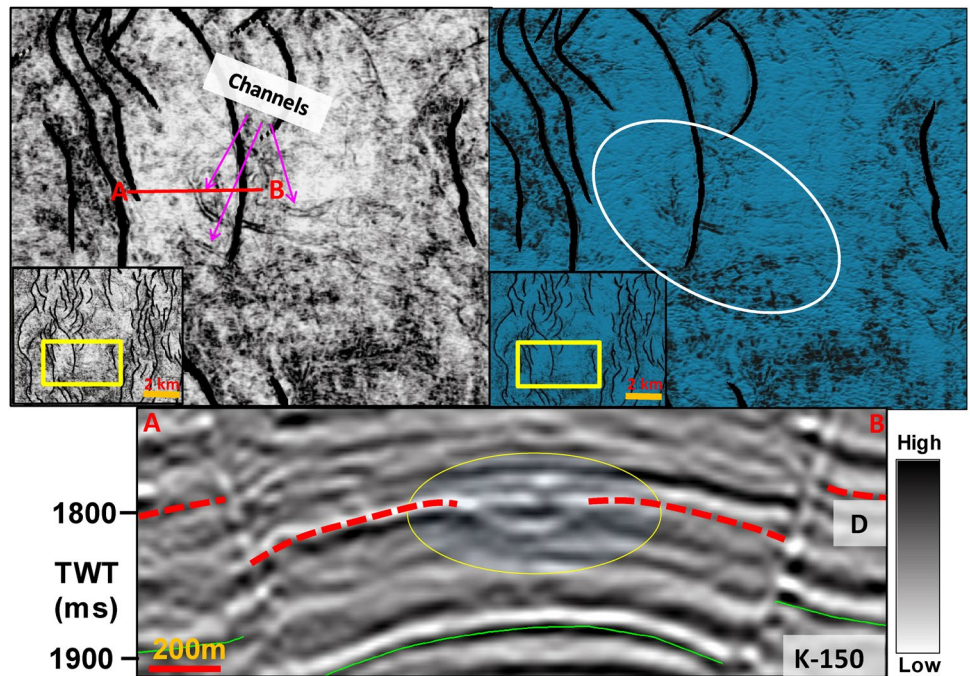
length (24 ms) required by DFT algorithm. In the study area, most of the encountered sands are less than 24 ms. On the other hand, the other spectral decomposition technique (CWT) reveals that amplitude is different for each frequency. As shown in Fig. 10c, high-amplitude anomalies





**Fig. 8** The cross sections of identified features on semblance map of horizon B+80 clearly show channels of various dimensions in the vertical section

**Fig. 9** Dip-steered similarity slice of horizon D showing channel features which were not evident in semblance slice. Cross section along A–B shows the presence of channel in vertical section

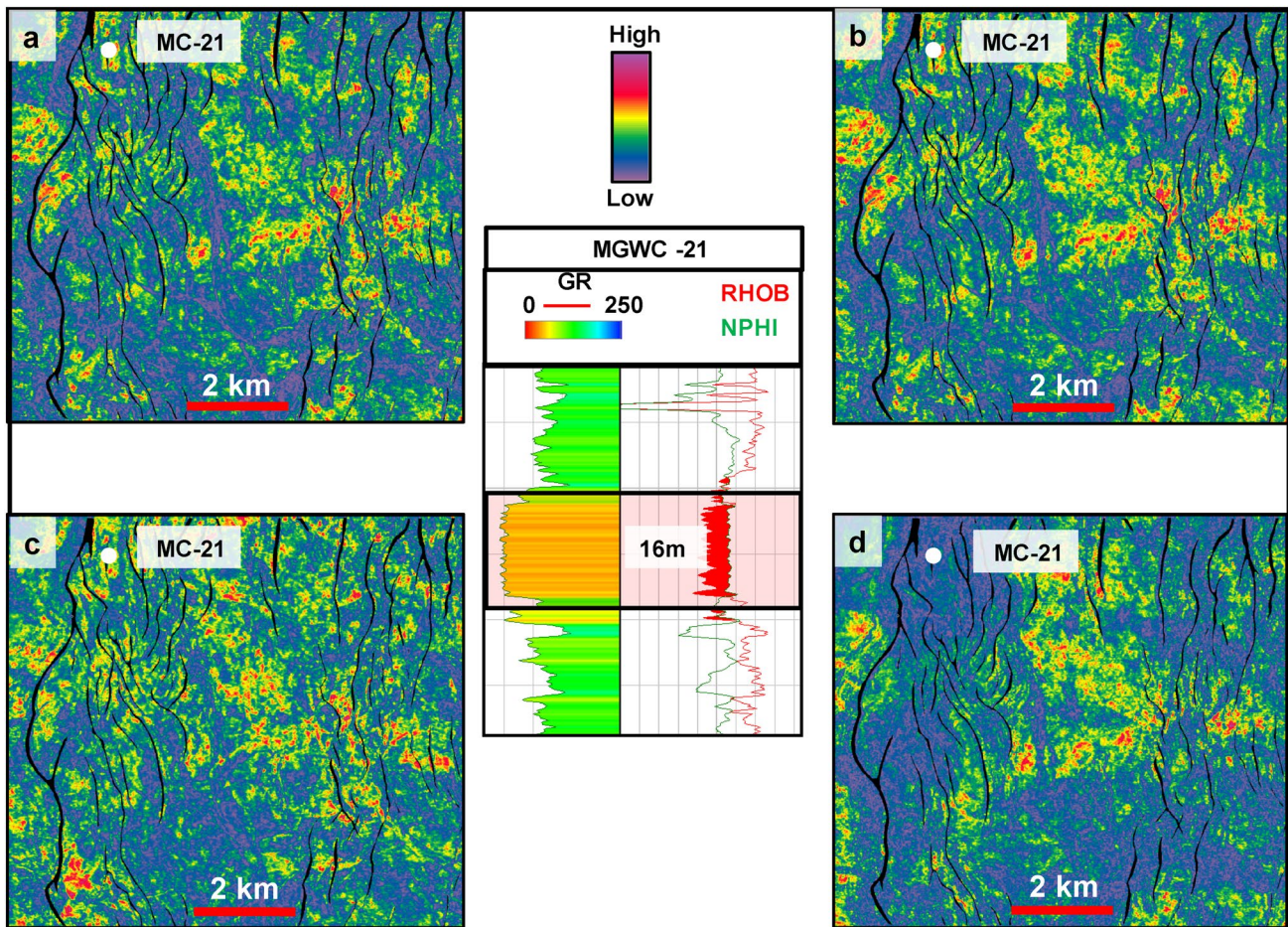


can be observed at the well location in horizon K at 20 Hz of frequency, and low-amplitude zone is observed for 45 Hz (Fig. 10d). It has been observed that different thicknesses show higher amplitude at different frequencies. Figure 11b

shows that thinner sands (less than 15m) show high amplitude at 45 Hz.

Iso-frequency volumes show that in the Moragot field, the 15 m or higher thickness sands response to low frequency





**Fig. 10** Spectral decomposition (DFT) gives similar response for 16 m thick sand in horizon K at 20 Hz (a) and 45 Hz (b) at the well location, whereas CWT gives different responses for 20 Hz (c) and

45 Hz (d). 20 Hz can detect this thick sand, whereas 45 Hz cannot. White dot indicates well location

(20 Hz) and high frequencies (45 Hz) are responding to thinner sands (Fig. 10).

RGB blending was particularly useful in delineating fluvial systems in some horizon slices (D, K-30) which were not possible using other attributes (Figs. 11, 12). Moreover, it was also useful in differentiating thicker sands from thinner sands (Table 1).

Fluvial system parameters have been mapped based on seismic attribute analysis from the stratal and horizon slices. Periods 1 and 3 show large meander belts with wider channels, whereas both the channel belt and channel are narrower in period 2. Sinuosity is higher in periods 1 and 3 compared to period 2.

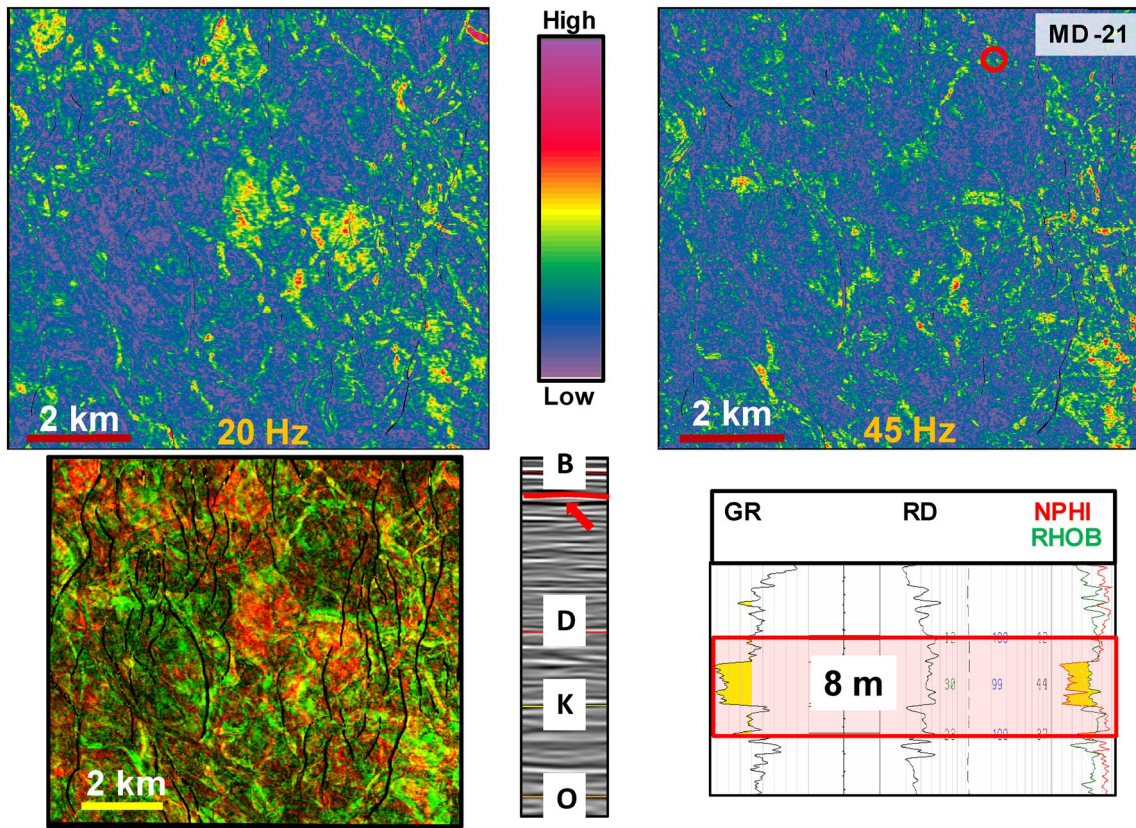
## Discussion and conclusion

Different geophysical and geological techniques were applied to map the reservoir sand distribution. Key results and conclusions of the present study are summarized as follows:

The amplitude response of CWT spectral decomposition is different for different thicknesses of sands. Low frequencies (20 Hz) 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).

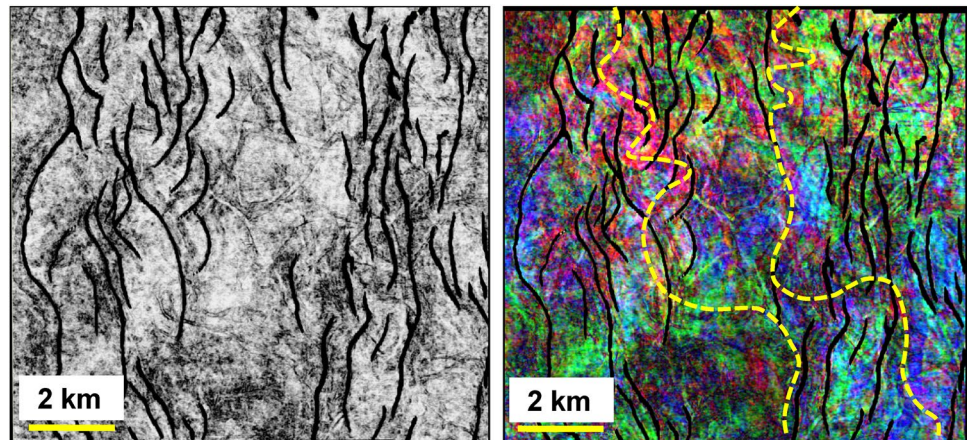




**Fig. 11** Spectral decomposition CWT gives different responses at 20 Hz (a) and 45 Hz (b) at horizon slice B+80. Well location shows high amplitude at 45 Hz since the sand is thinner confirmed by well

log. Blending of two frequencies (c) can be used to differentiate thick sands from thin sands. Here, red color indicates 20 Hz, i.e., thicker sands, whereas green color indicates 45 Hz, i.e., thinner sands

**Fig. 12** RGB blending of 20 Hz, 35 Hz, and 45 Hz showing the presence of fluvial channels which were not visible in other horizon slices



Dip-steered similarity gives more accurate delineation of channel features than semblance calculated from raw seismic volume in D to K interval.

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.

**Table 1** The dimensions of the fluvial system parameters at different stratigraphic intervals

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		200–800	80–140		
			K-150	200–400	90–220		
			K-80	250–450	110–200		
			K-30	230–420	60–170		
				250–800	152–347		
			Early Miocene	Period 3	O-100	500–2000	170–300
					O-50	800–2500	130–280
O	1500–3000	120–330					

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## References

- Brown AB (2001) Understanding seismic attributes. *Geophysics* 66(1):47–48
- Burnett MD, Castagna JP, Méndez-Hernández E, Rodríguez GZ, Garcaí LF, Martínez-Vázquez JT, Avilés MT, Raúl Vila-Villaseñor R (2003) Application of spectral decomposition to gas basins in Mexico. *Lead Edge* 22:1130–1141
- Castagna JP, Sun S (2006) Comparison of spectral decomposition methods. *First Break* 24:75–79
- Castagna JP, Sun S, Siegfried RW (2003) Instantaneous spectral analysis: detection of low-frequency shadows associated with hydrocarbons. *Lead Edge* 22:120–127
- Chopra S, Marfurt KJ (2007) Seismic attributes for prospect identification and reservoir characterization. Society of Exploration Geophysicists, Tulsa
- Davies RJ, Posamentier HW, Wood LJ, Cartwright JA (2007) Seismic geomorphology: applications to hydrocarbon exploration and production, vol 277. Geological Society of London (Special Publication), London, pp 1–14
- Farfour M, Yoon WJ (2014) Ultra-thin bed reservoir interpretation using seismic attributes. *Arab J Sci Eng* 39:379. <https://doi.org/10.1007/s13369-013-0866-9>
- Farfour M, Yoon WJ, Jo Y (2012) Spectral decomposition in illuminating thin sand channel reservoir, Alberta, Canada. *Can J Pure Appl Sci* 6:1981–1990
- Farfour M, Ferahtia J, Nouredine D (2017) Seismic spectral decomposition applications in seismic. In: Gaci S, Hachay O (eds) Oil and gas exploration. <https://doi.org/10.1002/9781119227519.ch6>
- Gang C, Mingjun S, Qingzhou Y, Honglin G (2011) Application of spectral decomposition technique in reservoir exploration in the Junggar Basin of West China. Oral presentation at AAPG annual convention and exhibition, April 10–13, 2011
- Hossain S (2018) Seismic geomorphology as a tool for reservoir characterization: a case study from Moragot field of Pattani Basin, Gulf of Thailand. *Malays J Geosci (MJG)* 3(1):45–50
- Loizou N, Liu E, Chapman M (2008) AVO analyses and spectral decomposition of seismic data from four wells west of Shetland, UK. *Pet Geosci* 14:355–368
- Miall AD (2002) Architecture and sequence stratigraphy of Pleistocene fluvial systems in the Malay Basin, based on seismic time slice analysis. *AAPG Bull* 86(7):1201–1216
- Morley CK, Racey A (2011) Petroleum geology. In: Ridd MF, Barber AJ, Crow MJ (eds) The geology of Thailand. Geological Society, London, pp 223–271
- Partyka G et al (1999) Interpretational applications of spectral decomposition in reservoir characterization. *Lead Edge* 18:353–360
- Peyton L, Bottjer R, Partyka G (1998) Interpretation of incised valleys using new 3-D seismic techniques; a case history using spectral decomposition and coherency. *Lead Edge* 17(9):1294–1298
- Posamentier HW, Kolla V (2003) Seismic geomorphology and stratigraphy of depositional elements in deep-water settings. *J Sediment Res* 73:367–388
- Rider M (1996) The geological interpretation of well logs. Whittles Publishing Roseleigh House, Latheronwheel
- Sinha S et al (2005) Spectral decomposition of seismic data with continuous-wavelet transform. *Geophysics* 70(6):19–25
- Suarez Y, Marfurt JK, Falk M (2008) Seismic attribute-assisted interpretation of channel geometries and infill lithology: a case study of Anadarko Basin Red Fork channels. In: 78th Annual international meeting, Society of Exploration Geophysicists, expanded abstract, pp 963–967
- Welsh A, Brouwer FGC, Wever A, Flierman W (2008) Spectral decomposition of seismic reflection data to detect gas related frequency anomalies. 70th In: EAGE conference and exhibition. Extended abstract, pp 263–267
- Zhang K, Marfurt KJ, Slatt RM, Guo Y (2009) Spectral decomposition illumination of reservoir facies. In: 79th Annual international meeting of Society of Exploration and Geophysics (expanded abstract), Houston, pp 3515–3519

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