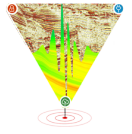




Tide- influenced delta versus Tide- dominated delta interactions: Deciphering a depositional enigma using trends derived from RGB blend and advanced seismic attributes in Miocene sands of Tripura, India

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Keywords

Tide-influenced data. Tide-dominated delta. RGB blend. Vp/Vs attribute. Avulsions.

Summary

Ancient deltaic deposits have proven to be prolific petroleum provinces worldwide and are regions of hydrocarbon exploration activities globally. Tide-dominated and tide-influenced deltas are one of the most abundant examples and usually represent different stages of deltaic development in a province. The difference between the two, however, has never been adequately distinguished especially in ancient systems. Tide-dominated deltas are subaqueous in nature and are tidally reworked during relative sea-level rise. Tide-influenced deltas, on the other hand, are significantly river-dominated in upper delta-plain and contain tidal indicators in delta-front and lower delta-plain areas. Similarities of depositional characteristics derived from sedimentological studies, palynological inferences and electro-log motifs only tend to provide a generalized understanding of interactions between tidal and deltaic activities. In this paper, sub-surface imaging technique derived from RGB blend and advanced seismic attribute is used to visualize distinctive depositional features suggestive of a tide-influenced deltaic deposit in Miocene sands in Tripura, India. Understanding the intrinsic nature of the depositional environment helps in de-risking future hydrocarbon exploration and development activities by predicting suitable areas with good reservoir facies.

Introduction

Deltaic deposits the world over are formed in the transition zone between fluvial and marine activities (Dalrymple and Choi, 2006). The difference between tide-dominated and tide-influenced deltas is mostly based on deltaic morphology. While tide-dominated deltas portray a straight, funnel-shaped geometry, tide-influenced deltas are more similar to river- or wave-dominated deltas thereby consisting of

dominantly fluvial or wave-generated deltaic features (Bjorklund and Milkeviciene, 2009).

The present study area is the Khubal anticline, which is a 30 km long and 15 km wide NNE-SSW trending *en-echelon* in Tripura Fold Belt, Assam and Assam-Arakan Basin, India (Figure 1).

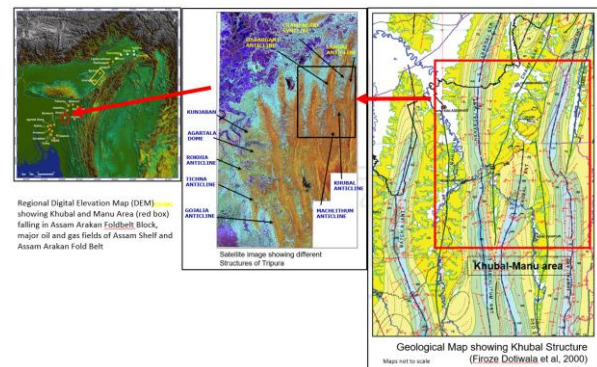


Figure 1. Geological map of Khubal area in Tripura Fold Belt, India (Firoze Dotiwala et al., 2000).

In Khubal Field, KHT sand in Bhuban Formation of Miocene is an established gas producer (Figure 2) and consists of fine to medium-grained sandstones, mostly sub-lithic arenite to lithic arenite in nature. Prediction of lateral continuity of KHT equivalent sands is a challenging task due to its discrete nature and lateral heterogeneity. Sedimentological studies and palynological inferences have always given the impression that KHT sand bodies were deposited in a tide-dominated deltaic setting. Subsurface imaging using RGB blended and seismic pre-stack inversion studies was applied to visualize the depositional trend and reveal the exact nature of KHT pay sand in Khubal area.

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Chronostratigraphy		Lithostratigraphy		Generalised Lithology	Thickness	Environent
Period	Epoch	Group	Formation			
Quaternary	PLIESTOCENE TO RECENT	-	DIHING	Pebble beds, Conglomerates and sandstones with thin bands of clay	400	Fluvial
			UNCONFORMITY			
Neogene	PLIOCENE	DUPITILA	DUPITILA	Coarse, pebbly sandstone & mottled clays	1000	Fluvial
			UNCONFORMITY			
	MIO-PLIOCENE	TIPAM	GIRUJAN	Variegated soft & sticky clays, often silty Sandstone with sandy clays & claystone	1500-1700	Fluvial
			TIPAM			
	MIOCENE	SURMA	BOKABIL	Claystone & siltstone with thin beds of fine grained sandstone	700-1500	Brackish to Marginal Marine
			Upper Bhuban			
Middle Bhuban						
Lower Bhuban						
Palaeogene	UPPER EOCENE TO OLOGOCENE	BARAIL	Renji	Dominantly sandstone with thin shale beds	700-1000	Brackish to Marginal Marine
			Jenum			
			Laisong			
EOCENE	DISANG	Disang	Dark grey shale with thin beds of sandstone	1750+	Reducing Marine	

Figure 2. Stratigraphy of Tripura area (D.S.N. Raju et al., 2009). Yellow shade shows penetration up to Lower Bhuban Formation in few wells in Tripura Fold Belt. Red shade indicates gas producing Formations.

Methodology

Pre-stack seismic inversion

In the present study, 3D pre-stack seismic volume was inverted using the model-based inversion method. The model-based inversion utilizes the principles of convolution theory, which asserts that the seismic trace can be created by convolving a wavelet with the reflectivity series of the Earth (Narayan et al., 2023). The fundamental idea behind model-based inversion is to hypothesize a low-frequency impedance model, which is then converted into the reflectivity series, serving as the basis for generating a synthetic trace. The discrepancy between the synthetic trace and the actual seismic trace is computed, and the method aims to minimize the square of this difference using least-square optimization approach. Using well-log data, an initial low-frequency model was prepared for the P-impedance and Vp/Vs ratio. Further, the seismic reflection data was inverted, and P-impedance and Vp/Vs ratio volumes were estimated (Figure 3).

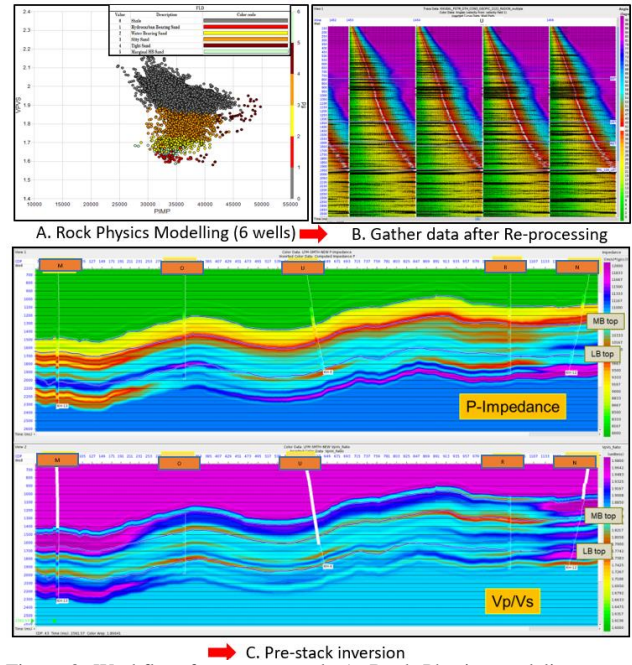


Figure 3. Workflow for current study. A. Rock Physics modeling, B. gather data conditioning, C. Prestack inversion

Spectral Decomposition using CWT

Spectral decomposition is also one of the most effective techniques to delineate the channel geometry and its continuity (Chopra and Marfurt, 2016).

The wavelet transform technique known as the continuous wavelet transform (CWT) has found extensive use in the spectral decomposition of seismic data. Mathematically, the CWT technique is expressed as the inner product of the wavelet family $\psi \sigma, \tau (t)$ with the signal $u (t)$.

$$S_w (\sigma, \tau) = \frac{1}{\sqrt{\sigma}} \int_{-\infty}^{\infty} u(t) \bar{\psi} \left(\frac{t-\tau}{\sigma} \right) dt$$

Where $\bar{\psi}$ the complex conjugate of ψ , and S_w is the time scale map used to extract the instantaneous frequency. The τ is the time shift applied to the mother wavelet, and σ is the scale.

Results

Considering seismic frequency bandwidth, mono-frequency volumes of 17.5, 25 and 30 Hz was generated. Attribute extracted at KHT pay top from RGB blended volume of iso-frequency was used to

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translate the lateral disposition of reservoir sands. Additionally, this method also aids in signifying variations in target thickness in 3D space (Chopra and Marfurt, 2016). Vp/Vs ratio attribute map, for a 15 ms window, close to KHT pay equivalent sands was also extracted to decipher the depositional trends and facies dispersal pattern.

Validation with litho-facies, petrophysical parameters and initial production details of key wells have indicated Vp/Vs values in the range of 1.70-1.84 are representative of good reservoir facies. These sands mostly consist of fine to medium grain size with good effective porosity. Whereas medium Vp/Vs ratio range of 1.84-1.87 represents tight reservoir facies with silty in nature having effective porosity less than 10%. Vp/Vs ratio values greater than 1.87 comprises non-reservoirs facies representing silty shale or shale with insignificant effective porosity (Figure 4).

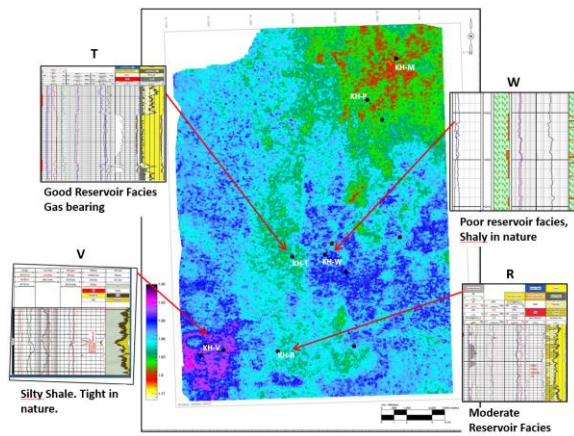


Figure 4. Attribute extracted within window of KHT pay top (plus5ms to plus20ms) from Vp/Vs volume, showing facies distribution and calibration of petrophysical properties of drilled wells.

Inferred sedimentological understanding derived from core studies in well C, reveals depositional features like wavy bedding, parallel laminations, mud clast and convolute bedding (Figure 5). Such features are, however, arbitrary and represent the dominance of tidal processes, i.e., not specific either to tide-dominated delta or tide-influenced delta deposits (Ponten and Bjorklund, 2007).

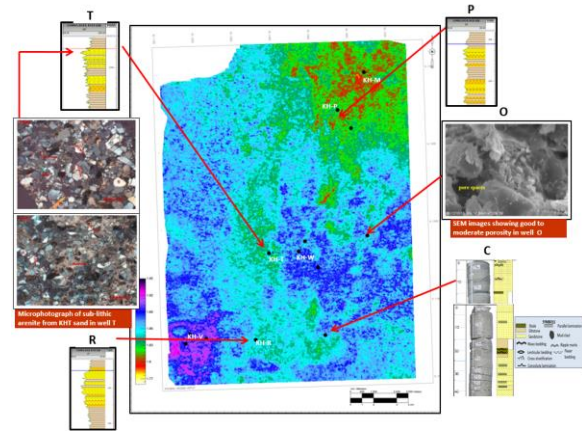


Figure 5. Log motifs showing fining and coarsening up sequences. Microphotograph showing lithic arenite in well T, XRD image showing moderate visual porosity (well O) and core with interpreted sedimentary features.

Extracted RGB blend and Vp/Vs ratio attribute maps at KHT level show distinctive multi-event lateral migration of distributary channel-like features mostly trending in north to south direction (Figure 6 and 7). Some features which are faintly captured by RGB blend are better enriched in Vp/Vs ratio attributes and vice versa. Channel geometry derived from both Vp/Vs ratio attribute and RGB blended maps depict depositional features resembling fluvial or unidirectional current channel features representative of an upper to mostly lower delta plain setting, especially in the northern part. In the southern part of the study area, the envisaged channels are better discernible in Vp/Vs ratio attribute.

A prominent channel is seen in the north-central part which seems to be an amalgamation of multiple channels. These distributary channels are separated by interdistributary areas with shaly facies (Figure 8). Fluvial environment being susceptible to frequent avulsions, it is evident that some of these clay-filled interdistributary areas were earlier traversed by channel deposits. Also, some of these areas are replaced by channel deposits due to the continual process of channel migration at a later stage (Bristow and Best, 1993; Mackey and Bridge, 1995; Holbrook, 1996).

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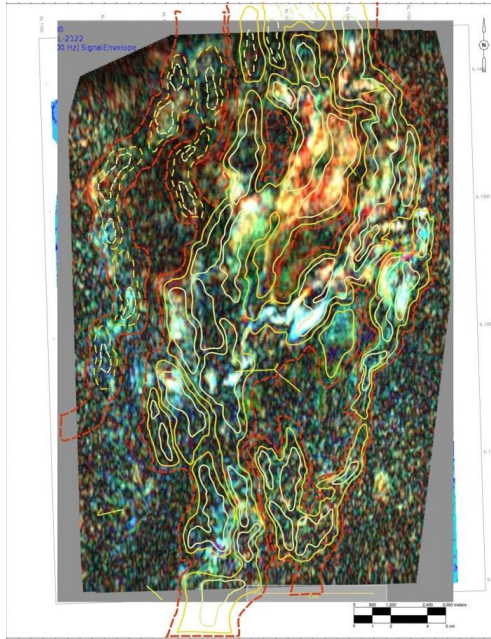


Figure 6. Attribute extracted within window of KHT pay top (plus5ms to plus25ms) from RGB blended volume of iso-frequency volumes (17.5, 25 & 30hz).

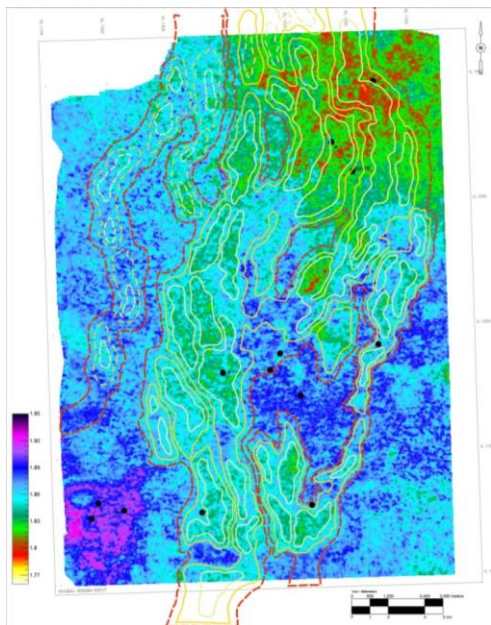


Figure 7. Attribute extracted within window of KHT pay top (plus5ms to plus25ms) from Vp/Vs volume, equivalent to KHT pay showing distributary channels.

KHT sands depicted by RGB Blend and Vp/Vs ratio attributes revealed the presence of distributary channels which are dominantly unidirectional in nature. A typical elongated funnel-shaped geometry,

inherent in tide-dominated deltas, is absent. These fluviially derived sediments were less reworked and re-oriented by tidal processes, resulting due to high sediment supply that overcomes tidal currents.



Figure 8. Integrated facies map of KHT equivalent sand showing areas with good, moderate and poor reservoir properties.

These features indicate the dominance of tide-influenced deltaic activity mostly occurring in a lower delta plain setting in the northern part. Depositional trends in the southern part show mixed scaling and demonstrate transitional features of a tide-dominated delta to a tide-influenced delta setting.

Conclusions

Understanding the depositional nature of subsurface reservoir sands using RGB blend and Vp/Vs ratio attributes brought out the lateral disposition of distributary channels in a tide-influenced delta versus tide-dominated delta environment. The study enables a distinctive visualization of channel geometry with multi-event lateral migration features. Better reservoir sands are expected in the distributary channels. The inter-distributary areas are mostly clay-filled and have poor reservoir facies. Understanding the intrinsic nature of the depositional environment and prediction of facies quality helps in better judgment and decision-making for future hydrocarbon exploration strategies.



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Views presented in this work are those of authors only.