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Illuminating meandering channel through AVO analysis and spectral decomposition of 3D seismic data: A case study in Gandak sub-basin, Ganga Basin, India

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Abstract

In pursuit of hydrocarbon in Ganga Basin, exploration focus had been on Neoproterozoic-Paleozoics, however, gas indications in Lower Siwaliks (Tertiaries) have also been observed in some of the drilled wells. During the study of recently acquired 2D and 3D seismic data in northern part of Gandak sub-basin has revealed channels in lower part of Lower Siwaliks which has been further authenticated by attribute analysis of the 3D seismic data.

Class III AVO anomaly has been observed within lower part of the Lower Siwalik where Channel are seen on time slices and were further subjected to AVO analysis. Spectral analysis in the window encompassing the channel interval has established the meandering channel. Furthermore, AVO inversion can also reveal additional information about lithology and fluid content in the channel. This opens a new vista for hydrocarbon exploration in Ganga Basin.

Introduction

Ganga basin represents multiple basinal set-up with a long geological history from Mesoproterozoic to Pleistocene. The basin with a vast areal stretch of about 3,00,000 km^2 and a huge sediment thickness of more than 8 Km, possesses the characteristics that make a basin lucrative for hydrocarbon exploration (Figure 1). Advance seismic studies like AVO and Spectral Decomposition have indicated positive results for possible hydrocarbon in clastic reservoir of Tertiary Sediments.

The AVO (amplitude variation with offset) technique assesses variations in seismic reflection amplitude with changes in distance between shot points and receivers corresponding to a CDP. This analysis is widely used in hydrocarbon detection, lithology identification, and fluid analysis, as seismic amplitudes at layer boundaries are affected by the variations of the physical properties of the rocks.

The application of amplitude versus offset (AVO) in the analysis of HC reservoirs is on the increase in various Sedimentary Basins of the world. This has contributed to a rapidly increasing knowledge of the physical properties of rocks, and in the active exploration and delineation of reservoirs. Porosity and the fluid effects may be determined through AVO based methods in certain types of facies. Seismic information from a reservoir can be modelled and extracted from basic AVO conditioned gathers using attribute analysis and elastic parameter inversion.

The spectral decomposition of seismic data is the process that transforms seismic amplitudes as a function of space and time to spectral amplitudes as a function of frequency, space and time. The frequency cubes that result from this process can potentially be used to map variations in bed thickness, geologic discontinuities and differentiation of fluids in the reservoir.

Spectral decomposition provides a novel means of utilizing seismic data and the Discrete Fourier Transform (DFT) for imaging and mapping temporal bed thickness and geological discontinuities over 3D seismic surveys (Partyka and Gridley, 1997). By transforming the seismic data into the frequency domain via the DFT, the amplitude spectra delineate temporal bed thickness variability while the phase spectra indicate lateral geologic discontinuities. This signal analysis technology has been used successfully in 3D seismic surveys to delineate stratigraphic settings such as channel sands and structural settings involving complex fault systems.

Spectral Decomposition of seismic data is able to discern temporal bed thickness, as the reflection from a thin bed has a characteristic expression in the frequency domain, e.g., a simple homogeneous thin bed introduces a predictable and periodic sequence of notches into the amplitude spectrum of the composite reflection. The seismic wavelet however, typically spans multiple subsurface layers and not just one simple thin bed. This layered system results in a complex tuned reflection that has a unique frequency domain expression.

Geological Setting

Ganga Basin has had a long and complex evolutionary history. The basin initiated as an intra-cratonic rift during Mesoproterozoic in extensional settings and subsequently changed over to passive margin setup. Ganga Basin is subdivided into four depressions viz., (i) Sahaspur, (ii) Sarda, (iii) Gandak and (iv) Madhubani. All these depressions are separated from one another by intervening basement ridges viz., Delhi-Kalka Ridge demarcating western limit of Ganga Basin, Chandausi Structural Nose dividing Sahaspur and Sarda depressions, Lucknow-Faizabad within Sarda depression separating Bahraich Low, Bundelkhand–Faizabad ridge dividing Sarda and Gandak depression (*area of study*) and Sitamarhi ridge separating Gandak and Madhubani depressions (Figure 2). Although, all the four depressions have been probed since the onset of exploration in 1950s, the focus of exploration has kept shifting among different depressions depending on gradually updating of knowledge base.

At Well G-1 within the 3D area of the study, minor gas (C1: 95%) and nitrogen have been reported from the gas samples collected during drilling from Lower Siwalik. On breaking of a core taken (CC#5; Lower Siwalik and CC# 9; Karnapur Formation) in G-1 well, hydrocarbon like substance oozed out giving oily odour. As per source rock data and testing, argillaceous sediments of the Neoproterozoic-Early Paleozoic sequence and the Lower Siwalik Formation (Middle Miocene) indicate potential to generate hydrocarbons in the Gandak Depression. Good TOC in the well (S-1: 10.97% and B-1: 3.79% in Sarda Depression and L-1: 2.21% in Gandak Depression) recorded in the lower part of Tertiary towards northern deeper parts indicates existence of envisaged younger petroleum system. Tertiary having source as shale unit and cap rock as flood plain/ overbank shales of the Siwalik fluvial system with channel sands within Lower Siwalik may act as effective petroleum system.

Experimental Details

Study of 3D seismic data has brought out a channel like feature along Inline-160 (Figure 4) also perceived in time slice 1822ms (Figure 5).In order to explore the possibility of accumulation of gas within Lower and Middle Siwaliks, special studies through AVO analysis and spectral decomposition were carried out in order to confirm any possible anomalies arising due to the channel observable in the 3D area. The attribute studies like signal envelope also revealed a channel like feature at time 1822ms which brings out better development of amplitude clearly defining the limits of a meandering channel in the Lower Siwalik (Figure 6)

Spectral Decomposition at 27.3 Hz shows better amplitudes in the south indicated as Area-1 which can be probed, whereas Spectral Decomposition at 28.3 Hz shows better amplitudes in the north-western corner of the 3D area marked as Area-2 and this can be investigated depending on the results of Area-1 (Figure 7).This amplitude development appears related to splays sands. Discrete frequency cubes and tuning cubes were computed with the DFT technique of spectral decomposition for the frequency bandwidth of 10–60 Hz. The tuning cube, generated in short-interval windows with reference to a horizon of interest, contains slices of all the frequencies in the computation range. These frequency volumes were scanned for frequencies giving maximum response (amplitude). Based on the above studies AVO analysis was done to decipher the possibility of gas sand in Lower Siwalik. Pre-stack gathers have been taken for the study. SEG-Y, log data, check shot data and velocity data were loaded in the Hampson Russell software. Well-seismic tie were correlated to identify the gas bearing objects in the gathers to perceive their AVO effects before carrying out AVO procedure. The complete AVO work -flow is given in (Figure-8).

Angle stacks of the ranges 5-15 degrees, 15-25 degrees, 25-35 degrees and 35-45 degrees were generated for different lines to see the amplitude variations with different angle stacks to reveal AVO anomaly. Whereas, Gradient Analysis (Figure 9) shows increase in amplitude with increase in offset, AVO Cross plot shows a significantly larger scatter and better separation of the anomalous values in the first and third quadrants (Figure 10). This confirms Class-II-III AVO anomaly, indicating probability of gas filled sediments. Product of Intercept and Gradient (A*B) (Figure 11) also confirms AVO anomaly within Lower Siwalik in the time range 1778ms to 1776ms. This gives impetus towards gas exploration for a shallow prospect to explore gas entrapment in the Lower Siwalik.

Results and Discussion

Presence of meander channel which was observed in the seismic section has been established by the attribute analysis and AVO study has brought out development of amplitude anomaly adjacent to a meandering channel. This anomaly being very adjacent to channel is attributable to crevasse splay deposits which can form a good clastic reservoir within Lower Siwalik.

A comparison of attribute analysis (amplitude envelope) and AVO anomaly (Intercept and Gradient product) clearly indicates and confirms the existence of a meandering fluvial channel. Keeping in view the AVO anomaly and attribute analysis along with thermal history of Lower Siwalik, a shallow prospect can be considered for the hydrocarbon entrapment.

Conclusions

AVO anomaly and attribute studies confirm the shallower channel sand within Lower Siwalik which may open a gateway for the HC exploration in Ganga Basin. Lower Siwaliks of Gandak depression can be productive due to the presence of distributary-channel sandstone and the crevasse splay deposits may form potentially important stratigraphic traps.

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Partyka, G.A., Gridley, J.M., and Lopez, J., 1999. Interpretational Applications of Spectral Decomposition in Reservoir Characterization, The Leading Edge, vol. 18, No. 3, pg 353-360.

Figures and Tables:

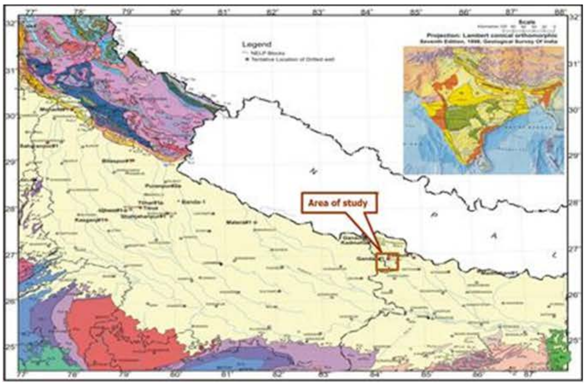

Figure 1: Geological Map of Ganga Basin

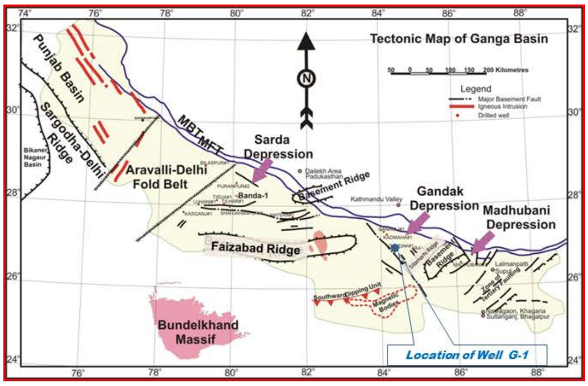

Figure 2: Tectonic map of Ganga Basin

ERA	AGE	FORMATION	LITHOLOGY
CENOZOIC	1.5 Ma - Recent	ALLUVIUM	Loose sand, Kankar, Gravels and pebbles.
	5.5 - 1.5 Ma	UPPER SIWALIK	Interbedded Sandstone, Silty-claystone and pebbles at places.
	10.8 - 5.5 Ma	MIDDLE SIWALIK	Sandstone, with subordinate claystone and siltstone.
	18.3 - 10.8 Ma	LOWER SIWALIK	Sticky clay, sandy claystone and hard siltstone.
R E G I O N A L U N C O N F O R M I T Y			
NEOPROTERO ZOIC - PALEOZOIC	635 - 540 Ma	KARNAPUR	Claystone and Shale.
	670 - 635 Ma	TILHAR	Argillaceous Limestone, Dolomitic at base with splintery Shale.
	U N C O N F O R M I T Y		
	800–700 Ma	UJHANI	Quartzitic Sandstone with Shale, Claystone and Limestone
U N C O N F O R M I T Y			
MESOPROTER OZOIC	1450 – 1350 Ma	BAHRAICH GROUP	AVADH: Quartzitic Sandstone, Limestone and shale.
	1550 - 1450 Ma		SARDA: Basic rocks, Phyllitic shales and Schists
Paleoproterozoic /Archean Basement		not penetrated	

Figure 3: Generalized stratigraphy of Gandak Depression, Ganga Basin

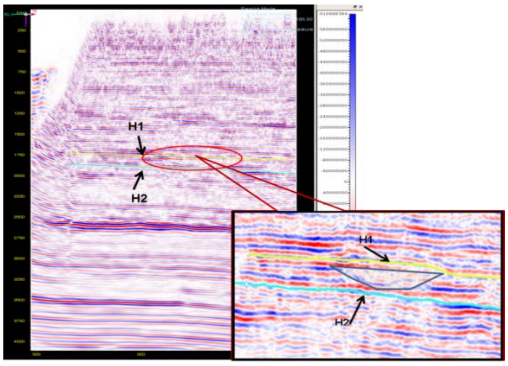

Figure 4: Inline 160 showing channel feature and its Zoomed part

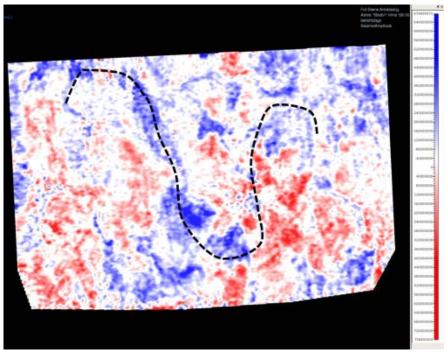

Figure 5: Time Slice at 1822

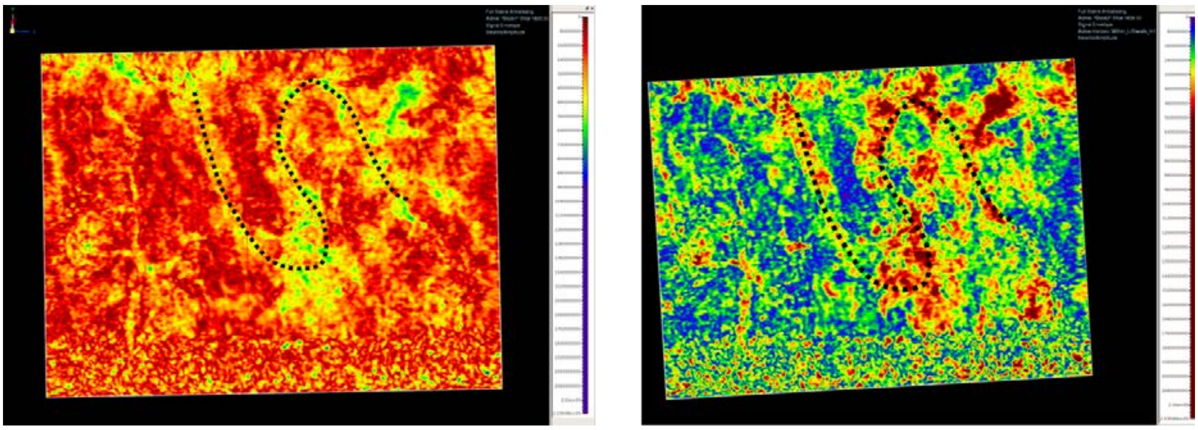

Figure 6: Signal Envelopes at time 1822 ms using different color schemes

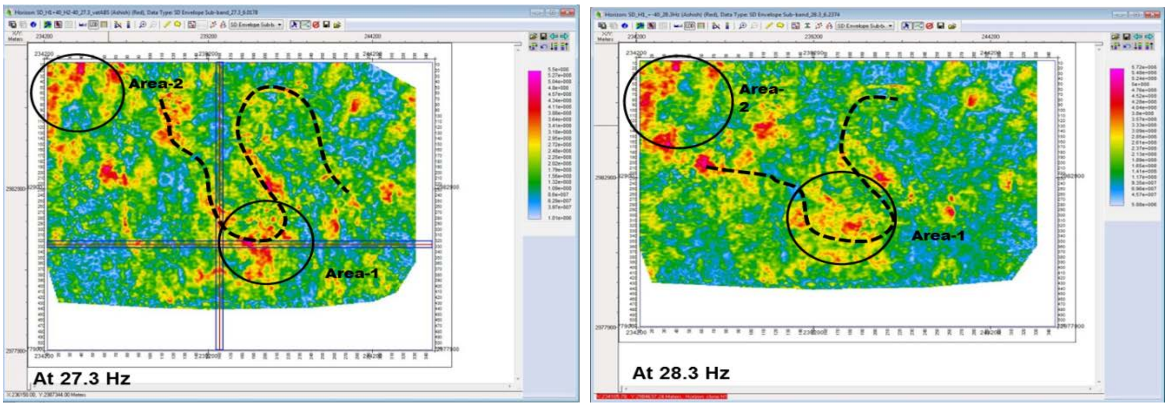

Figure 7: Spectral decomposition at different frequency generated from the tuning cube

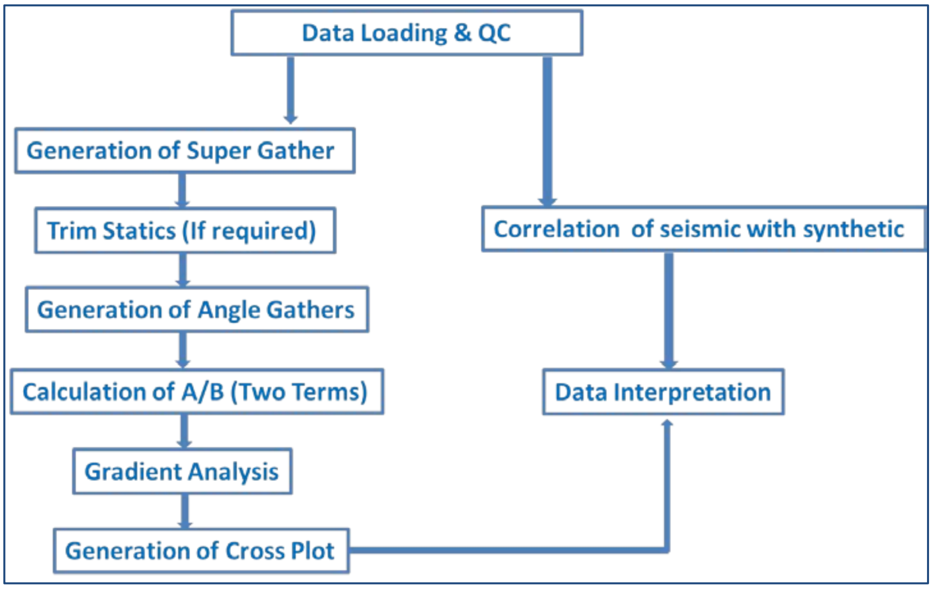

Figure 8: Complete work Flow for AVO

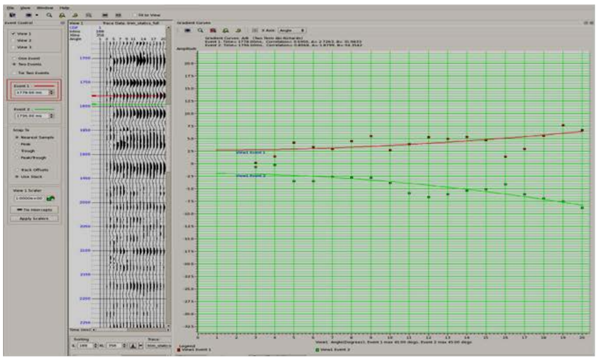

Figure 9: Gradient analysis with target time range 1778-1796ms at Inline-188 and Crossline-258

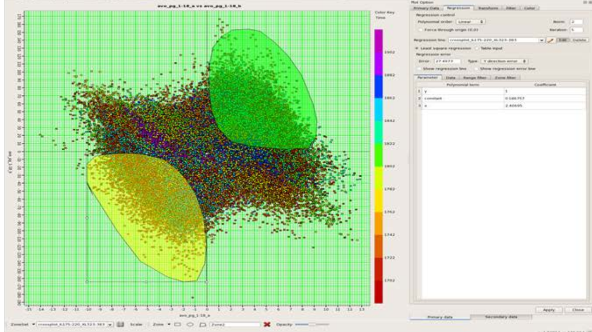

Figure 10: AVO cross-plot of 3D volume in the time

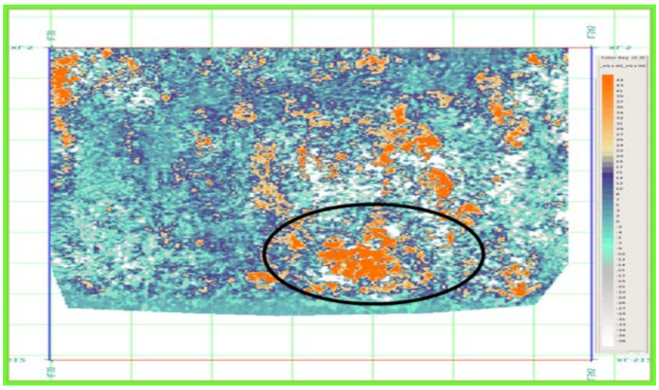

Figure 11: Product of Intercept and Gradient (A*B); Target Time Range: 1778-1796ms at Inline-188 and Crossline-258