Jaya gas field discovery by integrated geophysical workflows to delineation & characterization of subtle stratigraphic traps in Hazad channel sands of Cambay basin

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Abstract

Cambay basin is one of the highly prolific and most exploited rift basins in India. Hazad member of Ankleshwar formation is main reservoir unit with strati-structural hydrocarbon entrapment system for several small to giant size fields in this area. The sand distribution pattern is guided by deltaic depositional processes; hence the sands distribution is very discrete in nature. Identifying such subtle and laterally less extensive sand packages is challenging due to resolution limitation of seismic data. This paper presents how subtle stratigraphic traps in Hazad formation are delineated and characterized through integration of spectral decomposition, rock physics and AVO analysis, which led to Jaya gas and condensate discovery. The first step in the integrated workflow is the application of CWT based spectral decomposition method on seismic data which helped in delineating the stratigraphic channel features at different levels within Hazad interval. The identified channel features were then validated with existing wells and nearby fields data. Next, the amplitude responses of these channel bodies were characterized in terms of lithology and fluids with aid of rock physics analysis and AVO analysis. This study revealed that amplitude responds dominantly to changes in lithology than fluid. And amplitude variations within channel fairway illustrating sand thickness changes rather than hydrocarbon presence. Finally, the exploration risk was mitigated by defining the robustness of the strati-structural trap for identified Prospect by integrating the channel sand geometry and its extension against raising structural setting information. Based on this study results, an exploration well was drilled in the channel sand fairway and made Jaya discovery with good production rates of gas & condensate from Hazad formation.

Introduction

Cambay basin is one of the most prolific and heavily exploited rift basins in India. Hydrocarbon exploration began in 1958 and since then persistent geoscientific study has led to more than 90 oil and gas discoveries. To date, nearly all the major structural features in the basin have been drilled and the days of drilling simple structural closures have gone. Consequently, the exploration interest has been shifted to undrilled strati-structural traps. The study area is in Jambusar-Broach block of Cambay basin is in western part of India, the zone of interest is post rift, mid Eocene age, Hazad member of Ankleshwar formation (Figure-1).

Figure-1: Cambay basin regional map, study area & stratigraphic chart

The Ankleshwar Formation consists of two arenaceous members Hazad and Ardol separated by Kanwa shale. Hazad is the main reservoir for several small to giant size oil and gas fields. It is the lowermost member of the Ankleshwar formation and comprises a total of 13 sandstone units within the fining upward larger transgressive cycle. The Hazad member is overlain by Kanwa shale interpreted as a transgressive shale unit which acts as regional top seal for hydrocarbon accumulations. Intra-Hazad shales also form top and lateral seals for the main Hazad sandstone reservoirs. Hazad sandstones are deposited by deltaic processes, specifically, as a distributary channel within the floodplain shale. As a result, reservoir sandstone distribution is discrete in nature with a high degree of lateral variation and thus identifying subtle and laterally less extensive sandstone reservoirs is challenging due to seismic data resolution limitations.

Methodology

The study area covered by 3D PSDM seismic data with fair to good quality at the target interval of the Hazad member. As Hazad deposited at post rift stage top of structural map (Figure-2) is very flat gently rising beds towards NE side and no significant faults were there to trap the hydrocarbon. Only stratigraphic traps are possible in this interval. The effective sandstone thickness of Hazad member varies from 2m to 18m in the study area and most of the sandstone units are below seismic resolution and are laterally discrete in nature such that identifying discrete stratigraphic channels is challenging. To address this challenge, a workflow was designed by integrating the seismic interpretation, spectral decomposition, well-log validation, rock physics, AVO analysis and interpretation. This workflow helped in delineating sand bodies and their characterization to identify the stratigraphic traps in the study area. The details of the workflow are presented below.

Figure-2: Depth Structural map on top of hazad member showing that gentle monoclonal structure rising NE in study area study.

Figure-3: Frequency spectrum showed frequency bandwidth is ~10 to ~50Hz with dominant frequency is 26Hz.

Spectral decomposition

Thin reservoirs like Hazad member, are not easily mappable using conventional seismic stack data. Spectral decomposition is a proven technique for mapping channel geometries of thin sandstone reservoirs by decomposing seismic data into selective frequency channels (Partyka et., al 1999). Spectral decomposition has been continuously improving over the last two decades. The conventional method using the Short Time Fourier Transform (STFT) limits the time-frequency resolution by a predefined window length, whereas CWT method does not require pre-selecting a window length and does not have a fixed time-frequency resolution over the time-frequency space. In this study, we applied CWT algorithm on 3D seismic data with Morlet wavelet-based function by utilizing the strength of automatic window selection as a function of frequency. First, we extracted frequency spectrum of PSDM seismic data in the zone of interest and identified good frequency bands that are between 10 Hz to 50Hz with dominant frequency is 26Hz Wedge mode indicating that tuning thickness range at Hazad interval (Figure-3).

Based on seismic spectrum and wedge model, CWT was applied on the seismic data to generate frequency cubes from 12Hz to 48 Hz with an interval of 2 Hz. Subsequently, stratal slices of the frequency cubes within Hazad interval were extracted and analyzed. Some frequency slices from 18Hz to 32 Hz showed

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interesting stratigraphic morphologies. The RGB blending of three different frequencies was used to enhance the geomorphic features, which helped in identifying and interpreting meandering channels in the lower part of Hazad interval. After multiple iterations of analyzing the RGB volumes, a final cube with 18 Hz, 20 Hz, and 22 Hz was generated and used in identifying channel fairways in different depth levels within Hazad interval. One of the channel bodies shows as brightened channel in morphology named as channel-A and is located close to the proven Jambusar channel field (Figure-4).

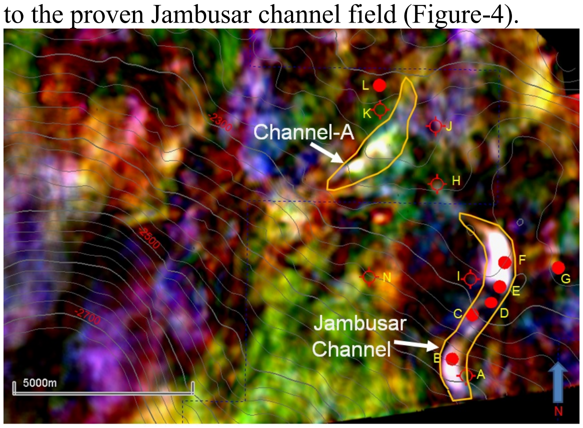

Figure-4: RGB blended spectral decomposition stratal slice map within Hazad interval showed that channel morphologies of proven Jambusar field channel body and interpreted channel-A feature.

Validation of channel sand features

The channel fairways features were also compared with conventional seismic amplitude maps, and polarity change in the seismic vertical sections. Seismic data correlation between Jambusar channel and channel-A show a similar seismic amplitude response (Figure-5). The seismic and spectral decomposition studies revealed that channels enclosed within flood plain shale facies as a stratigraphic trap. This was validated with offset wells close to channel-A. These offset wells L, K and H did not encounter any channel sandstone and the amplitude response was dim (Figure-6). This observation provides a qualitative validation of presence of shale facies outside the channel fairway forming a stratigraphic trap for hydrocarbons. This trap geometry is proven in the nearby Jambusar field within the channel sand facies. Hence, the similar characteristics of Jambusar Channel and Channel-A provided crucial well calibration and help in gaining confidence in channel-A as an exploration target.

Figure-5: Seismic arbitrary line through Channel-A and Jamubusar channel shows that Jambusar amplitude characteristics matching with Channel-A amplitude.

Figure-6: Seismic arbitrary line through Channel-A and nearby wells showing that Channel-A amplitude does not present at nearby dry wells.

Reservoir characterization

Rock physics analysis was carried out on wells with shear sonic logs with different fluid types of hazad sands well-A (Water) and well-F (Gas). Cross plot of P-impedance and Vp/Vs analysis on these wells showed that P-impedance is not able to discriminate sand shales, but Vp/Vs clearly discriminates sands from shales. Sands with different fluid types overlapped at same lower Vp/Vs range so, it’s not showed any fluid effect (Figure-7).

Figure-7: Cross plot Analysis of P-impedance & Vp/Vs of within channel wells F(Gas) and well-

A(Water) showing that both gas (green) and water bearing sands (blue) are overlapping with lower VP/Vs values for sands.

To understand fluid effect on seismic used Jambusar wells drilled in channel. Picked the horizon on near, mid, far & ultra-far angle stacks at channel reflector which showed amplitude brightening on far angle stacks as a claas-3 AVO response. This field has established OWC contact and AVO brightening effect observed below OWC sands also. It confirms that brightening of amplitude is dominantly by lithology than hydrocarbon fluid effects (Figure-8). These studies revealed that amplitude responds dominantly to changes in lithology and sand thickness within meander channel architecture rather than fluid changes (Figure-8A).

Figure-8: Channel-A amplitude response from Near to Ultra Far stacks shows the AVO brightening effect at far angle stacks which is like Jambusar channel reflector. AVO Plot showing class-3 response for Channel wells.

Figure -8A:sand thickness vs, Amplitude relationship.

Interpretation & Results

The spectral decomposition studies reveal that geomorphic channel features on stratal slices within Hazad interval. The amplitude characterization suggests that channel-A response representing negative trough amplitude corresponding to the sand. Changes of brightening of trough amplitude within Channel-A are dominantly by tuning effect due to sand thickness variation and there could be very less hydrocarbon effect on amplitude responses. This integrated workflow was used to mitigate reservoir presence risk. The lateral seal for the channel body is crucial for hydrocarbon trapping as it is considered a critical exploration risk for this channel-A stratigraphic prospect prior to drilling. Spectral decomposition demonstrated the areal extension of channel-A feature is limited and isolated within flood plain shales and structurally up-dip from proven producing fields from Hazad it is indicating that possible hydrocarbon entrapment. Based on this study results, an exploration well was drilled in the channel-A sand fairway and made Jaya discovery with good production rates of gas & condensate from Hazad channel sand (Figure-9 &10).

Figure-9: Hazad depth map with Jaya well location and Log motif of Jaya channel Pay zone.

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Figure-10: Well correlation with Jaya and its nearby wells clearly showing that Hazad channel sand not encountered in other very nearby wells.

Conclusions

The primary Objective of this study was to identify the subtle stratigraphic channel sand reservoirs in Hazad member as hydrocarbon exploration targets and mitigate the exploration risk by characterizing the interpreted stratigraphic bodies. In this paper, we showed a novel way of integrating seismic interpretation by mapping target reservoir, spectral decomposition which delineated channel-A morphology and fairways within Hazad interval and qualitative and quantitative characterization of seismic amplitudes for de-risking the reservoir presence and lateral seal for hydrocarbon entrapment. Results of this study also helped in de-risking the prospect, which was instrumental in discovering Jaya Field. The efficacy of this methodology opened the stratigraphic play potential in Hazad and other post rift strata in Cambay Basin for further exploration.

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