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Delineation of Hydrocarbon Prospects through integration of different Seismic Attributes in Kural-North Sarbhan Area of South Cambay Basin – A Case Study

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Abstract

The Hazad sands of Ankleshwar Formation in Cambay Basin are known to be good hydrocarbon producers, but towards the eastern precincts of the basin margins, as they thin out drastically, the thicknesses of the individual sand units often fall below the ambit of seismic resolution. Proper delineation of these sands remain a challenge, more so, considering their discontinuous, sporadic and heterolithic nature. In the Kural – North Sarbhan area of South Cambay Basin, exploration of these sands has been primarily limited towards probing structural traps. With exploration in the area reaching a mature stage, focus needs to shift towards subtle traps. Conventional amplitude attribute analysis have obvious limitations in the area because of inherent issues related to thinness of the sands units and it is often difficult to detect subtle changes in the seismic character that may help in understanding the clastic dispersal pattern and disposition of stratigraphic features. The probable key lies in analyzing such sands in light of various physical attributes and establish which one or combination can bring the more appropriate and objective discrimination to represent changes in lithology or rock properties. In the present study, seismic facies analysis was found to be an effective way to estimate reservoir properties by seismic attributes through pattern recognition algorithms. This enabled deciphering of certain subtle /stratigraphic features that can be potential hydrocarbon traps. Probing of such features may supplement exploratory efforts, focusing structural traps and help in better prediction of hydrocarbon distribution in the area.

Introduction

The Cambay Basin is one of the major hydrocarbon producing basins of India. This basin is an intra-cratonic rift graben situated in the western part of the Indian sub-continent (Fig. 1a, inset) and forms the northern extension of the large Bombay Offshore Basin. The Kural-North Sarbhan field of South Cambay Basin lies to the north-east of the main Gandhar field (Fig. 1a), which is a prolific hydrocarbon producer from the Hazad sands of Ankleshwar Formation, belonging to Middle to Upper Eocene age. The regional stratigraphy of South Cambay Basin is given in Fig. 1b. The Hazad member was deposited under fluvial, distributary channel environment as multi-stacked sand bodies. These sands are broadly divided into twelve units (1 to 12) from bottom to top. These individual sand units are further sub-divided into smaller sub-units which are selectively charged and producing hydrocarbons in different parts of the south Cambay Basin. In the study area, though sand units GS-4, GS-6, GS-7, GS-8 and GS-9 are reported to be present, in some part or the other, hydrocarbon production / shows have been seen mainly from sands of GS-6 and GS-8. Delineation of these sands is, therefore, crucial in deciphering further prospectivity of the area. But the thickness of the Hazad member reduces drastically from ~ 250 m in main Gandhar field to ~ 35-80 m in this part, as we approach the eastern precincts of the basin margins. The individual sand units are often not quite trackable, being nestled up mostly within one seismic cycle or so and, therefore, well below the ambit of seismic resolution. The geophysical challenge is further compounded by the discontinuous and sporadic nature of the sands which make their delineation an even more complex task.

Structural & Strati-structural entrapments are supposed to be the major plays for accumulation of hydrocarbon in Hazad sands in this area. The deep seated basin margin parallel, longitudinal faults were the likely conduits for up-dip migration of hydrocarbons from the Tankari & Broach depression, the potential kitchen, lying south-west. Subsequent transverse faulting have played major role in the formation of fault closures, suitable for entrapment of hydrocarbon in the area. However, exploration efforts, targeting the Hazad sands in the area with primary focus on structural traps, have only met with limited success, perhaps, due to lack of proper understanding of character and heterogeneity of the reservoir. Exploration today has reached a mature stage and to explore the full prospectivity of the area, the focus needs to be widened to include potential subtle traps. That is wherein the challenge lies, with the thinness and the discontinuous nature of the sands posing a major constraint on standard geophysical methods for understanding probable clastic dispersal pattern and reservoir characteristics.

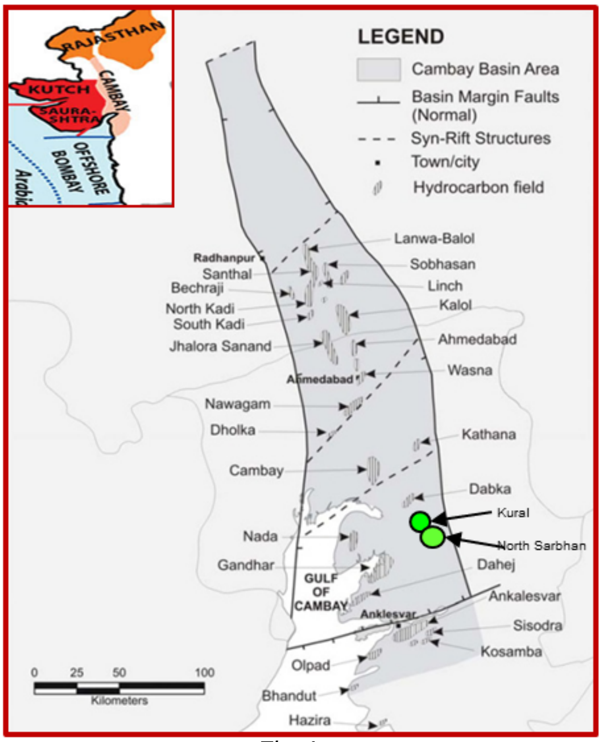

Fig. 1a

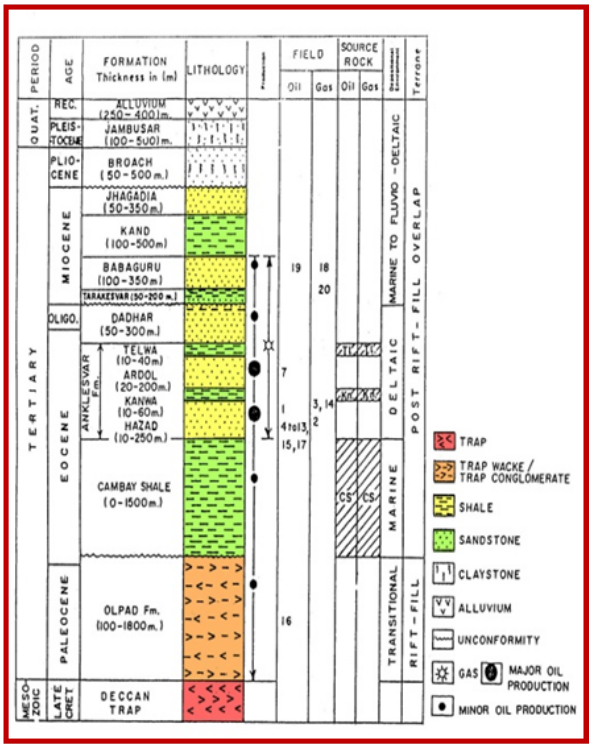

Fig. 1b

Fig. 1a: Location of Study Area with respect to Oil Field Map of Cambay Basin; Fig. 1b : Generalised stratigraphy of South Cambay Basin

Conventional amplitude attribute studies were unable to give meaningful results due to the absence of discernible subtle changes in the seismic amplitudes, particularly in the thinnest parts. Post and Pre-stack inversion studies also did not provide any meaningful information in terms of lithological variations or fluid content. Reservoir characterization approach, using seismic pattern recognition methodology, based on principal component analysis and 3D multi-attributes based classification, was attempted, through which some discernible geometrical pattern could be brought out, which, in turn, helped in enhancing the confidence on geological model building.

Methodology

The objective of the seismic facies classification is to describe enough variability of the seismic data to reveal details of the underlying geologic features, through recognition of clusters (groups) of similar facies, where the clusters can be thought to represent variability in lithology, rock properties or fluid content of the strata. Changes in any of the physical parameters of the seismic signal are reflected in a change in the values of the input seismic attribute volumes. The volume based classification technique requires multiple 3-D seismic attribute volumes as input. The output is a single 3-D seismic classification volume through the simultaneous integration of the information from multiple seismic attributes. Each seismic sample in the facies volume has a facies class number and colour assigned to it. The assumption is that two samples belong to the same class and consequently, to the same ‘seismic facies’, if they are characterized by similar values of all input seismic attribute volumes. Therefore, they are likely to correspond to a similar geological environment, defined from the selected seismic attributes.

The interval for the study was defined between the top and bottom of Hazad Formation. Five seismic attributes were used for the classification: *Full stack, Instantaneous Frequency, Instantaneous Phase, Relative Acoustic impedance* and *Signal Envelope* to establish which one or combination could bring the more appropriate and objective discrimination for describing rocks and fluid properties in the reservoir. To improve the results of the multi-attribute classification, an analysis step was carried out with the Principal Component Analysis (PCA) method, a statistical process, to analyze data redundancy and to bring several individual attributes volumes to a fewer contributory components for further analysis. This helped in understanding which attributes are contributing the most in describing the variance and trend of the dataset, the attributes dependencies and correlation. By applying this methodology on the N-samples within the interval of interest for a selected seismic attribute, the resulting principal components are sorting a different level of useful information to reveal possible undetected geological features like channel etc. The PCA components were ranked in accordance to the amount of their contribution to the data based on Eigen values contribution and cumulative inertia (Fig. 2). As a rule of thumb, components with an Eigen value less than 1 are generally assumed to provide the least contribution to the maximum spread of the data and can be eliminated. The least important PCA components were deemed to be noisy or redundant and removed from the classification process. Based on Eigen value analysis, we have selected the first three of the five seismic attributes mentioned above as input attributes for classification to carry out the non-linear discrimination for seismic facies classification.

EigenValues and Cumulated Inertia

	Eigen values	Contributions	Cumulated
Component 1	1.797434	35.948675	35.948675
Component 2	1.050828	21.016556	56.965231
Component 3	0.991491	19.829822	76.795053
Component 4	0.815217	16.304332	93.099386
Component 5	0.345031	6.900614	100.000000

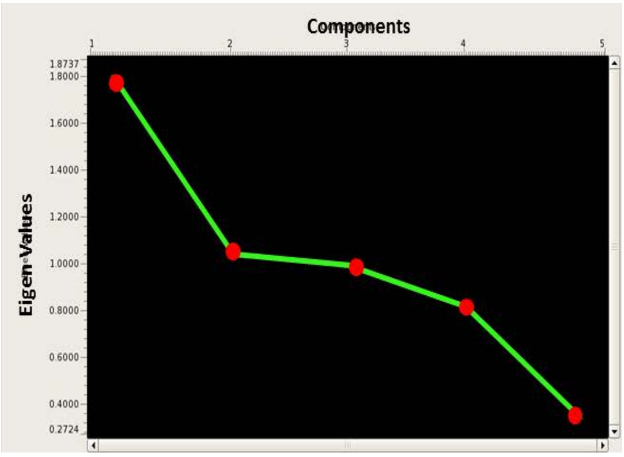

Fig. 2 : On basis of Eigen value analysis, the first three components having Eigen value ≈ 1 or > 1 were considered further for the classification process

Neural Network (NNT) method, based on the Kohonen Self-Organizing Map (SOM) methodology, one of the most suitable algorithms in Artificial Intelligence which excels in pattern recognition, was used for classification of the seismic information. This unsupervised clustering technique was found to be most effective in handling the present data set. The objective of the algorithm is to organize the data set of input seismic attributes into a geometric structure called the SOM, where natural clusters are identified on the basis of similarity in attribute types. Here, the model facies are organized as a sequence of neurons or prototype vectors (PV) in one dimension, represented as nodes, with the PVs having the same dimensions as the number of input attributes (3 in this case). The clustering starts by first specifying arbitrary nodes. The data in the input space is represented as a set of multi-attribute data vectors which are projected onto these nodes. A sample input is then chosen randomly from the set of input vectors and compared with all the nodes on the grid. The node that has the minimum Euclidean distance from the sample input is said to have the best correlation or match and is called the winner node. As a part of SOM neighborhood training, the winner node and its adjacent neighbours are adjusted towards the sample input vector. The above step is repeated iteratively, in which other winner nodes - along with their closest neighbours - are updated to become more like the selected input sample. The trained neurons are colour coded and the input data sample is associated to the colour of the neuron that corresponds to the winner node, in each case.

The result is a map of seismic facies block where identical colour indicates a similar seismic attributes and hence, a similar seismic response to the geological environment. The classification process was carried out with 5, 7 and 9 classes, each time with 50 iterations and sampling of 4x4. It was found that the one with 7 classes was optimal to best represent the data variability in the area for seismic facies depiction (Fig. 3).

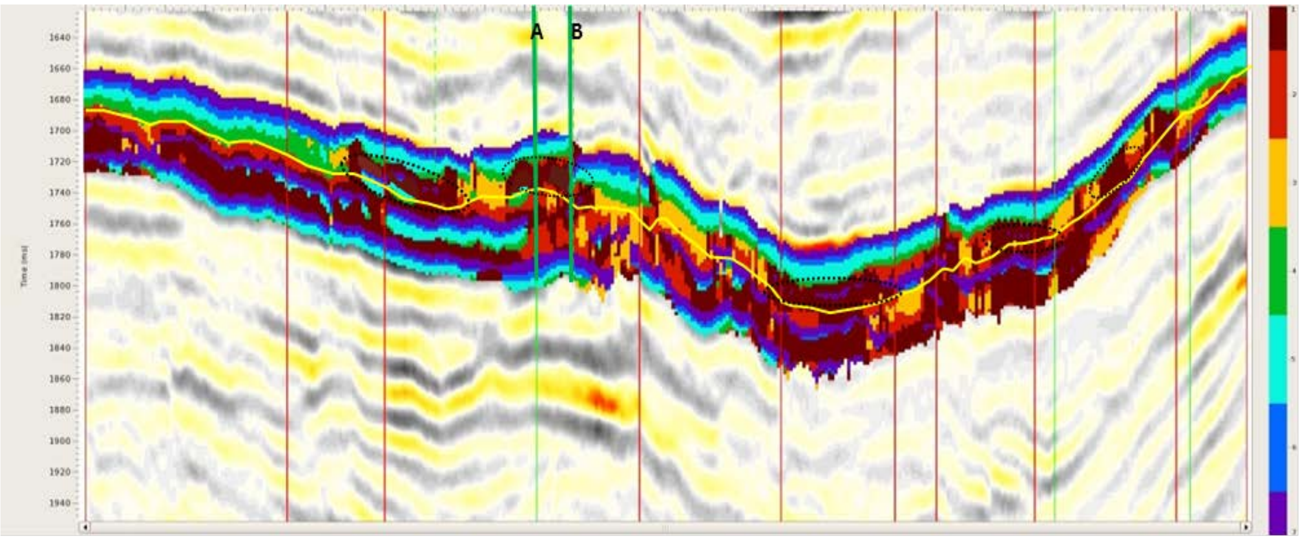

Fig. 3 A random line showing the facies block in the zone of interest, realized with 7 classes. Note the distribution of the maroon facies (encircled in dotted black) above the yellow horizon which has been encountered by hydrocarbon bearing wells A & B and may be associated with hydrocarbon prospectivity.

Outcome and Validation

Stratal slices were generated between the sequence boundaries mapped, *i.e.,* Hazad top and bottom to examine the Facies Block and to explore it at a sub-seismic resolution. Because they are geologically compliant and do not depend on seismic polarity changes, they become a good source of information to detect and understand stratigraphic events and reservoir architecture. The Facies Block, realized with 7 classes, was examined across 20 stratal slices to view the spatial distribution of the facies within the interval of interest, for possible detection of geologic features or events. An impression of a channel morphology was seen in the central part of the study area, the definition of which becomes particularly conspicuous in the map extracted for Slice No. 7 (Fig. 4a) and to a lesser extent for the slices thereabout (Slices 5, 6, 8 & 9). These horizon slices (Slices 5 to 9) are found to correspond to GS-6/GS-8 sand units. Such a channel feature has not been detected hitherto during the previous studies carried out in the area and could be an important target for exploration of subtle stratigraphic traps in the area.

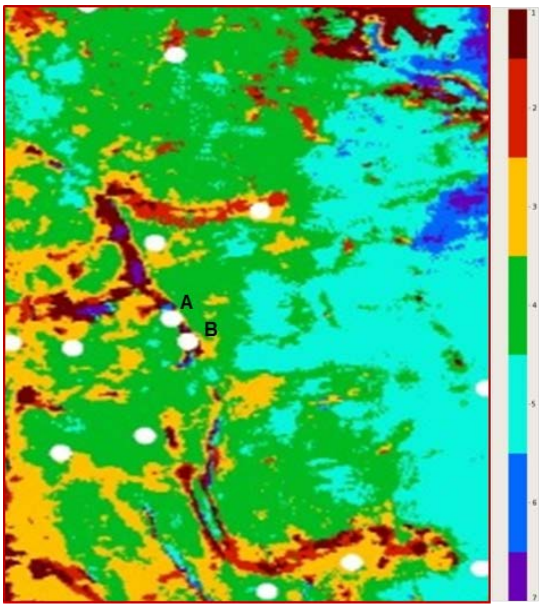

Fig. 4a

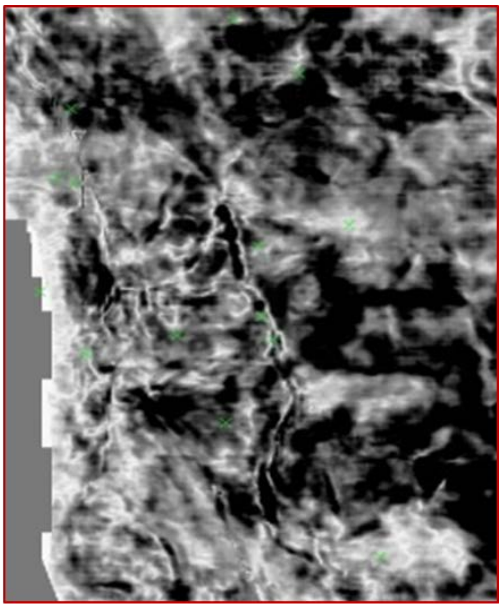

Fig. 4b

Fig. 4a : Depiction of a channel morphology clearly seen in the seismic facies map, with two hydrocarbon bearing wells, A and B, falling on the channel axis

Fig. 4b : The existence of the channel is corroborated through spectral decomposition analysis and is found to have a tuning frequency of ~ 40 Hz

The existence of the channel was sought to be validated using Spectral Decomposition studies, to characterize the time-dependent frequency response of the sub-surface within the zone of interest for better imaging the channel (if it existed) and the geologic discontinuities across it and also map its temporal bed thickness. By using the Discrete Fourier Transform (DFT) method, spanning an adequate window length to cover the seismic event corresponding to the channel, the channel feature was reasonably brought out (Fig. 4b), though resolution of some parts of the channel may have been affected by the averaging effects inherent in the fixed-window method. The tuning frequency was found to be ~40 Hz.

Interpretation and Integration

As seen above, Seismic Facies analysis has thrown up some interesting pattern in the Seis-Facies classification map, where a facies class is seen largely aligned along conspicuous channel morphology (*Fig. 4a*) and is further corroborated by Spectral Decomposition studies (*Fig. 4b)*. The said facies class aligning along the channel axis has been found to correspond to geological feature associated with localized extra development of seismic event, seen as splitting of cycle (*Fig. 5*). Two hydrocarbon bearing wells, A and B, incidentally fall on the axis of the channel and have their pay zones (GS-6/GS-8) corresponding to similar seismic signature and facies class. It may, therefore, be surmised that hydrocarbon occurrence is likely wherever there is an extra development of seismic event along the channel, as suggested by the said wells. The facies class encountered along the channel is thus provided with a reasonable validation for reservoir character and hydrocarbon potential. Based on favorable structural disposition and facies class colour (maroon), certain pockets in the channel axis are likely to have hydrocarbon potential. Such prospects can be probed to explore the hydrocarbon prospectivity of the reservoir within the channel bearing distinctive seismic facies class and if successful, can open up new vistas for looking beyond obvious structural traps for exploration in and around the area.

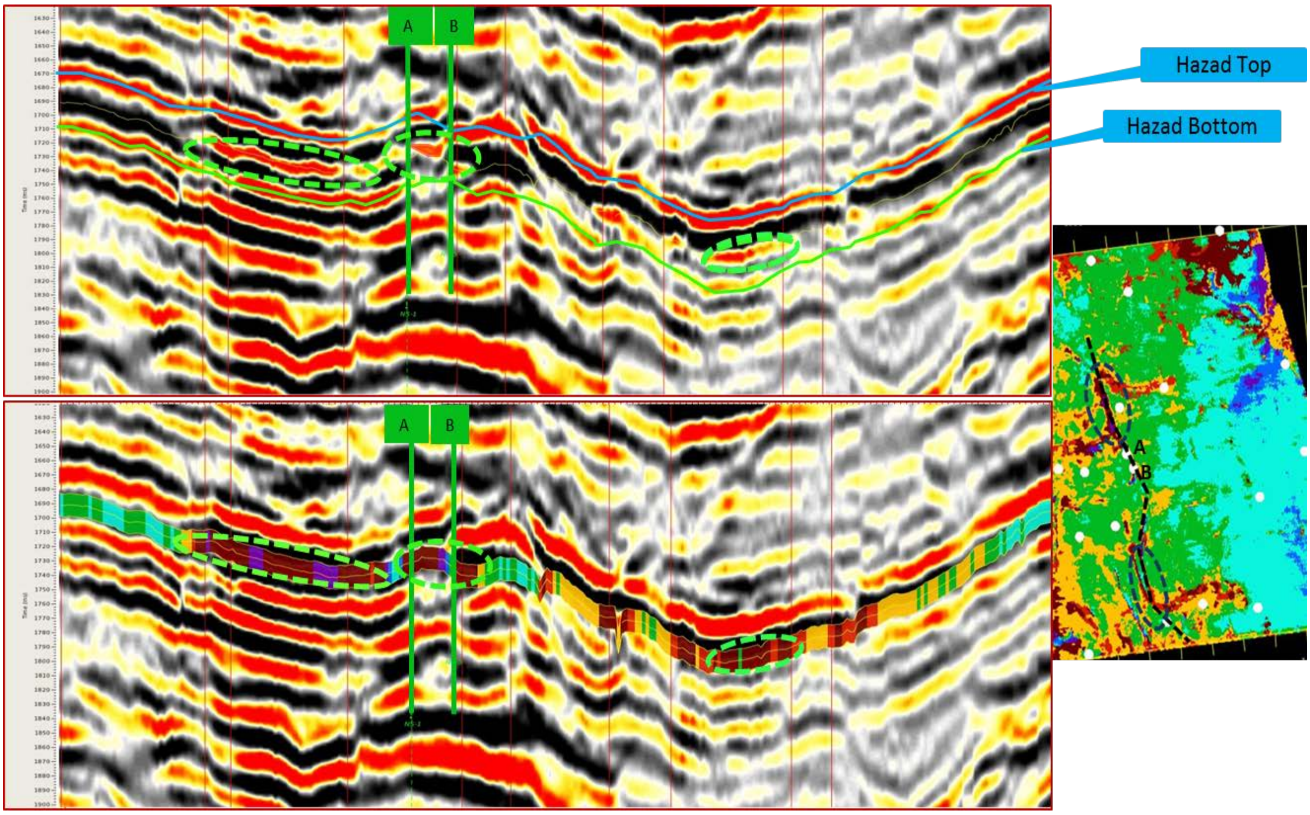

Fig. 5 : Random Line along the Channel Axis passing through hydrocarbon wells, A and B, show seismic facies class (maroon) in the prospective zones (encircled in dotted green) similar to ones encountered in pay zones. Splitting of cycle is seen in the corresponding seismic signature (in the upper panel) against this facies class, which may be suggestive of localised development of reservoir facies associated with hydrocarbon occurrence

Conclusions

The challenges with regard to sub-seismic thicknesses of the Hazad sand units and their discontinuous nature were sought to be circumvented through seismic facies studies, using Principal Component Analysis and 3D seismic multi-attribute volume classification and examining the output seismic facies volume with stratal slicing. Distinct channel morphology, previously undetected in the study area, has been brought out through the present work, which is further corroborated by spectral decomposition analysis. On the seismic section, splitting of cycle, due to localized extra development of seismic event, is seen in parts of the envisaged channel against a specific seismic facies class and it can be surmised that hydrocarbon occurrence is likely wherever such splitting is observed along the channel, as suggested by hydrocarbon bearing wells lying on the channel axis. Exploring such subtle / stratigraphic targets may open up new vistas for exploration strategy in the area and supplement exploratory efforts hitherto made in the area on the prevailing concept of hydrocarbon association mainly with structural elements.

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