Stratal Slice Method and Delineation of Thin Sand Geometry in Cambay Basin, India

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Summary
The Kalol Formation in Cambay basin is mainly composed of eleven pay sands, namely K-I to K-XI from top to bottom with intercalation of thin sandstone/siltstone, shale and coal. In some areas, thin channel sands deposited above and below the coals, are the main producer, but it is hard to classify in vertical section of normal seismic data, due to its resolution issue.

Zero-phase wavelets are deemed superior in seismic interpretation as its many advantages, including wavelet symmetry and best resolution, described by Wood (1982) and Brown (1991). However, zero-phase wavelets, designed for optimal mapping of single interfaces, become archaic to detect Kalol reservoir geometry, as most reservoir facies in Kalol Formation are inter-bedded and small in vertical dimension and many are below seismic resolution.

A case study from Kalol Formation of Cambay Basin area provides an example that requires special attention for slicing, phase rotation considerations for optimal depositional imaging.

1. Introduction

Cambay Basin, explored since 1950s, is one of the most prolific hydrocarbon basins situated in western part of India. Exploration in Cambay Basin is fairly mature, most of the field-scale geologic and depositional prospects based on structural component has already probed and substantial amount of hydrocarbon resources have already been converted into initial in-place volume of hydrocarbons. With the development of high quality 3D seismic, the exploration targets are being shifted from field scale to reservoir scale, industry is turning its attention to reinterpretation of thin bedded stratigraphic features, which was over looked earlier.

Thin bedded reservoir zone of Lower Eocene Kalol Formation in study area were tested as Hydrocarbon bearing in Well A1.

On well-log, Kalol Pay exhibits dominantly coarsening up log motif, characterized by low natural gamma and low density (Fig.1.1).

3D seismic data of Study area has been examined to test the benefits of 90° phase rotation for identification of thin-bedded reservoir geometry. A phase rotation of 180° will produce a reverse polarity version of the input trace, while a ±90° rotation will alter the seismic trace in such a way that peak or trough on the input trace will become a zero-crossing on the output trace, and vice-versa (Fig.1.2).
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For thin bedded reservoir, where thickness is below the resolution limit and hard to distinguish from the amplitude background, are difficult to identify in vertical section of 3D Seismic. One strategy to map depositional systems with high resolution is to change the emphasis of seismic interpretation from vertical sections to horizontal sections.

In order to analyze thin bedded reservoir geometry in Lower Eocene Kalol Formation, conventional slicing method was first applied to depict the channel geometry. As per study it has been observed Stratal Slices produces more desirable result, especially in case of thin bedded reservoir, where reservoir thickness is below the resolution limit and are difficult to identify in vertical section of 3D Seismic.

2. Geology of the Study Area

Cambay Basin has been characterized as a narrow elongated intra-cratonic rift-graben surrounded by Saurashtra Uplift in the west, Aravalli-Delhi Fold Belt in north-east, and Deccan Craton in the south-east. The entire basin is divided into five tectonic blocks based on transverse fault systems namely, Narmada–Tapti, Jambusar–Broach, Tarapur–Cambay, Ahmedabad–Mehsana and Sanchor–Patan (Raju et al., 1971; Biswas, 1987). The study area, very near to well-known Sanand field, in Ahmedbad-Mehsana Tectonic Block (Fig.2.1).

The lithostratigraphy of different blocks of the Cambay basin (Fig.2.2) has been described by various authors (Bhandari and Chowdhary, 1975; Biswas, 1982, 1987; Pandey et al., 1993; Kundu et al., 1997). In this Ahmedabad–Mehsana tectonic block Deccan Trap forms the basement which is overlain unconformably by Olpad Formation (Datta Gupta et al., 2012). It is further subdivided into two units designated as Older and Younger Cambay Shale Formations. The Younger Cambay Shale has an unconformable relationship with the overlying Kalol Formation. The Kalol Formation has a conformable relationship with the overlain Tarapur Formation.
3. Estimating Vertical Resolution from Seismic

Resolution of thin layers is dependent on frequency content of seismic data and may be prominent at the seismic tuning frequency.

Fundamentally, the tuning thickness is determined by the compressional velocity of the unit and the wavelength of the seismic pulse ($\lambda$).

$$\text{Tuning thickness} = \frac{\lambda}{4} \quad \text{(Widess, 1973)}$$

$$\lambda = \frac{V_p (\text{m/s})}{F_d (\text{Hz})}$$

$$F_d = \frac{1}{T}$$

Where, $\lambda$ =wavelength (m), $F_d$ = dominant frequency and $T$ = ‘period’ (measured in seconds from trough to trough or peak to peak) on a seismic section (Fig.3.1).

A worked example based on our study area shows,

$$T = 0.030 \text{ s}$$

$$\lambda = 64.54 \text{ m} \quad \text{(if } V_p = 2130 \text{ m/s})$$

$$\text{Tuning thickness} \approx 16.13 \text{ m (TWT)}$$

As per well log data, the thin bedded reservoir in tested well (A1) is lying just above a thin coal marker, hence special concentration and quality check has been carried out to achieve a consistent tie in each coal layer between the well and the seismic volume. In section, the Gamma Ray (GR) curve is displayed for the reference of litho logical variations.

Typically, sandstones have a low AI (acoustic impedance) and shale profile have high AI. In an inter-bedded Sandstone-Shale-Coal Eocene succession in the Cambay Basin area, well log data show coal layer has low AI as compare to sandstone and shale, however sandstone have low acoustic impedance (AI) to shale or high porosity zone relative to low porosity. Three key horizons H1, H2 and H3 namely Kalol Top, Coal Top and Coal Bottom were mapped throughout the 3D post stack migrated seismic data volume and interpolated to obtain continuous horizon surfaces for scanning of various seismic attributes.

Seismically, the reservoir zone is difficult to resolve as it masked by underlying coal layers and they are beyond seismic resolution. When applying 90° phase rotation of this seismic data, then it can be found that the main lobe of strong amplitude coincides with coal and sandstone detected by GR and Density log. Sandstone bodies do not have simple relationship with seismic events. A match between seismic and synthetic profiles of phase rotation volume shows a better tie between seismic amplitude traces and litho logy-indicative logs. (Fig.4.2)

4. Well to Seismic Tie

Synthetic seismograms were generated for well A1 to link logs (in depth domain) to time domain seismic data and to observe the seismic character of sands within the area (Fig.4.1).
5. 90° phase rotation of 3D Seismic Data

Interpretive advantages of zero-degree phase data include wavelet symmetry, centre lobe (maximum amplitude) coinciding with reflection interface and higher resolution. Zero phase data are ideal for identification on an unconformity or in a thick bed.

For thin bed reservoir the simplest and most effective way to improve interpretive value of amplitudes is to apply a 90° phase rotation to the zero-phase data so that seismic traces are converted from reflectivity series to relative impedance series (Sicking 1982; Zeng & Backus 2005a, b). In 90° phase rotation data maximum amplitude correlates to the centre of a thin bed as compared to zero phase data.

In an interbedded Sandstone-Shale-Coal Eocene succession in the Cambay Basin, a 90° phase rotation of nearly zero-phase seismic data significantly improves lithologic and stratigraphic interpretation. Although seismic data resolution is not improved, the seismic profile is transformed into a superficially-geologic section similar with impedance one, which makes interpretation of thin bedded reservoir geometry more imaginable and more intuitive.

After calibrating normal seismic data with well A1, it has been observed, oil-bearing sandstone centre is consistent with the position of zero point, which means that the dislocation exists between the strong amplitude detected in seismic profile and oil-bearing sandstone in study area. In order to get intuitive relationship between sandstone and seismic reflection event, it is necessary to make a phase rotation of seismic data. After application of 90° phase rotation, it can be found that the main lobe of strong amplitude trough perfectly coincides with sandstone detected by GR (Fig.5.1). Therefore, geologic sense of strong amplitude is confirmed.

6. Stratal Slicing & Seismic Amplitude Extraction

Unfortunately, although many reservoir-scale (well-to-well scale) features can be detected in well log data, however few such features can be resolved and interpreted in the vertical section of 3D seismic, because of the data’s limited bandwidth.

There are many different ways to view a 3D seismic volume in a horizontal section. Time slices and horizon slices (Fig.6.1) are currently the most commonly used seismic-surface displays to extract stratigraphic information. However, for depositional strata, where thickness changes occur, both methods show their limitations. A refinement of this idea is to use “stratal slices” (Zeng et al., 2001). A stratal slice, proportionally between two references horizon, enable a more accurate analysis and useful for high-resolution seismic imaging of thin depositional systems.

To implement horizontal-view seismic interpretation, we must pick geologic-time surfaces (or stratal surfaces) from 3-D seismic volumes so that seismic attribute maps across these fixed-geologic-time surfaces can be analyzed in terms of depositional systems. Zeng (1994) proposed the method of stratal slicing, where an extracted surface follows a fixed-geologic-time surface and useful for high-resolution seismic imaging of thin depositional systems. Posamentier et al. (1996) offered a similar approach, known as proportional slicing. Stratal slicing improves seismic-surface display mainly by making slices proportional between geologic time-equivalent seismic-reference events.

Sometimes, in case of strati-structural reservoir a horizon slice can depict a part of thin bedded channel geometry in an area, where strata are almost sheet like and without faulting. However, limitations occur due to thickness change across the area. Since Horizon tracking is time consuming; only the key horizons are typically tracked. Therefore, only a small part of the available data is usually analyzed. To analyze more data, horizons are often shifted, which is in most cases only valid in the vicinity of the original horizon. A stratal slice, proportionally between two references horizon, enable a more accurate analysis and useful for high-resolution seismic imaging of thin depositional reservoir geometry. Stratal Slices produces more desirable result, where reservoir thickness is below the
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resolution limit and are difficult to identify in vertical section of 3D Seismic.

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Selecting the right slicing method for extracting geomorphic patterns properly from the 3D seismic data is therefore crucial.

A time slice, sampling the thickest part of the reservoir sand at TWT 1152 ms, unable to depict the reservoir geometry in most of the study area because of significant structural dip and faulting. A horizon slice, made 24 ms above reference Coal Top, depicted part of channel geometry in an area where strata are almost sheet like and without faulting, limitations occur due to thickness change across the area. So, the slice is unable to reflect the planar variation of sand-body. However, stratal slice is proportionally interpolated between two interfaces according to thickness, it considers sedimentary space variation with position and decreases error, therefore, it is more reasonable than time slice and horizon slice.

The thickness of stratal slices varies depending upon the thickness variation of the formation. Based on well to seismic correlation 14 stratal slice has been generated in between Kalol Top and Coal Top (as well log analysis indicates the reservoir zone is in between Kalol and Coal Top). The slices are highlighted on the well to seismic section (Fig.6.2) to show position of representative stratal slices in two-way time and their relationship with seismic events, and well log characteristics. The thin bedded channel sand body in the area is characterized by low natural gamma and low density. Sliced based amplitude anomaly (Extracted Value Amplitude), predict a subtle channel geometry. The highlighted slices demonstrate, out of 14 slice, only 2 slices (Slice 5&6) are coincide with reservoir trough as identified from well to seismic relation, depicted a better view of channel geometry.

The selection of the time window is also a key factor of extracting seismic attributes. A set of amplitude stratal slices in the formation (Fig.6.3) reveals the presence of a meandering fluvial system.
7. Application of Frequency based slicing attributes

The frequency of the seismic data plays very important role in seismic attribute extraction method.

For typical broadband seismic data, geologic thin layers may not identifiable at one frequency or may be prominent at the seismic tuning frequency that relates the actual layer thickness. It is important to understand seismic pulse and its decomposition of spectra that can reveal the acoustic response related to certain thicknesses. Resolution of thin layer is dependent on frequency content of seismic data, hence stratal slice of data volume in a particular frequency range is effective to identify thin layer reservoir geometry and sedimentary bodies, like thin bedded river channel.

Amplitude Extraction of different frequency band, represent difference in channel is more obvious, the high frequency data is more sensitive to thin strata and low frequency data for thicker strata. Higher frequency slices above the band limit contain more noise because the signal-to-noise ratio normally decreases with increasing frequency.

A set of amplitude slices in a particular frequency band (near the dominant frequency range) reveals the presence of a meandering fluvial system (Fig.7.1).

In study area the sensitive frequency range is 19Hz-39Hz. Although, every single frequency section cannot reflect the whole picture of sedimentary bodies, however by a series of continuous frequency section (28Hz-32 Hz) and their animation confirms presence of subtle meandering channel geometry in study area.

8. Conclusion

Standard zero-phase seismic data are less desirable for litho logic interpretation of thin bed. Phase rotation of seismic data can be critical for thin bedded reservoir-scale analysis and prediction.

For depositional facies analysis, time slice and horizon slice can be treated as special cases of stratal slicing when a flat lying or sheet lying formation is encountered. The selection of the time window is also a key factor of extracting seismic attributes. If the selected time window is too small, the slice which is used to extract seismic attributes will lose useful geological information. Conversely, if the time window is too large, the slice will include too much unnecessary geological information. Stratal Slices produces more desirable result, where reservoir thickness is below the resolution limit and are difficult to identify in vertical section of 3D Seismic.

According to study, the frequency of the seismic data plays very important role in slice based attribute extraction method and in a particular frequency range can delineate thin bedded channel sand geometry, thereby leading to more optimal positioning of well locations with minimized geological risk.

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