SEISMIC VELOCITY MODEL BUILDING: AN AID FOR BETTER UNDERSTANDING OF SUBSURFACE- A CASE STUDY FROM CAMBAY BASIN, INDIA

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Summary

A seismic velocity model is necessary to map depth and thickness of subsurface layers interpreted from seismic reflection images. Depth conversion is a way to remove the structural ambiguity inherent in time and verify structure. A good approach to depth conversion, especially in a complex geological environment, is first to perform a depth migration with a velocity model optimized for structural imaging, second to render the resulting laterally positioned depth image to time using the initial velocities, and finally to convert the depth-migrated seismic data (now in the time domain) to true depth using a true vertical velocity model. Velocity modeling is a step forward beyond direct conversion because velocity information adds two features to the conversion to depth. First, the velocity model can be evaluated numerically, visually, and intuitively for reasonableness (i.e., tested independently of its ability to predict depth, thus increasing its reliability), something that cannot be done with a global time-depth correlation. Second, velocity modeling enables the use of velocity information from both seismic and wells, providing a much broader data set for critical review and quality control.

Key words: TD relationship, raw depth grid, velocity transformations, slope relationship, mis-tie analysis, error correction.

Introduction

Present study deals with velocity modeling of Kalol field with the help of VelPAK module of Kingdom Suite by average velocity method derived by stacking and interval velocities of the area. More particularly it describes an integrated methodology of velocity modeling by using TD relationship and time surfaces to have a better understating of sub-surface which is most useful for further G & G activities.

Kalol Field:

Kalol field, located 20 km NW of Ahmedabad is on production since 1968 and produces oil and gas from nine main pay zones The field has an aerial extent of 300 sq km. The field is broad and is flanked by two important intra-basinal depressions, namely Wamaj Low in the West and Nardipur low towards east. The field has a prominent high oriented NNW-SSE located towards the central and western portions which appears to be a resultant of transpressional tectonism. As per the figures of 1.4.2012 the field has In Place (PD) reserves of 149.86 MMt of oil and 7989 MMm$^3$ of free gas with an Ultimate (PDD) component of 22.55 MMt oil and 6465.5 MMm$^3$ free gas component. Pay Zone II, III and IV are both oil and gas bearing while Pay zones V, VI+VII, IX+X, XI and XII are oil bearing.

Tectonically, Cambay basin is divided by a series of NE-SW trending faults into five prominent tectonic blocks / sub-basins which are bounded by transverse basement faults, namely Sanchor - Patan, Mehsana - Ahmedabad, Tarapur -Cambay, Bharuch - Jambusar and Narmada – Tapti blocks from north to south. The area of the current study falls in the Ahmedabad sub block. The NE-SW trending transverse faults are basement faults and were reactivated in the Middle Eocene-Oligocene and Late Miocene ages. Strike slip along the faults resulted in segmentation of the basin, localized uplift and erosion and development of the main structural hydrocarbon traps (Biswa, 1987; Zutshi et al., 1997). The Ahmedabad tectonic block has an important doubly plunging anticlinal
trend, namely, Kalol - Ahmedabad - Wasna trend. It is over this trend that main Kalol field is located.

Figure 1: Index map showing study area

Figure 2: Base map showing wells taken for the study

**Basic Theory:**

There are mainly two methods namely Dix equation method & Smooth function method for converting RMS velocity function to an interval velocity function. In present study Dix conversion is used. A brief of this method is given below:

**Dix Equation Method**

This is the old standby recognized by most geoscientists and used to compute the interval velocities posted along with stacking velocities across the top of a stacked section. With Dix Equation conversion, a single interval velocity is found between any two knees within the RMS velocity function using the equation:

\[
V_{int}^2 = \frac{(V_{rms,1}^2 - t_1^2) - (V_{rms,2}^2 - t_2^2)}{t_2 - t_1}
\]

Interval velocity functions are converted to RMS functions with the equation:

\[
V_{rms}^2 = \frac{1}{\Delta t} \sum v_i^2 \Delta t_i
\]

The interval velocity function consists of a series of blocks, with each block having a constant velocity, giving the Dix Equation Method several interferences:

- For each single point in the RMS velocity function, there must be two points in the interval velocity function to constrain the function to a uniform velocity over an interval. Converting from RMS to interval velocity and back again with Dix Equation does not yield exactly the same function as started with because of the additional points added. The result is close, but not exact.

- With Dix Equation, blocked interval velocity function can have large velocity discontinuities between blocks. During migration or time-to-depth conversion, adjacent seismic data samples might be processed with radically different interval velocities introducing undesirable artifacts into the output section.

Further smooth function is used which gives conceptual best fitted curve for velocity. As it is seen from the Figure 3 that original RMS function stays out as it is not suited with the conceptual velocity curve. It has to be modeled to get the optimum velocity in the range of velocities calculated at the well point by changing the Dix conversion factor or percentage. The comparison of these two conversion method are given in Figure 3.

Finally, for the extraction of average velocity from interval velocity in time the following equation is used:

\[
V_{avg}[i] = \frac{[V_{int}[i-1] + V_{int}[i] + V_{avg}[i-1]]}{3} + 0.5 \cdot \frac{((V_{int}[i] - V_{int}[i+1])^2 + (V_{int}[i] - V_{int}[i-1])^2)}{(i-1)[i]}
\]

Where \(V_{avg}\) & \(V_{int}\) represent average and interval velocities.
The Figure 3, 4, & 5 represents the relationship of depth and velocity as derived by velocity modeling. The difference between modeled and actual velocities can be observed from the curve. The main aim of any velocity modeling is to reduce the gap between modeling and actual curves. (Figure 4)

In Figure 5(a & b) it is demonstrated that limitation of any velocity modeling if velocity model is forced to produced zero depth error at well point it loses its controls other than the well point and in second case if it will be tried to make the velocity model which ties over all surface then the non-depth zero error will be produced. The velocity model build by second case will be superior if the non-zero depth error is minimum. One of the major causes of error in depth predictions is misties in time between seismic horizons and the corresponding geologic well pick in time. Direct methods hide these errors by forcing the wells to tie, thus altering the velocity provided independently by the well and creating a new back-calculated velocity to ensure a correct tie. This means that the translation function is now no longer simply a model of the true velocity in the ground rather it is a composite correction factor.

Methodology:

In order to create depth maps at desired stratigraphic levels Velocity Modeling was undertaken using the available stacking velocity data. The primary protocol followed was to convert Time-Mapped horizon into Depth ensuring that the resultant map did not violate the depth at which stratigraphic level was being encountered in a well. A data bank of 239 wells was used, spread evenly across the seismic volume, to ensure that sufficient control points were available for the resultant depth grid to bring out the horizon spread within volume. These control point were used as guides for establishing a “slope” relationship between two known points at well bore and taking time grid trend.

Data utilized:

- Well data (239 vertical wells)
- Well Markers
- Mapped and Gridded Time Seismic Horizons
- Seismic Velocity Cube (Stacking Velocity)
- TD / Sonic Log (77 verticals wells)

The desired data, namely, seismic survey, well, well picks, TD or Sonic logs, Velocity volume, mapped horizons / grid were imported into the VelPak module for velocity modeling. It is to be ensured that the time range of the
imported grid in VelPak matches with those in actual interpretation. Later, Velocity Module is used for displaying the staking velocities with respect to activated grid. After this the staking velocities are converted to interval velocities using the Dix Conversion. The resultant Interval Velocity volume is used to extract average velocity corresponding to active time grid in X,Y and Z format where Z is the average velocity while X, Y are the co-ordinates of Inline and Cross Line cross overs in the active time grid. Validation of these average velocities at well positions is shown in Fig.7.

These X, Y and Z values are gridded using available gridding algorithms (Collocated co-kriging or global method), during this procedure the corresponding Time Grid is used as a Parent Grid which provides control trend for the velocity gridding (Fig.13). This grid is further validated at well point to have a better control for depth conversion. Example of this validation is given at well location ‘A’ in Fig.7. Later the depth conversion is done using Simple Average Velocity method where above gridded average velocities (Fig. 13) are used. This output is used to produce Raw Depth Grid.

It is important to define the stratigraphic levels at which the depth needs to be created. These layered definitions are propagated at each of the chosen well to ensure uniformity in establishing a time depth relationship (Fig. 8).

Prior to advancing in depth creation it is imperative to establish a “Tie” between well picks / formation top and Raw Depth Grid which will quantify the ‘mistie’ or the ‘error value’ at each well position (Fig. 8& 9). These error values are further grided to generate error grid. This “error grid”, linked to a particular stratigraphic level (Parent Grid) is used to create Final Depth Grid by compensating these error factor/ values in the Raw Depth Grid extracted earlier (Fig.10). The Final Depth Grid, thus generated, is exported to use for map generation purpose.

It is also advisable to export, independently, the error and average velocity grid so that these too can be mapped for the purpose of quality check.
Results & Discussions:

This is a case study and gives the practical approach for velocity modeling which can be further utilized for time to depth conversion.

The depth map of K-IX level has been created using well tie with 184 wells of Kalol and Wadu fields (Fig.11). The position of prominent high and lows remains intact but there are places where the axis of the lows appears to have slightly changed. The axis of low, located towards the north eastern portion of the area, changes from E-W to NNW-SSE. Within the large flat area occurring towards central east portion of the map, few lows appear which were not so clear in the time domain map. The high and low justify the mapped faults. At K-IX level, there is a good match (around 97%) between the Formation tops and the depths values read from the depth map at well positions. Thus the overall slope picture created on depth matches with that observed in time.

The depth map at K-III level has been created using 185 wells of Kalol and Wadu field which were falling within the area (Fig.11). The time and depth map appear to be quite similar and most of the geomorphic features identified in time remain preserved in depth also. The axial trends of features have maintained their azimuthal relationship in time and depth. However at local levels there are small pockets in which the lows have widened.
while the high points have converged. These changes are localized and subtle. The high and low justify the mapped faults. Thus at K-III level, there is a good match (around 98%) between the Formation tops and the depths values read from the depth map at well positions.

Conclusions:

For proper reservoir development it is important to demonstrate subtle stratigraphic surficial undulations which help in accurate demonstration of sub-seismic faults and fault sealing efficiencies. The depth pictures obtained by average velocity modeling better demonstrate the sub surface undulations at stratigraphic levels. The depth matching at each well location (having K-III and K-IX tops) was performed for validation of this method which comes around 98% for K-III and 97% for K-IX levels. Moreover it is inferred from the study that the proper conditioning of sonic logs, TD relationship, velocity volumes & selection of right methodologies are utmost important to build a right picture of sub surface through seismic velocity modeling. Validation away from well location was also done to know the depth pattern between different well locations. It has been seen from the time and depth maps at these levels that the preservation of major structures (deeper and shallower event) are retained. Sometimes it is very tough to have the same picture of structure in time and depth due to inaccurate velocity volume and improper velocity modeling methodologies. These methods generally insist the depth surfaces to tie with the well tops due to which distortion of overall depth picture was introduced. While making velocity model of any area one should choose the methodology as per data availability, e.g. if sonic logs are not conditioned then better to use TD relationship of the wells.

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