A Comprehensive Approach to Velocity Modeling for Domain Conversion : A Case Study

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Abstract

An accurate velocity model is necessary to prepare structure map and thickness of subsurface layers interpreted from seismic reflection images. In order to propose some new borehole locations in the development field under present study, reliable domain conversion of the time structure maps was required. For this purpose, the most reliable seismic velocity available, i.e., PSDM (Pre-stack depth migration) interval velocity and time-depth relationship (TDR) derived from 'Well to Seismic Tie' were incorporated. Time horizon correlation was performed on CRAM (common reflection angle migration) processed seismic data which is supposed to have improved imaging. Five lithostratigraphic layers were considered for the seismic calibrated well based interval velocity modeling. All the time horizon maps were depth converted using the modeled interval velocity. The depth maps were found to be structurally consistent and the depth residuals at most of the blind wells were well within acceptable limit of less than 1% of the corresponding depth.

Introduction

The Nada field of Cambay basin, of nearly 45 Sq. Km, is located 50 km south-west of broach town, Gujarat (Fig. 1). The Cambay rift basin, a rich petroleum province of India, is a narrow, elongated rift graben. Seismic and drilled well data indicate a thickness of about 8 km of tertiary sediments over the Deccan volcanics.

Scaled to time PSDM seismic cube and the interval velocity cube used for depth migration were available for velocity modeling. Four time horizons were interpreted corresponding to HRZ1, HRZ2, HRZ3 and HRZ4. Fig.2 shows the base map of the study area. 14 wells were used as input to the velocity modeling. Additionally, 17 wells were reserved for blind testing of depth maps. Well to seismic tie was carried out for 14 selected wells in the area. The TDR of those 14 wells were incorporated.

Geology of the area

Nada field is located on the southern plunge of Devla-Malpur gravity high trend which is separated from Gandhar field in the southeast by the southern flank of Tankari low.

Main pay sands and the upper pay sands within Hazad member of Ankleshwar Formation (Middle Eocene) in the

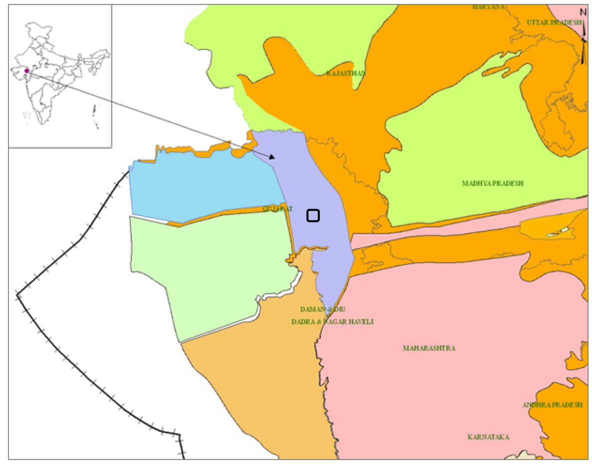

Fig.1 Position of Cambay basin (grey color) on the map of India and the Nada area (small rectangle).

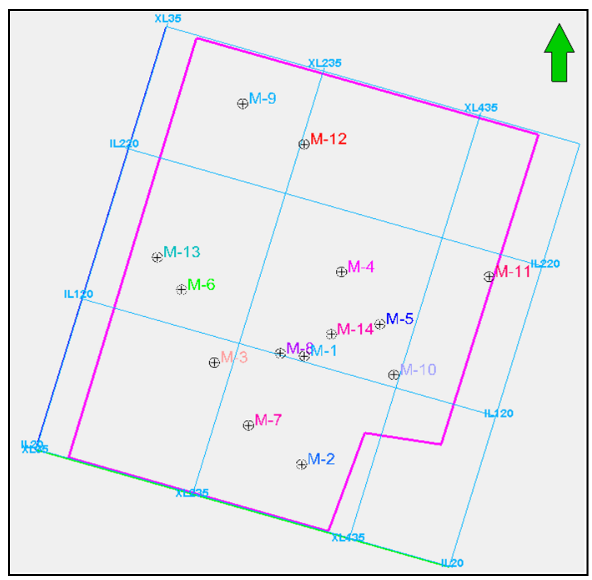

Fig.2 Base map of the study area showing the seismic grid and wells used for modelling.

depth range of 2720-2800m are the known reservoirs. Four genetically related sedimentary facies have been identified within Nada main pay sands. These are:

- Dark grey shales with thin intercalations of silts.

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- Bioturbated sandstones
- Interlayered siltstones and shales
- Massive sandstones.

Methodology:

Data QC and editing

In the time-depth relationship of any well, some T-D pairs may contain some spikes which give rise to anomalous interval velocity which needs to be checked and edited. The cross plot between well interval velocity and depth shows some spurious values (Fig.3) which were edited.

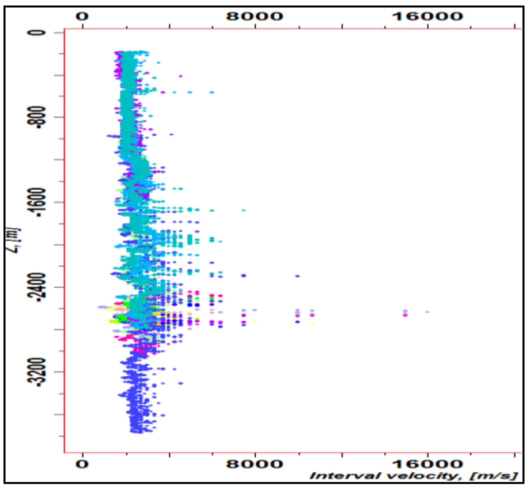

Fig.3 Cross plot of well interval velocity Vs. TVDSS using original TDR of all wells.

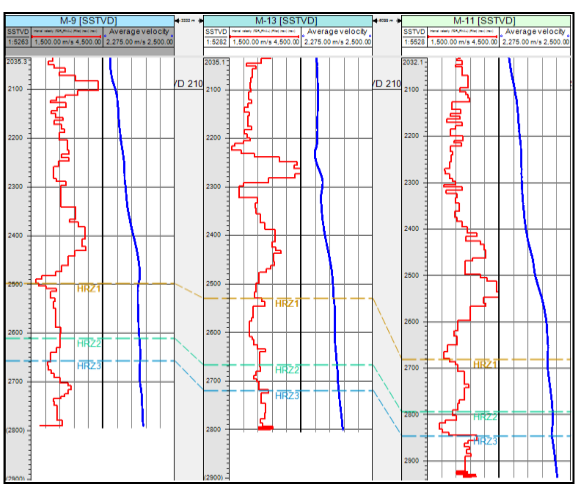

Fig.4 Well interval and average velocities for the wells M-9, M-13 and M-11.

Fig.4 illustrates the interval and average velocity variation with depth for three representative wells. A similar analysis considering all the wells was performed and it was observed that the match is good for rest of the wells. A broad understanding of compaction trends and the lateral and vertical velocity variations could be obtained from these analyses, which were taken into account while building velocity model.

Time residuals analysis

The difference between well markers and horizons were calculated in time domain for each marker with corresponding horizon. At some of the wells, the time residual was observed to be high. The well marker correlation and time horizon interpretation around such wells were revisited and corrections were applied wherever possible to minimize the time residuals. Time residuals calculated for final well tops and horizons are shown (Fig.5). Here, negative value for residual means that the well marker lies deeper than the horizon.

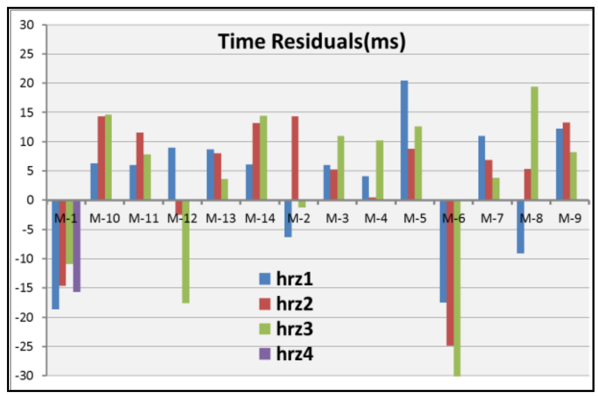

Fig.5 Final time residuals calculated for all the markers.

It was evident that only one well, i.e., M-1 which has time-depth information intercepts horizon *hrz4*. Consequently, the horizon *hrz4* did not have enough well control. Another fact which could be inferred here is that few wells need bulk shifting their TDR. Hence, TDR of two wells M-1 and M-6 were shifted by -15ms and -25ms respectively.

Deriving well interval velocity

The method of layer cake velocity modeling was adopted. For that, interval velocity at well locations for all the lithostratigraphic layers was derived using TDR of each well.

Seismic interval velocity maps

The seismic interval velocity which was available in depth domain was transformed to time domain. Then, seismic interval velocity maps were extracted along all the time horizons.

Seismic guided well interval velocity map

To derive the final interval velocity map at any particular level, the interval velocities at well locations were gridded and interpolated incorporating velocity trends from seismic velocity map. The correlation between seismic and well velocities was fairly good. Therefore, seismic velocity can be used for guiding the interpolation of well velocities. For this purpose, moving average method of interpolation with inverse distance squared point weighting was used. This algorithm produces good results even with less number of control points and, is fast.

The trend surface is calculated as discussed below.

Trend surface = a*Seismic velocity map(X, Y) + b

- Find 'a' and 'b' in order to fit the trend to the well velocities using least square method.
- Calculate the residual of the well velocities by:
  Residual= Well velocities- trend surface
- Perform the interpolation of the residuals.
- Back transform the result by:
  Result surface =Residual surface + Trend surface

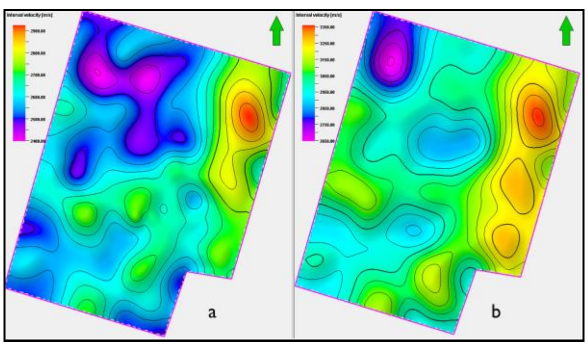

Fig.6 Seismic guided well interval velocity map (a) and seismic interval velocity map (b) for horizon *hrz2*. Purple and red color ends of color legend bar indicate lowest and highest velocities respectively.

The seismic calibrated well interval velocity map honors the velocities at wells and takes trend from seismic interval velocity map for interpolation and extrapolation away from wells (Fig.6). The seismic interval velocity map for *hrz2* has velocity range of 2650 m/s to 3350 m/s, whereas the same for seismic guided well based interval velocity map is 2400 m/s to 2900 m/s.

Building interval velocity model

Similarly, seismic guided well interval velocity maps were generated for first three layers. For modeling, the base was considered at 2600ms. Since only one well penetrates down to the last horizon, a reliable interval velocity could not be obtained based on time-depth information of well. Therefore, for fourth and fifth layers, the seismic interval velocity, scaled down by a factor of 0.9, was taken as input to the model. The scaling factor was chosen based on well to seismic velocity ratios calculated for all wells at all levels, which averages to 0.9 approximately. Interval Velocity model building was run considering layered earth model having five zones (Fig.7). An average velocity cube was also generated from interval velocity cube (Fig.8).

Finally, the time horizon maps and seismic cube were depth converted.

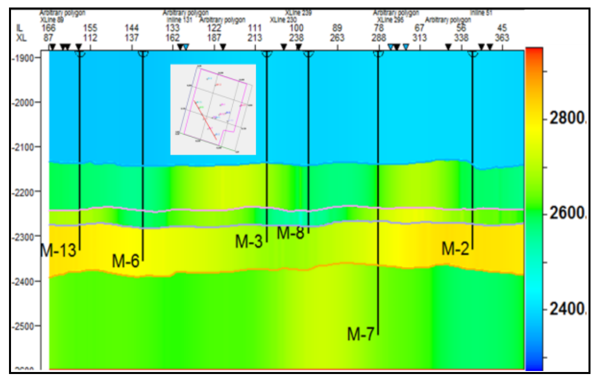

Fig.7 Interval velocity section (from 1900ms to 2600ms) through an arbitrary line with time horizons and wells displayed. Unit of velocity is m/s.

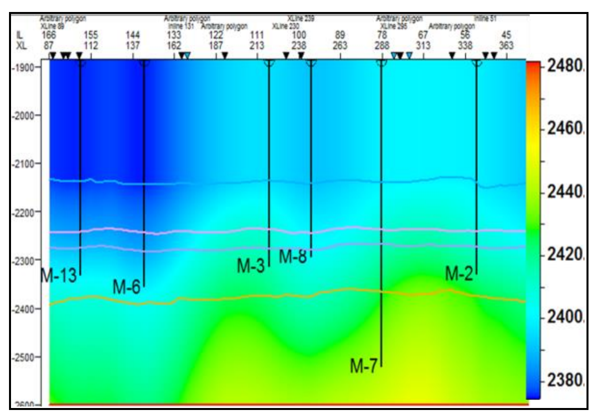

Fig.8 Average velocity section (from 1900ms to 2600ms) through same arbitrary line (as shown in fig.7) with time horizons and wells displayed.

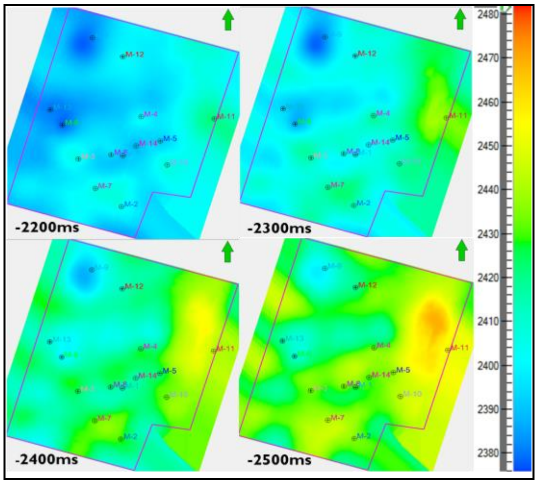

Fig.9 Time slices of Average velocity cube at four time levels as mentioned.

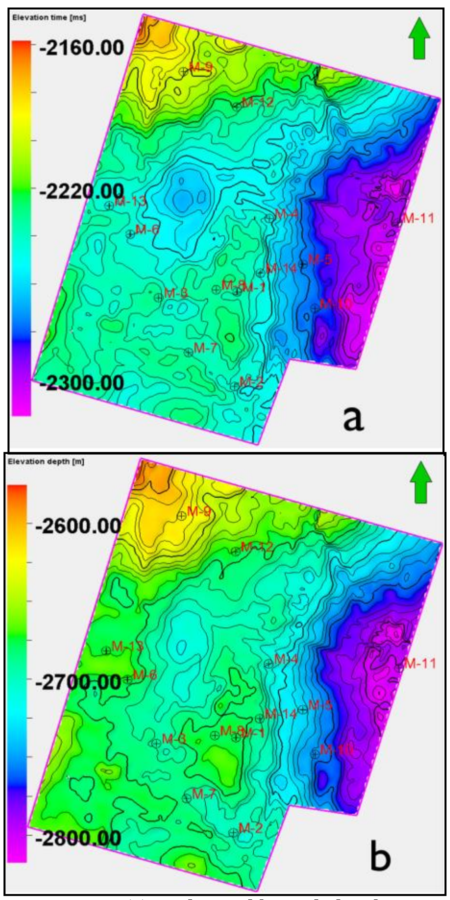

Fig.10 Time map (a) and uncalibrated depth map (b) for horizon *hrz2*.

Depth conversion and QC

Domain conversion was performed on all the time horizons and seismic cube by vertical scaling method. To appreciate the structural consistency of time to depth conversion, time map and the uncalibrated depth map for horizon *hrz2* is shown in fig.10. The contour intervals for the time and depth maps are 6ms and 8m respectively. The depth converted seismic cube does not show any stretching or squeezing of traces.

From the depth structure maps and well markers, the depth residuals were calculated and analyzed (Fig.10). It was observed to be within the acceptable limits, i.e., less than 1% of the depth, and consistent with the corresponding time residuals.

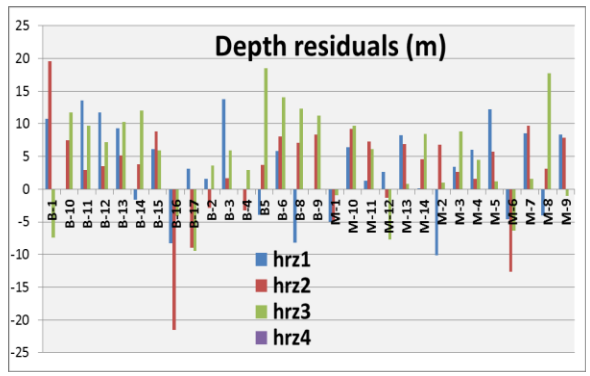

Fig.10 Depth residuals calculated for all the markers at all the wells. Depth maps lie in the depth range of 2450m to 3000m.

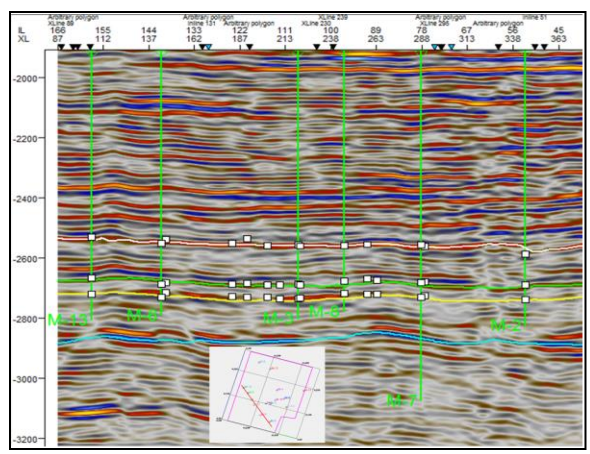

Fig.9 Section of depth converted seismic cube (2000m to 3200m) along an arbitrary line with depth horizons and well tops put over.

Results and Conclusions

The present study illustrates the method for an accurate velocity model building where depth conversion of the time horizons is done via vertical scaling. Depth structure maps show reasonable conformance with time structure maps. There are 17 blind wells in the study, namely, B-1 to B-17. Almost all of the blind wells have depth residual within 1% of the depth of the corresponding marker. $3/4^{th}$ of the blind wells have residuals less than 0.5% of the marker depth. As an additional QC tool, the depth converted seismic cube using the modeled interval velocity was compared with PSDM seismic and no stretching or squeezing of traces was observed.

The methodology can be adopted for velocity modelling wherever a reliable seismic velocity is available. Particularly, if detailed PSDM study on the seismic data was carried out, then the seismic interval velocity which incorporates the vertical as well as lateral velocity variations can be of great use. A modified workflow may be adopted for domain conversion of the time structure maps if the input horizons have steep dips (>15°). The procedure for modelling the interval velocity could be the same but depth conversion may be done by the method of map migration.

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