Seismic velocity trend guided modelling method for time to depth conversion

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Abstract

Traditionally, within the interpretation domain, in order to perform time to depth conversion, various schemes (vertical stretching methods like V0-k, layer cake based calibration or the more involved map migration) exist in order to model the layer velocities so as to ensure low residuals at the available wells. The most widely used method involves establishing a calibration factor (ratio of well and seismic instantaneous velocity) at the vertical wells followed by its interpolation as per a specific set of algorithms and then multiplying this calibration factor map to the seismic velocity map which is then used to generate the un-calibrated depth map followed by calibrating the residuals to the wells resulting in a calibrated depth map. Predominantly most of these methods do not use the level of detail that is present in the seismic velocities that is so painstakingly captured by the average seismic processor, except the map migration method, where, the seismic velocities are used as is but the resultant un-calibrated depth maps sometimes have mis-ties of the order of 2-5% of the depth range. Such large residuals are not desirable since, the objective of all velocity modeling is to improve predictability of the next well and on the same hand, it is also not in best interests if we only use the seismic velocity values at well locations in order to perform a calibration which is strictly algorithm dependent and which ignores the level of detail that has been captured during the seismic velocity picking process. The current paper, demonstrates a scheme which provides a means of capturing all the trends while also ensuring a high level of accuracy in terms of mis-ties in the available wells.

Introduction

The need for a velocity model for time to depth conversion is well understood in the geo-scientific community. Seismic based structural models are in time domain whereas the geological models need to be in depth domain. Thus, simply put, Velocity models transform time domain seismic data S (x,y,t) to depth domain geological model G(x,y,z) i.e. G(x, y, z)=f[S(x,y,t)]. **Figure 1** shows the impact of a velocity model on various aspects of the seismic driven processing and interpretation workflow. Moreover, the velocity models should integrate all available velocity information so as to generate a geologically consistent velocity volume. The key word being 'geologically consistent' which means that the model should not have a significant local bias due to wells (i.e. no or minimum bull's eyes in the model).

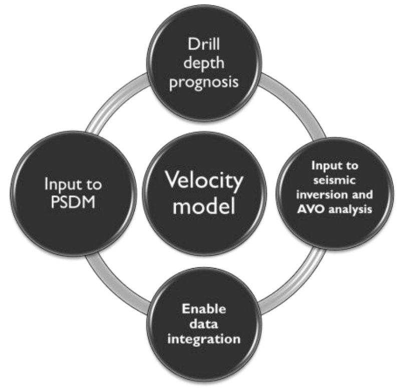


Figure 1: Impact of velocity modelling

Traditionally, velocity modeling for time to depth conversion involves the following steps:
Step 1: Load Well velocity functions, seismic velocity cube, interpreted horizons and well picks into the project
Step 2: Grid all surfaces to the resolution of the model
Step 3: Convert the RMS seismic velocity into instantaneous velocity using Dix equation (assumption- layered earth)
(Step 3 is performed because for calibration, the instantaneous well velocities need to be compared with the instantaneous seismic velocities)

Step 4: For each zone and each well location, compute:
- **Calibration factor = Well velocity/Seismic velocity**

Step 5: Grid the calibration factor using inverse square or minimum curvature algorithm

Step 6: Scale the seismic velocity volume by the calibration factor volume:
- **Scaled seismic velocity = Seismic velocity * Calibration factor**

Step 7: Convert the scaled seismic velocity into a smooth average cube for depth conversion

While, the aforementioned method is robust in its implementation, it generally ignores the trends that exist in the seismic velocity. These trends have a geological meaning in terms of the variation of seismic velocity in North-South or East-west directions. This is illustrated in **Figures 2-5**. **Figure 2** shows the time structure map of Horizon 'A' along with the 40 wells, shown as red dots, for which time depth relationship were available for velocity modeling. **Figure 3** shows its corresponding instantaneous velocity map extracted from the seismic velocity volume. **Figure 4** shows the interpolated calibration factor map generated by dividing well and seismic velocity (wells shown in red dots). This calibration factor map is used to rescale the seismic velocity. **Figure 5** shows the scaled seismic velocity map. A quick comparison of **figure 3** and **figure 5** clearly reveals significant change in the velocity trends that were initially present but were later lost as a result of the ad-hoc calibration process.

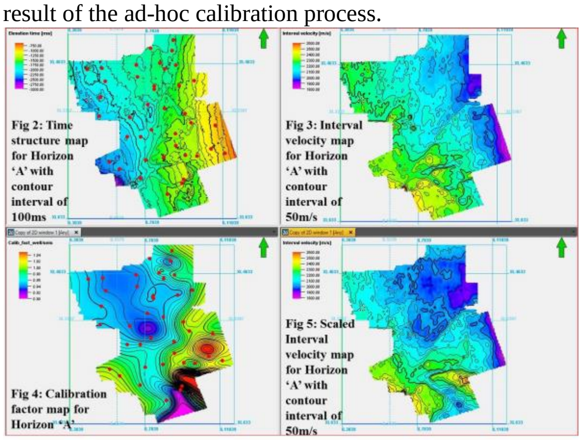


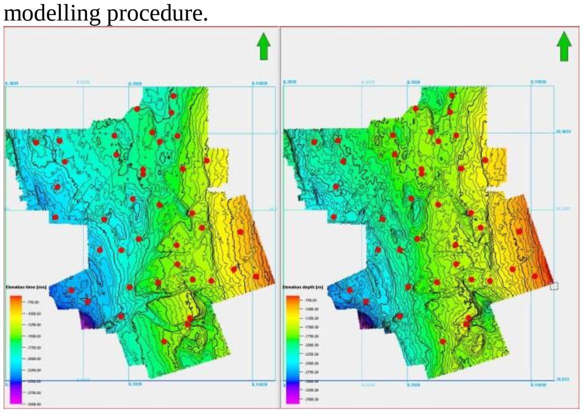
Fig 2: Time structure map for Horizon 'A' with contour interval of 100ms

Fig 3: Interval velocity map for Horizon 'A' with contour interval of 50m/s

Fig 4: Calibration factor map for Horizon 'A'

Fig 5: Scaled Interval velocity map for Horizon 'A' with contour interval of 50m/s

Figures 2-5 illustrates the results of conventional velocity modelling procedure.



Figures 6 and 7 compare the time and depth structure map for Horizon 'A'. The depth map was generated using the conventional velocity modeling procedure. There are some obvious differences between the two maps, particularly in the central and southern part of the maps. The difference is attributed to the resultant velocity map i.e. **figure 5** generated as a result of the calibration process.

While the real seismic velocity values may not have the ability to provide the real sub-surface depth however, their inter-relationship across a map does have geological information implicitly attached to it. This paper is an attempt to tap into this implicit relationship and generate depth maps which may serve as a representative most probable depth map, within the uncertainty limits of the available data. The methodology suggested is independent of the study area and may be applied in all sub-surface scenarios where the seismic velocities are reliable from the imaging point of view.

The following steps illustrate the proposed velocity modeling strategy:

Step 1: The well velocity functions, seismic velocity cube, interpreted horizons and well picks are loaded into the project

Step 2: All surfaces are gridded to the resolution of the model

Step 3: The available well velocity functions which generate the time-depth relationships (TDR) are QC'ed (Figure 8) for obvious anomalies and time residual analysis is performed in order to determine wells which have poor tie between the well pick and seismic horizon. The well pick, horizon correlation and seismic to well tie are revisited for the identified wells.

Step 4: Seismic velocity (average or interval) at all well locations are cross plotted w.r.t well velocity for each horizon and the linear or polynomial trend equation (of low order) is determined. The cross plot may also reveal issues with correlation that may have not been addressed in Step 3. Assuming, Step 3 and Step 4 have taken care of all anomalous wells, then the cross-plot will always reveal a positive correlation between well and seismic velocity.

Step 5: The trend equation is then used to modify the seismic velocity map.

Step 6: The well velocities are now interpolated using the modified seismic velocity map (as per Step 5) as a guide to interpolation. The resultant velocity map shows reasonable conformance with the input seismic velocity map and as a result, the output depth structure map shows reasonable conformance to the time structure map as well. The results of each of the above mentioned steps are explained below.

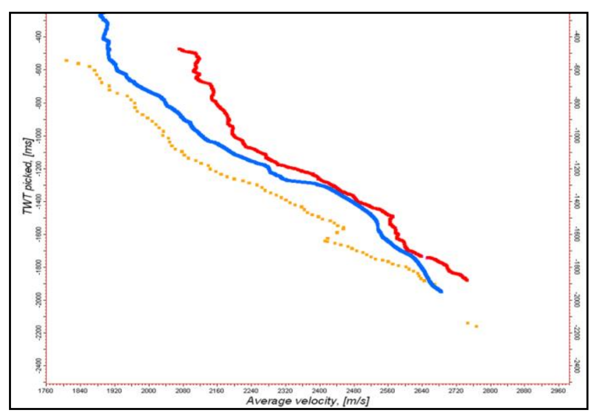


Figure 8 shows average velocity plotted against two-way time (Step 3) for three velocity functions for the same well. It is a well-known fact that multiple well velocity functions are generated by various interpreters during the course of a well to seismic tie exercise. While, each of the various velocity functions will generate a good seismic to well tie correlation coefficient, however, those velocity functions

which conform to the local velocity trends only need to be considered. In figure 8, above, the orange dotted curve shows a sudden drop in average velocity in the deeper time zone (1600-1800ms). This may only have resulted by an extensive stretching-squeezing during the well to seismic tie process. Similarly, the red curve shows an anomalously high velocity in the shallower time zone (400-800ms). However, the blue curve, which has been generated during the course of this study shows a gradual variation across the entire time window and hence is used to determine the time-depth relationship (TDR) for this particular well.

Once the TDR has been finalized, then the well depth picks can be converted into time and then difference between the time equivalent of the well pick and the time horizon at the well can be computed. This results in the time residual plot as shown in **Figure 9.**

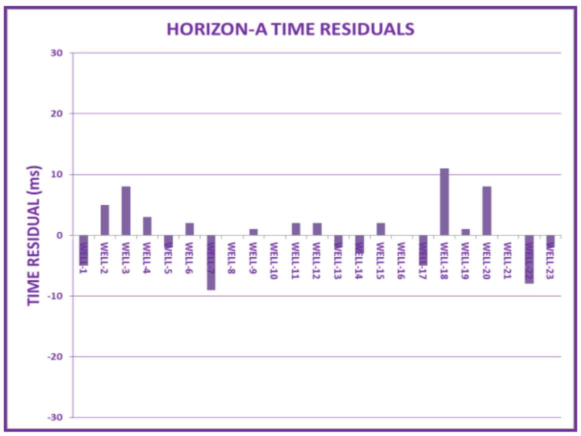


Figure 9 shows the time residuals for Horizon A. It is obvious from the above figure, that there is very little time uncertainty in Horizon A interpretation. However, the strength of the aforementioned QC of well velocity functions and time residual analysis is realized once we take a look at **Figure 10** below.

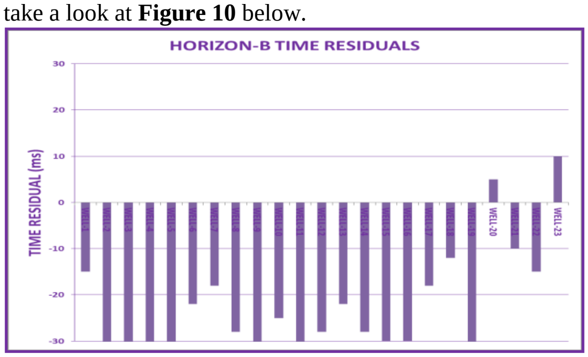


Figure 10 shows the time residuals for Horizon-B, a horizon which is deeper than Horizon A. It is obvious that the horizon has been interpreted such that it is always shallower to the well-pick. This normally happens when the seismic character at the well marker is not continuous, and interpreter, judiciously decides to intentionally pick an event slightly shallower (in this case) or deeper depending upon the continuity of the seismic wiggles.

From the velocity modeling point of view, the horizon B needs to be depth converted and maps need to be generated with minimum residuals at wells. So, the horizon B is now bulk-shifted by a constant amount (average of the residuals at wells) and the time residuals are re-calculated.

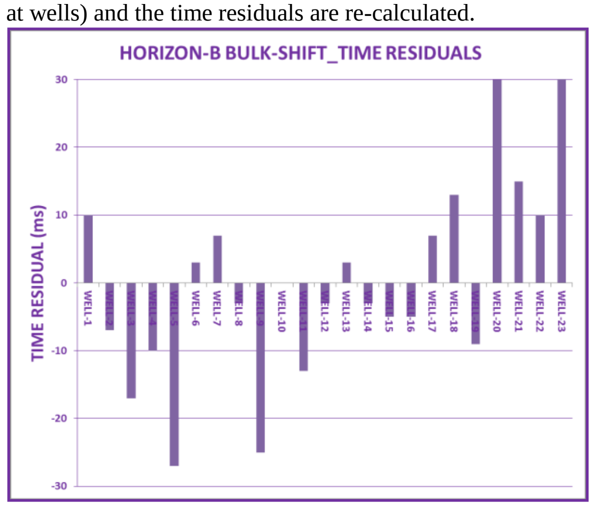


Figure 11 shows the time residual corresponding to the bulk-shifted horizon B, which also now clearly shows that the pick correlation at wells 5, 9, 20 and 23 need to be revisited because of the large amount of time mistie. Once the well pick correlation was revisited, the well picks were modified and the time residual was updated.

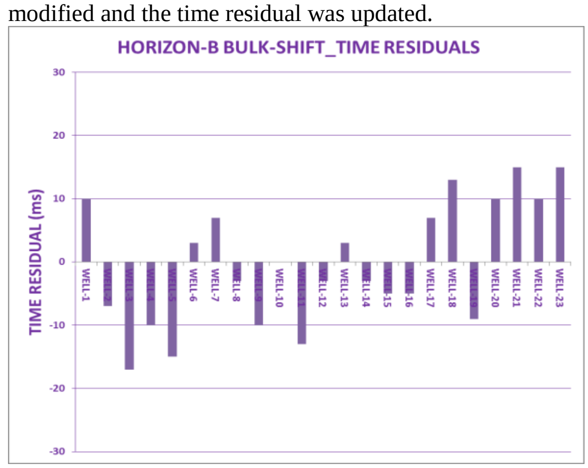
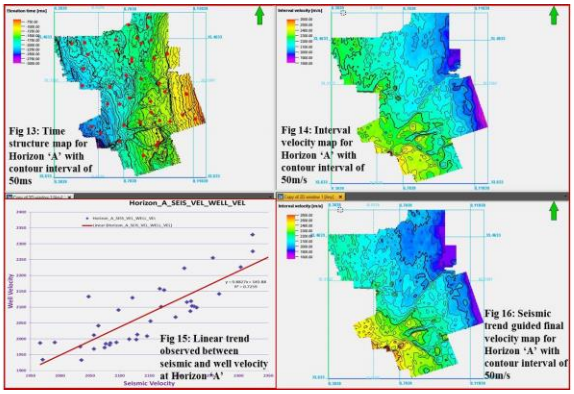
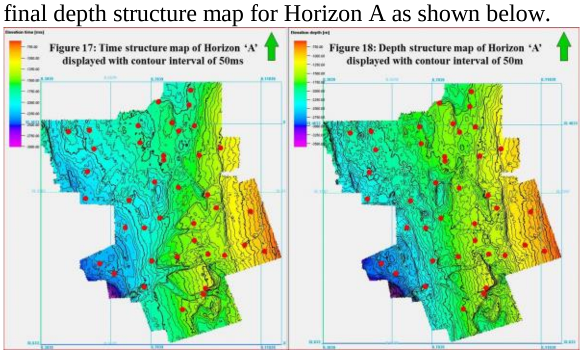


Figure 12 shows the final time residual for the bulk shifted Horizon B which is a significant improvement to **figure 10**. Once, the time residuals are within an acceptable range for all the horizons, then the cross-plot can be generated between the seismic velocity and well velocity for the final step in velocity modeling as discussed below.



Figures 13-16 describe the final results of the afore-described velocity modelling procedure. Figure 13 shows the time structure map for Horizon A. Figure 14 shows the interval velocity map for Horizon A. Figure 15 shows the cross-plot between seismic velocity and well velocity and the red lines shows the trend line whose equation is used to scale down the seismic velocity followed by trend-guided gridding of the well TDR derived velocities which result in Figure 16. This final velocity map is used to generate the final depth structure map for Horizon A as shown below.



Figures 17 and 18 compares the time and the updated depth structure map for Horizon 'A' generated using the new velocity modelling scheme. The two maps show reasonable conformance with each other.

The robustness of a modelling strategy needs to be judged by the ability of the model to predict accurately at blind wells. This enables depth uncertainty estimation. Depth uncertainty is a function of the uncertainty in time interpretation as well as the uncertainty in velocities. Time uncertainty is controlled by the well to seismic tie and the resolution of the seismic data and hence may only be controlled upto a certain extent, however, velocity uncertainty is driven by velocity information; hence its range and standard deviation can be reduced by appropriate modelling. The depth uncertainty is measured by the residuals between the un-calibrated depth map and the well pick depths at the blind wells after the depth conversion exercise. Like all physical measurements, there is an inherent uncertainty in the depth maps that is prepared through seismic interpretation and velocity modelling. As a thumb rule, for the un-calibrated depth map, a depth uncertainty of the order of 1% of the depth of interest implies a reasonable estimate of depth.

In the example used for this paper, the maximum residuals observed at the blind wells were well within the 1% range (~16m) of the depth of interest which was 1640m. The final residuals need to gridded using trends from structure such that there are no or very few bulls eyes in the residual map. This final residual map may then be added to generate the final calibrated depth map

Conclusions

This paper demonstrates a new method for velocity modeling and time to depth conversion. The strength of this method lies in its ability to capture lateral geological information that is implicitly present in the seismic velocities that have been picked by the seismic processor. Moreover, this paper also aims at establishing some best practices in the form of quality control of the available well velocity functions and generating time residual plots before proceeding for a velocity modeling exercise. Finally, all velocity models need to have reliable predictability which may be determined by performing blind well tests using the depths generated by the velocity model.

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