Assessment of Depth Positioning Uncertainties for PSDM Seismic Data

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Abstract

A proper estimation of the structural uncertainties inherent to time-depth conversion or directly received and interpreted data in depth is important. This is the basis for correction of wells positioning, thickness to be encountered, contacts, faults, etc. All these factors are keys to a general estimation of *in-place* and/or reserve volumes uncertainties.

Discrepancies are commonly observed between depth forecast from uncalibrated seismic images and the obtained results when drilling wells. These discrepancies are directly related to the seismic method itself, regardless of the strategy chosen for the processing, whether it is time (*Pre or Post-Stack Migration*) or depth migration (*Pre or Post-Stack Depth Migration*).

The target of this work is to present a simple methodology to quantify this uncertainty that is intrinsic to the seismic processing and, using simple statistical tools, to insert it into velocity fields. This procedure allows a more realistic depth positioning of seismic data, horizons and interpreted faults to generate several possible scenarios.

Introduction

Time migration uses *Normal Move Out* (*NMO*) velocities to correct seismic reflection hyperboles. Assuming *NMO* velocities as *Root Mean Square* (RMS), interval velocities calculated from RMS are a good mathematical approximation of the medium velocities, but not necessarily representing the existing three-dimensional geology in the area, even if it is not complex.

On the other hand, depth migration, even minimally, attempts to use interval velocities of the area, seeking to better comply with Snell's Law. However, the velocity field used in this process is just a smoothed version of a reliable geological velocity model.

According to depth migration strategy used, the velocity model complexity becomes more pressing. In order of necessity, in particular with regard to vertical resolution, it is possible to establish the following: Kirchhoff integral, described in *Schneider* (1978) and its variations; Spectral techniques, for example phase shift, or *Stolt* (1978) migration, finite difference techniques, such as for example RTM (*Reverse-Time Migration*) as idealized by *Claerbou*t (1970).

In addition to previously described*, Vigh & Starr* (2008) argue that success in applying the RTM technique depends on the resolution of the velocity model adopted in the migration process. These same authors indicate that the use of the *Full Waveform Inversion* (FWI) methodology has the potential to generate velocity models with more resolution, further improving the depth imaging through RTM technique. *Vigh et al.* (2009) indicate that one of the challenges of using the FWI technique is precisely to produce an initial velocity model that may be able to predict seismic data that is closer to the actual data where it was acquired.

Parallel to the evolution of depth migration techniques, advances in terms of anisotropic considerations have been used in velocity models. Both concepts, in association with seismic tomography technique, seems to be the best way to be treading in order to obtain the best seismic results.

In any case, a good initial velocity model is imperative for the application of all the described considerations: migration technique, anisotropy or tomography. *Maul et al.* (2016), (updated version of *Maul et al.*, 2005), suggests the concept of construction of seismic velocity models using 3D geological model concepts based on previous seismic images, migration velocity fields, interpreted horizons and faults and well information (sonic logs and well-tie relations).

Sexton (1998) in his work already emphasized the need of more accurate interval velocities for seismic migration purposes. This same concept is very well explored by *Costa et al.* (2015).

Even with all these precautions and criteria mentioned above, *Rosa* (2010) indicates that even a good depth migration does not ensure the correct depth positioning of any event, but rather the best construction of the seismic image to be interpreted, when compared to time migrated image.

Only by oral information, without any specific origin, it is accepted that, in the so-called "good depth migrated data", the errors should be at most 1%, regarding estimation and verification. It will be verified in a specific set of data at this work. It is intended to explore the magnitude of those intrinsic errors through the comparative analysis of information from a received migration (without characterizing it with any quality concept) and direct depth information from drilled wells.

Methodology

An initial estimate of uncertainty, a priori assumed to be random and "at most 1%" (oral information received), was necessary to correctly limit this uncertainty to be modeled in scenarios.

Trying to escape from discussions about seismic quality of geological markers (many are notable interfaces in logs, for example, but not seismically significant), or about interpretation quality (whether the horizon interpreted is correct or not), a simple but very precise methodology was used. It consisted in the reliable tie of a synthetic seismogram, the geological marker identification in time (independent of its seismic response) and the depth of the marker in the well (*hard data*).

The depth difference between marker and its estimation from tie was considered the best estimation of the conversion uncertainty. Tying examples of this are those showed at **Figure 1** and **Figure 2**.

Analyzing these figures, it is noticed that, although the markers are not seismic remarkable (the interpretation was performed by the seismic event), only the final seismogram and, consequently, the resulting pseudo-depth of the marker, which is not exactly the measurement in the well (*hard data*).

The perceptual resulting difference is a good velocity uncertainty approximation at the well position.

From this specific project, after establishment of these differences, it is possible to idealize ways of distribution and/or correction of these errors, using the most variable forms of extrapolation, even with more robust geostatistical resources, such as specific algorithms and models and scopes of variograms.

The geostatistical interpolation of the well tied velocity points (time-depth pairs) were considered together with the mean seismic velocities and their perceptual variations through the *Kriging with External Drift* methodology.

This methodology is commonly used for modeling seismic velocities (*Dubrule*, 2003), requiring a variogram modeling to estimate the property variation (velocities from the seismic tie process) as a function of its neighborhood. These hard data are therefore honored during the interpolation process.

In the continuity of the well values extrapolation process, the original seismic velocity (considered as the soft or secondary variable) is adjusted to the values of these wells through a linear regression, being its residue estimated by kriging and added to this trend.

In this way, the resulting calibrated model (to these wells) is automatically obtained. And, in this case, this process has been carried out considering the original model of seismic velocities obtained from the migration process and its variations in percentage terms, as showed.

Seismic Well Ties Uncertainty Results

For this study, 14 (fourteen) wells with very reliable tie in the field under study were selected, which presented the results indicated in **Table 1** according to the methodology described above.

For better visualization, a graph with the resulting errors is shown in **Figure 3**.

Applications

Taking the uncertainty interval information inherent to the velocity field, from a base model, "Optimistic" and "Pessimistic" structural scenarios can be constructed.

For this set of data, the *Time to Depth Conversion* (PSTM seismic data) or *Depth to Depth Calibration* (PSDM seismic data) considered correction factors which were: 0.97 (-3%) to obtain a base case; 0.99 (-1%) for a pessimistic case; and 0.95 (-5%) for an optimistic case.

The terms "Optimistic" and "Pessimistic" were used here solely by leaving, respectively, a greater or lesser rock volume above any fluid contacts or reference.

From this analysis, with all the available geostatistical tools, "Optimistic", "Base" and "Pessimistic" scenarios can be constructed using interpreted and tied seismic horizons.

Conclusions

Even considering all the effort in the velocity models construction as an aim to honor real depth information, in the best possible way, the existing geology in the area, errors and uncertainties in depth cannot and should not be neglected, especially in regions considered as complex in terms of geology .

The estimated depth errors from migrated data (in time or in depth) are influenced by several factors, such as: choice of the migration method (algorithm), anisotropic assumptions and criteria, tomographic updates, initial velocity models, etc.

From the distribution of conversion errors applied to this set of seismic data (particular conclusion) it is noticed that:

- Contrary than expected (verbal information), the conversion error obtained from this particular processing is not "on the order of 1%" (meaning Gaussian distribution of 0% mean). The measured errors have a mean distribution of -3%, indicating that the velocities received from this processing are systematically higher than those that would better correct depths in a Time-to-Depth conversion;

- Uncertainties for the entire velocity field are assumed as "on the order of 1.5%, with a mean of 3%", that is, a distribution ranging from -2% to 5%;
- Would not be possible to ensure this is a typical range of uncertainties regarding errors in seismic processing. Therefor this kind of study should be applied in other datasets to better stablish a feasible range to be considered.

A great deal of effort is required in defining the distribution and limits of this depth uncertainty, so that the resulting scenarios perfectly embody the actual inaccuracies of the velocity fields.

In general, it is important to establish metrics for the more objective quantification of these inconsistencies, as observed in this work.

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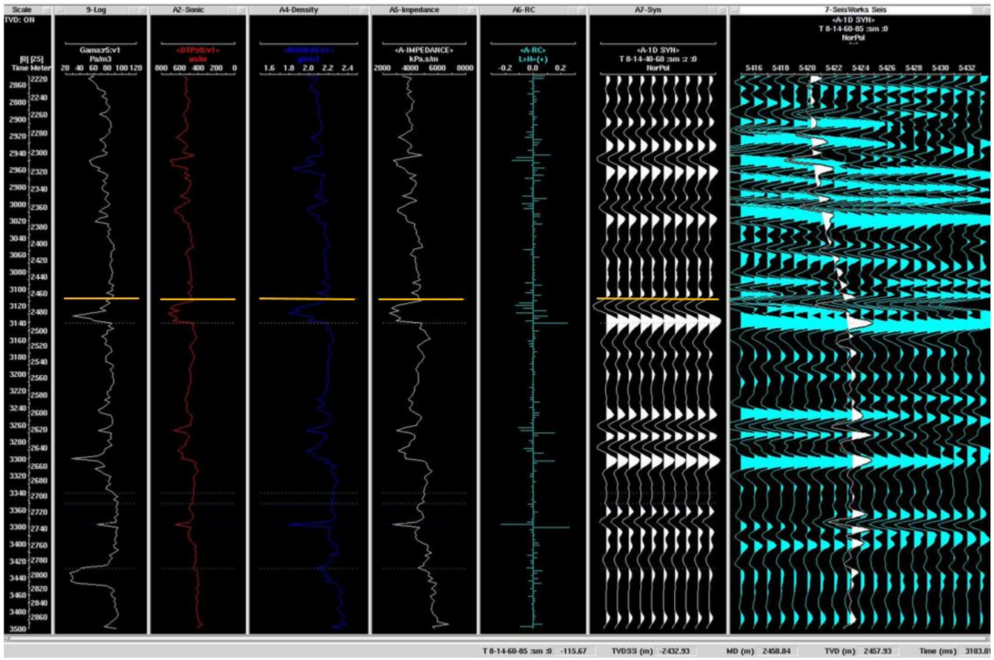


Figure 1 – *Time-to-Depth tie. It is possible to realize that the geological marker is not seismically remarkable.*

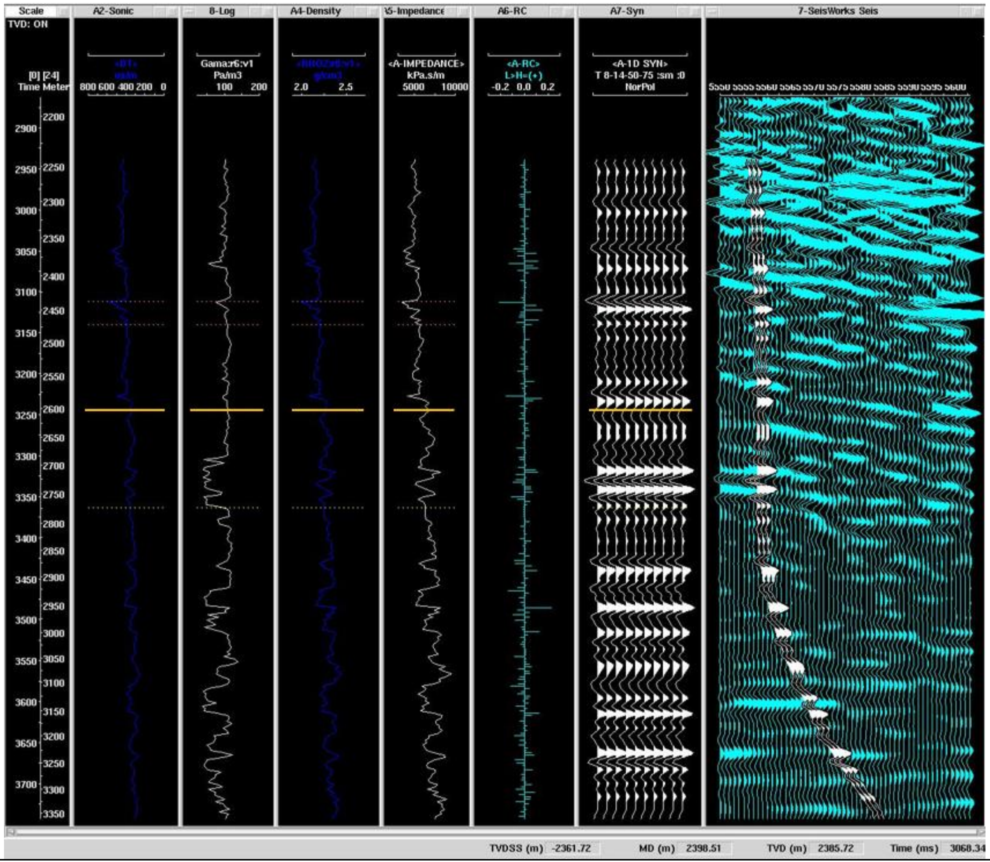
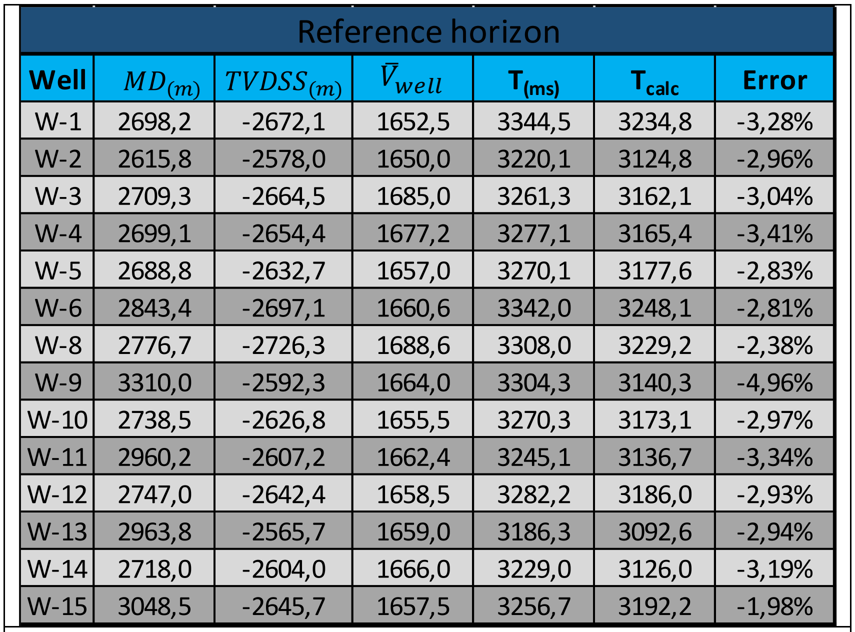


Figure 2 – *Another Time-Depth tie (upper and lower apparent displacements are caused by projection only).*



Reference horizon						
Well	$MD_{(m)}$	$TVDSS_{(m)}$	$\bar{V}_{well}$	$T_{(ms)}$	T_{calc}	**Error**
W-1	2698,2	-2672,1	1652,5	3344,5	3234,8	-3,28%
W-2	2615,8	-2578,0	1650,0	3220,1	3124,8	-2,96%
W-3	2709,3	-2664,5	1685,0	3261,3	3162,1	-3,04%
W-4	2699,1	-2654,4	1677,2	3277,1	3165,4	-3,41%
W-5	2688,8	-2632,7	1657,0	3270,1	3177,6	-2,83%
W-6	2843,4	-2697,1	1660,6	3342,0	3248,1	-2,81%
W-8	2776,7	-2726,3	1688,6	3308,0	3229,2	-2,38%
W-9	3310,0	-2592,3	1664,0	3304,3	3140,3	-4,96%
W-10	2738,5	-2626,8	1655,5	3270,3	3173,1	-2,97%
W-11	2960,2	-2607,2	1662,4	3245,1	3136,7	-3,34%
W-12	2747,0	-2642,4	1658,5	3282,2	3186,0	-2,93%
W-13	2963,8	-2565,7	1659,0	3186,3	3092,6	-2,94%
W-14	2718,0	-2604,0	1666,0	3229,0	3126,0	-3,19%
W-15	3048,5	-2645,7	1657,5	3256,7	3192,2	-1,98%

Table 1 - *Tie errors in the reference horizon.*

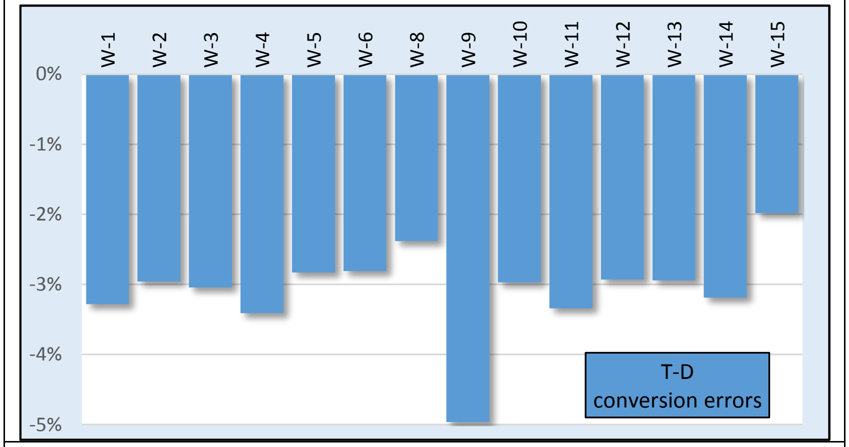


Figure 3 - *Perceptual distribution of tying errors in the 14 (fourteen) selected wells. A 3% reduction was considered as a base case.*