Well based 3D velocity cube

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Abstract

How accurate is a seismic velocity cube? Those involved with depth conversion have an immediate answer: there is no accuracy. The seismic velocities are related to rock velocities but are not equivalent to those we may obtain in laboratory. So, how can we explain the differences? It is not a hard job to find the answer, because there are many uncertainties and interferences involved in obtainment of seismic velocities. Seismic velocities are obtained from seismic reflections usually grouped in Commom Depth Point method, the well known CDP method. The main uncertainty in CDP technique is the correct 3D position of seismic events due to heterogeneity of geologic layers: to find the correct position we should know the geologic model. If we know the geologic model there is no necessity to find rock velocities: they are part of the geologic model. Some techniques were developed considering an enhancement in positioning the seismic events. The DMO (dip moveout) method is an attempt to remove the influence of layer dip in obtaining seismic velocities. The CRP (commom reflection point) arrangement is another attempt, quite dependent on well informations. Both techniques (DMO and CRP) are valid and enhance the seismic velocity quality. About interferences and other uncertainties, we may build a long list associated with survey acquisition, wave propagation itself and also with the seismic velocity analysis methodology. Among then, we may point out stretching, dispersion, attenuation, phase change, all type of noise interferences, multiples, inaccurate acquisition data (cable positioning, cable depth, source depth, source total energy, recording, ...). We may be sure that the list above is incomplete. Also, there is a good chance a future paper/technique brings a new fact/property with influence in seismic velocities measurements. What about the seismic data quality itself and the experience of the geophysicist involved in the seismic velocity interpretation? It is easy to assert that bad quality seismic data and young seismic interpreters is a good combination to achieve a poor quality seismic velocity cube.

Introduction

I've been working for 14 years in seismic processing and 16 years in seismic interpretation. From my experience, after tens of thousands seismic velocities analysis done, it is possible to assert:

- the interpreter experience is quite important in the seismic velocity final quality
- in case of poor/regular quality data and/or deep horizons, errors in seismic velocity interpretation around 100 m/s are trivial
- as a general rule, don't believe in automatic velocity pickings. They will be acceptable only in case of very good seismic quality data. Automatic velocity algorithms frequently pick multiple trends and diffractions.

Other seismic velocities considerations one may find in Souza, 2005.

People who work with exploratory wells are quite accustomed to errors in horizon depth previsions. These errors in general are associated with non accurate velocity models retrieved from seismic data. Many efforts have been done along decades to enhance the seismic velocity quality. We may point out the use of a database is quite important when picking seismic velocities: all previous velocity information from seismic analysis, vertical seismic profiles, checkshots and any type of well time-depth curves may help the seismic interpreter in defining the velocity trend. **Figure 1** is part of a paper presented at an internal seminar. This figure presents an isovelocity section from seismic velocity picking. Clearly may be recognized the left part of section differentiate from central and right part. The left part of section was revised (reinterpreted) using an online velocity database and better represents the local geology. **Figure 1** is an example to show the difficulties obtaining velocities from seismic data.

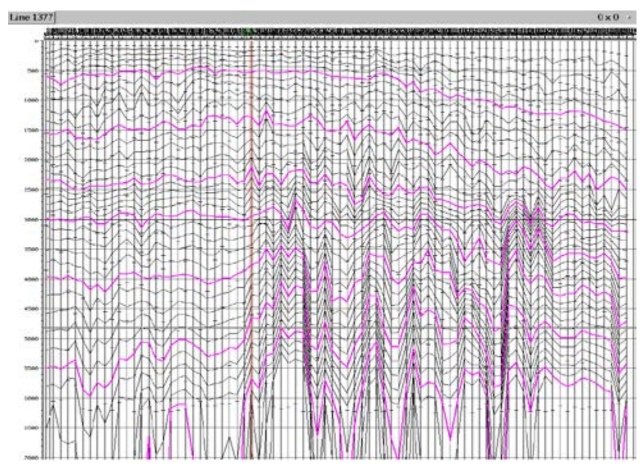

Figure 1 - Isovelocity section (time in left) from seismic velocity picking. The interpretation of left part of section was revised being supported by an online velocity database.

It is a general procedure to do depth conversion with seismic velocities and after adjust depths do well ties. In daily work we reached a very interesting conclusion: in case of high density drilled area (4 km average well distance) the use of only well-seismic ties to do horizon time-depth conversion showed good results. In some cases the results are better than using seismic velocities together with well ties. This conclusion came out from exercises removing one specific well tie and doing depth previsions at position of removed well, with and without seismic velocities. The main explanation to this is related to deviations in seismic velocity picking in the 3D context, since velocities are generally picking in a 2D arrangement (inline sections). Based on conclusion above, we have made ourselves the question: Why not to build a well based 3D velocity cube?

Time-depth curves

Actual paragraph is a resume of what you may find in Souza, 2007. It is easy to understand and here is very important to mention that the quality of a 3D velocity cube based on well time-depth curves is directly related to the quality of seismic to well correlation. It is not an easy task to obtain good time-depth curves. **Figure 2** presents what we may assert: a good seismic-well correlation. From Souza(2007) some remarks may be listed:

- sonic logs have enough quality to be used in seismic to well correlations;
- the topic "sonic drift" has been quite minimized after quantifying a new main actor: the named "seismic drift";
- be careful when using density logs. They are quite dependent on well wall rugosities (caliper) and bad readings are frequent;
- checkshots tie very well with sonic integration. The key is to define a good correlation between one seismic event and the corresponding geologic layer top;
- The definition of a good synthetic pulse (phase, frequency, amplitude) is very important to reach a good seismic to well correlation.

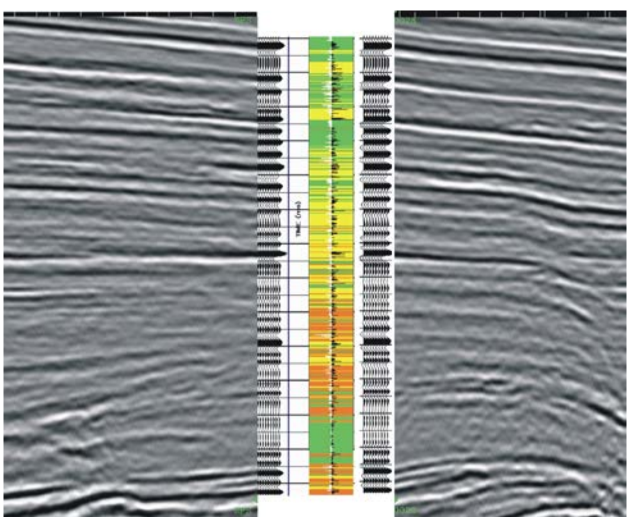

Figure 2 - Well to seismic correlation

The main input to build a well based 3D velocity cube is the set of time-depth curves. Since we have time-depth pairs, velocities are on the hand. The better seismic quality is, better time-depth curves will be obtained with corresponding good result in generating the 3D velocity cube. In **figure 3** one may found a graphic representation of a Time x Depth curve obtained with shift/drift methodology. This methodology is described in Souza, 2007.

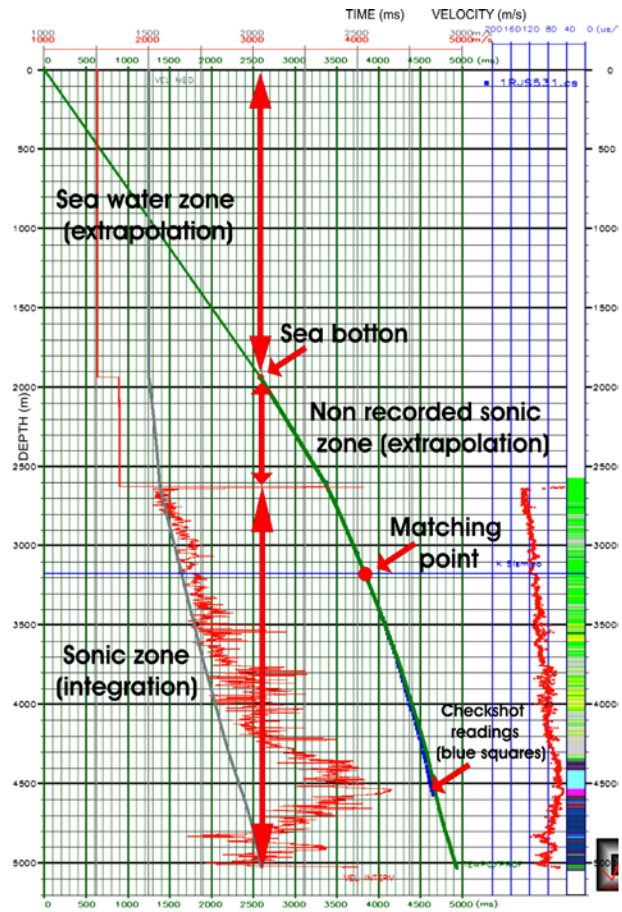

Figure 3 – TxD curve obtained with shift/drift methodology (figure 6 in Souza, 2007).

Generating the 3D velocity cube

The amount of sonic profiles from wells drilled in one specific area will define the accuracy of 3D velocities obtained: more sonic profiles, better quality. **Figure 4** shows a basemap where the black circles represent 39

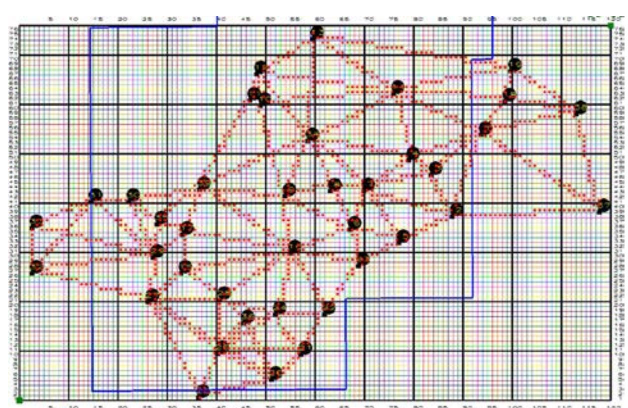

Figure 4 - Basemap showing 39 well positions (black circles) and interwell red lines. The red lines indicate whose wells were selected to be velocity interpolated.

wells with computed time-depth curves. These wells cover an oil field. This basemap was generated by Velpoço algorithm, developed in a Windows based Graphic Fortran. The user defines a cell size to configure the grid. The minimum and maximum map coordinates are defined based on input well coordinates. The red lines indicate what wells were selected to be velocity interpolated, configuring kriging. Along this red line, every crossed cell will receive an interpolated velocity function, weighted by distance from 2 wells chosen to be interpolated. The main suggestion here is to do interpolation selecting the nearby wells or minimum distance, avoiding directions crossing existing red lines. One inspecting **figure 4** will not find any red line crossing over other.

By user selection, extrapolations are allowed. These extrapolations will obey velocity gradients in a defined direction and are weighted by distance. After interpolations and extrapolations, with part of cells with velocity representations (figure 4), it is time to do interpolations to fill all cells with velocity functions. Velocity functions are interpolated first in X direction (horizontal) and after in Y direction (vertical). Every empty cell inside interpolation and extrapolation red lines will receive 2 velocity functions, one from X interpolation and the other from Y interpolation. These 2 velocity functions are summed up and weighted. See **figure 5**, a basemap showing the final result. Blue dots inside red lines are at cell center position and imply this cell has an interpolated velocity function. In this example, map is 30 km in X direction and 19 km in Y direction. Exactly 4027 velocity functions were generated, creating a 3D velocity cube.

Figure 6 is an isotime map (t=2000 ms) where colors represent values from the 4027 velocity functions.

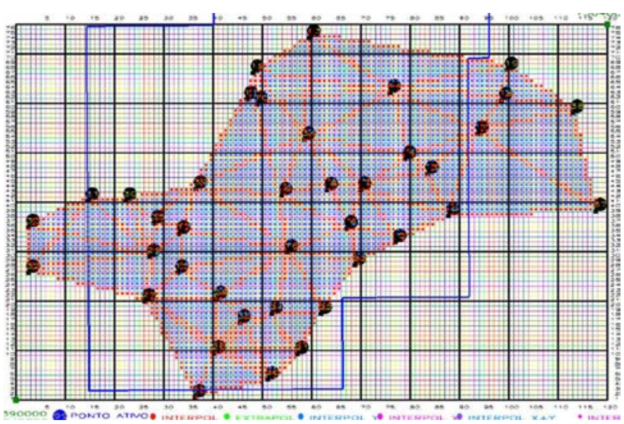

Figure 5 – Final basemap presenting blue dots inside cells. Every blue dot represents position of an interpolated velocity. The velocities were generated by X and Y interpolations between velocities from red cells.

Comparing well derived and seismic velocities

Figure 7 presents an Oligocene seismic horizon converted to depth by using velocities from time-depth curves (based on well sonic profiles). Same horizon is presented in **figure 8**, now a depth map based on seismic

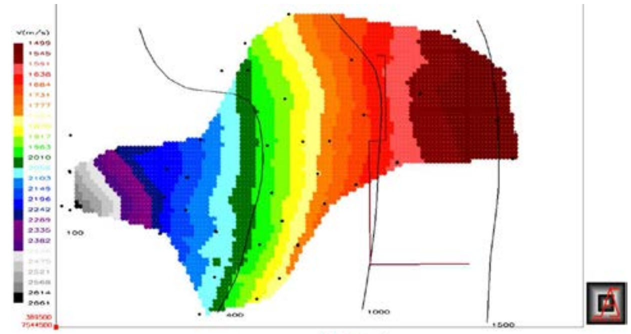

Figure 6 – Isotime map (t=2000 ms) where colors represent velocity values. The 3D velocity cube was generated by Velpoço algorithm. Black dots are well positions and black lines are bathymetric lines.

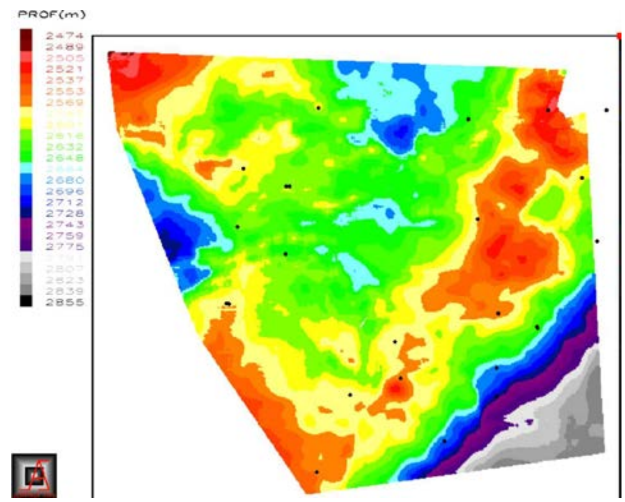

Figure 7 – Horizon depth map based on well derived velocities. Small black circles are well positions

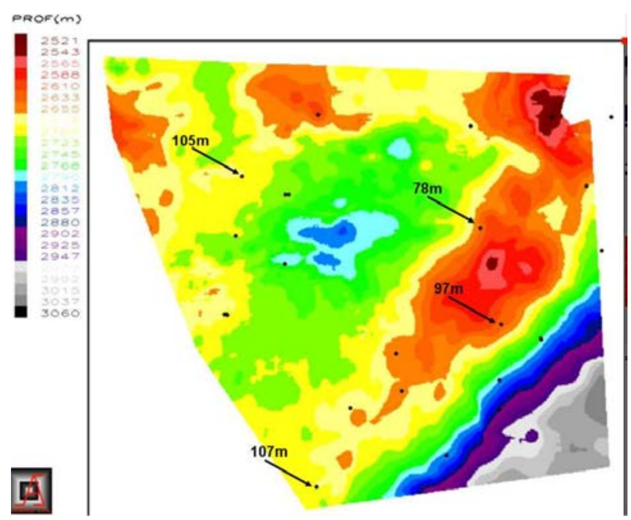

Figure 8 – Same horizon of figure 7, now depth converted with seismic velocities. At four well positions, the depth differences are 105, 78, 97 and 107 meters

velocities. There are main differences between 2 depth conversions. Map based on wells are depth matched, so differences are errors related to seismic velocity conversion. In four wells, aleatory selected, the errors are: 78, 97, 105 and 107 meters. The average error is close to 3.46% and medium depth is 2600m. It is important to mention that seismic data is offshore with regular to good quality and the geologic structures are monotonous at horizon depth (passive margin, low tectonic activity).

Figure 9 is a map presenting the depth differences between figure 7 and figure 8 data. Big differences are in N-NW area, associated to low well depth control and also to lower seismic quality. The SE portion has the lowest depth differences and this is associated to better seismic quality resulting from water depth increasing. The better seismic quality is, better are the seismic velocities picked.

One may find also some alignments in figure 9: this is associated to velocity interpolation direction, showing we still have chance to improve the 3D velocity cube quality. One option is to perform a velocity field smoothing in 3D context.

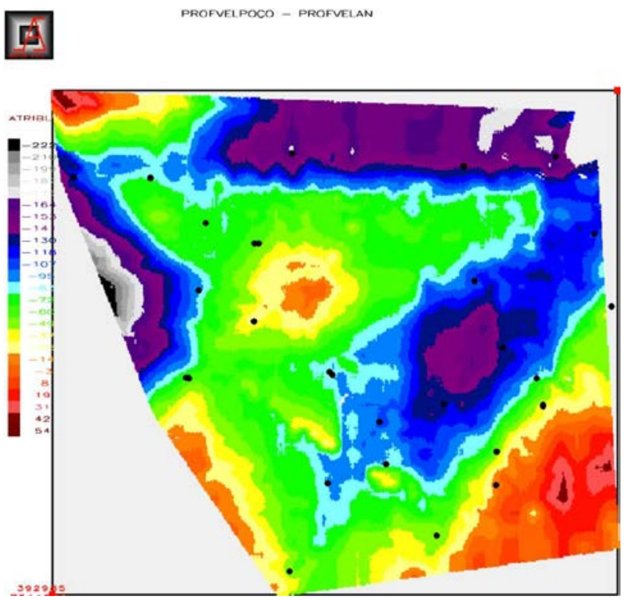

Figure 9 – map showing depth differences between data converted with seismic velocities and Velpoço (well velocities). Average error is 3.46% and medium depth is 2600m

Conclusions

In this paper it is showed a new methodology to build a 3D velocity cube based in well sonic profiles. Time-depths curves obtained from these profiles are interpolated and extrapolated in 3D context. Algorithm may be user parameterized, with kriging option, since he can select the wells being interpolated. The number of wells and related well distances are the main factor to reach a good velocity cube: less distance, better velocity cube quality. This quality is also dependent on time-depth curves accuracy: more accurate, better quality.

Acknowledgments

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References

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