Thickness-based Approach for Evaporites Seismic Velocities in Campos Basin

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Abstract

The velocity field is an important input for several geophysical/geological studies, once it is an information usually covering the entire area of interest. However, it is intrinsically a low-resolution field and, most likely, takes into account only the information derived from the seismic data processing.

In this work, we present a methodology applied in a deep water pre-salt field in Campos Basin, Brazil, in order to obtain an improved velocity model. This velocity model can truly represent the complex lateral velocity behavior created by thickness variations in the salt layer, as well as allows us to incorporate all available information such as conceptual geological model and well logs data. This obtained model is accurate enough to tie the well markers to mapped horizons, as well as to be used as an input for other process that demand a high-resolution velocity field.

Introduction

The velocity models used for depth migration (such as Reverse Time Migration) need to represent the geological aspects better than for other migration algorithms. Usually, building a velocity model using "flooding" methodology the delivery model will be a smoothed one and it will not fill this need.

Still, most of the current migrations algorithms are based on Kirchhoff equation and those are not well representing the best response for reservoir in the pre-salt section both in Campos and Santos Basins. Therefore, there is a need to perform the migration with more robust techniques (for instance, RTM) for those projects and it is mandatory to better think about the complexity when building the velocity model.

In this work we present a way to build this velocity model using a based thickness approach proposed by Petrobras exploration team (known as Hédio Selbach´s equation, described in Borges *et al.*, 2014) for the salt-section based on drilled well information (sonic velocities), as well as a vertical velocity trend for the post-salt carbonate section.

In order to build a good geological velocity model it is mandatory to take into account all the available information in the area. From the seismic method, we have the seismic velocity (commonly the migration velocity, which we will treat as the RMS – Root Mean Square velocity) and the mapped horizons – both usually comprising the whole area of interest. From the drilled wells, we have a broad suite of logs (including sonic or velocity logs) and information about the lithology. These data, albeit with higher vertical resolution, are restricted to the region nearby the wells. Combining seismic data and well logs, it is possible to generate synthetic seismic traces alongside the wellbore, which allows us to establish a time-depth relation between these two domains and furnish us very important (and trustful) control points for the velocity. Ultimately, when we are in the production phase of the field, the conceptual geological model of the area is fairly built, so we can usually rely on it to increase the complexity and accuracy of our velocity model.

This work will present the obtained results for a small part of Campos Basin and the purposed methodology is an adaptive approach derived from Maul *et al*., 2014.

Method

It is common that the velocity information from the data processing comes in a file as a series of velocity functions v(t), each one associated with a surface location (x,y). in the CMP/CDP (Common Mid Point/Common Depth Point) method. This information is obtained from the velocity analysis in the NMO (Normal Move Out) correction and may be further improved by seismic tomography.

Even when the data processing takes into account well information, it may happens that the mathematical procedures that have the velocity as output can reach a *local minimum* of their objective function, for the problem itself is very similar to the seismic inversion. Therefore, in order the improve the accuracy of these techniques, we can provide a more geological velocity model – by giving a good velocity model as a "initial guess" for these algorithms, we can dramatically increase the chance of getting a good output. Moreover, a good velocity model is also the input for several other activities in reservoir characterization, such as time-depth conversion, illumination studies and geo-mechanical analysis.

With that in mind, we took a velocity model (output from a previous TTI – Tilted Transverse Isotropy Kirchhoff migration) and started working out on it, firstly with the goal of achieving a better time-depth conversion. It was then noticed that the velocities in the salt section were slightly different from the values obtained through the well logs and also from the values calculated from the well-seismic tie.

The salt velocity is a problem currently being addressed by many fronts, since there is great complexity in salt stratification in Santos Basin. In this portion of Campos Basin, however, the conceptual geological model foresees a simpler salt layer: the wells usually detect a very thin anhydrite layer (around 15m) at the top of the salt formation, then a (mostly) homogeneous halite pack and, at the end of the evaporate section, another thin anhydrite layer, with thickness similar to the top one.

Since the seismic velocities for both halite and anhydrite are stablished with a very short deviation, we took $V_{Halite} = 4.500\ m/s$, $V_{Anhydrite} = 6.000\ m/s$ and built an analytical expression that would generate an average interval velocity (V_{int}) for the whole salt layer based on its "time thickness", i.e., the two-way time difference between the mapped top and base salt horizons:

$$V_{int} = \left[\frac{60 + 4.5 * (TWT - 10)}{TWT}\right] * 1000\ (m/s)$$

One can see that, in the extreme case of no halite in the salt layer, we would end up with a single 30m-thick anhydrite, resulting in a velocity of $6.000\ m/s$. On the opposite side, a very thick salt layer would have its velocity dominated by the halite, thereby asymptotically approaching $4.500\ m/s$ as $TWT \rightarrow \infty$.

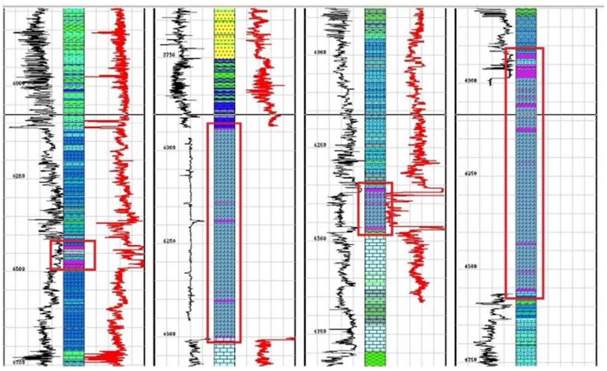

Figure 1: Well logs of a few wells in Campos Basin. As one can see, the evaporites sections (highlighted in the red boxes) are usually comprised of a thin anhydrite layer (colored in pink) both in the top and the bottom, with the whole portion left being massively filled with halite (colored in blue), except for some eventual internal bedding. On the first well to the left, it is possible to see that the top and base anhydrites are quite close, almost forming a single layer.

Though this expression did improve the model and the depth-converted horizon better fitted the well markers, we still had some significant misfits – most of them indicated that our salt velocity was too slow, meaning that we have very likely underestimated the amount of anhydrite in the salt layer. This, in fact, is true: there are a good number of wells whose lithology profiles indicate some thin anhydrite internal bedding alongside the halite layer, which implicates a higher velocity for the whole package.

An empiric approach was then considered, based on the data collected and analyzed by the exploration team, as mentioned before. They obtained a correlation between the average velocity of the salt layer and it's thickness for several wells. These wells covered a wide range of thicknesses and velocities alongside Campos Basin, so we do believe this correlation is reliable enough to be incorporated in our velocity modelling.

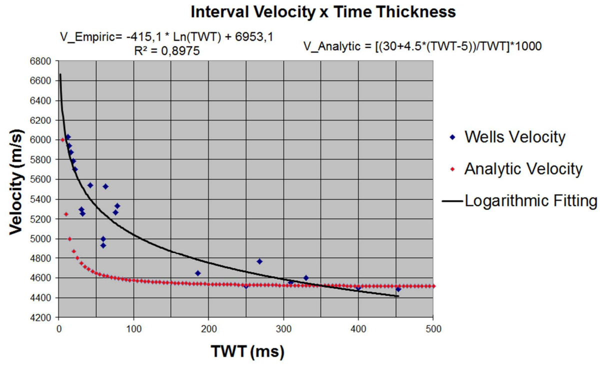

Figure 2: Relations between interval velocity and thickness (analytic in red, empirical in black). It is interesting to note that, due to our underestimation of the amount of anhydrite in the analytical model, the empirical relation pretty much always delivers a higher interval velocity.

Combining this velocity model (with altered salt velocity) with the time-depth table from the wells, we achieved a very good match between the horizon of the top of the pre-salt reservoir and the respective well markers. However, when we analyzed the lateral distribution of the velocity, we could see that in some areas the post-salt carbonate velocity was not following the mapped carbonate structures ("rafts"). You can see that on the figure below:

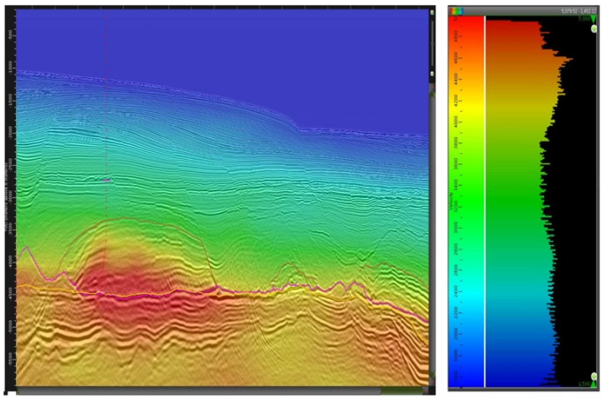

Figure 3: Seismic section with the velocity field overlaid. The pink horizon is the top of salt and the brown horizon is the top of the post-salt carbonate. Paying close attention to the carbonates on the right, one can see that the velocity model does not behave like the mapped structure.

In an attempt to correct this difference between velocity and mapped structure, we proposed replacing the *velan* carbonate velocity for an analytical one. By looking at the qualitative behavior of the velocity inside the post-salt carbonate structure, it seems clear that there is a vertical velocity gradient – this behavior can be identified in many other carbonate *rafts* through the studied area.

Thus, we calculated the average interval velocity around both the top and the base of these structures and used them to stablish the inferior and superior limits of this vertical gradient approach, generating a linear trend from the top of the carbonates to the bottom. This did not change the efficacy of the ties between wells and horizons, since most of the post-salt carbonates needed "fixing" were located in areas without drilled wells – yet, it is important to take that correction into account, for these areas presented abnormally low velocities, causing the pre-salt structure below them to be overestimated.

Results

The improvements described above were implemented in the migration model we began with. Then, this model with altered salt and carbonates velocities was calibrated using the time-depth tables calculated in the well-seismic tie. The methodology used for calibration was kriging with external drift (see Maul *et al*, 2014), where the average velocity obtained in the wells locations was used as hard data and the average velocity from our velocity model was used as trend. This calibrated velocity yielded a much better tie between the depth-converted seismic horizon and the well markers (see table below).

Misfit between Well Marker and Depth-Converted Mapped Horizons (m)		
Well Number	**Before Velocity Modelling**	**After Velocity Modelling**
1	-99	-4
2	-141	-10
3	-36	10
4	-99	-1
5	-55	-5
6	-78	-1
7	-48	7
8	-49	19
9	-36	21
10	-10	11

Figure 4: Misfit between depth-converted reservoir top and respective well marker for the original velocity model (left) and the improved, calibrated one (right). A negative signal means that the horizon is deeper than the marker, which in this case leads to a pessimist scenario.

The better tie between wells and horizons gives us confidence to stablish our development plan for the field, once the known oil reservoir column is almost the same than the seismic resolution for this studied target. Also, this is a reservoir which has been in production for a few years and hitherto there have been some difficulties in adjusting the production history of some wells. With the obtained structures with this velocity model, this history match has been accomplished in a simpler and "geological" fashion, without relevant needs for changing properties such as porosity or permeability.

It's worth mentioning that, even after this workflow for correcting these anomalous velocities behaviors, there is still some considerable misfit in wells number 8 and 9. That is due to a slight change in the salt thickness above these reservoirs – since the thickness of the salt becomes lower than the one fourth of the wavelength of the seismic wave, we get some tuning effect, which alters the seismic signature of the top of the reservoir. Since it is hard to identify in which point this starts to occur, the horizon mapping is usually performed following a single criteria (peak, through or zero-crossing) and the eventual differences are incorporated in our uncertainty analysis.

The built model was able to honor the well data (markers), the seismic data (well-seismic tie) and the production history of the field, so we feel comfortable to use it as an input to studies which demand a high-resolution, high-accuracy velocity model, such as RTM, illumination analysis and geo-hazard evaluations.

Conclusions

We combined the *velan* field obtained for a Kirchhoff TTI depth migration with well logs information, time-depth tables obtained from synthetic seismic traces at the position of the wells and the conceptual geological model of the area in order to create a high-resolution, high-accuracy velocity model. The improvements were mainly focused on the salt section (where we used a thickness-based approach based on well data, developed by our exploration team) and on the post-salt carbonate section (using a vertical velocity trend).

This velocity model was used to convert the mapped horizons from time to depth, yielding results that better fit the drilled wells and ease the production history matching of the reservoir. Also, it is ready to be used in other studies that demand any trustworthy velocity information in a 3D sense, such as RTM, geo-hazard and illumination studies.

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