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3D velocity model: a multidisciplinary approach, a South America experience

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ABSTRACT

The structural uncertainty is the most common issue in risk analysis for exploration and production purposes. It is a consequence of the time-depth conversion which is a function of the velocity field. An integrated multidisciplinary analysis to generate a 3D velocity model will increase the volumetric accuracy of time-depth relationship, attenuating the structural uncertainty and reduce the risk. During the procedure, well logs analyses were carried out by geo-statistical analysis in order to calibrate and normalize well log and also to generate synthetic seismograms. Creation of synthetic seismograms by sequential analysis in Well logs was used to calibrate, correlate and tie to seismic interpretation to geological markers, and to time-depth relationship (TDR) function. The velocity model was constraint by seismic stratigraphy and sequential analysis from wells, to be able to develop a velocity framework to be used to calibrate each velocity function from each well to the 3D velocity model. The propagation and correlation from seismic processing velocities were carried out by neural network methods under 3D grid structural framework. Several iterations were carried out in each stage of the model to make it the most suitable velocity and honor each control point already established. The final velocity model proved to be very accurate on each one of the surfaces tested, and the time to depth conversion to be able a successful risk reduction.

RESUMEN

La incertidumbre estructural es el problema más común en el análisis de riesgo para propósitos de E&P. Esto es una consecuencia de la conversión de tiempo a profundidad el cual es una función del campo de velocidades. Un análisis multidisciplinario integrado para generar modelos de velocidades incrementara la precisión volumétrica de la relación tiempo-profundidad, atenuando la incertidumbre estructural y reduciendo el riesgo. Durante el procedimiento, los análisis de los registros de pozos fueron llevados a cabo por análisis geo-estadísticos a fin de que calibrar y normalizar los registros de pozos así también para la generación de sismogramas sintéticos. La creación de sismogramas sintéticos por medio de análisis secuencial en los registros de pozo fue usado para calibrar, correlacionar y unir la interpretación sísmica a los marcadores geológicos, y para la relación de la función tiempo-profundidad (TDR). El modelo de velocidades fue restringido por la estratigrafía sísmica y el análisis secuencial de los pozos, para ser capaz de desarrollar un marco de velocidad que será usado calibrando cada función de velocidad en cada pozo para el Modelo de Velocidades 3D. La propagación y correlación de las velocidades sísmicas se llevaron a cabo por los métodos de redes neuronales bajo un armazón estructural grillado en 3D. Se realizaron varias iteraciones en cada estadio del modelo hasta obtener la velocidad más adecuada y que honre cada punto de control ya establecido. El modelo final de velocidades ha probado ser muy preciso en cada una de las superficies probadas y la conversión de tiempo a profundidad de ser capaz de una exitosa reducción del riesgo.

Key Words: geo-statistical analysis, neural network, risk analysis, sequential analysis, structural uncertainty, time-depth conversion, synthetic seismograms, velocity model, 3D grid structural framework.

1. Introduction

The objective of this work was to show how to use some familiar geo-science concepts to make a consistent, technically calibrated and well based velocity model and avoid the unfortunate classical human error (Rose & Associates, 2010).

Build up a Velocity Model implies making all geo-sciences to converge in qualitative and quantitative relationship, in such a way that each of them will honor their own procedure and calculation (Shultz, 1999).

This research was done based on compressional structural basin styles and was successfully applied in South America along trust fault belts structures in different locations.

The methodology used is in this paper divided in different parts just for didactical purposes through the general procedure, nevertheless it does not mean that these can be realized simultaneously or can interchange order following the complexity of the environment.

The software used to develop this work including analysis, calculations and illustration was Petrel 2013.2.

2. Well Calibration Process.

One of the geo-statiscal tools are the histograms that show the well logs distributions (O. Dubrule, 2003). Those histograms will be used to evaluate the limits of the investigation for each well, together with good sampling interval and standard deviation measurements. These will help the relationships to normalize those limits.

Cross plots between well logs properties and seismic attributes will be used to identify anomalies and the relationship between them, simultaneously isolate those anomalies (Chopra et al., 2014). Those results will be correlated with the other wells by variograms (Figure 1).

3. Sequential Analysis Process

In early stages of geologic interpretation, the interpretation logs did not match with seismic reflection as well as expected, the inconsistency was referred to uncertainty, consequently the risk analysis was high (Dubrule, 2002 and Rose & Associates, 2010).

After geological and well log calibration the interpretation and logs correlation is more coherent, the reflection coefficient from synthetic seismogram visualizes what should be the issues that we must face and take care of to the confront following steps, thus to correlate well and seismic data.

To achieve this, we have to think in a way that the scale on wells and seismic work. The sequential analysis is a good tool to start, because of the boundaries that can be interpreted as a variation on physical properties; these will have response on the reflection coefficient and wave length (Kendal, 2008). Those elements are essential components in seismic reflection.

The use of sequential analysis interpretation will provide not just geological interpretation but also relevant information to be used to tie well markers to seismic reflectors with more coherency and consistency (Figures 2 and 3).

4. Synthetic Seismogram Generation

To generate a synthetic seismogram the logs required are: sonic (DT), density (RHOB) and check-shot; their results will be acoustic impedance (AI), reflection coefficient (r), Interval velocity, average velocity, velocity functions. (Sheriff et al., 1995).

In order to achieve a reasonable approximation of the synthetic seismogram and seismic section, it is imperative to edit the sonic log in order to eliminate spikes and outlier's values, most part of the time this procedure will be done by series of iterations applying the standard deviation and length sampling interval on the log.

It is strongly recommended that calibrating sonic logs against check-shots to lead to a corrected time-depth relationship (TDR) curve.

All close well logs correlated with TDR and well markers create also geological intervals; those intervals correspond to sequence boundaries that also represent variations in physical properties (van Dalfsen, 2006).

Consequently, we expect that the calculations, that will represent the best approximation to the geologic interval as well as the reflection coefficient (Figure 2).

There are many options at this point, to achieve to extract information from the seismic volume, but we must choose the most suitable one in function of what you have and what you want to a particular evaluation.

In the early stages of E&P, prepared structural maps using TDR curves were good enough for depth maps, although the sedimentary and structural homogeneity should be considered to extrapolate the TDR relationship.

However, this is not the case in structural complex units, like a lot of occurrence of normal or inverse faults and unconformities and lithological variations in small areas.

In those cases, it is strongly recommended that the velocity model is generated using velocity modeled intervals by statistical techniques and/or neural network to complete the dataset to satisfice the structural model.

It is important at this point to be able to recognize, that there is a possible mismatch from well logs markers and the sequential boundaries because both must be coherently related, otherwise the velocities will not honor the structural model.

However, there will still be some kind of uncertainty because of the nature of the indirect measure itself from a geophysical point of view.

It is a common practice to manipulate the velocity curves or markers, to make fit the relationship between the seismic reflectors and the well logs. This practice is not a technical method and it could result in a wrong interpretation.

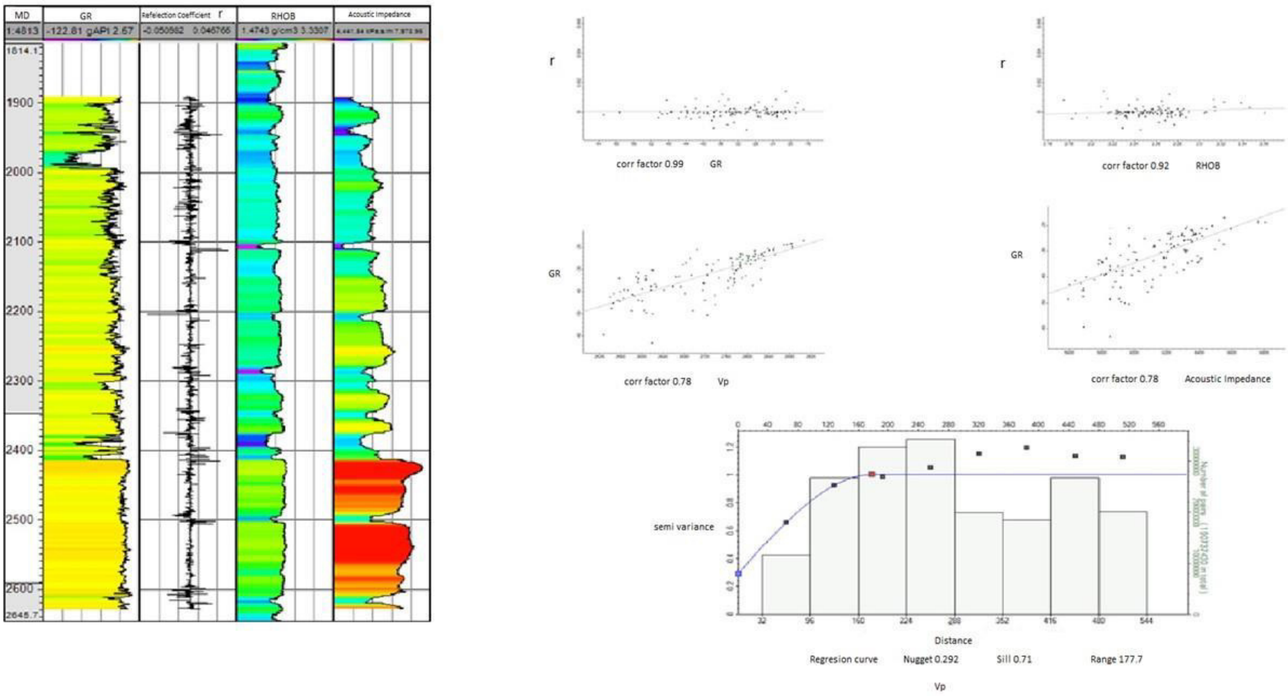

Figure 1*. Based on evaluation on well logs variograms, cross correlations and after some iterations carried out, the final results show a good relationship between the well log and the expected geology, consequently some of the potential risk were been reduced.*

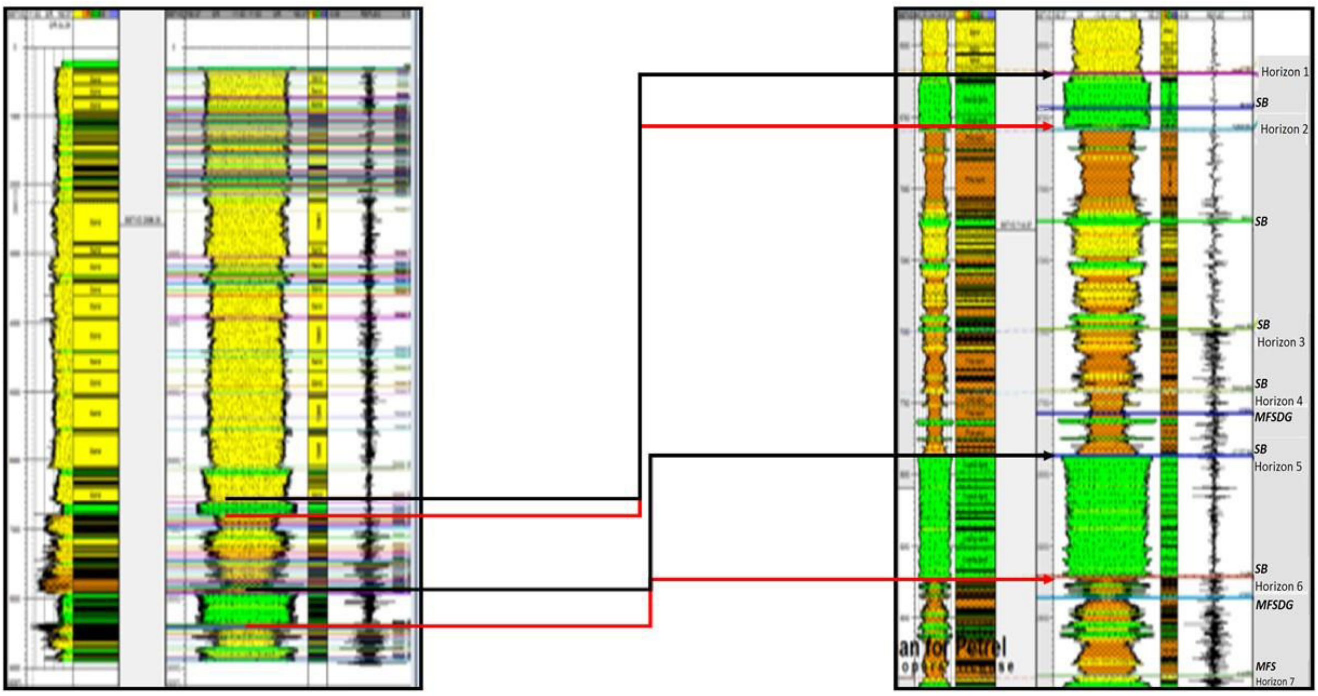

Figure 2*. Left side figure is 5th order sequential analysis. Right side is a 3rd order sequential on calibrated GR log matching the reflection coefficient.*

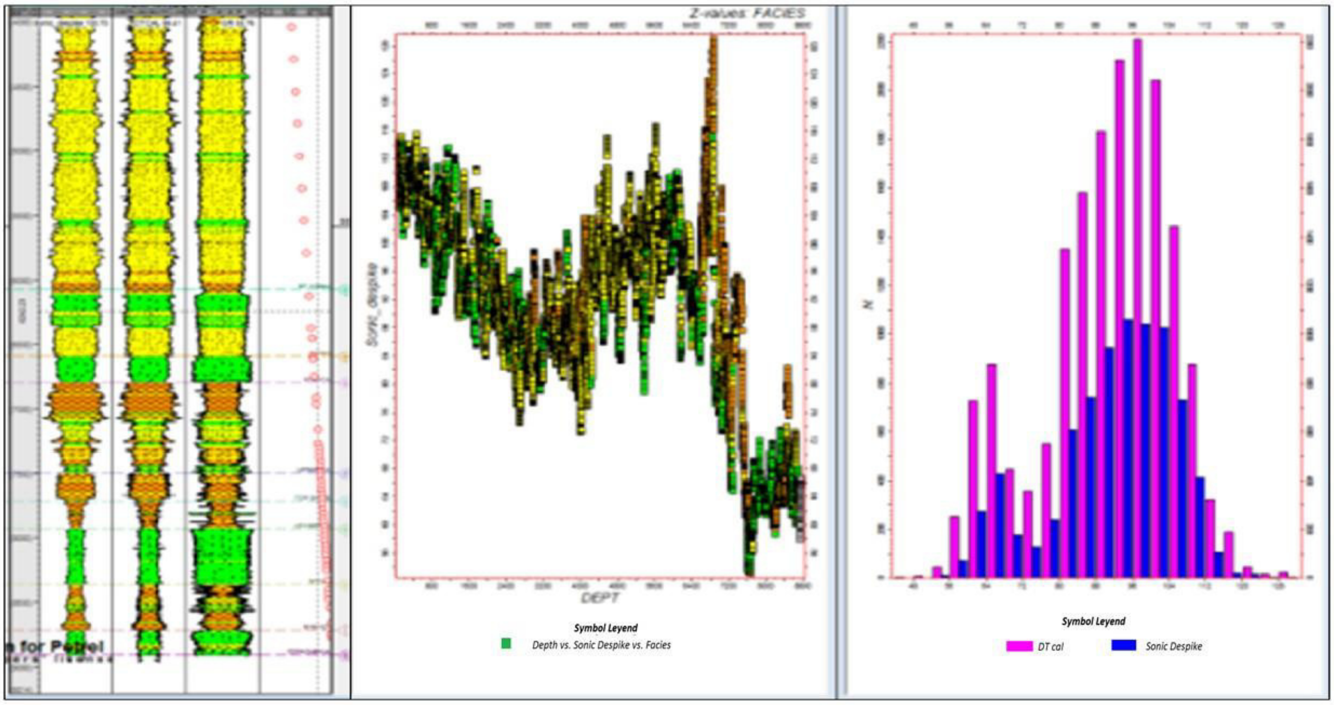

Figure 3. *This image after calibration shows a very good TDR tie between markers and sequential boundaries.*

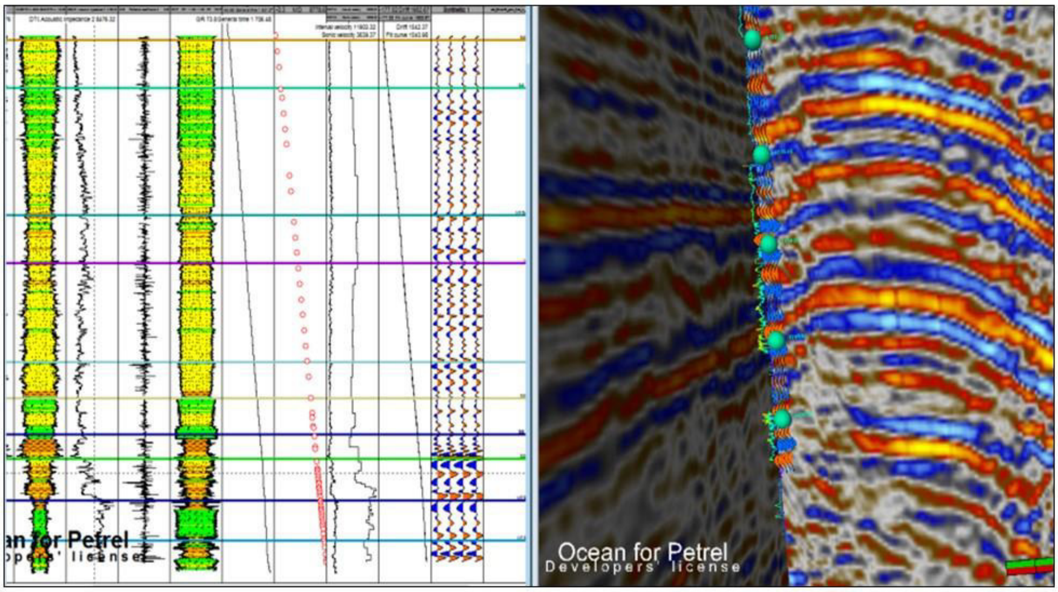

Figure 4. *The generated synthetic seismogram shows a good correlation with the well markers and the crossing seismic sections.*

The consequences can be serious and will force to manipulate following applications, especially in petrophysical analysis.

At this point we already have calculated and calibrated the TDR curve; identified well logs sequence boundaries, synthetic seismograms that match with the seismic sections, the representative reflector in the seismic section and the sequence boundaries from the well logs against markers, and finally the geological event that enclosed exploration and production main target (Figures 3 and 4) .

5. Velocity Analysis

The evolution of the structural styles and depositional environments in series of times, drive us to establish as a fact that those series of rocks have a variable degree of anisotropy: lateral and vertical and with pressures variations.

From a geophysical point of view, the sonic wave is propagated following the physical laws in an anisotropic media (Chopra et al., 2014), the nature of the seismic reflection acquisition give us the difference in series of time, from the instant of the fired shot up to the recorded reflected wave.

The seismic processing will give a processed seismic wave, which will show the actual form of the subsurface. However, there is much more information hidden in the seismic traces because it is not just a nice seismic section.

Each point of each seismic trace is an expression of a geological attribute in the space (3D Volume), when the traces are gathered one by one they will reveal a geological event expressed in a seismic way, that is why it is very important to take special care in preserving the true amplitude and the velocity treatment during the seismic processing.

The true amplitude is a successful method extracting hidden information from the sediments (seismic attributes), the velocity treatment is crucial for the structural and stratigraphic expression of the sub surface (uncertainty analysis) and together they will be used to quantify the seismic interpretation and to be used as variable input to evaluate the weighted risk (Figure 5).

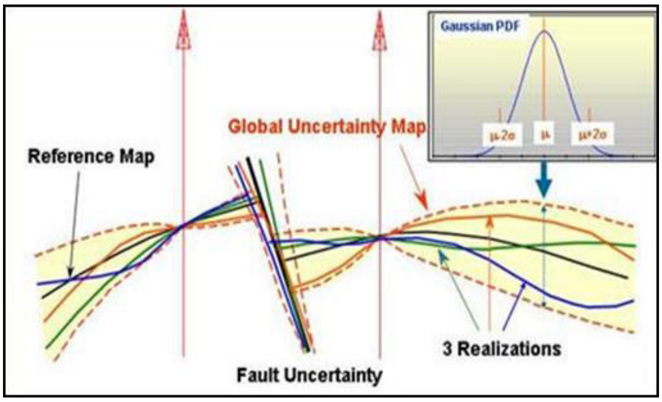

Figure 5. *This figure shows a variation of the structure and stratigraphy. On top right is visualized the quantified Gaussian uncertainty (Figure Cuemene, J.M. Taken from O. Dubrule et al., 2002).*

As we analyzed previously the velocity field will not respond equal horizontally as vertically to the 3D velocity volume. Nevertheless, there are preferential directions following the stratigraphic characteristics, thus the velocities will vary slightly in stratigraphic directions, but is of course fully dependent on the complexity of the area (Figure 6).

Fortunately, there is a way to solve this issue; the information delivered from processing stage must include at least stacked and rms. velocities that belong to each velocity pick during seismic processing.

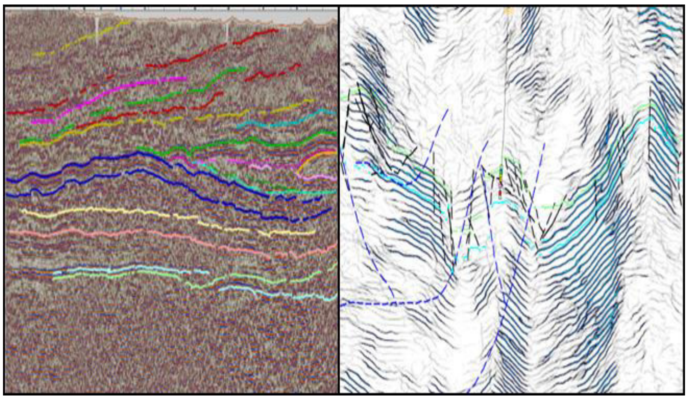

Figure 6. *Left image shows a stratigraphic complexity, right figure shows a structural complexity.*

The quality of these velocities is very important because they will be used as correlation between seismic sections and the velocities already known from the wells (Figure 7).

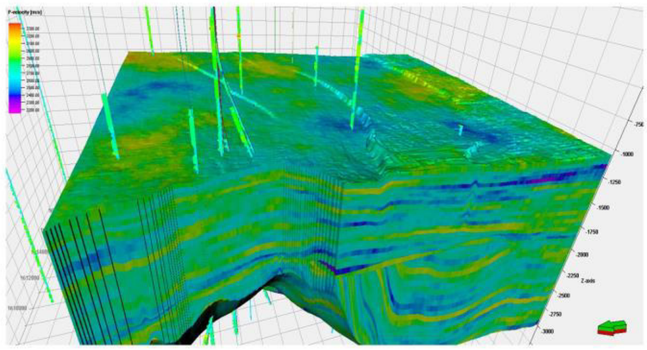

Figure 7. *The 3D plot of stacking velocities gives us a perspective on the variation of the velocity field, which is a response of the field anisotropy.*

At this stage we have the velocity field of the area which represents the general velocity gradient.

In order to achieve a velocities model that matches the sequence boundaries from the well logs and seismic, it is imperative that the velocities do not cross the stratigraphy as well as the structures. Then and only then, these will have consistent correlation between wells and seismic, so we can convert the seismic interpretation from time to depth.

At this point we have measured what is the scope of this job and what will be the best way to achieve our goal. The objective of this job was to find out the best velocity model to be used as a conversion to depth.

Whatever the seismic is, we have to assure the reflectors continuity, especially in complex zones. To do that the use of some seismic attributes will be helpful. We do know that first of all there are some parameters that must be worked on with the attributes to improve the final results (Figures 8 and 9).

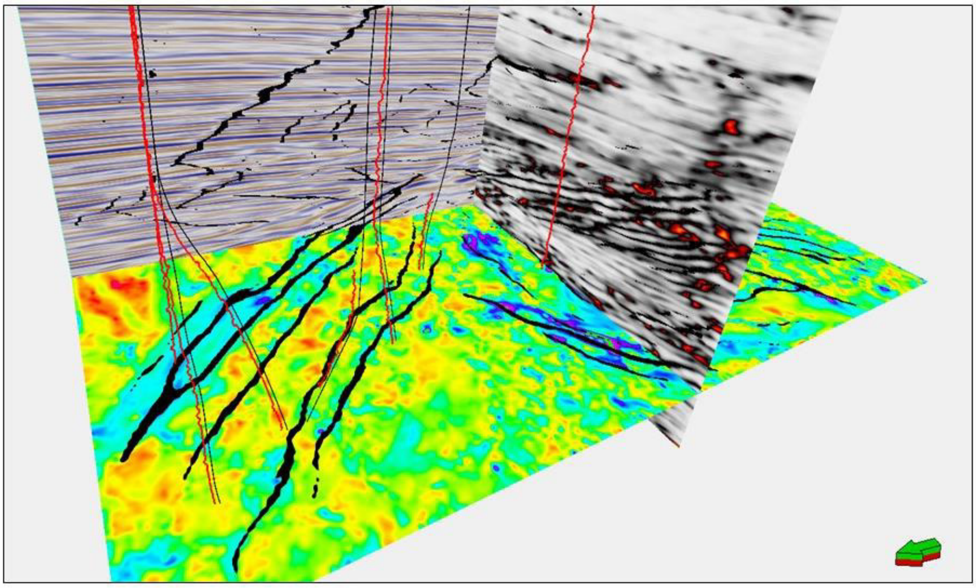

Figure 8. *The achievement of the maximum approach is a matter of study of the seismic attributes; the combination of those attributes will lead us to a graphic visualization, which must represent the required geology events.*

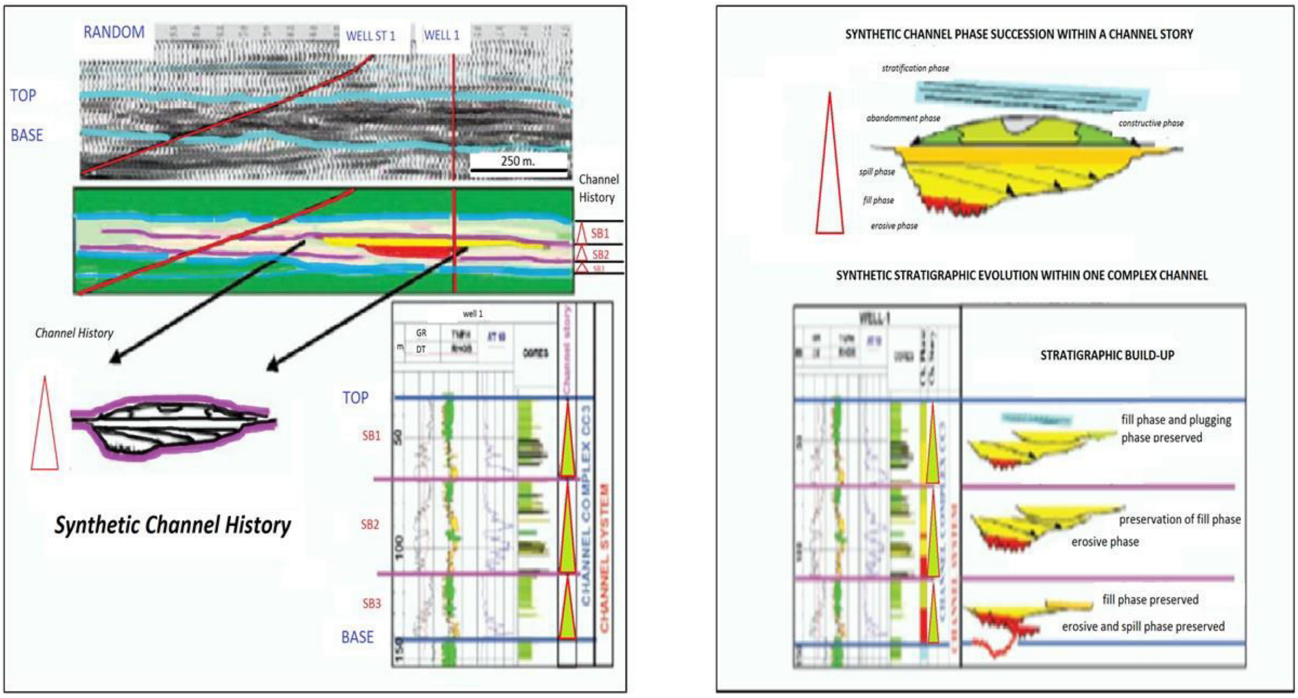

Figure 9. *The seismic attributes and the sequence analysis taken on the well logs will confirm the validity of the markers position in seismic stratigraphic sections. Modified from Navarre et al. (2002).*

6. Velocity Model

It is demonstrated that the velocities from wells will work around its location and when those velocities are extrapolated, may affect the real position and shape of the structure, especially at farthest points (Sheriff et al., 1995) (Figure 5).

To compensate this, we need another source of velocities which could be other well logs, seismic velocities or both to extrapolate the corrected velocities to a 3D Volume (Carter, 1989 and van Dalfsen et al., 2006).

Therefore it is recommended to build a 3D grid model that includes the structures, stratigraphy and velocities in a 3D framework. Choosing the sizes of the cells will be a matter of investigation and must be proportional to the geological complexity.

The velocity model made by 3D gridded process populated with velocities already calculated (wells and seismic reflection) into each cell by extrapolating their values (stochastically or neural network), spread into each cell weighted by the adjacent cells, thus the model has a balanced control ensuring the corrected time to depth conversion at any point (Hinks et al., 2009) (Figure 10).

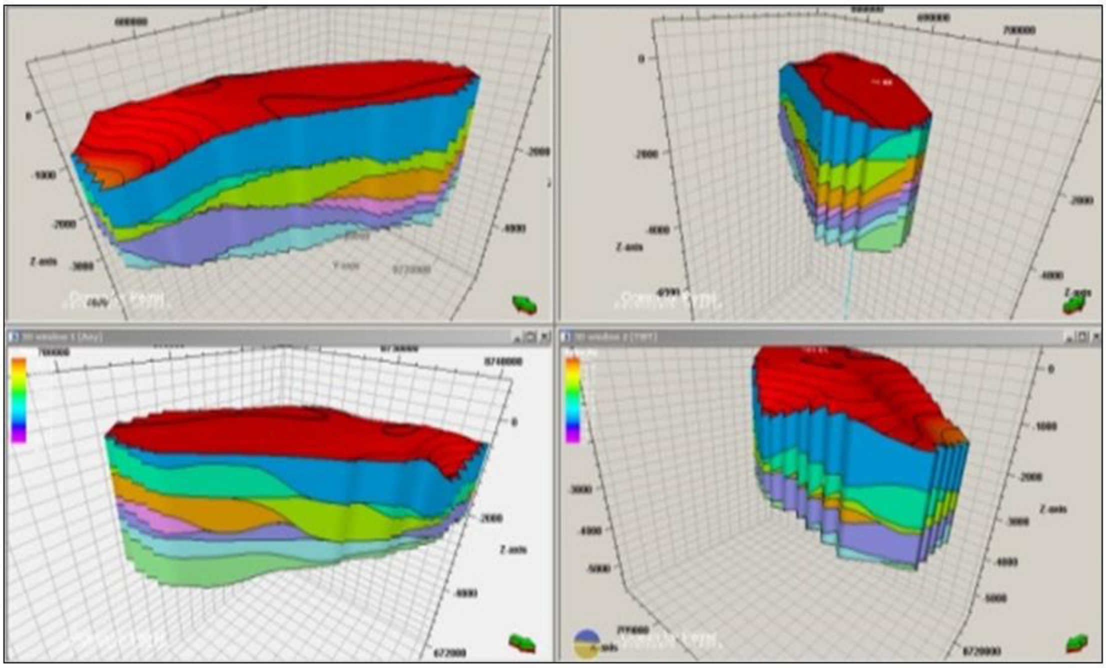

Figure 10. *Final 3D velocity model block diagram perfectly matches the sequential analysis model (colored). This velocity model can be used to convert time to depth.*

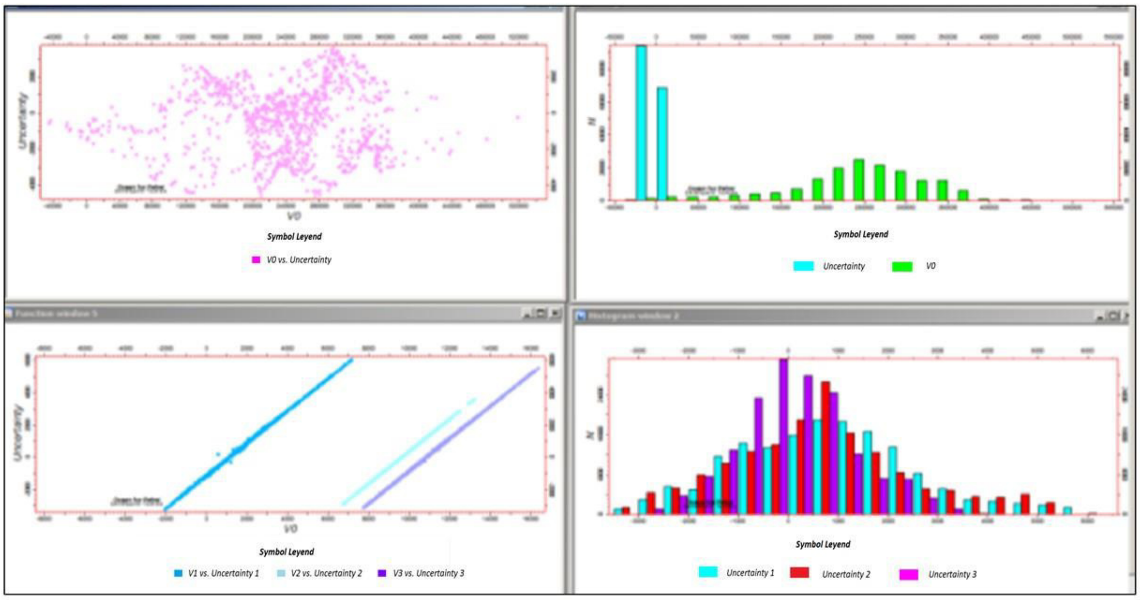

Figure 11. *On top, both figures show no correlated uncertainty against velocities. On bottom, both figures show weighted correlation on surface uncertainty with their velocities.*

7. Depth conversion

To convert any surface: fault, horizon, interval, from time to depth, it is necessary to understand that this surface will be submitted to a calculus of all velocity variations above the surface, this means the whole column of rocks at each point of the selected surface (Marsden, 1989).

The depth conversion process has a series of steps which can reveal some mismatches from the early stages of the velocity analysis (Vega, 2009) (Figure 11).

In order to eliminate these errors, the depth conversion process will be carried out iteratively up to an acceptable range (Figures 12 and 13).

It is always recommended to quality control the sequence boundaries fitting the seismic sections with well log; this will ensure the calculated sequential analysis is matching the depth conversion. In that case the calibration process was well done (Figures 14 and 15).

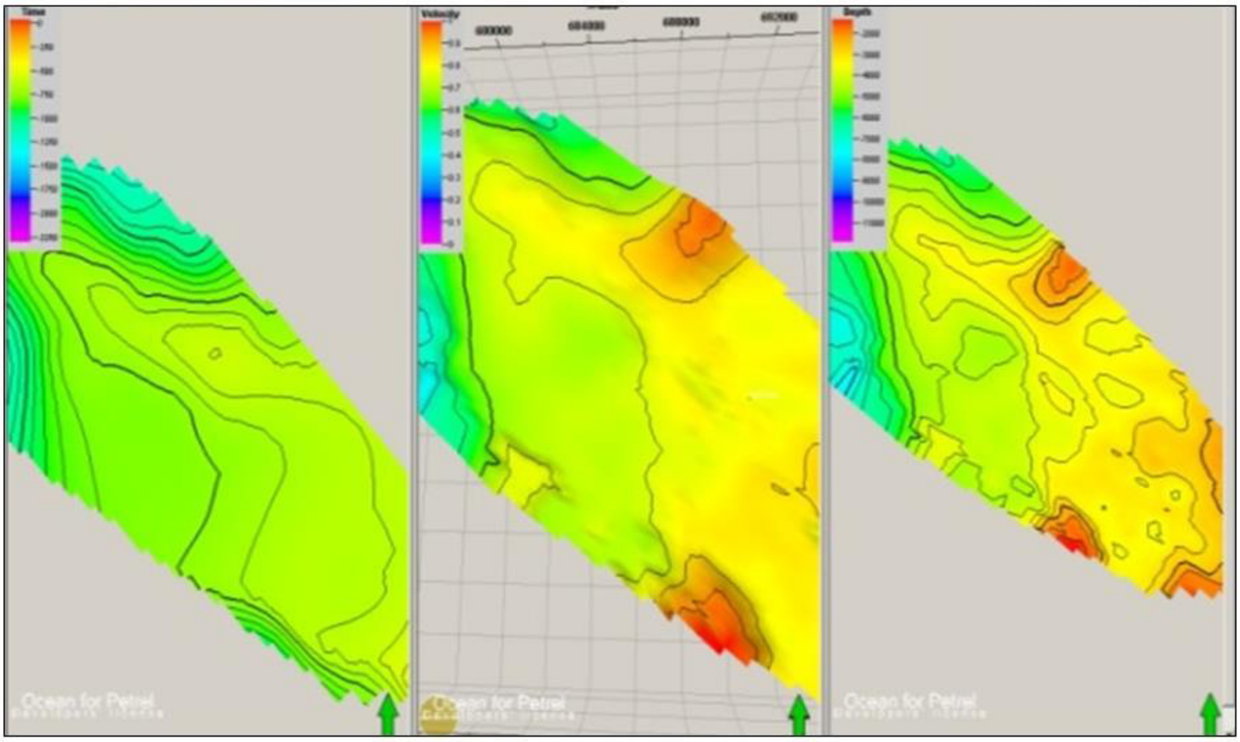

Figure 12. *The figure from left to right shows the input surface in time, the velocity map and the same surface converted to depth.*

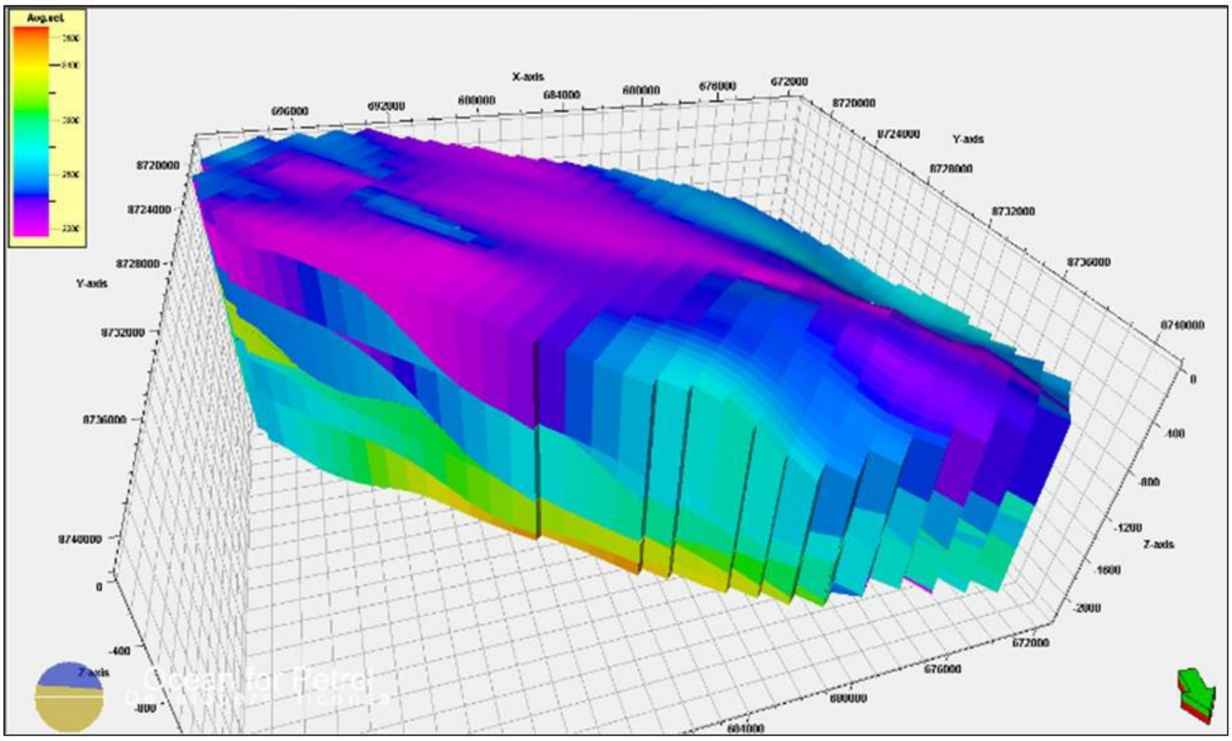

Figure 13. *The final 3D gridded velocity model with vertical and horizontal variations of velocities.*

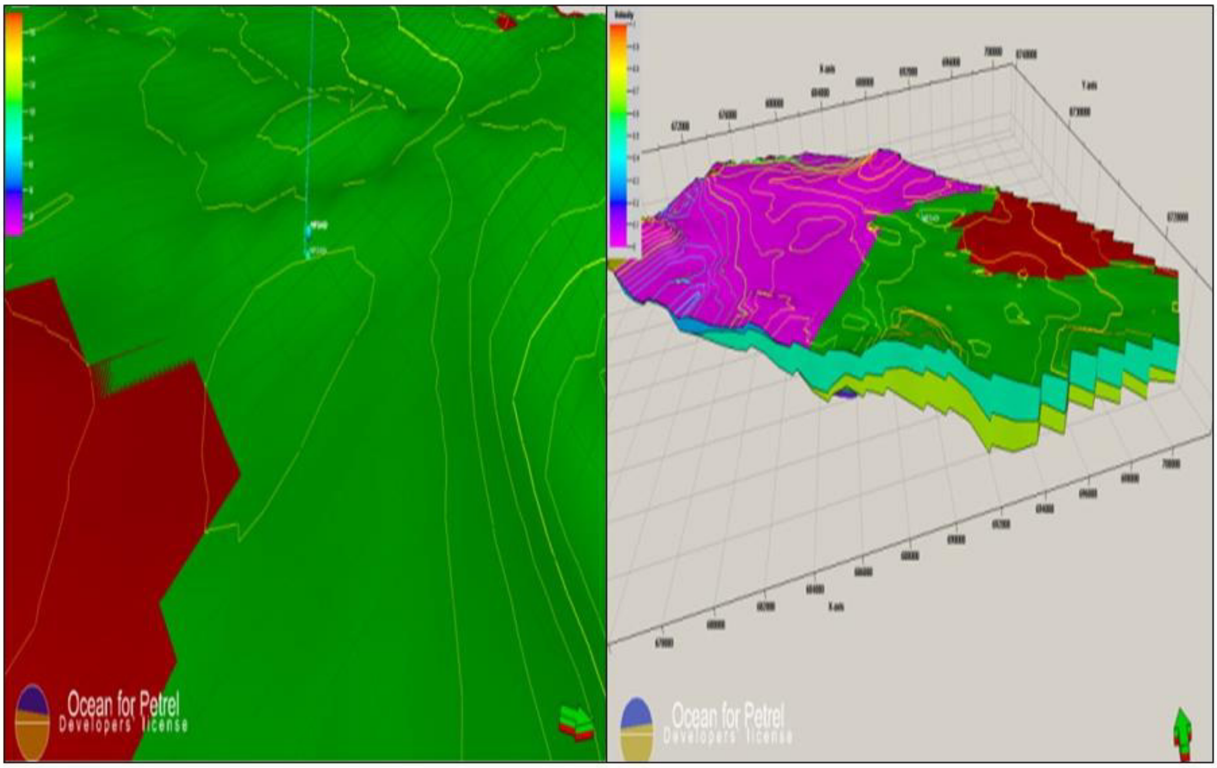

Figure 14. *The velocity analysis taken from the sequence analysis boundaries will give the properties variation from inside the boundary itself. The lateral variation is more consistent even to the farthest points on seismic stratigraphic interpretation.*

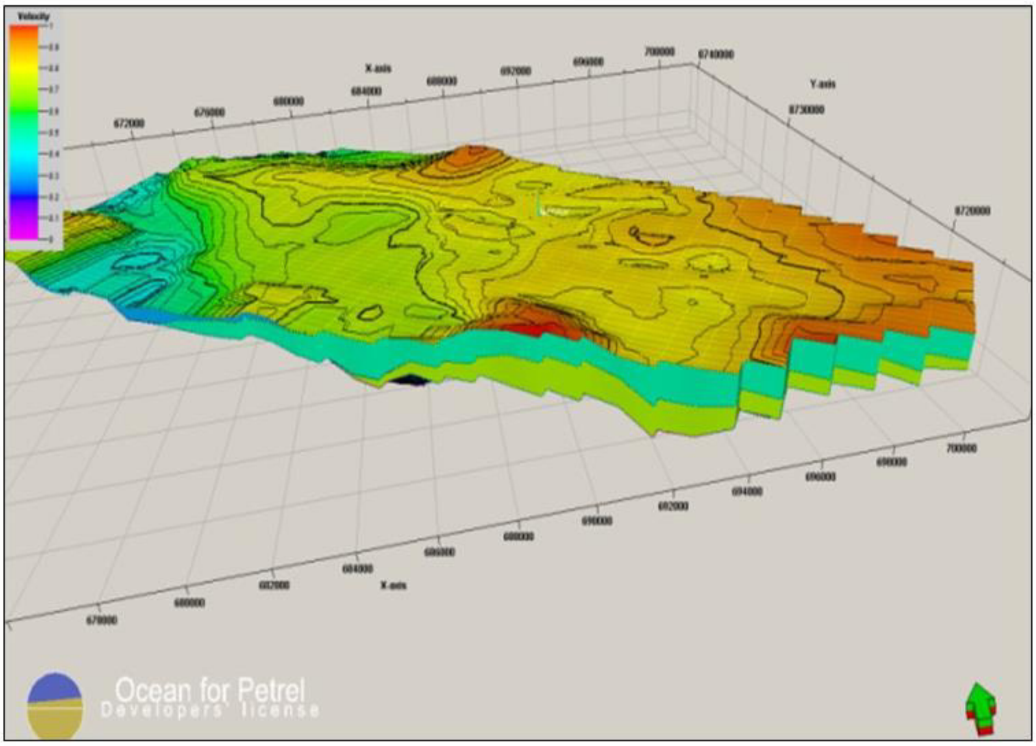

Figure 15. *Structural interpretation from the velocity analysis process converted to depth showing a continuous surface with consistency to the farthest points.*

8. Conclusions

One of the biggest issues in oil and gas in exploration and production is to increase the chance of success variable by risk reduction. The uncertainty calculated during risk evaluation in compressional structures is related to time to depth conversion procedures, and is strictly a function of the velocity field.

Geo-statistics is the media to calibrate and normalize the link between well logs and seismic reflection data.

The sequential analysis is a very powerful tool to match equivalent scales from well logs to seismic, preserving the structural emplacement and stratigraphic intervals and by consequence obtain an accurate correlation between reflection coefficient, sequential boundaries as well as geological markers.

The third order well log sequential analysis is a good approach to start correlation with seismic-stratigraphy boundaries (which is equivalent to sequential analysis interpretation on logs).

In order to achieve a velocities model that matches the sequence boundaries from the well logs and seismic, it is imperative that the velocities do not cross the stratigraphy as well as the structures. Then and only then, these will have consistent correlation between wells and seismic, so we can convert the seismic interpretation from time to depth.

The velocity model made by 3D gridded process populated with velocities already calculated (wells and seismic) into each cell by extrapolating their values (stochastically or neural network), spread into each cell weighted by the adjacent cells, thus the model has a balanced control ensuring the corrected time to depth conversion at any point.

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