Pre-Stack Seismic Data: A new Border to the Exploratory Interpretation

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Abstract

The Technology for petroleum exploration has been developed in an impressive way. This evolution imposes to the interpreter a constant technological updating and this, he/she needs to know different areas in a multi-disciplinary environment.

We accompanied in the 80´s decade the implementation of several computational tools and we have nowadays applications for volumetric seismic interpretation and also spectral decomposition that allows the interpretation of fine layers.

A better workflow that allows the asset team to high-grade prospect rapidly, improve reservoir property prediction, reduce uncertainty and enhance collaboration will be presented. This will be accomplished using post-stack and pre-stack seismic data in a integrated environment where many mainstream interpreters work.

Modern analyse techniques have been implemented in the petroleum industry with the objective of translating a seismic section in geological information. The search for the hydrocarbon has motivated the research. Studies show that some relationships, using the crossploting of the data, they can esteem the lithology or fluid, without however to do any perforation.

That is innovative. The denominated technology "Fusion the well to seismic"- WellSeismicFusion - it allows the interpreter to take place such study.

Introduction

The objective of this article is to present a better workflow to analyze and to identify anomalies of Amplitude Vs Offset, integrating the analyses of the pre-stack gathers.

Bright Spot observations are known since 60´s decade and they were decisive to Shell in 1986 participated in a exploration bid of Mensa, Auger and Mars fields in the Golf of Mexico.

In the same period, Petrobras, in the Campos basin, began studies that were shown efficient in the search of Hidrocarbonate, especially in the form of gas.

As said by Tom Velleca (1986), Manager of Shell Exploration in GM: "Bright Spot technique was crucial for the decrease of the risk and also for discoveries of great oil reserves in deep waters in the Golf of Mexico."

The technique "Bright Spot" takes the name because of the "brightness" that appears in the seismic section when sandstones are filled out with HidroCarbone, in matter gas (classified as class III). That "brightness" translates himself in the anomalous variation of the seismic amplitude, fruit of a happy combination of the impedances of the medium, in other words, between the seal layer and the sandstone filled with gas.

After several history of successes using AVO methodology, a deepest study was made necessary in the understanding of that technique. The geophysical interpretations stopped just considering the structures and they began to look for the stratigraphycal interpretation, therefore the analysis and the understanding of as the amplitude varies with the offset began to have relevance. Until then, just the stack and migrated data , were taken into account.

Nowadays, the workflow goes inexorably by AVO studies. Several seismic volumes were generated as participant elements of that study. Volume Near, Volume Far and Volume Mid (intermediate) - this relatively recent and no as spread as the other ones .

Several exploratory projects failed when following AVO indicative, taking to the discredit the indiscriminate application of that technology, however there is still a lot to publish in the sense of finding a safe and reliable workflow.

The seismic response is associated to several factors, such as: reflection coefficient and transmission, acquisition arrangement, effects of border of layers (tuning effect), noises, spherical divergence, emergency angle, curvature of the reflector, fronts of spherical waves, effect of the instruments, seismic processing, inelastic attenuation (Ostrander 1984). When we analyze the AVO, It consider the effect of the reflection coefficient in the seismic amplitude.

In the equation below Keith Aki and Paul Richards in the classic text book "Quantitative Seismology" (1980), Shuey (1985) deduced a simplified, however efficient, formula of quantifying the reflection coefficient based on the angle of incidence θ and in the petrophysics parameters (velocity "v "and density "ρ" of the medium), which is:

$$R(\theta)=A + B \sin^2(\theta) + C (\tan^2(\theta) - \sin^2(\theta)) \quad (1)$$

Where:

R = Reflection Coefficient P wave

Θ = incidence angle

A = acoustic properties- Near - (0-20°)

B = elastic properties- Mid-Far- (20-35°)

C = Contrast of P Velocity- Far- (25-45°)

Each one of the terms is influenced differently by different components. The first term is influenced strongly by the acoustic impedance – called also intercept, while the second (B) for the elastic properties or gradient. The third term (C) it is influenced more by the contrast of the P velocity. See on the figure bellow the three terms of the Shuey equation separated.

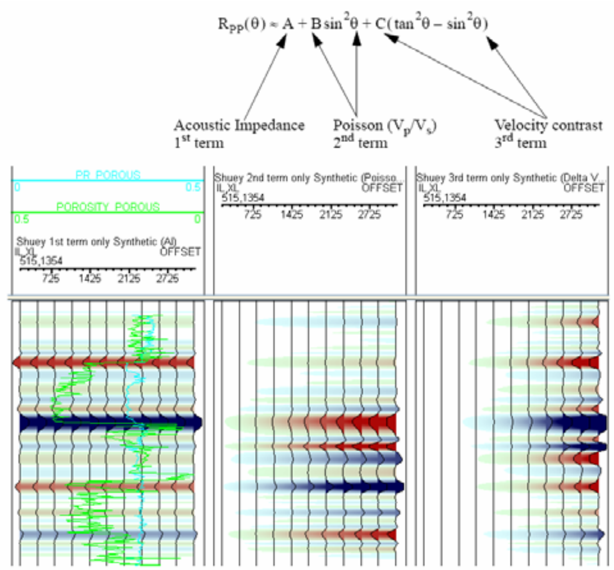


Fig 1: decomposition os Shuey eq in three terms

Following that above descrition, near traces are good for porosity indicators, lithology (soft rocks) and fluid effects (hard rocks), the intermediate traces (B) they are affected strongly for fluids (soft rocks) and lithology (hard rock), while the far traces (C) they are influenced by the saturation and of the lithology (WellSeismicFusion training manual). An Mathematical approach take the simplification of the Shuey equation:

$R(\theta) \sim ANI + B \sin^2 2(\theta)$ (2)

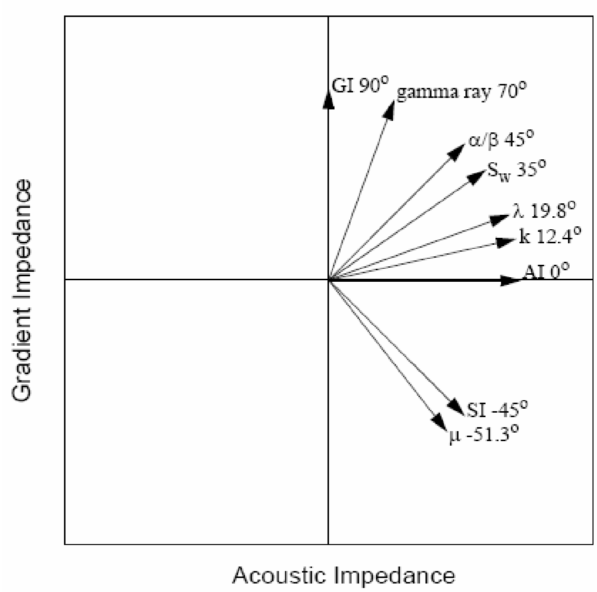
Allowing the linearization of the solution and analyses of intercept and gradient, very common in the industry.

However, in spite of the whole scientific approach, recent results lead to the discredit of the technique, fruit of exploratory failures.

The near traces represent the intercept on Shuey equation and are good indicators of acoustic impedance. (Density*Velocity P). Those amplitudes can be tied to the well through electric logs using synthetic seismograms. However the analyses with larger offset are good indicators of elastic impedance (EI) that is the generalization of the acoustic impedance for different incidence angles.

The elastic impedance (EI) can differentiate fluid from rock matrix. That implies the equation of the elastic impedance relates to the module bulk and constant of Lamé. The extended elastic impedance (EEI) expands the elastic impedance normalized up to 90 degrees. EEI substitutes $\sin^2(\theta)$ for tan χ and it normalizes EI dividing for cos χ, with this substitution, EEI varies from 0 to 90 degrees. The parameters bulk and Lame tend to be between 10 and 30 degrees, while shear modulus from -30 to -90 degrees. In agreement with Whitcombe (2002) the function EEI can be used to represent any elastic parameter approximately just with the change of χ. See some established relationships below:

EEI(χ=0) ~ EI(θ =0) = acoustic impedance
EEI(χ=12.4) ~ EI(θ =28.0) = bulk modulus
EEI(÷=19.8) ~ EI(θ =37) = Lamè parameter
EEI(χ=35) ~ EI(θ =57) = Water saturation
EEI(χ=45) ~ EI(θ =90) = ratio vp/vs
EEI(χ=70) = gamma ray
EEI(χ=90) = impedance gradient
EEI(χ=-45) = impedance shear
EEI(χ=-51.3) = shear Modulus



EEI projections for some well known moduli (Whitcombe 2002)

Fig 2: Extended Elastic Impedance for different angles

A link can be established between EI and reflectivity (R(θ)).

$R(\theta) \sim ½ (\Delta EI) / EI = ½ \Delta \ln (EI)$ (3)

As it demonstrates the illustration below, just based on anomalies, the wells had different results in terms of presence of HC:

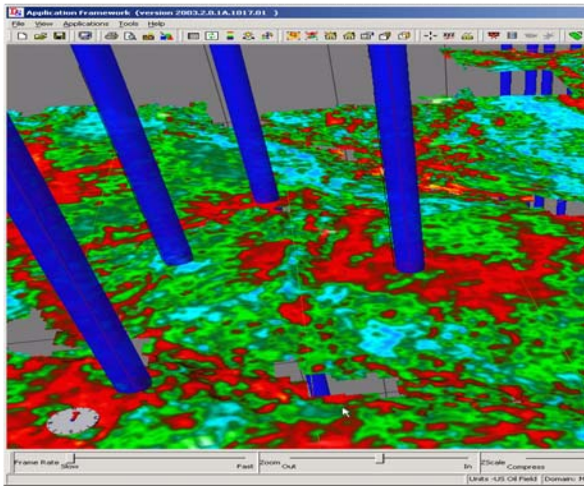


Fig 3: Amplitude map for a migrated seismic data

They were the lithological variations that caused similar anomalies on seismic response leading the interpreter to propose extensions of the reservoir that had not confirmed the presence of HC. A detailed analyses on gathers for each well show different CDPs in terms of Amplitude vs Offset. The interpretation of that “signature”, at least, bring suspicions as the extension of the reservoir and force more detailed studies.

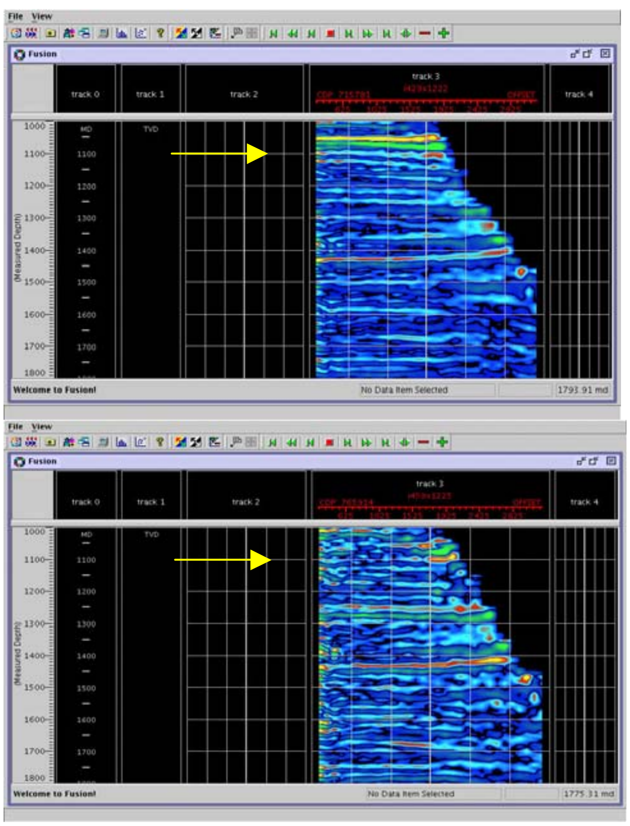


Fig 4: Gathers indicating different amplitudes

It is noticed differences in the first reflection, however when staking the gather cdp, they get the same amplitude, taking the conclusion of false anomaly.

Other Studies are necessary for a more reliable inversion of the seismic data into geological information. For that happens, it is necessary that there is a modelling of different sceneries (fluid x lithology) and a tool that allows to correlate the data modeled with the real seismic data, making possible an analysis of the pre-stack data that it is richer in information.

A link between the seismic data and the petrophysical properties was established by Biot-Gassmann (1956). starting from velocities and densities informations, (electric profiles DT, DTS and RHOB) to infer physical parameters of the rock. This study was based on isotropic and homogeneous medium.

$$V_p = \mathrm{sqrt}((k+4/3\mu)/\rho) \quad V_s = \mathrm{sqrt}((\mu)/\rho) \qquad (4)$$

Where k represents Bulk modulus (or the inverse of compressibility) and μ the shear modulus or rigidity module). Those relationships are valid for most of the clastic rocks, failing on rocks with very fine granulations (mudstones). In relation to Vs, the geological enviromment that more contributes is the compaction, followed by form of the mineral grains, organization for the sizes (sort) and the lithostatic pressure. To smallest contribution it comes from the saturation (Anstey 1991). A crossplot between Vp and Vs can discriminate the lithologies.

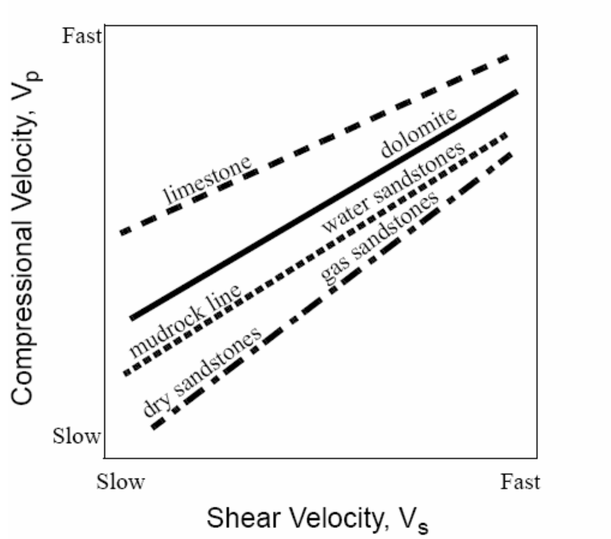


Fig 5: Xplot of VpxVs, separation of lithologies

There are several variations of the Gassmann equations, however, it should have in mind that the petrophysics parameters (k, μ, ρ) they are function of the combination of the parameters of the constituent matrix of the rock, of the porosity and of the present fluid. See the diagram below:

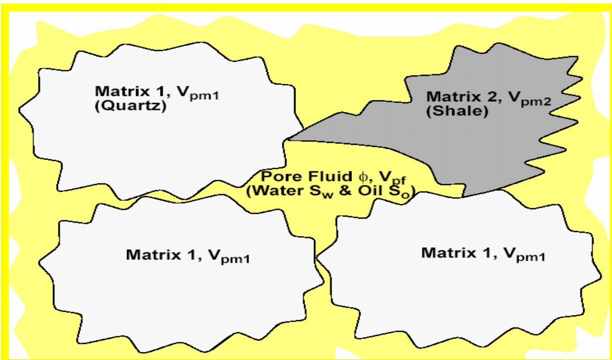


Fig 6: illustration of rocks contents

A variety of relationships exists between Vp and Vs and prediction technique for Vs, however most is reduced to two approaches:

1- empiric relationship VpxVs based on the porosity (more conmum for saturation of water).
2- use of the Gassmann equations (1956)

Although some of the rehearsals esteem the velocities P and S, considering certain geometries idealized. At the laboratories it can be measured. The normal conditions of enviroment and the frequency of the tests influence in the measurements , theoretical methods give us reasonable answers including geometry of the pores.

The challenge is identifying through the crossplot of information among seismics and logs, regressive models of patterns where it is found good local relationship between the properties known as petrophysics and the seismic amplitudes, in the way to expand for the whole model throughout the volume.

The objective of the structural seismic interpretation is to create a geological model the closest possible of the reality. However, for an understanding of the geological model, far away from the existing wells, with their lithologies and fluids, it is necessary an interpretation of the seismic amplitudes.

Methodology

From the electric profiles registered in the well, it is simulated, through Gassmann equations, lithological changes or in fluids. From new profiles DT, DTs and Rhob, a synthetic seismogram is calculated with the same geometry which real seismic data was acquired. With the calculated synthetic sismogram, a crossplot between real and synthetic data is performed and a mathematical relationship is found.

Starting from the local analysis, in the well, the regression model is applied for whole pre-stack data :

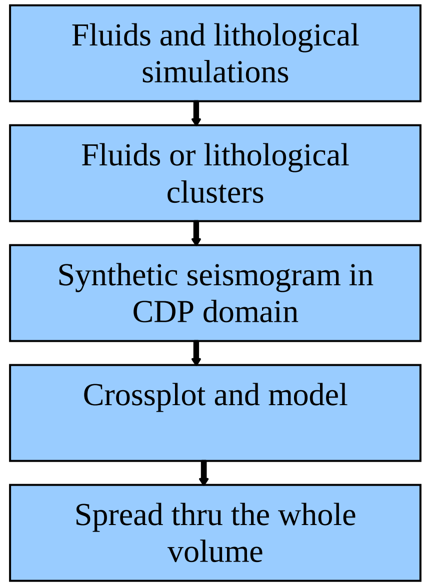


Fig 7: WorkFlow for AVO and lithological analysis

With this methodology, the interpreter can create different geological sceneries, modifying the petrophysical parameters or simulate differents fluids.

Through the crossplot among the new generated profiles lithological groups (clusters) are selected to look for in the seismic their correspondents correlated.

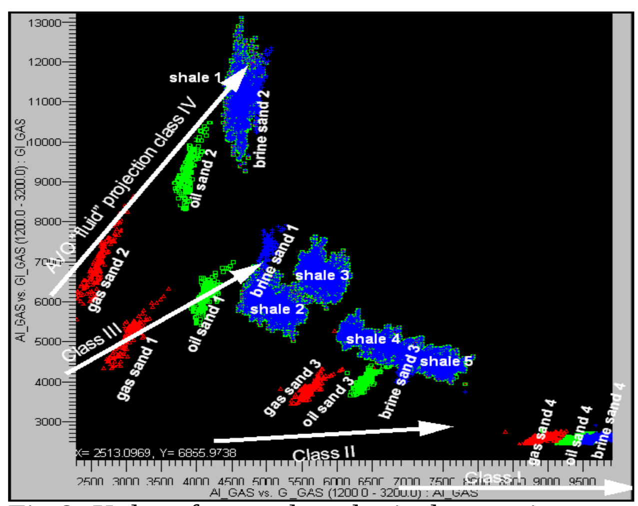


Fig 8: Xplot of several geological scenarios

For the case of the fluid substitution, it can be studied different models. The illustration below presents simulated logs of Vp, Vs, Rho for different sceneries of fluids.

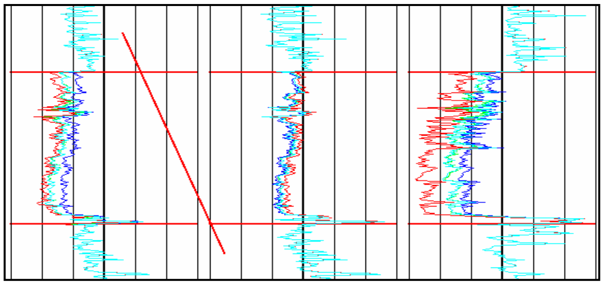


Fig 9: synthetics logs for Fluid substitution

The curves represent the petrophysival parameters changes when HC is added during the fluid substitution using Gassmann. It can remove the effect of the invasion of mud in the reservoir, that cause changes on the results because of substitution from HC to invasion mud.

A concern that the interpreter should have is when he links petrophysical parameters with seismic amplitudes. Remember that amplitudes are relative to the interfacies while the Impedances are to the layers. Some companies prefer to work with the impedances, because they are correlated more easily with the petrophysical parameters. Below is presented an illustrative figure to show that an integrated tool can easely plot differents informations leadind the interpreter to undertand better the behavior of the reservoir. Synthetics logs, synthetics seismogram with different fluids, real pre-stack gather, migrated data with picks and horizon interpretation are ensembled in the same window.

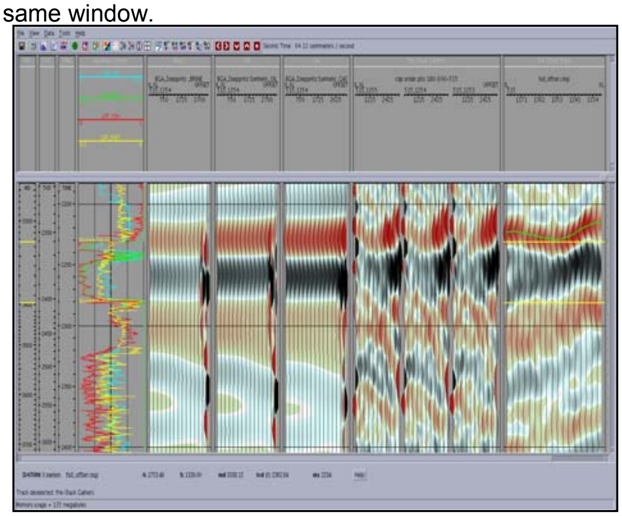


Fig 10: Logs, synthetics, pre-stack and migrated data, horizon and picks in the same environment

An integrated tool allows access, analysis and edit on several datas and simulations avoiding that cold analysis of AVO take to precipitated conclusions in terms of presence of HC.

Conclusion

An innovative workflow and to reduce the cycle time of the convencional way of working is suggested. With the 4D acquisition and studies, this aproach can help to solve the feasibility study and discriminate a very subtle fluid variations and then place in a better location injectors and producers.

A complete AVO analysis is now allowed not just with the intercept and gradient data but also with the information of the whole gather to reduce the uncertainty in the analysis of the information, reducing the exploratory risks.

Acknowledgments

To Landmark that has delivered this technology and it allowed the publication.

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