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Use of Seismic Inversion Attributes In Field Development Planning

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Abstract:*The development of any field is an important stage in exploration and production projects. Conventionally most Field Development Planning (FDP's) are performed without the use of seismic inversion products. This paper demonstrates the advantages of integrating seismic inversion products into FDP and its added values in the process with some case studies. The lithology and fluid volumes were computed using the acoustic impedance (AI) and Poisson's ratio (PR), these parameters are seismic inversion products. The volume obtained shows oil, gas or water probabilities, which are crucial in well placement program and optimal well planning (FDP's common goals). The values seismic inversion integration added to FDP includes improved volumetrics from high fidelity porosity and permeability volumes, better lithology and fluid discrimination.*

Keywords: *Seismic inversion, Attributes, Fluid Content, Lithology, Discrimination, Acoustic impedance, Poisson ratio, Delineation.*

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I. Introduction

Seismic inversion products are high resolution data, which are used to constrain and build high fidelity models for reservoir simulation. Expects in reservoir studies require accurate knowledge of the reservoir geometry, reservoir properties and parameters (especially its porosity, water saturation and permeability volumes) to build reservoir models and compute volumetrics. These parameters are often not known with precision and accuracy (some degree of certainty), because of scaling issues, uncertainty in production test results and spatial sparse patterns of sampling. Thus production history matching often suffers nonuniqueness and poor comparison of the initial simulation results with measured pressure and production data, but seismic inversion provides the necessary accuracy parameters needed such as precise densely sampled attributes which are incorporated in building high fidelity reservoir models for improved volumetrics.

II. Theoretical Background

Real earth rock layers have an inherent acoustic impedance (layer based property), but contrast in their acoustic impedance (AI) between the layers gives rise to a reflection coefficient (RC).When this is convolved with the wavelet, it produces the seismic data of the area (Figure 1).

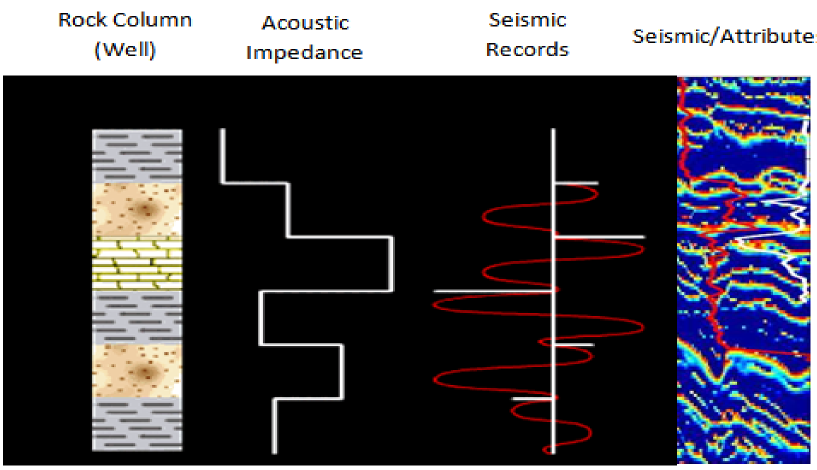

Figure 1: Schematics of Rock Properties and Production of Seismic and its attributes

So, inversion processes either "reverses" or "inverts" the whole forward process…i.e. the removal (extract) of the wavelet and then derive the AI from the Reflection Coefficients together with a background (low frequency) model. The acoustic impedance (AI) sometimes together with other properties e.g. Shear Impedance, Poisson's Ratio, are used to infer or describe the rock properties of the field.

Seismic inversion attributes are normally derived from post-stack inversion and pre-stack inversion techniques. The post stack inversion techniques are used basically to obtain information about the acoustic impedance, which is commonly used in porosity modeling and lithology delineation while pre-stack inversion techniques gives information about the acoustic and shear impedances, and the density, commonly used for fluid discrimination (Table 1).

Table 1: Inversion Techniques and Expected Output

Inversion Method	Outputs	Common Uses
Full Stack	Acoustic Impedance (AI)	Porosity Lithology Indicator
AVO (Simultaneous	Acoustic Impedance (AI) Poisson ratio (PR) Density	Porosity Lithology Prediction Fluid discrimination (Gas, Oil, Water)

Spatial distribution of petrophysical properties within any given heterogeneous reservoir formation are using performed using only well data and statistical techniques, which are often affected by uncertainty factors. However, the spatial modeling of the reservoir properties can be constrained using seismic data especially away from the well location because of its high resolution.

Therefore seismic inversion attributes can be used to reduce the risk and uncertainty common in integrated reservoir characterization, which are generally use to map sand bodies, building static reservoir modeling, understand the reservoir properties changes, stimulation and production history match.

As opposed to "elastic" inversion (where each angle stack is inverted separately to produce elastic impedance) the Simultaneous inversion combines the information from all the angle stacks and inverts them at the same time (…hence one reason for the name simultaneous). Performing the inversion simultaneously allows the direct generation of the three rock properties; AI (Acoustic impedance), PR (Poisson's Ratio) and Density (Figure 2).

These are all physical rock properties and therefore get us into the quantitative domain. These properties can then be used to determine quantitative reservoir properties such as lithology, fluid, porosity, saturation … which can lead on to net pay and volumetrics.

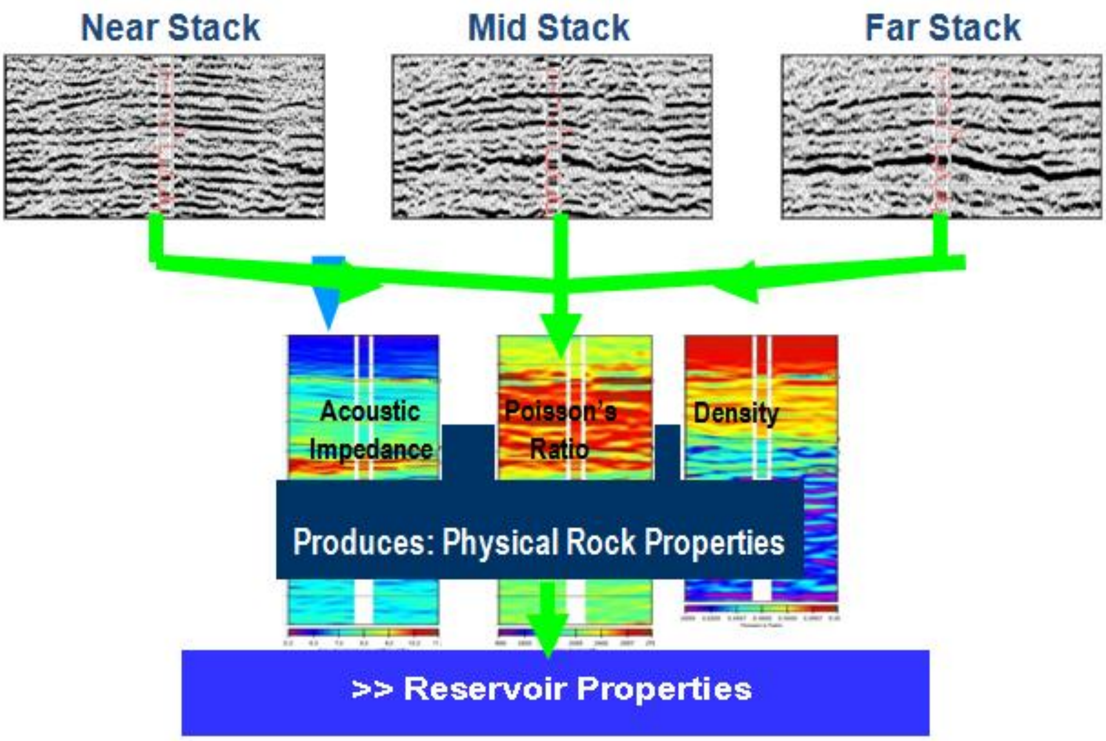

Figure 2: A typical Simultaneous AVO Inversion Schematics (Pre stack Technique).

Seismic inversion generally involves:
- Transforms the reflectivity wavefield to interface or layer properties
- Performing post-stack and pre-stack techniques for evaluation and analysis
- Also deterministic and statistical inversion techniques exist

Some of the possible extractable properties include:
- Acoustic Impedance (AI)
- Velocity
- Poisson's ratio
- Elastic impedance
- Seismic logs
- Note that for seismic inversion techniques calibration to log and core data is essential.

III. Methodology

A typical Seismic data inversion technique workflow includes the following steps
- Log Conditioning, editing of the wash outs, cycle skipping, shales alteration, modeling the Vp and density of the reservoir formation
- Petrophysical and geophysical well log analysis, in which mud filtrate invasion is corrected and the lithology of the reservoir formation delineated using Vshale and Vclay. The total and effective porosities are also determined as well as the pore fluids. Rock physics modeling is performed to determine the permeability, fluid substitution and shear wave modeling.
- Preconditioning of the seismic data, which involves zero phasing of the seismic data, enhancement of the seismic signal bandwidth, removing of residual normal movement applying non-rigid matching techniques and spectral balancing between angles stacks.
- Building of low frequency modeling, which includes horizon and fault guided interpolation of well log impedance and density across the entire survey area.
- The modelled low frequency is extracted and used to invert the acoustic impedance to generate the absolute impedances of the reservoirs.
- Lithology delineation, fluid discrimination and rock property are finally performed
- Calibration/Prediction of Reservoir properties

IV. Case Study and Results

Two different scenarios are performed to show the advantages of integrating seismic inversion in Field development planning programme.

CASE 1: FULL STACK INVERSION FOR ACOUSTIC IMPEDANCE AND POROSITY

Static Inversion for Carbonate porosity mapping: A study ofLobina field in Gulf of Mexico fields, operated by Pemex oil Company (Figure 3).

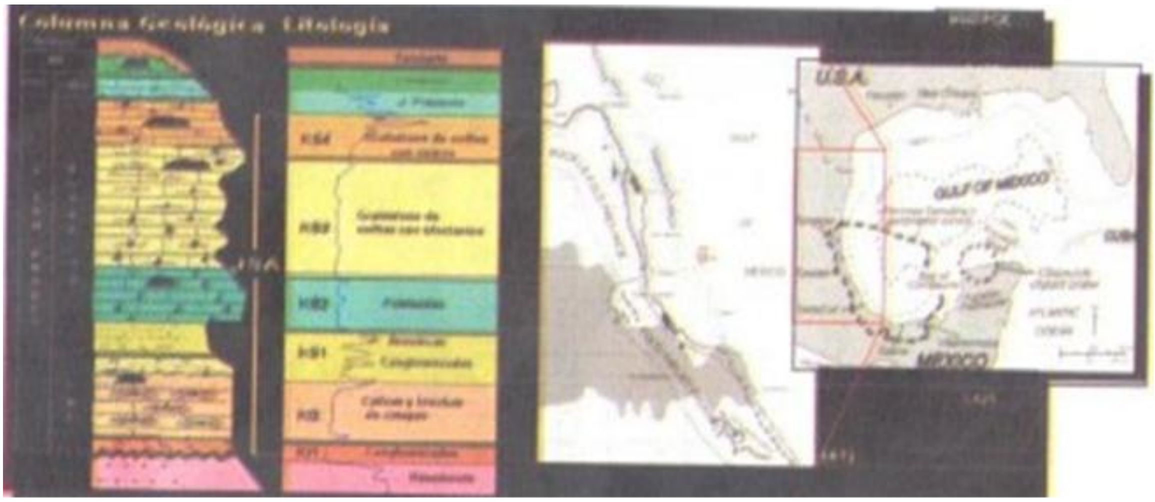

Figure 3: Location of Study Area

V. Method

Thisstudy examines a carbonated filed, with the aim to guide in the well placement program for the field, optimizing the field well planning and possible targeted reservoir. The seismic data of the field was inverted to carbonate porosity using the reservoir specific rock physics model, which enable us to generate the porosity- height maps for the field. In the study the quality of the initial seismic data was highly poor to produced reliable porosity prediction. Thus, a new acquisition was made for the field, from the new data porosity height map and time structure map of the field were produced (Figure 4).

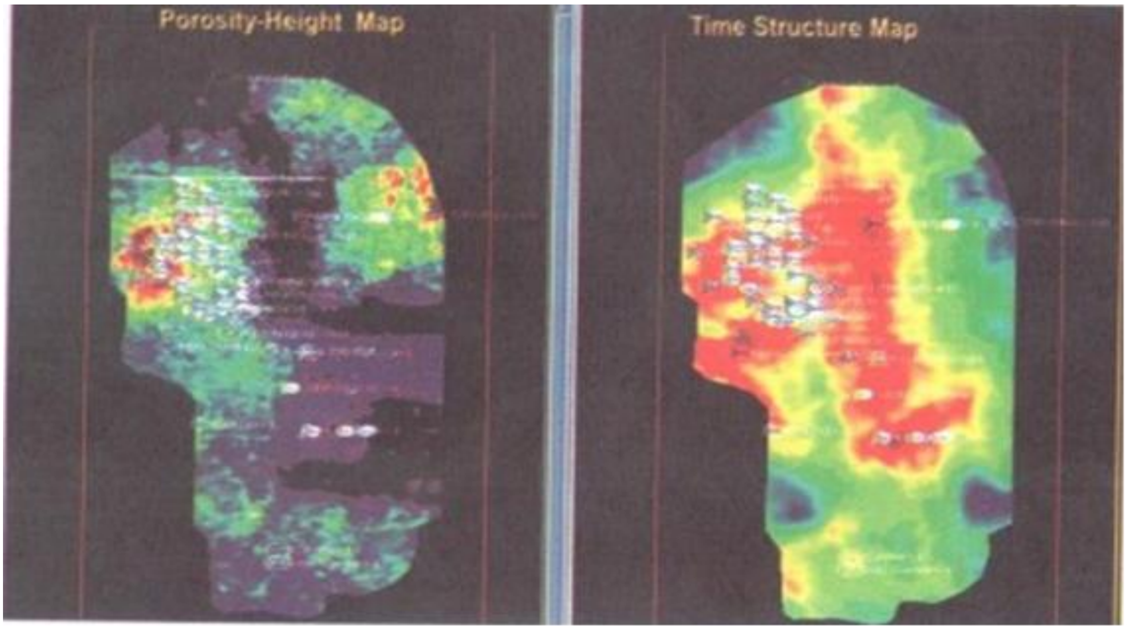

Figure 4: Time structure map and Porosity Height map of the field.

After inversion of the seismic data using the acoustic impedance, two carbonate porosity profiles (locations) were derived from the inversion results. The first location,Well-A was the original high priority well based on the original data and the second location, Well-B based on re-prioritization using the inverted seismic data, which gave a better quality. A carbonated porosity section of the field through Well-B was generated, and the calculated porosity logs were superimposed on the seismic porosity section, an excellent tie was observed between the porosity facies on the seismic and those observed from the well (Figure 5).

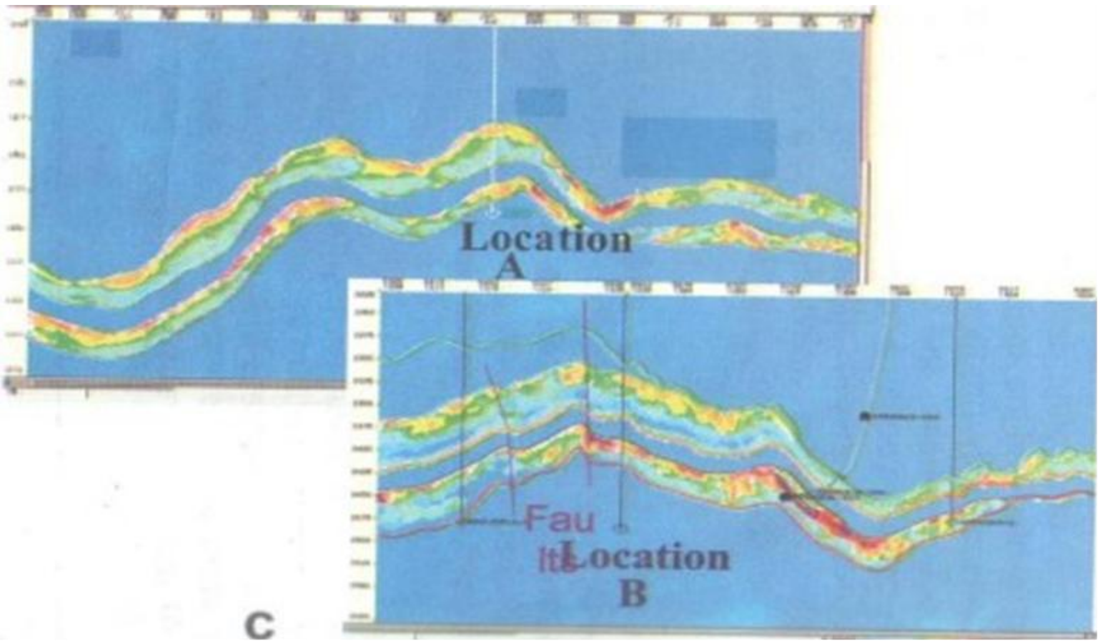

Figure 5: Static Inversion for Carbonate porosity mapping: Porosity profiles of the field

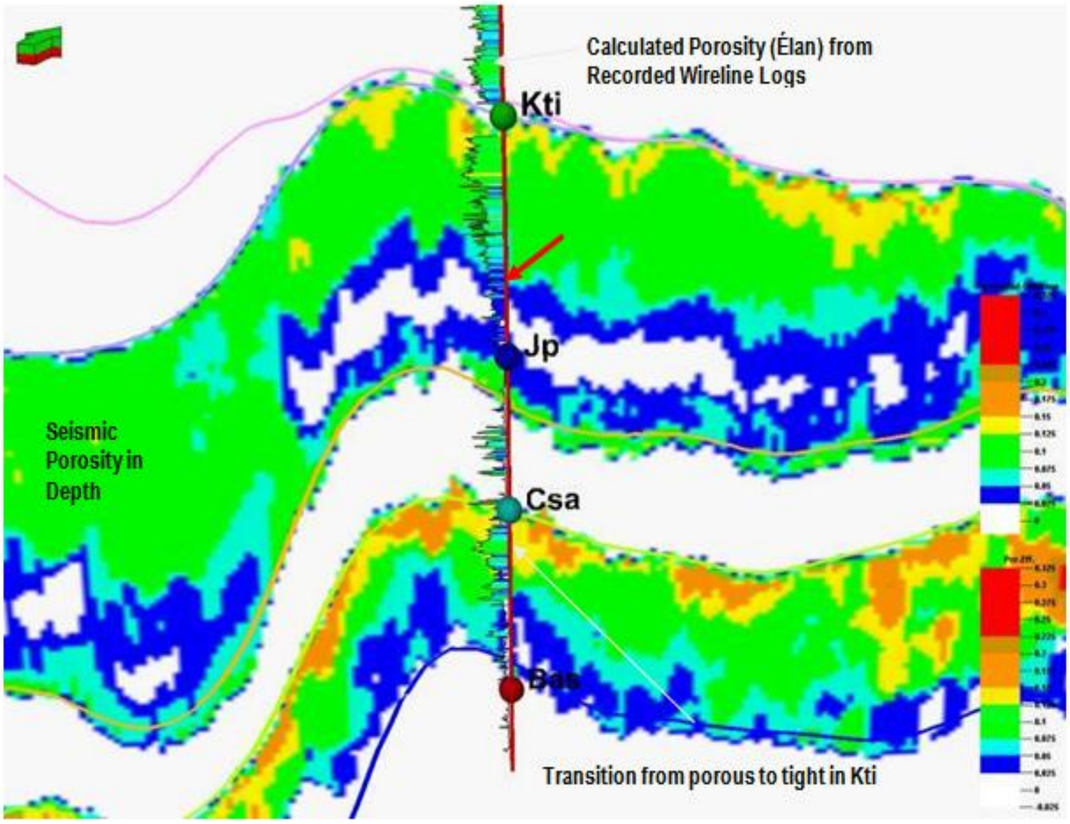

Figure 6: Static Inversion for Carbonate porosity mapping (Gulf of Mexico data):Seismic Evolution, from images to porosity maps.

VI. Results and Discussion

The survey data was used in a fully integrated workflow, driven by rock-physics analysis, to produce a reservoir model with maps of reservoir parameters. What you see here shows one of the results of the survey. The shaded areas running from left to right are seismic porosity maps in depth. The upper reservoir is the Cretaceous Tamaulipas Inferior carbonate, the lower the Jurassic San Andres carbonate. The color scale ranges from lower porosities in blue to higher porosities in orange and red.

Two points are of importance. First, note the heterogeneity of the carbonate formations-- the higher porosities at the top of the reservoirs are far from uniform. Information like this is of critical significance in placing the well profiles needed to maximize production. Second, the slide also shows the Elan petrophysical interpretation from the recorded Schlumberger logs that display excellent agreement with the seismic-derived porosity (Figure 6).

With definition such as this now available from high-resolution, high-fidelity seismic, it is becoming more and more essential to be able to put the well exactly into the sweet spots identified in this way.

Kti = Cretaceous Tamaulipas inferior carbonates, Jp = Jurassic Pimienta Shale
Csa = Jurassic San Andres carbonates, Bas = Top of Basement
Value it identified were drilled and tested at 2000 barrel oil per day (bopd) step out location

The color on the graphic is seismic acoustic porosity converted to depth and displayed in Petrel. The color scale on the right is effective porosity. The white strip between the two colored strips is the Pimienta shale (source rock) - as this is not reservoir we gave it a 0% porosity value. To clarify the upper colored zone is the Cretaceous which has a separate AIp to porosity transform to the lower colored strip (Jurassic San Andres).

The result obtained was used to re-prioritize the well planning with emphasis on well B location. The well was drilled based on the results of the inversion study and the well tested gives an extra 2000 barrels of oil per day and added an extra total sum of 6million barrels of oil and 8.7 billion cubic feet of gas from the field (Evaluation of its performance has subsequently enabled 6 MMbo, and 8.7 Bcf of P1 proven reserves to be added to the field). Additional drilling opportunities were identified, which improved the reserve estimate for optimal production by the company.

CASE 2:

Amplitude versus Offset inversion for oil and gas probabilities: study of a deepwater field (Diana Field) in Gulf of Mexico operated by Statoil.

VII. Method

The seismic data was pre-conditioned and inputted into the AVO workflow, the generated inversion attributes were used to performed litho-cube analysis (Figure 7), which is subsequently used to generate the hydrocarbon probability maps (measurements). The seismic attributes, namely the acoustic impedance and Poisson ratio, generated are further used for the litho-cube analysis, a map of the reservoir sand (reservoir A50) in the field was generated (Figure 7).

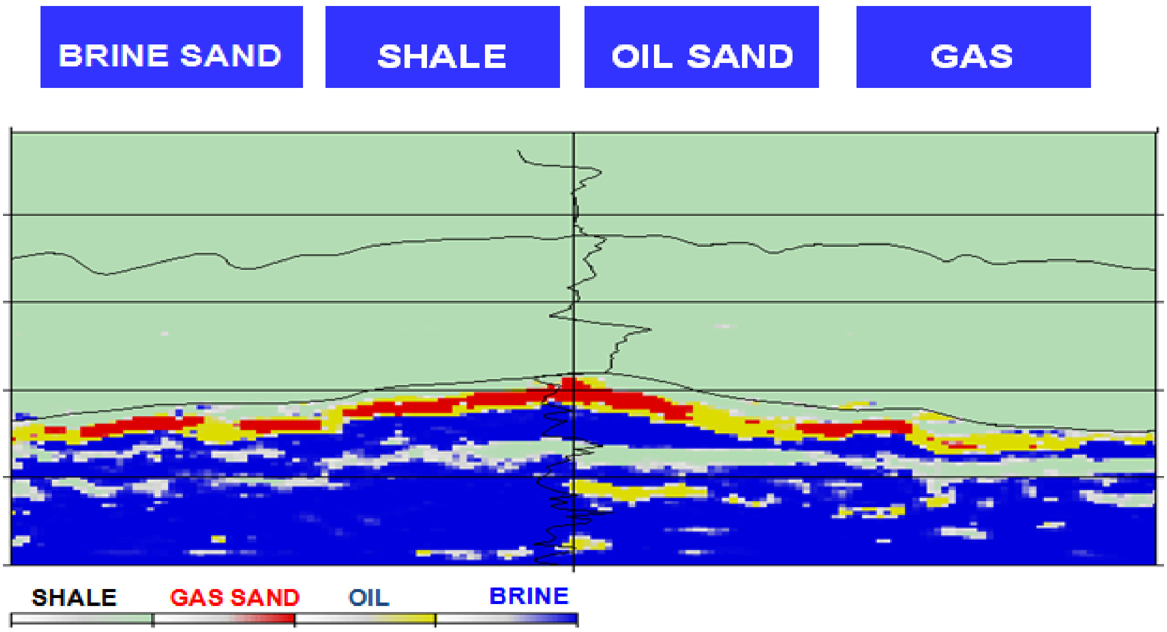

Figure 7: Litho-Cube Analysis of Sand units

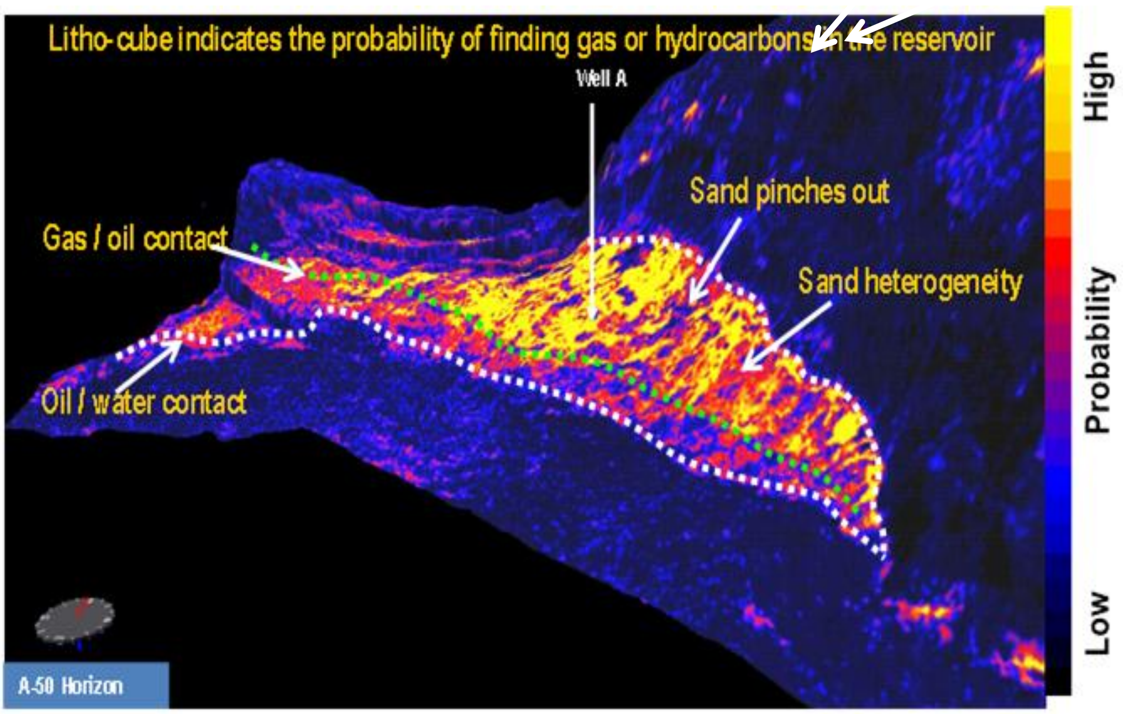

Figure 8: AVO inversion for oil and gas sand probability map of A-50 reservoir(Data from Diana field, Gulf of Mexico -Pemex).

VIII. Result and Discussion

This example is from the Diana field in deepwater Gulf of Mexico. It shows the results of a litho-cube analysis resulting in a gas sand probability measurement on a Q seismic dataset. The gas sand probability utilizes a combination of AI and PR as described earlier.

The main points of note are:

- View of A50 reservoir, the maximum probability of gas sand unit is found within the reservoir at Well A location, showing the Maximum probability of Gas Sand Class distributed through the reservoir.
- We observe the heterogeneities, and the rich HC sand gas area at the south of well.
- We also observe that the GOC and OGC can be easily identified and help to interpret the gas oil contact and oil-water contact from the probability sand of the inverted and calibrated data.

IX. Conclusion

This study has shown the use of seismic inversion attributes in field development planning making use of the high resolution information offered by seismic inversion attributes. The benefits among others include: their application in constraining and building high fidelity models for reservoir simulation, their use in computing volumes that show oil, gas or water sand probabilities. These ultimately deliver improved volumetrics from high fidelity porosity and permeability volumes, better fluid and lithology discrimination. This integrated workflow has benefitted many field development programs, which has help in drilling successful development wells and effective reservoir management.

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