Risk Reduction at Exploration: How Different Scale Information Can Improve the Understanding of an Area

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Abstract

Integrate fluid-rock-log-seismic information is one of the most important challenges that Geoscientists faces in the Oil Industry today. This project shows a Brazilian case history where was possible to go a step further on integrating information. Rock/fluid data, well-logs and a good 3D seismic image were fully available. Besides that, geopressures information and a 2D controlled-source electromagnetic (CSEM) survey were accessible. So, a study was performed to understand the seismic and electromagnetic answers of different scenarios (rock types and fluid saturation) in order to reduce exploration risk. Two feasibility studies were conducted: one for understand the AVO characteristics and another one to comprehend how the Sea Bed Logging (SBL) survey would respond to different types of saturation fluids. Then all data were used to reach a conclusion about possible targets.

Introduction

This study was motivated after a wildcat well (henceforth, Well-A) drilled at a seismic anomalous amplitude only reached water saturated sandstones. The full analysis of the well data, such as salinity, pressure and petrophysics, pointed that the reservoir was composed by clean sandstones with porosity around 20%. Besides that, the saturation fluid was, almost, 100% fresh water with salinity around 7500 ppm (some residual gas was found).

In other hand, the SBL data interpretation figure 2 revealed EM anomalies that could be related to gas accumulations. A first feasibility approach showed that the kind of anomalies found by SBL could not be explained only by fresh water. So, after initial analysis, the main question remains: How so many variables can be tied together in order to, not only explain the dried well, but also help the exploration team find a commercial hydrocarbon accumulation?

Previous analysis of seismic data showed that the well-A would be drilled in a anomalous high pressure zone,

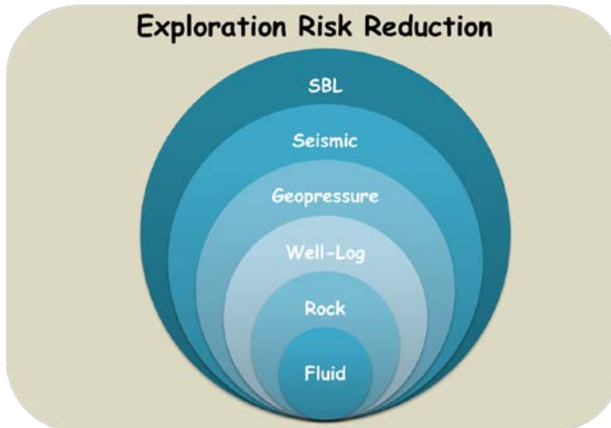

Figure 1: Using information from different scales.

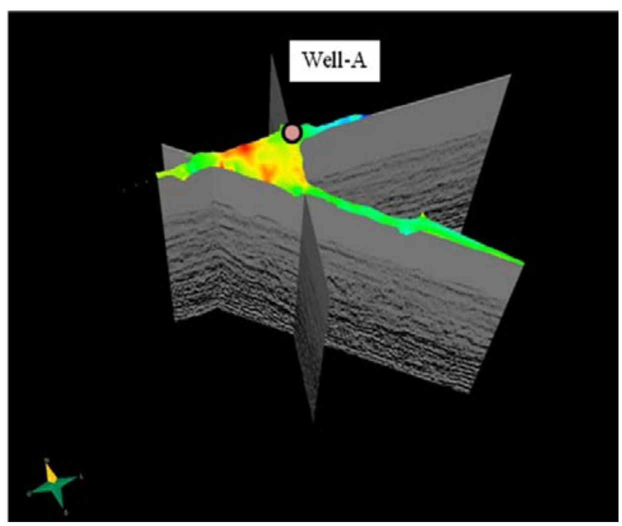

Figure 2: SBL survey at well-A. Hot colors denotes high resistivity anomalies.

Method

The project were divided into 4 parts:

- A feasibility focused on resistivity scenarios
- A feasibility focused on elastic attributes and how they are affected by a geopressure scenario

- A resistivity modeling using 3D seismic and well-log data
- Conclusion

The main factors that affects the resistivity are clay content, hydrocarbon saturation, formation water salinity and porosity. Modeling for different saturation fluid was conducted using Archie equation in order to understand the expected behavior of EM data and establish the cut-off between water and hydrocarbon saturated rock formations.

The second feasibility focused on elastic attributes. For this part of the study made use of well logs (slowness P and S, density and porosity) in order to simulate 1D AVO behavior of the target sandstones sampled by Well-A. Synthetic angle gathers were constructed using a convolution model. Then, AVO analysis were conducted with Aki-Richards approximations to plot an Intercept x Gradient graph and the anomalies divided in usual AVO Classes.

Several scenarios changes for different pore pressure and water/hydrocarbon saturation were constructed. The different fluid saturation were modeled by usual Gassmann equation. Meanwhile, pore pressure variation were modeled using the procedure rock physics modeling. Latter laboratory analysis (made after project time line) confirmed pore pressure scenarios.

The next step was construct a large-scale Resistivity (henceforth, R) model based on Well-Log data (Horizontal Resistivity, Rh) and Seismic Data (Pseudo-Impedance, IP). In order to convert IP into R, one has to find a non-linear function Rh=Rh(IP) between this properties using Well-logs. Basically, this is done with a plot Rh x IPw (Well-log Pseudo Impedance), where IPw is defined as:

$$IPw = \left\{ \frac{304800}{DTP} \times RHOB \right\} * F$$

Where F is a filter responsible to guarantee that the frequency spectrum of IPw is similar to frequency spectrum of Seismic Data. The plot can be see in figure 3. The function L, was found to be:

$$Rh = 1.47007 + 0.00173027 \times IPw + 2.40301e^{-06} \times IPw^2 + 5.42894e^{-10} * IPw^3 * 1.21954e^{-13} IPw^4$$

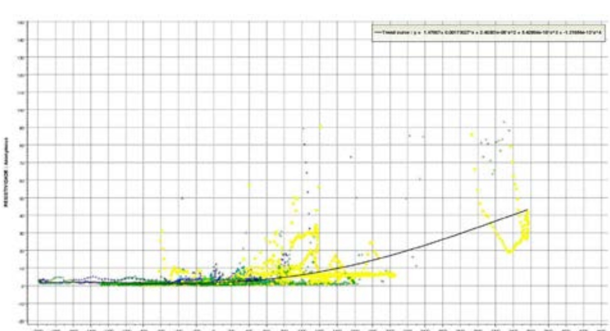

Figure 3: Well-log crossplot from Impedance versus Resistivity

After apply Rh in Seismic Data, the Resistivity large-scale model R was constructed. An isotropy approximation was done here: horizontal resistivity component is equal to the vertical one.

At last, all information were gathered to construct different exploration scenarios and illuminated possible targets.

Results

EM Feasibility

Since the SEM (Scanning Electron Microscopy) images (figure 4) shows that the reservoirs are constituted by low-content clay sandstones, Archie equations were used to simulated a wide range of saturating fluids:

1. From fresh water (1000 ppm) to salt water (30.000ppm)
2. Different mixtures of Hydrocarbon for each salinity scenario.

Then, all results were compared with the original saturated fluid (Sw = 99%, 7500 ppm).

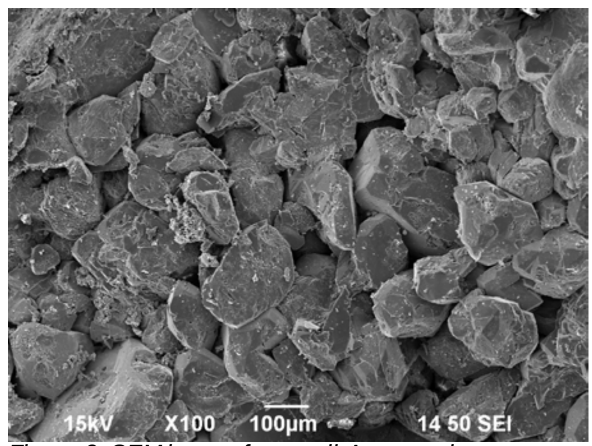

Figure 2: SEM image from well-A reservoir.

Common values of resistivity for water saturated sandstones bears around 0.5 ohm.m and 10 ohm.m. In other hand, for HC saturated sandstones one can find resistivity values between 5 ohm.m and 1000 ohm.m.

The simulations results can be found on figure 5 It shows that there is an overlap between the expect resistivity values for fresh water and mixtures up to 40% of HC. This means that, by the point of view of resistivity, commercial saturates sandstones should be easily distinguished from fresh water.

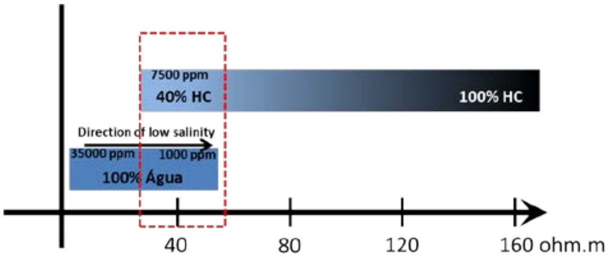

Figure 3: Results from EM feasibility

However, SBL detects EM field that is proportional to the Resistance of a material, i.e., a product of resistivity and the corpse dimension. In day-to-day use, this means that, a big amount of fresh water saturated sandstones could easily be confused with a medium-size reservoir 100% HC saturated.

Apart from the pitfall caused by a scenarios constituted by a large amount of fresh water, one shall think in other geologic reasons for an EM anomaly. The absent of salt in the area doesn't avoid other common pitfall generator, such as igneous rocks or shallow carbonates.

Elastic Attributes Feasibility

This feasibility focused at the elastic attributes modeled with well data. The 2 main questions that needed a answers was:

1. What is the expected AVO behavior of the water saturated sandstones sampled in Well-A if it has HC (oil or gas)?
2. Well-A was drilled in a high-geopressure zone, but there are other targets out of this zone. Using Well-A as analogous, what AVO anomalies would the exploration team expect?

Both questions, and their solutions, can help decision-makers in the quest for good drilling opportunities.

First, 3 main interval were choose based on their porosity (higher porosity) and thickness (henceforth, sand A, B and C). Then Gassmann fluid substitution was performed sand A, B and C for comparison with original situation.

Then, a geopressure simulation was performed on the well-logs (RHOB, DTS and DTP) in order to model different pore-pressure scenarios.

This studies showed that well-A sandstones may have AVO 1 response regardless of saturating fluid (water or HC) and regardless of geopressure scenario. Even more, some HC-saturated scenarios showed no AVO response.

EM Modeling

The resistivity model R was build following the flow showed at figure 8

At figures 6 one can see the original seismic line (snapped from 3D) and the model R. Henceforward this line shall be identified as L1 (line 1 of the 2D SBL survey). Well-A was drilled at L1.

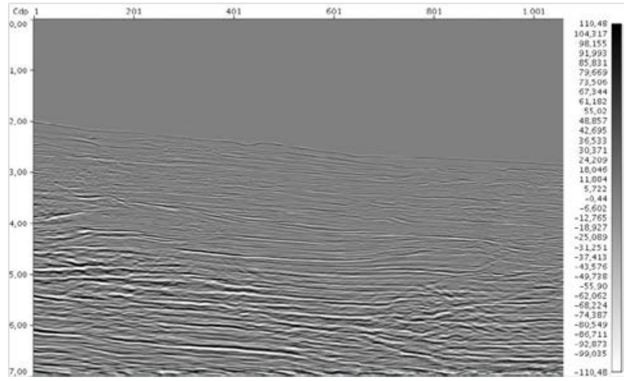

Figure 4: Seismic Line.

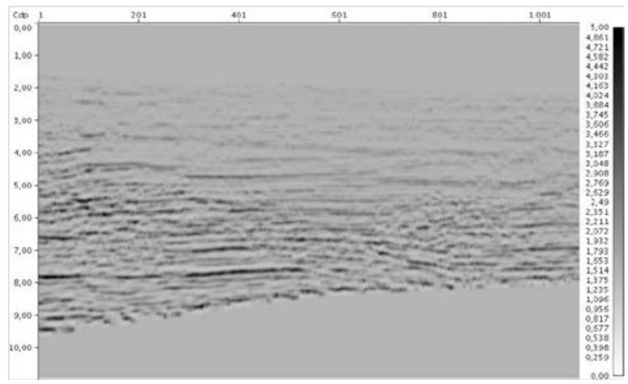

Figure 5: Resistivity line after flow showed in figure 8.

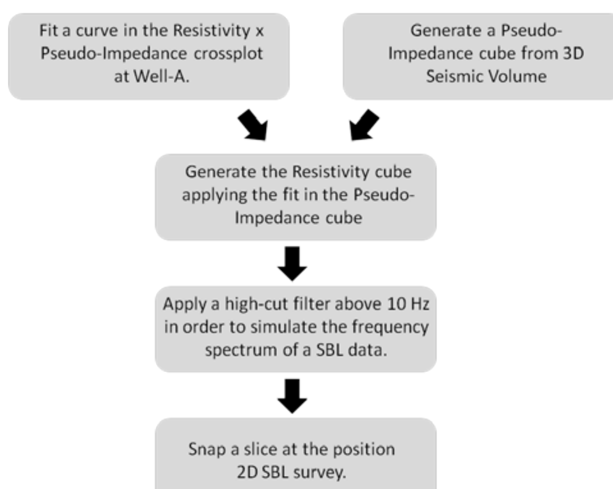

Figure 6: Flow used to build a resistivity cube.

Figure 7 and 9 shows the result after applying all the processing steps. Hot colors (at figure 9) indicates resistivity higher than 2.2 ohm.m. One shall not use this resistivity values as absolute. It only indicates rocks that are has larges values than background. A more accurate values may be obtained considering not only horizontal but also vertical component of the resistivity. Red ellipsis highlights possibly targets (this will be discussed at Conclusions).

At this point it is necessary to understand the limits of SBL. This kind o CESM survey has a natural limit at penetration depth around 4 km below water-bottom. So, it is not worth to care about all the high resistivity anomalies below the 5 km depth.

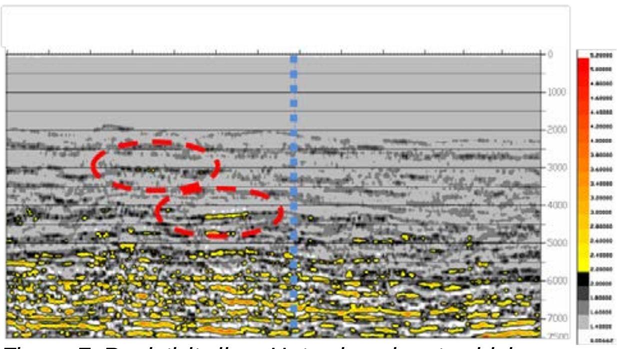

Figure 7: Resistivity line. Hot colors denotes high resistivity bodies.

Conclusions

Gather and interpret all necessary information are two different and equally important actions one should do in order to understand better an area.

Last sections showed different scale data for the same area: rock, fluid and well-log data from well-A, seismic images and also a SBL survey.

After the two resistivity targets were identified at figure 9 (red ellipsis), the exploration team perform an AVO study on it.

The deeper target happen to be the structure sampled by well-A which contain only fresh water.

The shallow structure have a small AVO response. But, further analysis showed that it was too shallow, if it was filled with HC, probably, the fluid would be biodegraded.

This project demonstrated how information from different scales could be joint together in order to reduce risks in exploration.

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