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Unconventional Pre-Salt Carbonate Reservoirs: Enhancing QI from Rock Physics insights

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Abstract Summary

This work investigates Rock Physics and Quantitative Interpretation (QI) for "unconventional" silicified Pre-Salt good reservoirs. We explain and exemplify how authigenic silicification profoundly alters elastic properties (low Acoustic Impedance - PI, abnormally low Vp/Vs), yielding a unique seismic signature. This distinct signature enables reliable detection and differentiation from other lithologies via QI procedures. The presented results may be significantly relevant to Pre-Salt exploration in more distal frontier areas.

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Introduction

Since the beginning of the exploration process and subsequently during the production development of Pre-Salt carbonate reservoirs, detailed petroseismic studies have been systematically conducted. These studies aim to better understand and calibrate the correlation trends between elastic attributes and *in situ* observed facies.

For example, as illustrated in Figure 1, a crossplot of elastic attributes from several wells in the Lula (Tupi) field shows that, since the first well drilled, it was identified (Dillon et al., 2008) that in Barra Velha (BVE) formation reservoirs of the Santos Basin Pre-Salt, purely acoustic attributes (PI) are not effective in distinguishing highly porous microbial reservoir zones (such as those generally found in the stratigraphic zone BVE 100) from non-porous reservoirs (due to argillaceous occlusion by magnesian clay), typically found in the Barra Velha 200 (BVE 200) zone. In both cases, similar and quite low PI values are observed. Given that elastic information was known to be essential, even with *a priori* low-quality seismic data, an effort was made to invest in elastic inversions early in the exploration process. This work specifically proposes a detailed discussion of special and distinct aspects of Rock Physics and their consequent implications for Quantitative Interpretation (QI) response in the reservoirs, which are identified as “Unconventional Brazilian Pre-Salt Reservoirs.” The study and understanding of these reservoirs can be quite relevant for more distal areas of the Brazilian Pre-Salt that are still within an exploratory frontier context.

Method

With the objective described above, but avoiding detailed geological information not directly relevant to the current study, we will use a specific example of a traditionally “Unconventional” Pre-Salt Reservoir characterized by a strong presence of silicification, notably due to authigenic silica. The formation of authigenic silica occurs through intense diagenetic processes, potentially leading to the complete replacement of previously existing minerals over geological time, as is the case for carbonate frameworks (Sombra, C. L., 2023).

Well X, belonging to this area, is an excellent example of a thick interval of good reservoir quality with significant authigenic silica content, being very suitable for understanding the correlation between elastic attributes versus other reservoir properties in the mentioned silicified intervals, (Dillon et al., 2015). In Figure 2, the well logs for Well X are shown, where its elastic attributes and authigenic silica content can be correlated. Subsequently, Figures 3 and 4 compare the correlation of Bulk Modulus (K) versus Phi, and Shear Modulus (G) versus Phi, focusing on porous hydrocarbon (HC) bearing reservoir intervals. In the crossplots specified in these figures, a series of other wells, mainly from the Lula field, whose reservoirs exhibit typical and traditional Pre-Salt behavior, were added as a background. Overlaid on this background are data points from Well X, from the unconventional area under focus. In the same figures, points referring to the positioning of the “cluster” of the authigenic silica-rich interval are also plotted. It is especially important to note that these reservoirs, despite the strong diagenetic process they undergo, can remain highly porous and that the process of calcite replacement by silica occurs mainly in the rock framework.

Results

Thus, in the K and G versus Phi crossplots, as expected, given the typical and known elastic moduli of calcite and silica, the cluster of the silicified reservoir (Well X) – specifically focusing on Bulk Modulus (K) – is noticeably positioned below the background relative to the other wells. This, however, is not the case for the Shear Modulus (G), which remains within the background alongside the other wells. Figure 5 illustrates what we expect to observe in terms of elastic attributes in the context of these thick reservoir zones altered by authigenic silicification. Indeed, it is observable that in these zones, the PI value is very low, but the Vp/Vs positioning is also abnormally low, making these lithofacies easily detectable within a traditional elastic attribute analysis. It is also important to highlight that the positioning of these thick silicified zones, being excellent and highly porous reservoirs, exhibit quite low PI values. This makes them a characteristic negative seismic reflectivity peak, contrary to traditional Pre-Salt carbonate reservoirs. Therefore, they could be confused with shale zones, but in this case, the Vp/Vs attribute is highly efficient in separating the clusters of each of these distinct lithologies into well-opposite positions on the crossplots: (a) shale zones – very high Vp/Vs; and (b) zones of good, silicified reservoirs – very low Vp/Vs.
Continuing with this typical QI study procedure, various analyses were performed in terms of elastic inversions and Bayesian classifications based on the distinct - *a priori* facies - classification proposals existing in the geological context for the area. In figure 5 shows the crossplot of elastic attributes (PI x Vp/Vs), colored by the identified petroseismic calibrated facies. Also, the obtained PDFs (probability density functions), for each facies cluster, are plotted.
In Figure 6, we show one example of the elastic seismic inversion attributes that were generated with special focus on the silicified – low PI&Vp/Vs – good reservoirs. Finally, figure 7 is an example of the results for the most probable facies section generated in seismic domain.

Conclusions

- Unconventional Brazilian Pre-Salt reservoir zones – generally due to intense diagenetic processes – can be relevant in exploratory frontier contexts. Zones exposed to intense silicification (authigenic focus) can generate thick and excellent HC reservoirs. It is important to better understand the Petroseismic in these reservoirs to optimize QI processes, both in an exploratory approach and for production improvement.
- Due to this intense silicification – in an authigenic context – good porosities are preserved, but there is intense replacement of calcite by silica such that all Rock Physics modeling is altered, generating new paradigms for facies classification in a QI context.
- The discussed example shows that the predicted behavior, in terms of the expectation from the performed Petroseismic studies, is in perfect agreement with what the real data showed us in practical terms.

References

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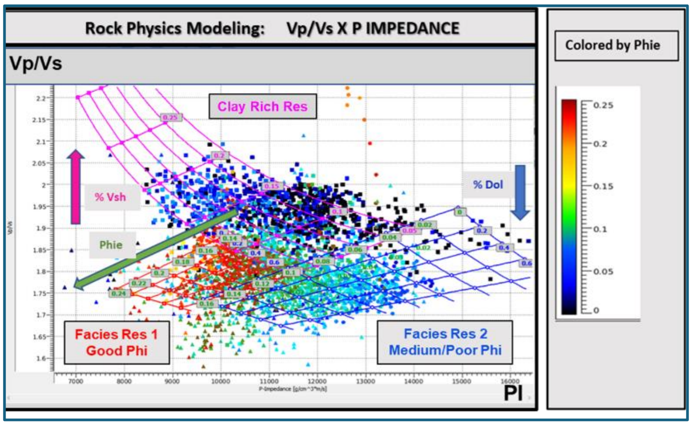

Figure 1: Vp/Vs x PI crossplot colored by Effective Porosity - five good calibrated wells from Lula Field were used here. The calibrated Rock Physics templates are superimposed.

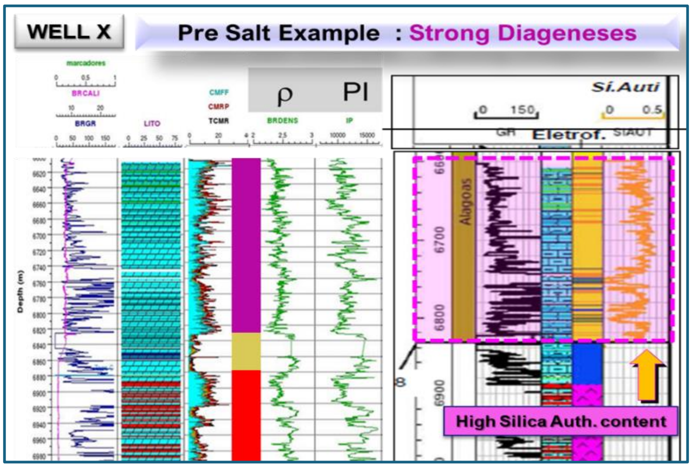

Figure 2: Plot of the Well X logs considered for this analysis. The pink square highlights the porous reservoir interval with authigenic silica high content.

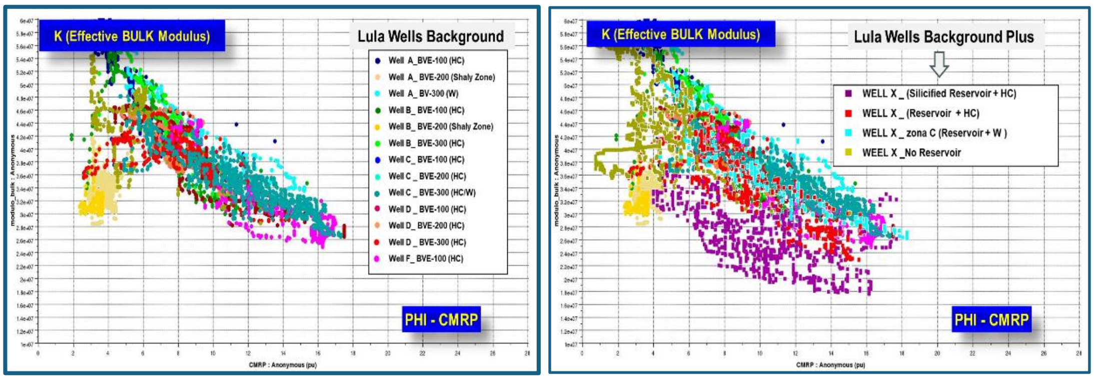

Figure 3: Bulk Modulus (K) x Effective Porosity (PHIe) crossplot - LEFT: background – Few Lula Field wells and RIGHT: also including WELL X - pink dots are from silicified zone.

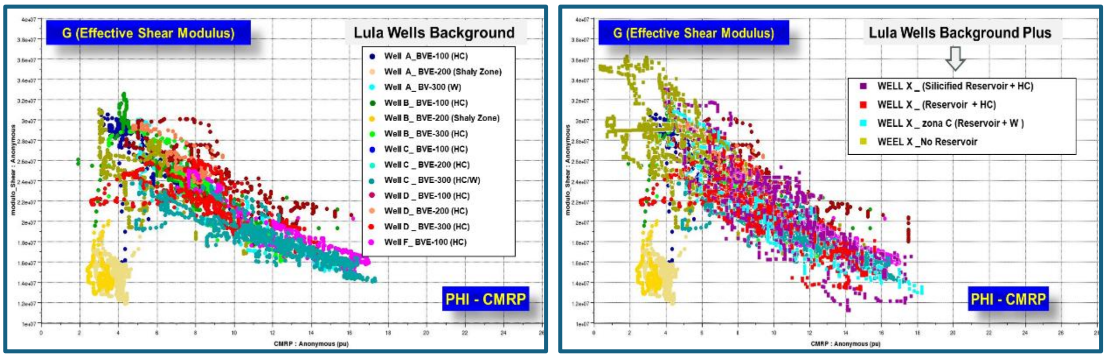

Figure 4: Shear Modulus (G) x Effective Porosity (PHIe) crossplot - LEFT: background – Few Lula Field Wells and RIGHT: including WELL X - pink dots are from silicified zone.

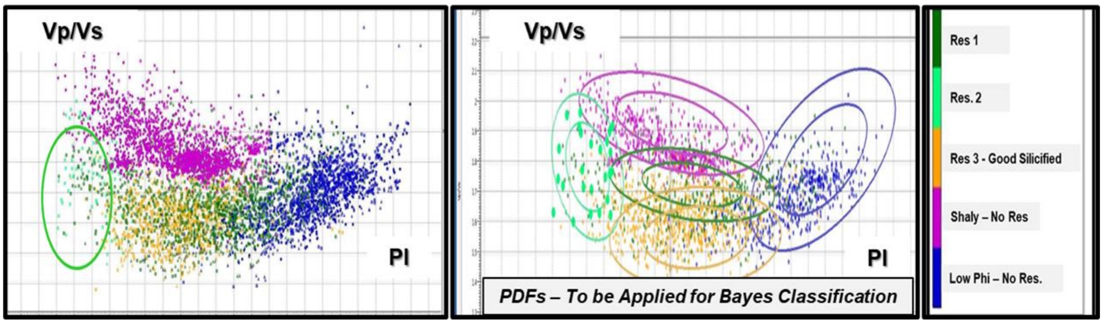

Figure 5: Rock Physics Vp/Vs x PI crossplots colored by the identified Petroseismic Facies. Note that, in this color code, the silicified good reservoir zone now appears in orange.

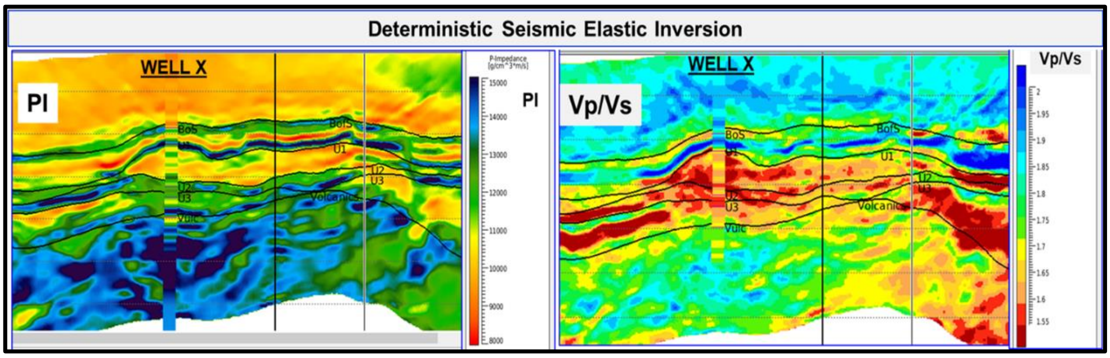

Figure 6: Elastic Seismic Inversion: PI and Vp/Vs arbitrary section passing through Well X.

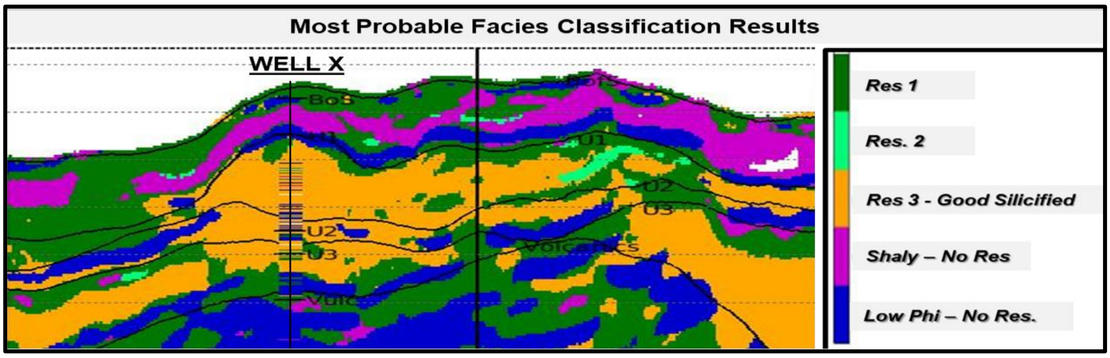

Figure 7: Same Arbitrary Section showing Seismic Most Probable Facies Results to be compared with the same Petroseismic Facies Classification generated directly on Well X.