Carbonate Raft Characterization through Seismic Inversion

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Abstract

Seismic data were inverted for acoustic impedance to better characterize porosity in fractured carbonate rafts. Velocity and stacked seismic data from a Chevron-processed PreStack Depth Migration were leveraged as input along with local well logs and regional rock physics trends.

The full-bandwidth output impedance volume was evaluated for porosity prediction at well locations, and expected prediction error was well within acceptable margins. Impedance overlap remains between hard shales and high-porosity carbonates, requiring good geologic interpretation or future inversion for shear-impedance.

The resulting data have assisted in inferring reservoir quality away from well control and between carbonate rafts.

Introduction

For many years, deep water Turbidite facies have been the most important producing reservoirs in offshore Brazil. Recent exploration along the coast has revealed a new potential in deeper intervals within Albian carbonate reservoirs.

Albian carbonate reservoirs are relatively poorly understood, and a great amount of uncertainties are introduced into reservoir development scenarios as well as in exploration opportunity evaluations.

This project was completed to better characterize a rafted carbonate reservoir interbeded with sandstones, shale and marl in offshore Brazil, with the goal of understanding some of the reservoir uncertainties of this relatively new play.

This characterization of the carbonate opportunity was progressed through acoustic impedance inversion on PSDM seismic data to understand the reservoir lithologies and porosity distribution along a rafted carbonate body.

Geological Setting

The target interval are carbonates deposited during the Albian in a shallow marine platform environment interbedded with lesser turbiditic sandstone, marl and shale in a overall transgressive setting.

This sequence is deposited directly above an Aptian salt layer, which starts its first diapiric movement when enough sedimentary load is deposited above introducing fractures and faults in the clastics and carbonates recently deposited.

The marine transgressive regime continuously creates accommodation space that is subsequently filled mainly carbonates growth and deposition with some siliciclastics sediments. Accommodation space is create via continued loading of salt and contemporaneous growth faulting, and the ensuing transgression allowing for deposition on dominantly carbonates and lesser clastics within this accommodation.

Different stages of sedimentation can be identified through the several fault sets observed in the target interval. Each fault set, with a specific age, is the result of the sediment above an evaporitic layer that is under diapiric movement.

The continued creation of accommodation, sedimentation overload, faulting and salt movement evolves through time to create isolated bodies of carbonates within salt domes as seen today.

Lithology and Porosity Distribution

The syn-depositional faults and fractures introduced an important reservoir heterogeneity that controls porosity enhancements as well as reservoir diagenesis.

Given the lithology types and sediment loading histories, considerable overlap of acoustic properties are probable, making impedance-based differentiation between shales and high-porosity carbonates very difficult. Thus, lithologic uncertainty remains following the inversion due to high porosity carbonates overlap with rigid shales.

To better distinguish lithologies, additional information is required and a simultaneous inversion for shear and acoustic impedance is being considered and will require additional gather conditioning.

Seismic Data

Open file seismic data were sourced from the Banco de Dados de Exploração e Produção (BDEP) and migrated by Chevron using proprietary Gaussian Beam PreStack Depth Migration (PSDM) technology. A combination of Gaussian Beam and radon multiple models predicted and removed multiples.

Additional pre-migration denoising and post-migration data conditioning were applied with a technical focus on structural interpretation. A wide-gate amplitude equalization technique was applied early in processing and was found to be non-detrimental to stack amplitude anomaly detection.

Velocity tomography and anisotropy analysis were followed by data migrations in an iterative fashion. Nine cycles were completed for the area of interest resulting in a high-quality velocity realization. Depths were tested by new well drilling and found to be accurate.

Wells and Extracted Wavelets

Six wells in the area of interest were also available with variable vintage and quantity of recorded logs. Only one well contained a full suite of acoustic logs and intersected the complete zone of interest. Two of the remaining wells had sufficient recorded acoustic information to develop velocity-impedance relationships.

Wells were tied above and through the zone of interest. Zero-phase wavelets were estimated for each well and were found to be consistent in frequency content and amplitude. A representative wavelet was chosen for each carbonate raft and provided as input to the final inversion.

A strong relationship was established between interval velocity and impedance based on well logs. The PSDM velocity was hi-cut filtered and converted to acoustic impedance using the log relationship. Seismic data frequency content was limited on the low end due to shallow streamer towing depths. For the inversion, the velocity-based low frequency model was limited above 2-Hz and the seismic data were limited for frequencies below ~10-Hz. The volumes were merged at 5-Hz as input for the inversion process.

Seismic inversion results

The inverted impedance products were found to be consistent with recorded logs when extracted along well bores. Both carbonate and clastic porosity relationships with impedance were retained in the inverted product.

Inverted acoustic impedance values observed in the carbonate rafts are consistent from raft to raft and provide guidance to relationships in depositional patterns that can be exploited in interpretation.

Using the velocity model as the basis for the low frequency model constrained the final results using information available in the form of offset-dependent reflector move-out. This approach resulted in a superior result including the description of large-scale impedance anomalies that would not have been achieved using a log-based approach. The velocity model also introduced risk in that an erroneous velocity anomaly will affect both structural interpretation and porosity analysis.

Conclusions

The interpretation of the acoustic impedance products allowed a better understanding of the reservoir heterogeneities within individual carbonate rafts. By tying the results with existing wells it was possible to spatially distribute the rock properties observed away the borehole control locations.

Consistent acoustic impedance values across multiple carbonate rafts allowed an estimate of reservoir properties to be calculated across undrilled areas. This process provides a more detailed understanding of reservoir heterogeneity uncertainty in the area.

Future work to improve the carbonate raft characterization may include simultaneous inversion for acoustic and shear impedance. This would allow for improved differentiation between shale and porous lithologies via more definitive method than observed with acoustic impedance done in this work.

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