A workflow for 4D seismic analysis in the Brazilian pre-salt based on carbonate rock physics

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Abstract

Brazilian pre-salt carbonate fields have gained notoriety in recent years for their high well productivity and large in place volumes. In these giant fields, anything that can contribute to increase ultimate recovery has a large financial benefit. Recovery depends directly on the number, location, and operation of injector and producer wells. In the perspective of the static reservoir model, 3D seismic and carbonate rock physics may be used to place the wells in more favorable locations and avoid others that may be more prone to water and gas breakthrough. In the perspective of the dynamic reservoir model, 4D seismic and carbonate rock physics may be used to optimize the operation of these wells, to observe and monitor the movement of gas and water towards the producer wells, and to help model dynamic aspects of the reservoir, such as dissolution and other rock-fluid interactions.

In this study we review a workflow for 3D seismic analysis based on carbonate rock physics and extend it to 4D seismic. While 4D seismic is a proven technique in many deepwater fields, it has only recently been proven as effective in pre-salt carbonate reservoirs, which lie below a very thick layer of salt. Such application is also challenging because the carbonate rocks are highly heterogeneous, are generally stiffer and less sensitive to fluid variations in comparison to clastic rocks, which have stronger 4D responses for equivalent saturation changes. To attain the necessary sensitivity to small 4D responses, ocean bottom node (OBN) acquisitions have been used, to improve repeatability and to deliver high-fidelity seismic data with an improved signal-to-noise ratio to enable the evaluation and quantification of small 4D signals related to water-alternated-gas (WAG) injection.

Seismic attributes are widely used to interpret 4D seismic data by indicating 4D signals consistent with softening or hardening effects due to the WAG injection switches over time. Our 4D seismic analysis workflow is based on carbonate rock physics and forward seismic modeling to generate 4D seismic attributes to compare with expected 4D attributes around WAG injection wells. We quantify the impact of different fluids (water, oil and gas with CO_2) on the pre-salt reservoir 4D seismic detectability (i.e., changes in elastic and seismic behavior) via a novel cascading analysis that links the WAG injection switches, the synthetic and expected 4D seismic attributes with the uncertainties in the saturation scenarios. We infer the minimum saturation changes to 4D seismic detection considering high-quality seismic data and illustrate 4D seismic signatures non-uniqueness due to acoustic impedance ambiguity between the injected CO_2-rich gas and the in-situ oil. This approach is illustrated using two WAG wells in a pre-salt field with 4D seismic.

We conclude that accurate analysis of 4D seismic signals can be very complicated due to the many reservoir variables that are uncertain, but that integration with rock physics models can constrain the analysis, especially if the 4D seismic data are acquired frequently enough to help disentangle the reservoir responses to the WAG fluid switches.