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FIZZ GAS CHARACTERIZATION THROUGH DENSITY INVERSION: A CASE STUDY IN DEEP-WATER SABAH

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Summary

Fizz gas detection is a critical step in field development as it is often difficult to differentiate it from commercial gas in reservoirs on acquired seismic data. In a shallow reservoir context, it is theoretically possible to observe a fizz gas effect through a joint analysis of P-wave velocity (Vp) and density (Rhob) properties. Although inverting density is routinely done in pre-stack inversion, it is generally too strongly coupled to Vp to achieve an efficient fizz gas characterization through a Vp versus Rhob crossplot.

This paper presents a pre-stack inversion case study conducted in offshore North Sabah, Malaysia, to characterize Late and Middle Miocene clastic, gas-bearing deposits. Very high-quality pre-stack seismic data allowed for the possibility to partially decouple Vp and density through an adequate inversion parameterization. Supported by fluid change predictions coming from a petro-elastic model calibrated to the field conditions, a fizz gas characterization routine could be established through a joint analysis of the inverted Vp and Rhob properties, giving access to a potential fizz gas detection over the targeted reservoir.

Fizz gas characterization through density inversion: A case study in deep-water Sabah

Introduction

Fizz gas detection is a critical step in field development as it is often difficult to differentiate it from commercial gas in reservoirs on acquired seismic data. Different elastic properties can be used as Direct Hydrocarbon Indicators (DHIs) to make this differentiation with varying effectiveness, including P-wave velocity (Vp) combined with density (Rhob). Although inverting density is routinely done in pre-stack inversion, it is in most cases too strongly coupled to P-wave Velocity to be useful in detecting fizz gas.

This paper presents an inversion case study conducted in offshore North Sabah, Malaysia, to characterize Late and Middle Miocene clastic, gas-bearing deposits, in which adequate decoupling of Vp and Rhob properties led to a successful detection of fizz gas. We will first introduce how fizz gas affects Vp and Rhob in shallow reservoirs, the geological setting of the area, and the data used to conduct the study. The inversion algorithm that decouples Vp and Rhob is then explained. The last part of the paper is a presentation of the results that were obtained during the study itself where a petrophysical analysis led to establish a rock physics model adapted to the reservoir. The elastic inversion results were used along with the well logs to generate litho-facies probability and most probable litho-facies volumes based on P-Impedance (Ip) - Vp/Vs ratio separability. Ultimately, we show how a Vp versus Rhob analysis was performed around one well and enabled the characterization of fizz gas.

Fizz gas effect on P-wave velocity and density

Fizz gas refers to gas in solution with brine or small amounts of free gas phase. This small gas content often generates seismic bright spots or DHIs similar to the response of a commercial gas presence, therefore making them difficult to differentiate.

Fizz gas can be theoretically characterized through an analysis of P-wave velocity and density, which respond differently to a small introduction of gas in a shallow water-bearing sand as illustrated in Figures 1a and 1b (Batzle and Wang, 1992). While density decreases progressively with increasing gas saturation, velocity drops rapidly due to a significant decrease in the bulk modulus. Figure 1c shows that the fizz gas effect is associated with a very distinctive path in the Vp-Rhob domain. It is important to mention that low gas fraction in water (< 30%) and low pore pressure (< 20MPa) conditions must be fulfilled to properly observe this phenomenon (Han and Batzle, 2002), which was the case in the current study. A differentiation of such Vp-Rhob behaviour on inversion results would therefore enable an efficient characterization of fizz gas.

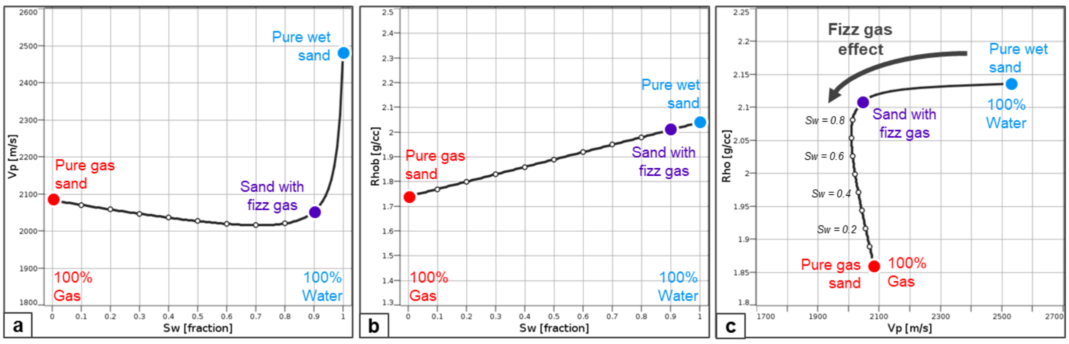

Figure 1 *Theoretical impact of an increase in gas saturation (Sw decrease) on Vp (a) and Rhob (b) in a shallow reservoir condition. The righthand plot (c) shows a cross-plot of Vp vs. Rhob with the path indicating Sw moving from 100 to 0%. The fizz gas effect appears as a distinctive path in the Vp-Rhob domain, due to the strong Vp decrease occurring when a small amount of gas is introduced.*

Geological setting and input data

This case study is located in the northern area of deep-water Sabah, targeting several gas discoveries in excellent quality, high net-to-gross Upper Miocene sandstones that accumulated in topographic lows ('mini-basins'), which formed in response to a syndepositional tectonism (Jones et al., 2016). Low-relief, combination structural-stratigraphic traps were developed and charged with a mix of thermogenic and biogenic gas. The gas accumulation studied in this paper occurs within a shallow (~2000m) anticline assessed by an exploration well (Well 1).

The input seismic data consisted of three seismic surveys that were jointly processed using a state-of-the-art Q-TTI Kirchhoff pre-stack depth migration algorithm. Four angle stacks were available with average incidence angles ranging from 11 to 42 degrees. The quality of the seismic signal was judged to be very good with a wide frequency spectrum of 5 to 80Hz, high correlation with the wells and a consistent class 3 AVO effect observed over the main prospects. A high-resolution velocity from full-waveform inversion (FWI) up to 12Hz was also available and used to bring the missing low frequencies during seismic inversion.

Seven wells with full sets of logs were available and went through a careful petrophysical review aimed at identifying spurious or missing data sections. A petro-elastic model (PEM), whose parameters were adapted to a cemented sandstone environment and calibrated to well data, was designed in order to analyse the expected elastic variations under different scenarios of porosity, lithology and fluid content.

Elastic inversion methodology

A 3D simultaneous elastic inversion was run to jointly invert the four angle stacks and derive the elastic parameters P-wave velocity (Vp), S-wave velocity (Vs) and density (Rhob). The iterative algorithm relies on Zoeppritz equations for the AVO modelling and is based on simulated annealing techniques to update the elastic parameters (Vp, Vs and Rhob) of the initial model, with the objective to optimize the match between the elastic medium response and the seismic data (Coulon et al., 2006).

The inversion process gives the choice to fully invert density or link it to Vp through an empirical rock physics relationship such as Gardner's law. The high quality of the seismic angle stacks available for this study motivated the use of an intermediate solution that combines a mild rock physics constraint with information coming from the seismic. This approach allowed for variations around Gardner's relationship in the Vp-Rhob domain and led to a moderate decoupling of both properties in the inversion results.

Another important feature of this inversion scheme is its ability to simultaneously update the layer thickness of the stratigraphic framework used (in two-way time) and the elastic parameters, which is especially advantageous for the detection of very thin layers.

Results

A cross-section of the seismic angle stacks along Well 1 (Figure 2) highlighted the existence of two separate contacts and the fact that the upper contact was almost not visible on the Far angle stack. Since the presence of gas is usually associated with a bright response on the far angles, this particular signature was suspected to be linked to a fizz gas section encompassed between the gas sand and the wet sand.

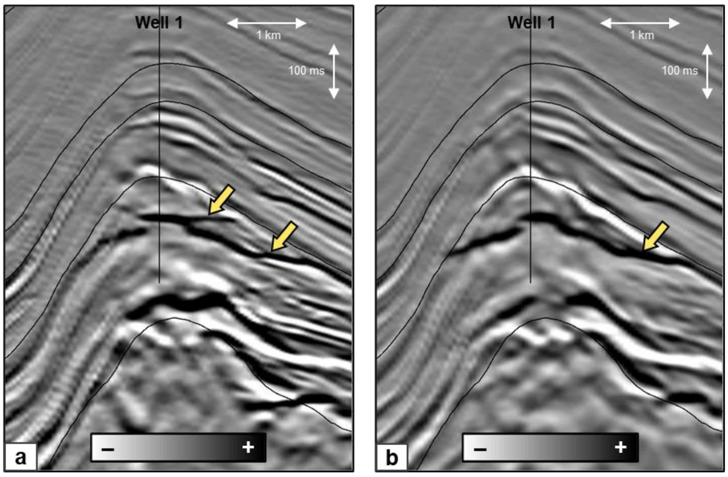

Figure 2 *Cross-section in TWT domain along Well 1 of Near (a) and Far (b) seismic angle stacks. Two contacts are interpreted along the anticline on the Near stack, while only the bottom contact can be clearly identified on the Far stack. A fizz gas section generally presents this type of seismic signature.*

Elastic inversion provided robust P-impedance (Ip) and Vp/Vs ratio volumes that could be used to predict shale, wet sand and hydrocarbon sand in most places. These litho-facies were defined at wells from cut-offs on petrophysical volumes. The separability of the three facies was assessed through Ip versus Vp/Vs crossplots and histograms. Figure 3a shows, however, that the litho-classification based solely on these attributes was not successful in differentiating the two gas accumulations and flagged the suspected fizz gas as a normal gas sand (red in Figure 3a). On the other hand, clear contrasts in inverted Vp and Rhob could be seen at the identified contacts, as illustrated by Figures 3b and 3c.

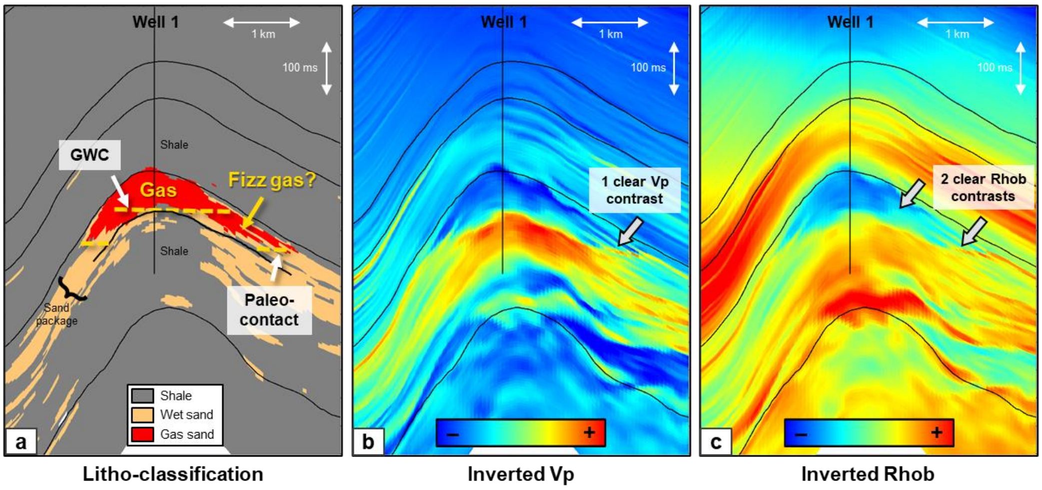

Figure 3 *Cross-section in TWT domain along Well 1 of the litho-classification results based on a discrimination in Ip and Vp/Vs (a), inverted Vp (b) and inverted Rhob (c) obtained with the elastic inversion. The litho-classification is unable to discriminate the fizz gas section from the gas sand above, but the section is associated with different Vp and Rhob contrast behaviours.*

A Vp versus Rhob crossplot of inversion results was then done from the reservoir samples located in the vicinity of Well 1 (Figures 4a and 4c). Two different polygons were drawn to isolate samples associated to a specific fluid scenario and highlight them in cross-section. The polygons were chosen broadly to account for the reservoir heterogeneity in terms of porosity and shale content, represented on the crossplots by three different Vp-Rhob PEM scenarios for varying water saturation (Sw). “Pure” gas sands could be easily associated with low Vp and density values and correctly discriminated in cross-section above the upper contact (Figure 4c). The same exercise was then done with a potential “fizz gas” region associated with low Vp but slightly larger density values, as defined from the different fizz gas effect scenarios predicted by the PEM. In the cross-section, the samples highlighted by this polygon appeared mostly between the two contacts along the reservoir, corroborating the hypothesis of a fizz gas section in the reservoir (Figure 4d).

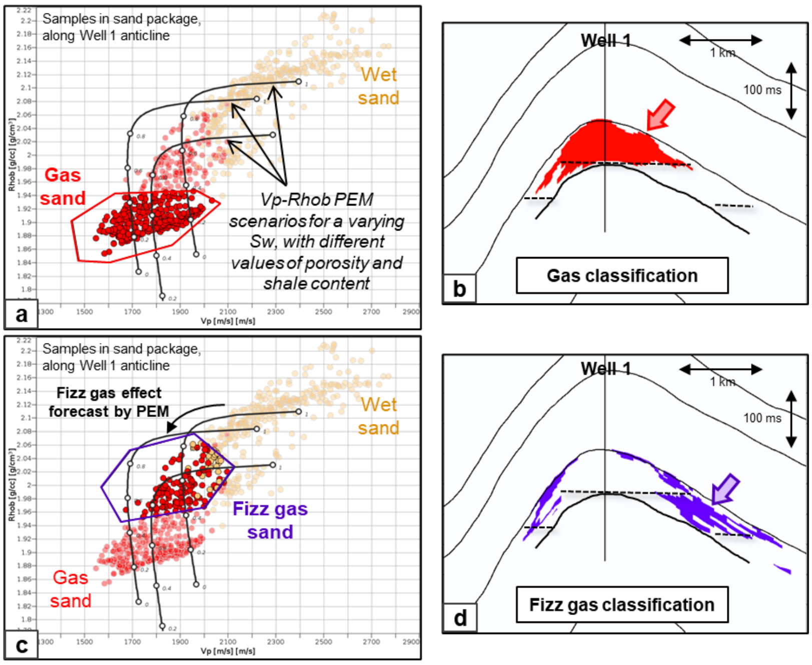

Figure 4 Gas characterization through a Vp vs. Rhob analysis on inversion results (coloured by litho-classification most probable facies). Polygons are drawn to isolate samples associated with a distinct fluid scenario and highlight them in the cross-section. Figures 4a and 4b: gas characterization. Figures 4c and 4d: fizz gas characterization based on PEM predictions. The samples flagged as "fizz gas" appear between the two contacts interpreted on the seismic data.

Conclusion

Elastic inversions generally do not give access to reliable density information due to the limited quality of the seismic data. This paper presents a case study of a shallow clastic, gas-bearing reservoir in offshore Sabah, in which very high-quality angle stacks allowed for the possibility to partially decouple Vp and density through an adequate inversion parameterization. Using the predictions of a petro-elastic model calibrated to the reservoir, a fizz gas characterization routine could then be defined through a joint analysis of the inverted Vp and Rhob properties. Although such an approach remains subject to uncertainties related to the reservoir heterogeneity or the resolution of the seismic image, it enabled this study to confirm the presence of fizz gas near two separate wells.

Acknowledgments

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