Lithology and Partial Gas Saturation

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Summary

Partial gas saturation or “Fizz water” remains a lively topic because of the questions related to its seismic detectability. Further understanding of the causes of partial gas saturation may help to avoid non-productive reservoirs. In this paper, we discuss the influence of lithology on partial gas saturation. It is found that shale content in rock has significant influence on both gas saturation and rock elastic properties. This is contributed to different physical condition that is determined by lithology variation. The results from this study indicate that low gas saturation due to lithological cause may be seismically detectable.

Introduction

Two types of mechanisms for partial gas saturation are widely accepted, one is pressure dissolving (e.g., Batzle and Wang, 1992) and the other is physical trapping such as patchy saturation due to spatial heterogeneity of permeability (e.g.; Dvorkin and Nur, 1998). Commonly accepted theory is that a small percentage of gas saturation, often within 10%, will result in a great drop in P-wave velocity. The drop in P-wave velocity has a magnitude comparable to that under full gas saturation. Consequently, partially gas saturated reservoirs may be mistakenly drilled as a prospect. This study explores the lithological effect on partial gas saturation and its relationship with seismic rock properties.

In this study, we examined the influences of petrophysical properties, including porosity, water saturation and volume of shale on elastic rock properties. The seismic responses for the cases with low and high gas saturation are compared in CDP gathers, pre-stack attributes and inverted elastic rock properties. The objective is to understand the relationship between gas saturation and lithology influence. Ultimate goal is to determine whether partial gas saturation can be seismically detected in a lithologically varying environment.

Rock physical relationships

A data set from the Western Canada Sedimentary Basin (WCSB) that has dipole sonics and petrophysical analysis was selected for this study. The reservoir rocks in this data set have a wide range of porosity (ϕ), water saturation (SW) and shale volume (Vsh). To examine how lithology variation influences gas saturation, P-wave velocity (Vp), shale volume (Vsh), gas saturation and other related petrophysical logs are shown in Figure 1. Direct observations from Figure 1 are: 1) water saturation is proportional to Vsh;

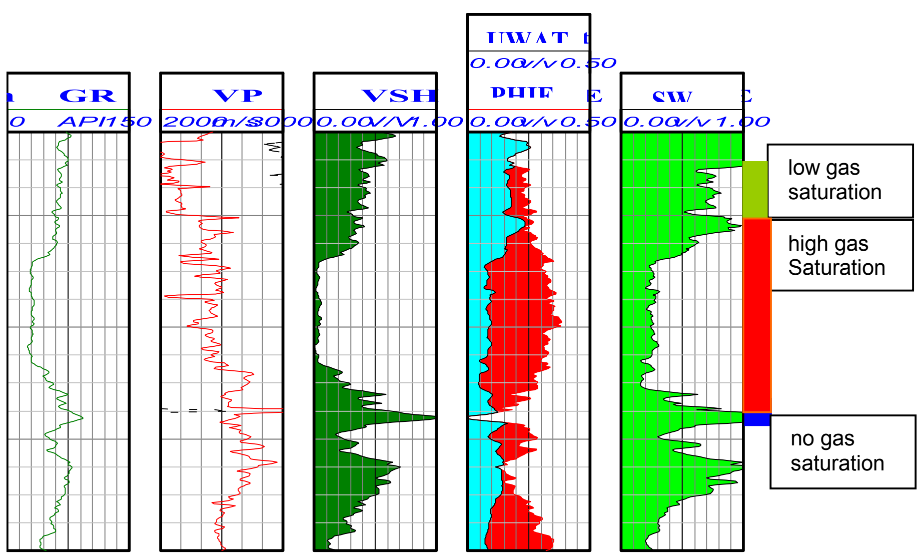

Figure 1.Petrophysical rock properties.

2) gas saturation is opposite from 1), that is, gas saturation increases with decreasing Vsh; and 3) porosity increases with decreasing Vsh. The other observations are 1) clean sand has high gas saturation and dirty sand has low gas saturation; and 2) the cleanest sand still has a water saturation of about 25%.

To have a general review how lithology influences on the reservoir physical rock properties, P-wave velocity, Vp/Vs ratio, Poisson's ratio, shear modulus*density ($\mu\rho$) and Lame parameter*density ($\lambda\rho$) are cross-plotted and shown in Figure 2, where the color represents shale volume. For this particular data set, porosity varies from 10% to 38%. The empirical relationships for wet sand, shale and full gas saturated clean sand are overlain on these cross-plots. These empirical relationships serve as references and can be used to qualitatively determine the sensitivity of rocks in responding to gas saturation. In Figure 2, we can see that the clean sand is sensitive to gas saturation since it takes the farthest place away from the wet sand line. It can be seen that the sensitivity decreases with increasing shale content (color from blue to red).

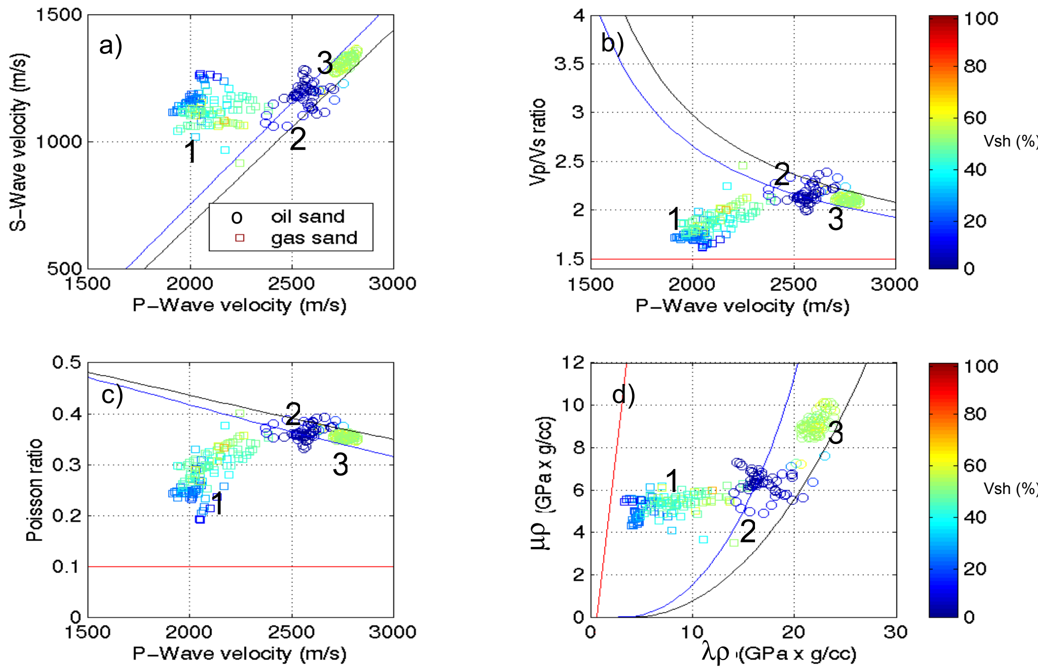

Figure 2. Relationships between rock properties. The labels 1, 2 and 3 represent gas reservoir, an oil reservoir with clean sand and oil reservoir with dirty sand. The black, blue, and red lines are the empirical relationships for wet sand, shale and clean gas sand.

Figure 3 shows the relationship between gas saturation and elastic rock properties. First, there is no rapid P-wave velocity decreasing at the low gas saturation that is described by Biot-Gassmann equation. In fact, the rock properties display a monotonic decreasing with increasing gas saturation. Second, Vp/Vs ratio decreases from 2.0 to 1.6 with increasing gas saturation. Notice that this Vp/Vs decreasing is accompanied with decreasing of shale content. Consequently, different AVO responses for low and high gas saturations are expected. Two typical cases would be the reservoirs with 10% gas saturation (Vp/Vs ratio is about 2.0) and 100% gas saturation (Vp/Vs is about 1.6). In addition, Figure 3 shows that $\mu\rho$ is almost constant but $\lambda\rho$ has a significant decreasing from low to high gas saturation. This indicates that one may be able to discriminate low gas saturated reservoir using inverted elastic rock properties. Figure 4 provides the relationships between elastic rock properties and porosity. We can see that the sand with low shale volume has high porosity and low P-wave velocity, Vp/Vs ratio, $\mu\rho$, and $\lambda\rho$.

AVO and attributes

We conducted AVO analysis for reservoirs with different gas saturation. Figure 5 shows two examples. In Figure 5, the upper sands for both cases have high gas saturation (60% to 85%). The lower sand has low gas saturation (20%) for the second case (Figure 5b). As expected, the seismic responses corresponding to the lower sands are different. This also can be observed from fluid stack. We may thus use this difference to determine the low gas saturated reservoir. In addition, elastic rock property inversion may be useful to further discriminate the low gas saturated reservoir.

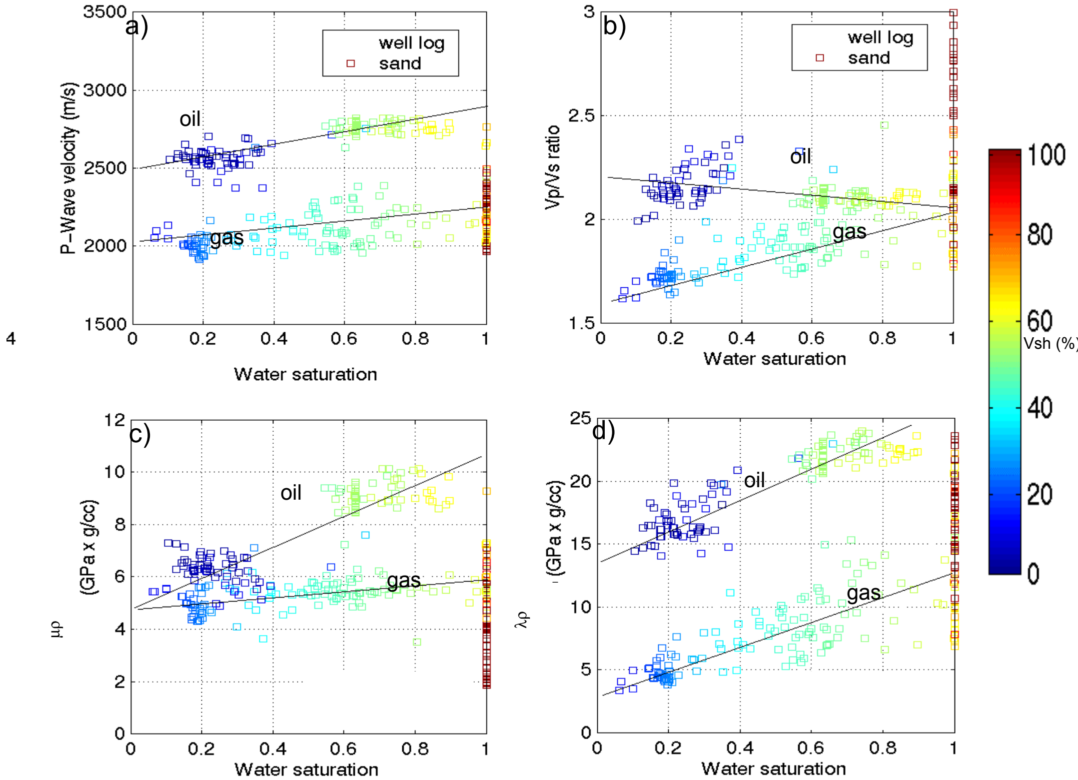

Figure 3. Relationships between rock properties and water saturation.

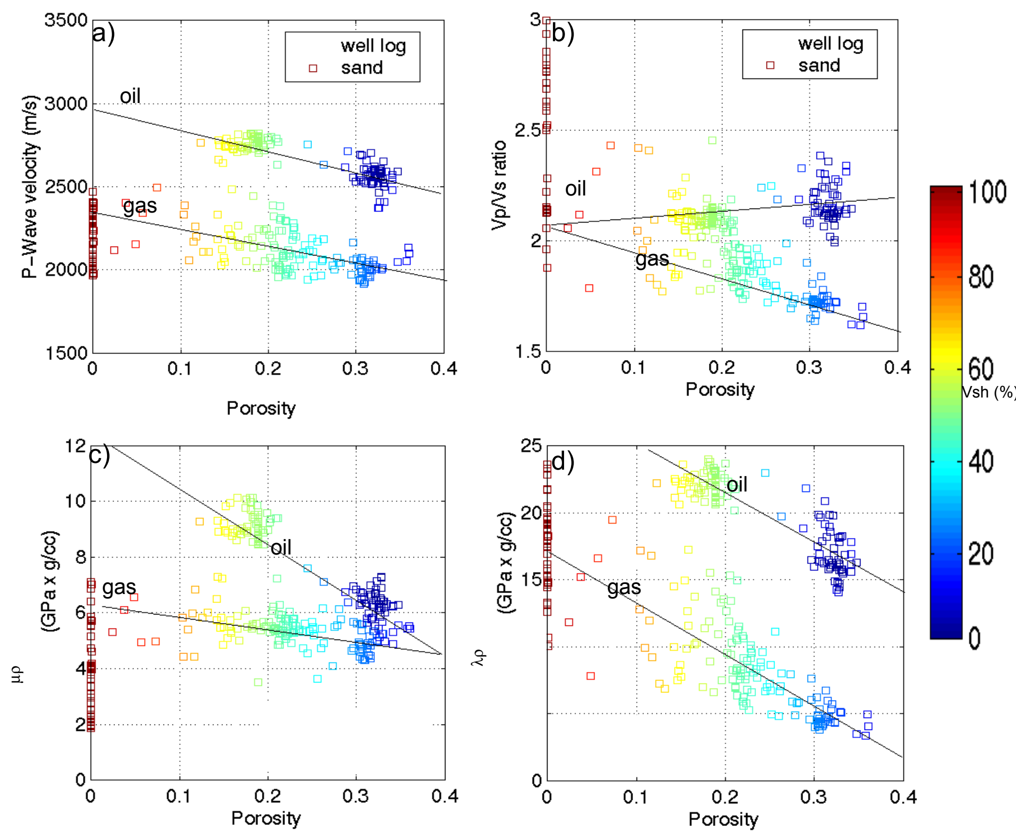

Figure 4. Relationships between rock properties and porosity.

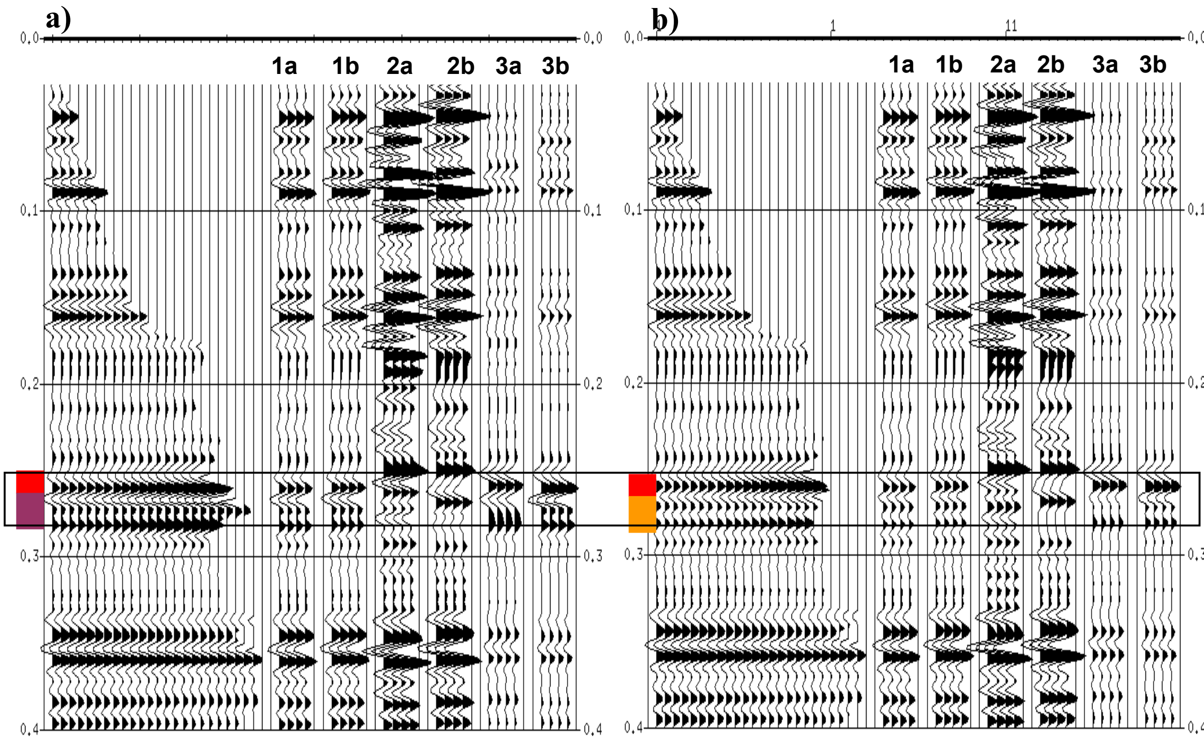

Figure 5. Synthetic CDP gathers and attributes: a) both upper and lower reservoirs have high gas saturation; and b) the lower reservoir has low gas saturation. The attributes are: 1a: P-reflectivity extracted from the gather; 1b: P-reflectivity calculated directly from the well logs; 2a: S-reflectivity extracted from the gather; 2b: S-reflectivity calculated directly from the well logs; 3a: Fluid Factor extracted from the gather; 3b: Fluid Factor calculated directly from the well log data.

Conclusions

Lithology or shale volume has significant influence on gas saturation because their effect on physical condition of rocks. Under lithological influence, significant difference exists in elastic rock properties between low gas saturation and high gas saturation. This is different from Biot-Gassmann theory. Consequently, this fact may help one to identify the reservoirs with low gas saturation seismically.

References

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