Fizz and gas reservoir discrimination by AVO inversion

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Summar

The elastic properties of the reservoir can be inverted from the prestack seismic angle gather. By using the elastic properties P-wave velocity, S-wave velocity, and density, the bulk modulus and shear modulus can be calculated. Gassmann's equation can be applied for the fluid substituation. For the different fluid, the saturated reservoir elastic properties can be derived for the saturated rocks by using Gassmann's equation. In this study, the simplified Gassmann's equation is applied and the fluid modulus can be calculated after the prestack seismic inversion. For the prospect area, using some known information, the predicted fluid properties are consistent with the drilling result.

Introduction

A few of gas dissolved into the water can make the fluid mixture more compressible. That can result in the P-wave velocity of the fizz water reservoir is similar to that of the full gas saturated reservoir. Data suggest that low gas saturation can generate similar seismic attributes but with the false hydrocarbon indicators that are similar to those of economic gas reservoirs (De-hua han, 2002). To differentiate the gas saturated reservoir and the fizz water reservoir is becoming difficult. By doing the analysis of the seismic amplitude, it is not enough to differentiate the different fluid properties (O'Brien, 2004). The seismic amplitude responses of the gas saturated reservoir and the fizz water reservoir are very similar and not easily separated. But commonly, the strong amplitude anomaly can be caused by the lithology variation and fluid variation. The lithology variation can cause the false hydrocarbon indicators for the exploration. The seismic anomaly responses caused by fluid variation are the focus of the exploration. In many cases, the seismic anomaly responses are caused by the combination of the lithology variation and the fluid variation together. To recognize the seismic anomaly response in the amplitude caused by lithology variation or by the fluid variation is still difficult in the real seismic data interpretation.

The prestack seismic inversion is a useful method to invert the elastic properties: P-wave velocity, S-wave velocity and density. The properties usually can show the anomaly of the reservoir properties. As the same as in the seismic amplitude, the anomaly in the inverted elastic properties is still caused by the lithology variation, the fluid variation, or the combination of the two variations. To separate the effect of the lithology variation and the fluid variation on the elastic properties of the reservoirs is very difficult too.

The new method is put forward to directly look at the fluid modulus using the elastic properties inverted by the prestack seismic inversion (Xingang Chi, 2006). So the anomaly on the reservoir properties caused by the lithology variation is not counted in.

If using the known information, the fluid modulus inversion method can be applied to the prospect area. Before the drilling, the inverted fluid modulus of the prospect area can predict the reservoir fluid property. This procedure can help to reduce the risk to drill the dry hole. The priori known information can be derived from the drilled well in the neighbor area which is assumed to have the same geological depositional environment as the prospect area.

In the fluid modulus inversion method, the empirical rock physics relationship is measured from the laboratory work. The simplified Gassmann's equation still can cause some errors for the inverted fluid modulus and to do the fluid modulus inversion is acceptable before drilling, which is only to help predict the fluid properties and its possible distribution in the prospect area.

In this study, the seismic data is from the Gulf of Mexico. There are two wells: Well A is in the drilled area and Well B is the well in the prospect area to be predicted. For Well B, the inversion use the Vs/Vp ratio from Well A according to the assumption that the two well have the similar geological depositional environment. In this inversion work, the seismic inversion uses the prestack AVA inversion where the relationship between P-wave velocity and density is needed. Also the inversion is band-limited in this study.

Method

The three term reflectivity approximation of Aki and Richards (1980)

$$R(\theta)=\frac{1}{2}\left(1+\tan^2\theta\right)\frac{\Delta V_p}{\overline{V_p}}-4\left(\frac{\overline{V_s}}{\overline{V_p}}\right)^2\sin^2\theta\frac{\Delta V_s}{\overline{V_s}}+\frac{1}{2}\left(1-4\left(\frac{\overline{V_s}}{\overline{V_p}}\right)^2\sin^2\theta\right)\frac{\Delta\rho}{\overline{\rho}}$$

Where V_p is the P-wave velocity, V_s is the S-wave velocity, and ρ is the density. The quantities with Δ are the contrasts. The quantities with bars on the top are the average or the background values.

If the reflection coefficients are known, the P-wave velocity, S-wave velocity and the density can be inverted from the angle gather.

For the full band inversion, the low frequency components are needed to be extracted from the well log data and merged in to the inverted elastic parameters.

For the elastic isotropic media, the bulk modulus and shear modulus can be written as:

$$M=Vp^2\rho$$

$$\mu=Vs^2\rho$$

Where M is the P modulus; Vp is the P-wave velocity; Vs is the S-wave velocity; ρ is the density; μ is the shear modulus.

Based on the Gassmann's equation, the shear modulus is not related to the fluid property, which indicates the dry rock and saturated rock have the same shear modulus.

In order to calculate the dry P wave modulus, the cross-plot of the dry P modulus and shear modulus is drawn by De-hua Han (2005).

After the simplified Gassmann's equation is applied, the fluid modulus can be handleed as the following :

$$\Delta K=V_p{}^2\rho-2.3083*V_s{}^2\rho$$

$$K_f=\Delta K/G(\phi)$$

Where ΔK is the fluid discriminator or bulk modulus increment after the fluid substitution; K_f is the fluid modulus; $G(\phi)$ is the gain function, which is related to the dry rock frame. The gain function approximately includes all the information about the effect of the lithology. The porosity and the minerals are the important components to decide the value of the gain function.

In this study, for shaly sandstone, the porosity is 0.3, and $G(\phi)\approx 2.5$.

The fluid modulus is sensitive to the pore fluid mixture in the reservoir, and the directive inversion of the fluid modulus is generally helpful to better understand the seismic amplitude anomaly caused by the fluid variation.

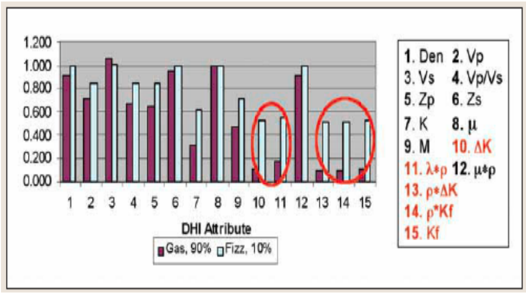

Figure 1. For deepwater sands, relative sensitivity of 15 seismic attributes from a fizz gas (10% gas) and gas (90%) sands normalized with those of wet sands (De-Hua, Han 2006)

In figure 1, the fluid modulus is a good choice for the inversion to differentiate the fizz water and the gas reservoir.

A three layered model is tried to test the method in this study. For this model, the AVO response is class III. The top and bottom shale layers have the higher P-wave velocity and density than the sandstone layer in the middle. The reflection coefficients of the modeling for the gas sandstone and the fizz water sandstone are plotted in figure 2. The blue curve is the reflection coefficients for the fizz water sandstone. The red curve is for the gas sandstone reservoir. The synthetic seismic data for the modeling of the fizz water sandstone and the gas sandstone are plotted in figure 3 and figure 4. Based on the modeling results, it is very difficult to differentiate the seismic amplitude responses of the gas sandstone reservoir from that of the fizz water sandstone reservoir.

It is assumed that for the gas sandstone reservoir the Vs/Vp ratio is already known and for the fizz water sandstone it is unknown. We use the Vs/Vp ratio of the gas sandstone reservoir for the fizz water sandstone reservoir in the procedure of the fluid modulus inversion.

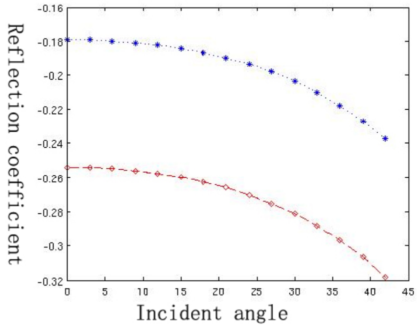

Figure 2. The reflection coefficients of the modeling

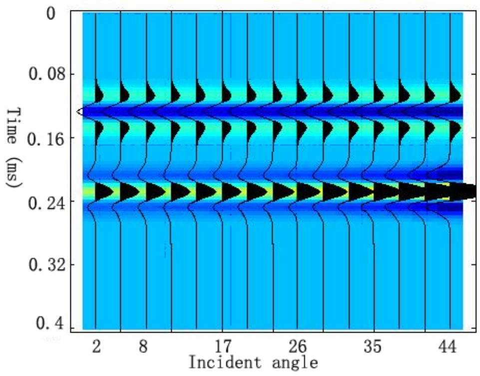

Figure 3. The synthetic data for the model of the gas sandstone reservoir

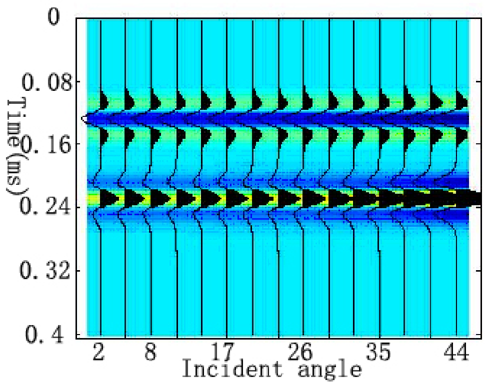

Figure 4. The synthetic data for the model of the fizz water sandstone reservoir

In figure 5, the red line is the inverted P-wave velocity for the fizz water sandstone reservoir and the blue line is the inverted P-wave velocity for the gas sandstone reservoir.

In figure 6, the red line stands the inverted S-wave velocity for the fizz water sandstone reservoir and the blue line stands for the inverted S-wave velocity for the gas sandstone reservoir.

In figure 7, the red line is the inverted density of the fizz water sandstone reservoir and the blue line is the inverted density of the gas sandstone reservoir.

In Figure 8, the red line represents the inverted fluid modulus

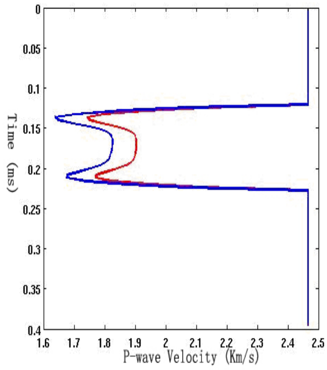

Figure 5. The inverted P-wave velocity

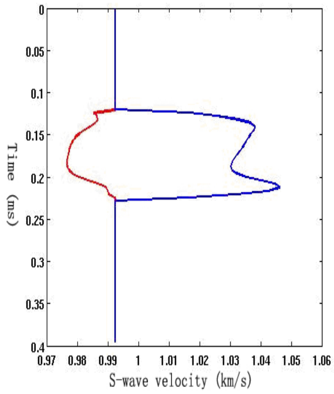

Figure 6. The inverted S-wave velocity

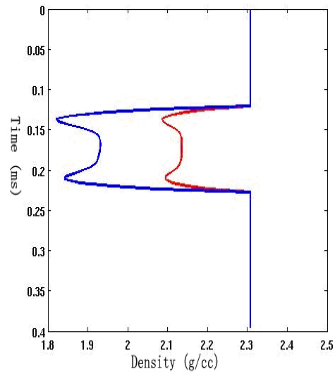

Figure 7. The inverted density

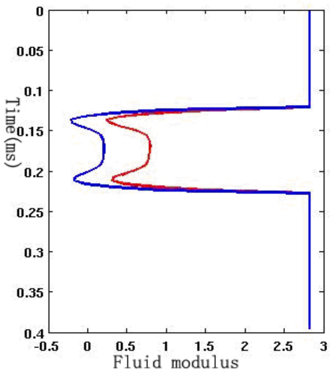

Figure 8. The inverted fluid modulus

of the fizz water sandstone reservoir and the blue line represents the inverted fluid modulus of the gas sandstone reservoir.

In the model of the fizz water sandstone reservoir, the water saturation is set up as 90%. The inverted fluid modulus from the modeling shows that the fluid mixture is the fizz water.

Example

The seismic data is from the Gulf of Mexico (figure 9). Two Patches of data and two wells are deployed in this study. The seismic data imply that it is obvious of the seismic amplitude anomaly in both patches of data. Well A is already drilled in Patch A and Well B is the planned well in Patch B. The two wells are located in the middle of each patch of seismic data (figure 10).

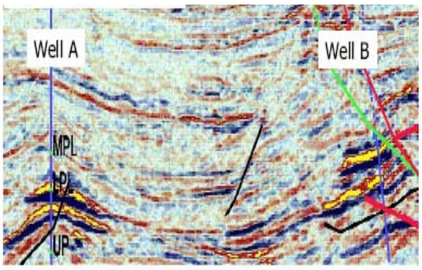

Figure 9. The seismic data

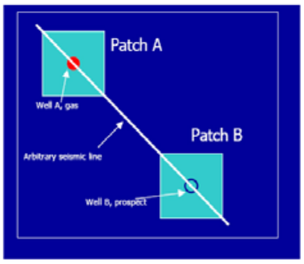

Figure 10. The location s of the two small patches of data

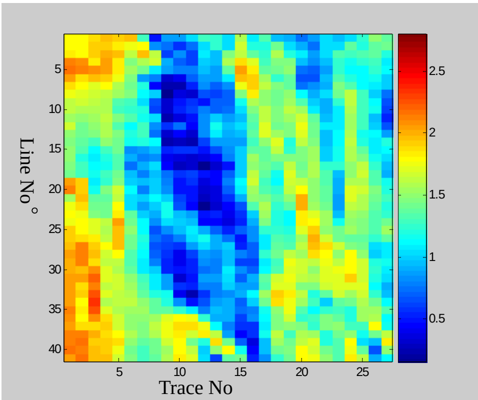

Figure 11. The inverted fluid modulus for Patch A

The inverted fluid modulus in Patch A (figure 11) showing that the sand reservoir is gas saturated and in patch B (figure 12) the sand reservoir is fizz water saturated, which is consistent with the drilling results.

Conclusions

The fluid modulus inversion is a method that can be

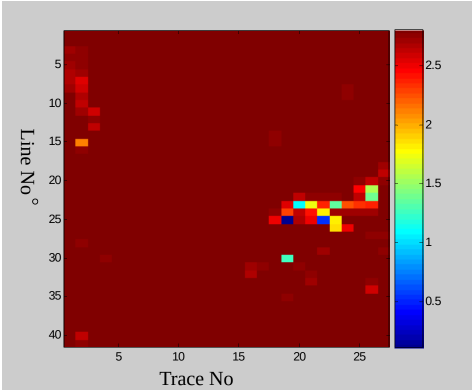

Figure 12. The inverted fluid modulus for Patch B

used to predict the fluid property in the prospect area before the drilling. The smplified Gassmann's equation varies with porosity and clay content. The constant porosity acts as a key assumption in this inversion so that the simplified Gassmann's equation can be used to calculate the fluid modulus which is an effective way to predict the fluid property.

Acknowledgements

Anadarko Petroleum and WesternGeco for permission to show the seismic data. UH/CSM Fluid/DHI consortium sponsors for their supports.

EDITED REFERENCES

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REFERENCES

Aki, K., and P. G. Richards, 2002, Quantitative seismology: Theory and methods: 2nd ed.: University Science Books.

De-hua, H., and M. Batzle, 2002, Fizz water and low gas-saturated reservoirs: The Leading Edge, 21, 395–398.

———, 2005, Velocities of deep water reservoir sands: 75th Annual International Meeting., SEG, Expanded Abstracts, 1051–1054.

———, 2006, Velocities of deep water sands, The Leading Edge, 25, 460–466.

O'Brien, J., 2004, Interpreter's corner-seismic amplitudes fron low gas saturation sands: The Leading Edge, 23, 1236–1234.

Xingang, C., and H. De-hua , 2006, Fluid property discrimination by AVO inversion: 76th Annual International Meeting, SEG, Expanded Abstracts, 2052–2056.