Reservoir properties inversion from AVO attributes

Xin-gang Chi and De-hua Han, University of Houston*

Summary

A new rock physics model based inversion method is put forward where the shaly-sand mixture model is applied. AVO attributes analysis of the intercept and gradient which are linked to the reservoir rock by the rock physics model, can help to understand the reservoir properties. The estimation of clay content, water saturation and porosity are the important parameters to estimate the reservoir properties. Xu-white model is the sand and clay mixture model theory. Based on this model, the P-wave velocity and S-wave velocity is tightly related. Also the AVO attributes can be connected with the rock properties using this model on the workflow. This method can simultaneously provide the inversion results of water saturation, clay content and porosity inverted from the AVO attributes. The method is applied to the seismic data of the Gulf of Mexico. The small dataset have two wells and two 3D cubes. Every well is located in the middle of one cube. The relationship is derived from the first well and applied in the second well. The water saturation, clay content and porosity are estimated for the two cubes of seismic data.

Introduction

In reservoir characterization, rock physics model as a useful tool is attempted to predict the lithology and fluid.

Conventionally, the reservoir properties can be inverted by doing the impedance inversion (P-impedance, S-impedance, and Elastic Impedance inversion) and inverting the reservoir properties using the rock physics relationship calibrated from the well. It is obvious of the drawback that the link between the amplitude and the reservoir rock properties is very weak. (Xingong Li et al. 2005). In this study, the AVO attributes are addressed to estimate the reservoir rock properties.

Intercept and gradient

The reflection coefficients vary with the incident angles in the following equation:

$$RC(\theta) = A + B * \sin^2(\theta)$$

Where $RC(\theta)$ is the reflection coefficient, A is the intercept and B is the gradient.

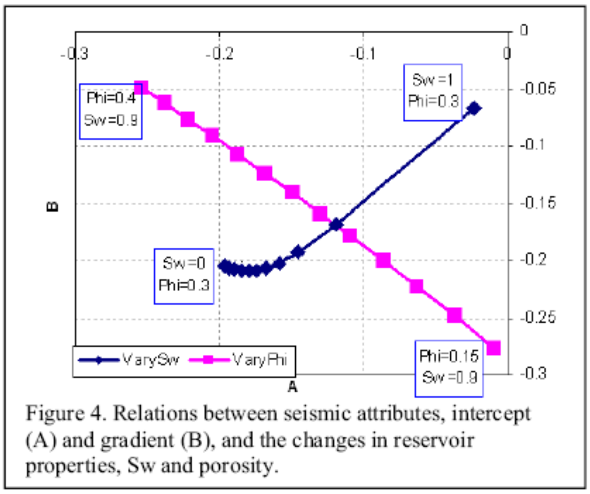

Figure 1. The relationship between the porosity, water saturation and the AVO attributes (Xingong Li, 2005)

In Figure 1, when the water saturation decreases, the absolute value for the intercept and gradient increase in the negative direction. When the porosity decreases, the absolute value of the intercept decreases and the absolute value of the gradient increases. This distribution shows the relationship between the rock properties and the AVO attributes. The clay content is not included in this figure. But when the clay content increases, the sandstone becomes much shaly. The lithology difference between the reservoir and the shale zone on the top and below of the reservoir is becoming less. So the absolute value of the intercept and gradient decrease when clay content increases. So the rock properties of the ideal reservoir are expected to locate in the left part of this figure: low water saturation, high porosity.

Rock physics model

The rock physics model in this study is the version of the shaly-sand mixture model described in Xu and White (1995, 1996) and Robert G. Keys (2002). The mathematical expressions contained within it provide a method for determining P-wave and S-wave velocities and densities of the subsurface rocks given clay content, porosity and fluid properties as well as properties of sand and clay grains and their pores. In this model, the elastic properties of the dry rock are derived by the Kuster and Tokso¨z equations (1974). The porosity is incrementally increased by using the differential effective medium theory. After the dry elastic properties are determined, the bulk modulus and shear modulus of the saturated rock are calculated by using the Gassmann's equation. Then the P-wave velocity and S-wave velocity can be obtained for the saturated rock. After the P-wave velocity and S-wave velocity are calculated, given the incident angles the intercept and gradient can be delivered from the reflection coefficients.

The posterior information analysis can be done by using the general probabilistic inverse theory which is developed by Tarantola (1987). According to the theory, a formula is developed to include deterministic models with error, data, and prior information.

$$\sigma(d(A,B),m(\varphi,Vsh,Sw)=k*\rho(d(A,B),$$
$$m(\varphi,Vsh,Sw))*\Theta(d(A,B),m(\varphi,Vsh,Sw))$$

Where k is the normalization const; d(A,B)is the observed intercept and gradient; $m(\varphi,Vsh,Sw)$ is the model; for the model the parameters are the water saturation, porosity, and clay content; $\sigma(d(A,B),m(\varphi,Vsh,Sw))$ is the posterior probability density function; $\rho(d(A,B),m(\varphi,Vsh,Sw))$ is the prior probability density function, which represents the information of the observed data; $\Theta(d(A,B),m(\varphi,Vsh,Sw))$ is the theoretical probability density, which represents the information of the physical relationship between the model and the data.

Inversion of the properties

First, to do AVO analysis

Second, to invert the intercept and gradient from the seismic angle gather

Third, to estimate the water saturation, porosity and clay content by minimizing the object function:

$$O=\|D-F(Sw,Vsh,\varphi)\|_2^2$$

Where D is the inverted AVO attributes; Sw is the water saturation; Vsh is the clay content; φ is the porosity. $F(Sw,Vsh,\varphi)$ is the model.

The inversion is constrained by the other information based on the rock physics theory. The water saturation is in the range of 0%-100%. The porosity is in the range of 0%-40%. The clay content is in the range of 0%-30%. The intercept and the gradient should be scaled after inverted from the seismic angle gather data.

Example

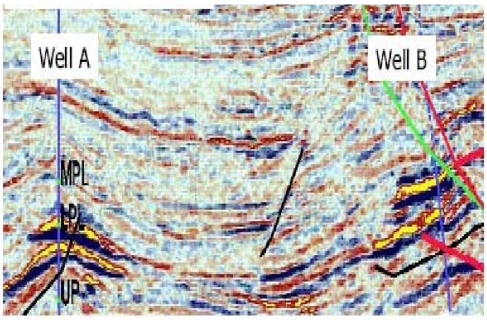

Figure 2. The prestack depth migration data

The two small cubes of seismic data used in this study are around the two wells respectively, which is shown in figure 3.

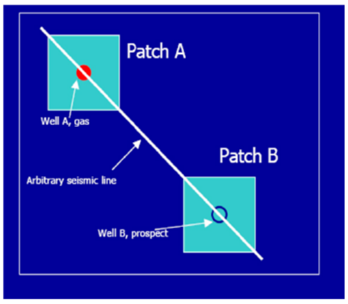

Figure 3. The locations of the two small patches of seismic data

The two small patches of seismic data are connected by an arbitrary line and the two wells are located in the middle of each data patch.

Sand 1A and sand 1B are the focused target in this study. The seismic well tie is shown for both wells and seismic data. The information of Well B is not used in the modeling and inversion, only for the tops of sand 1B.

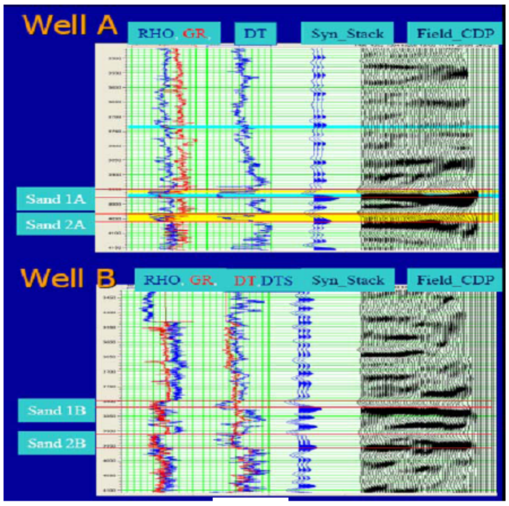

Figure 4. Well log for patch A and patch B

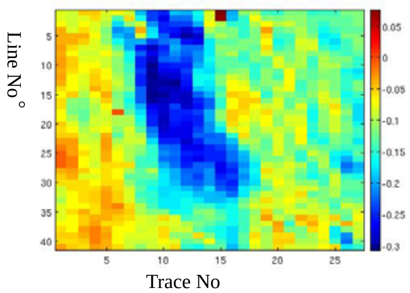

Figure 5. The intercept of Patch A

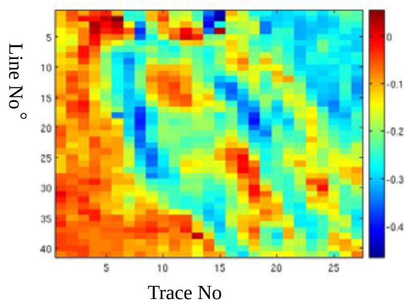

Figure 6. The gradient of Patch A

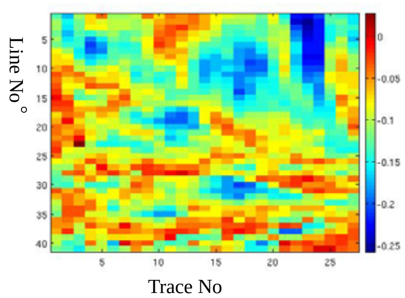

Figure 7. The intercept of Patch B

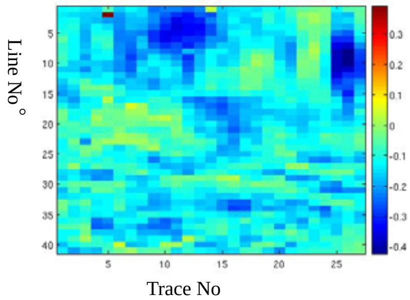

Figure 8. The gradient of patch B

The intercept and gradient of patch A is slightly different from the intercept and gradient of patch B. The qualitative analysis for the fluid difference is not enough for these two locations (O'Brien 2004, Xingong Li, 2005).

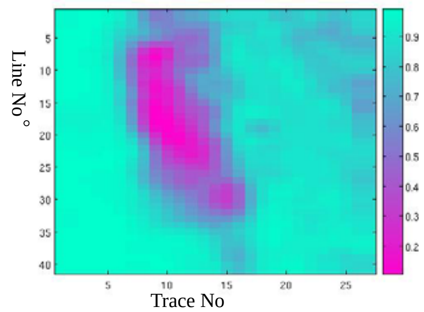

Figure 9. The inverted water saturation of Patch A

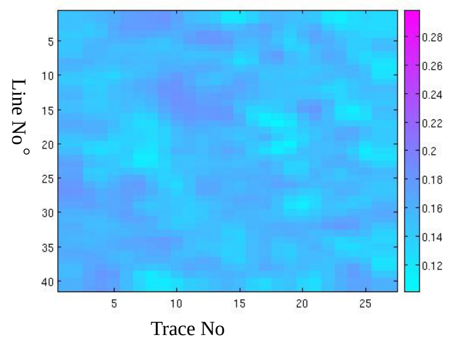

Figure 10. The inverted clay content of patch A

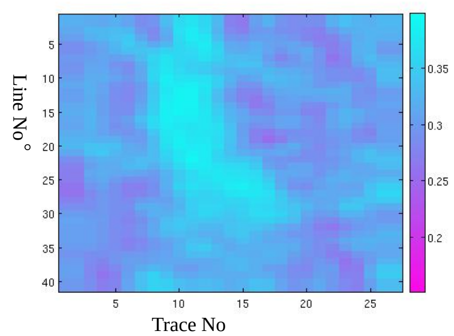

Figure 11. The inverted porosity of Patch A

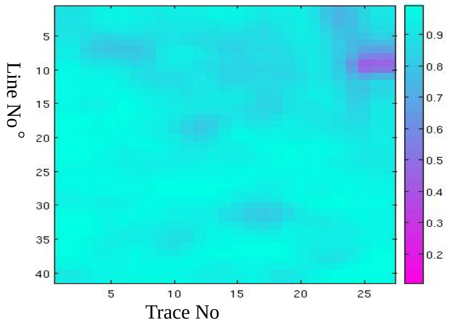

Figure 12. The inverted water saturation of patch B

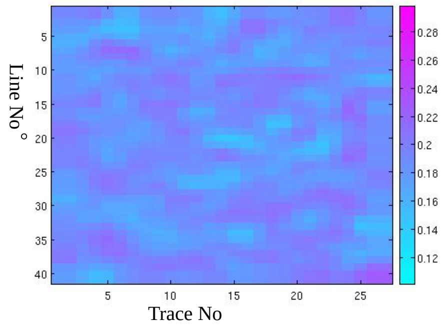

Figure 13. The inverted clay content of Patch B

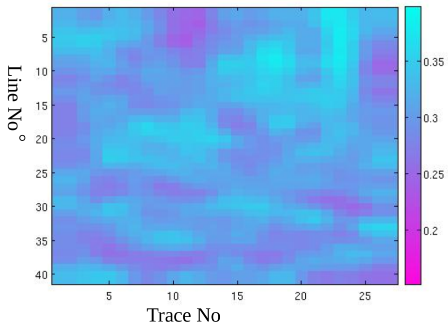

Figure 14. The inverted porosity of patch B

The quantitative inversion identifies that low water saturation is in Patch A (figure 9) and high water saturation in Patch B (figure 12). Also the porosity are simultaneously inverted for Patch A (figure 11) and Patch B (figure 14). The shale volume in Patch A (figure 10) is a little bit lower than the shale volume in Patch B (figure 13). In Patch A, the commercial gas is encountered, but in Patch B, the inverted water saturation indicates it is the fizz water saturated reservoir which is consistent with the drilling result.

Conclusions

The shaly-sand mixture model based inversion method is deployed to the seismic data of the Gulf of Mexico. The sand and shale mixture model method can help to simultaneously invert the water saturation, shale volume and porosity for the reservoir. The AVO attributes are determined as the observed dataset to be related to the rock properties. The inversion results show the distribution of the water saturation, shale volume and porosity for Patch A and the prediction of the water saturation, shale volume and porosity for Patch B. In Patch B, the inverted low water saturation is consistent with the drilling result.

Acknowledgements

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

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2007 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Keys, R. G., and S. Xu, 2002, An approximation for the Xu-white velocity model: Geophysics, 67, 1406–1414.

Kuster, G. T., and M. N. Toksöz, 1974, Velocity and attenuation of seismic waves in two-phase media: Part 1: Theoretical formulation: Geophysics, 39, 587–606.

Li, X., D. Han, J. Liu, and D. McGuire, 2005, Inversion of Sw and porosity from seismic AVO: 75th Annual International Meeting, SEG, Expanded Abstracts, 1307–1310.

O'Brien, J., 2004, Interpreter's corner-seismic amplitudes from low gas saturation san: The Leading Edge, 23, 1236–1243.

Tarantola, A., 1987, Inverse problem theory-mthods for data fitting and model parameter estimation: Elsevier Science Publ. Co.

Xu, S., and R. White, 1995, A new velocity model for claysand mixtures: Geophysical Prospecting, 43, 91–118.

———, 1996, A physical model for shearwave velocity prediction: Geophysical Prospecting, 44, 687–717.