Combined Bayesian AVO inversion with rock physics to predict gas carbonate reservoir

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Summary

A better understanding of fluid effects on carbonate rock properties is considered to be key issue in applying AVO inversion to carbonate reservoir characterization. Analysis of well log data in a gas carbonate reservoir of Southwestern China indicates that gas does influence carbonate's elastic rock properties, and low VP/VS ratio and low acoustic impedance can be treated as calibration for the interpretation of seismic inversion result. We invert prestack seismic data using Bayesian linearized AVO inversion to estimate elastic properties and assess their uncertainty. We also show how to combine a credible seismic inversion result with rock physics analysis to identify gas carbonate reservoir.

Introduction

Seismic responses in carbonates are poorly studied, and a lack of carbonate rock physics make the AVO classification and seismic inversion not applicable to carbonate reservoir characterization. Understanding the sensitivity of carbonate rock properties responding to fluids is critical to interpret seismic inversion result in carbonate reservoir. The common sense is that fluids are low sensitive to carbonate rock properties because carbonate rocks have very high modui. However, through the re-analysis of the data from Rafavich (1984), Li and Downtown (2000) illustrate that gas does affect carbonate rock properties with significant amplitude. They also examine the potential of AVO response and prestack seismic inversion to characterize carbonate reservoirs. Carbonates rocks are characterized by complex pore systems, attributed mainly to their complex diagenesis and cementation, fluids effect to seismic rock properties of carbonates can be relatively large due to more heterogeneity and fractures in carbonate reservoirs (Han, 2004).

The studied field represents a marine carbonate reservoir of Southwestern China. The targeted inversion area defines in-lines 209 and cross-lines from 100-250. Stacked image of the targeted area is shown in Figure 1, on which a red vertical line indicates the location of a well. The depth of the gas carbonate reservoir ranges from 5560m to 5650m, and the strong continuous negative reflectivity appearing at about 2.7s possibly indicates the top of gas reservoir. The deep targeted reservoir in this study makes it hard to get wide angle gather, so the elastic parameters (P-wave velocity, S-wave velocity, density) are not confidently extracted from prestack seismic data. In order to tell how much the seismic inversion result can be trusted, we perform Bayesian linearized AVO inversion to show the posterior distribution and uncertainty of elastic parameters.

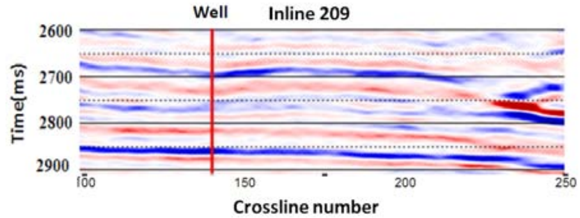

Figure 1: Stacked image of in-line 209(negative amplitude are blue, positive amplitude are red).

Rock physics analysis from well log data

Well logs play an important role in linking rock properties to seismic data which should be extensively analyzed prior to inversion, and rock properties can be discerned from well log data. In this study, lithology is identified based on well log data, some core information, and thin section description. Well log data are displayed as a function of two-way traveltime in Figure 2, on which four defined faceis are indicated by different colors: anhydrite, dolostone, gas-carbonates and limestone. Well log data also showed that the gas is trapped in dolostone from the depth of 2680ms to 2730ms.

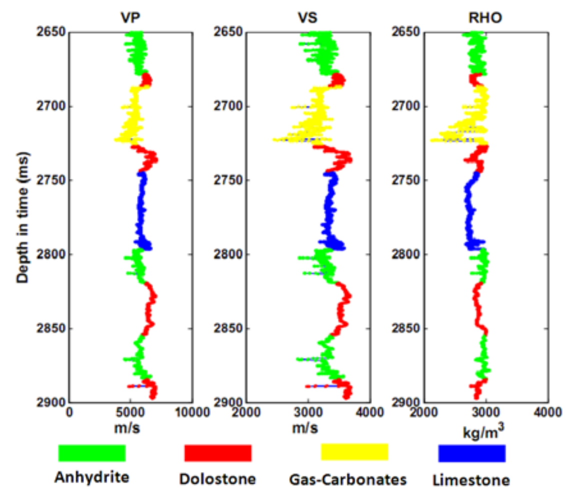

Figure 2: P-wave velocity, S-wave velocity and density are plotted in the depth of 2650ms-2900ms, different lithology is also classified here

Prestack seismic inversion to predict gas carbonate reservoir

The crossplot of P-wave velocity to S-wave velocity (VP/VS) ratio and acoustic impedance is shown in Figure 3. It is difficult to distinguish anhydrite, dolostone and limestone in this crossplot because they have similar elastic properties, while carbonate's acoustic impedance and VP/VS ratio decrease dramatically due to the effect of gas. We will use this crossplot as a template to interpret inverted elastic rock properties.

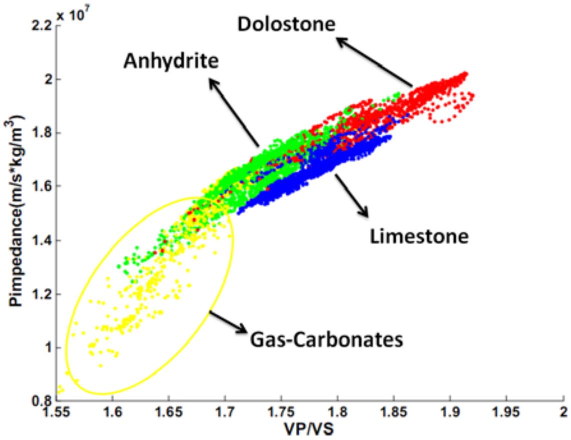

Figure 3: Crossplot of VP/Vs ratio and acoustic impedance for four facies

Bayesian AVO inversion

The inversion uses a linear seismic forward model for a angle gather defined in Buland and Omre (2003). The discrete matrix formulation can be expressed as,

$$\mathbf{d} = \mathbf{Gm} + \mathbf{e} \qquad (1)$$

where **d** refers to the seismic data, and **e** is the error term, **m** is the earth model which can be expressed as logarithm of elastic parameters:

$$\mathbf{m} = [\, \ln V_p ,\ \ln V_s ,\ln\rho] \qquad (2)$$

The matrix **G** is a linear operator that can be given by

$$\mathbf{G} = \mathbf{WAD} \qquad (3)$$

Where **W** is a block-diagonal matrix representing wavelet, **D** is a differential matrix giving the contrast of elastic properties in m, **A** is the matrix of angle-dependent weak contrast coefficients defined by Aki-richards equation (1980). For linear inversion problems, the expectation and covariance of the posterior distribution is given in analytical expressions (Tarantola, 1987, Buland and Omre, 2003):

$$\boldsymbol{\mu}_{\mathbf{m|d}} = \boldsymbol{\mu}_{\mathbf{m}} + \mathbf{C_m G^T (G C_m G^T + C_d)^{-1} (d_{obs} - G}\boldsymbol{\mu}_{\mathbf{m}}) \qquad (4a)$$

$$\mathbf{C_{m|d}} = \mathbf{C_m} - \mathbf{C_m G^T (G C_m G^T + C_d)^{-1} G C_m} \qquad (4b)$$

$\boldsymbol{\mu}_{\mathbf{m|d}}$ represents the maximum a posterior solution, $\boldsymbol{\mu}_{\mathbf{m}}$ represents low-frequency background model, $\mathbf{C_{m|d}}$represents posterior covariance matrix, $\mathbf{C_d}$ is the error covariance. This analytical equation provides a kind of fast, computationally efficient inversion method. The advantages of Bayesian AVO inversion is that not only maximum a posterior solution of model can be obtained, but also a set of models that can be used to quantify uncertainty of inversion results.

Prestack seismic inversion result

The seismic data has been relatively true-amplitude processed. Figure 4 shows five offset-domain common-image gathers (CIGs) produced by prestack time migration. As the targeted carbonate reservoir is so deep that the largest incident angle available in the inversion is about 33° . Figure 5 shows a transformed angle gather at the well position.

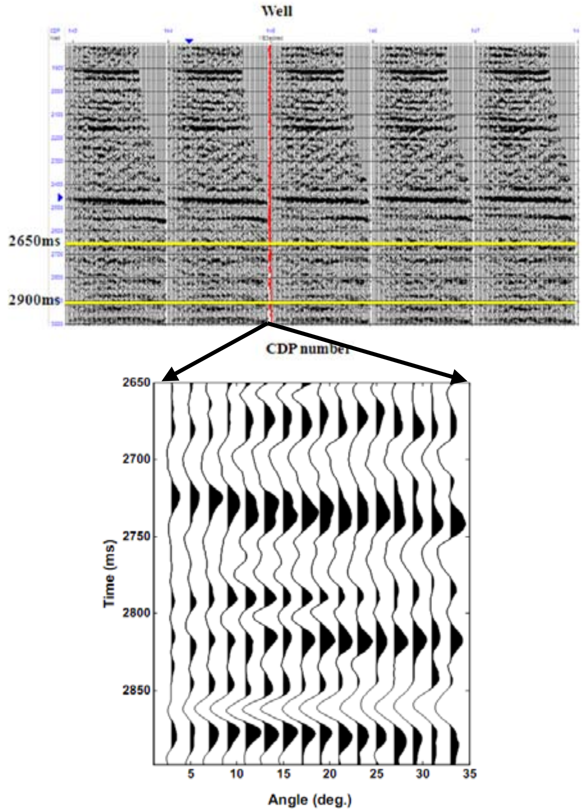

Figure 4: Five of the common-image gathers within the inversion zone and a transformed angle gather at the well position

Prestack seismic inversion to predict gas carbonate reservoir

The inversion result of well position (Figure 5) shows that the inverted P- and S-wave velocities fit quite well with well log trend, and even some details of the vertical change can be captured. However, the inverted density is not accurate enough to characterize the density change at the well position. The 0.9 prediction interval indicates that the uncertainty of the inverted P- or S-wave velocity is lower than that of the inverted density. This may be partially resulted from lack of reflectivity data of wide angle. The maximum posterior probability solutions in the targeted area are shown in Figure 6. The well logs are plotted for comparison and P- and S- wave velocity show good agreement with the inversion results. The inverted density in some area is unreasonably too high, so we consider that density inverted from the seismic data should be carefully used in this area.

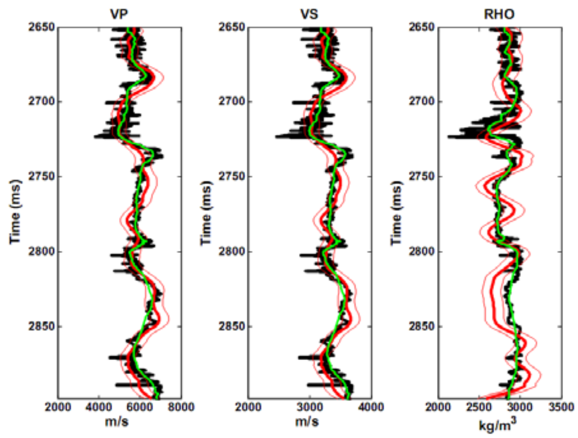

Figure 5: Inversion result of well(Black line indicate well log, Green line indicate well log trend, red thick line indicate Maxmium a solution, red thin line indicate 0.9 prediction interval)

Gas carbonate reservoir prediction.

In an attempt to better define gas carbonate reservoir, an extensive well log analysis tells us that P-impedance and VP/VS ratio can be important indicators for gas reservoir in this area. Figure 7 shows the maximum posterior probability solutions of acoustic and shear impedances, and VP/VS ratio calculated from the posterior distribution of P- and S-wave velocity and density after Bayesian AVO inversion. Possible gas reservoir is interpreted and denoted in the profiles.

Since the posterior solution of Bayesian AVO inversion shows that density is not trustfully inverted from prestack seismic data, we prefer VP/VS ratio as better gas carbonate indicator. The lower VP/VS ratio zone (below 1.65) was shown in Figure 8, the area inside the yellow cycle zone which features kinds of geological consistence is recommended as high potential gas reservoir.

Conclusion

We have demonstrated how to combine Bayesian seismic inversion with rock physics analysis to predict gas carbonate reservoir in Southwestern China. Rock physics analysis from well log data indicates that gas-bearing may decrease carbonate's VP/VS ratio and P-impedance significantly. A lack of wide angle seismic data in deep targeted carbonate reservoir requires that the uncertainty of the inverted P- and S-wave velocity, and density should be evaluated quantitatively. AVO inversion from prestack seismic data in Bayesian framework shows that velocity is more confidently inverted than density. Hence we take the low VP/VS ratio zones which also shows geological consistence as prospecting gas reservoir in this area.

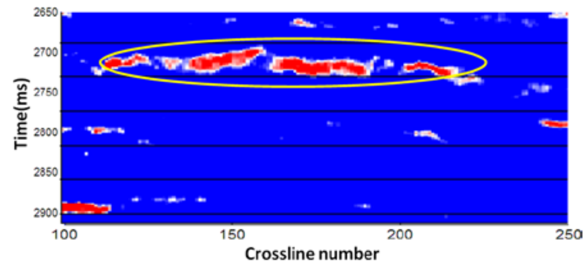

Figure 8: Low VP/VS ratio (below 1.65) zones, yellow cycle zone is the recommended high potential reservoir

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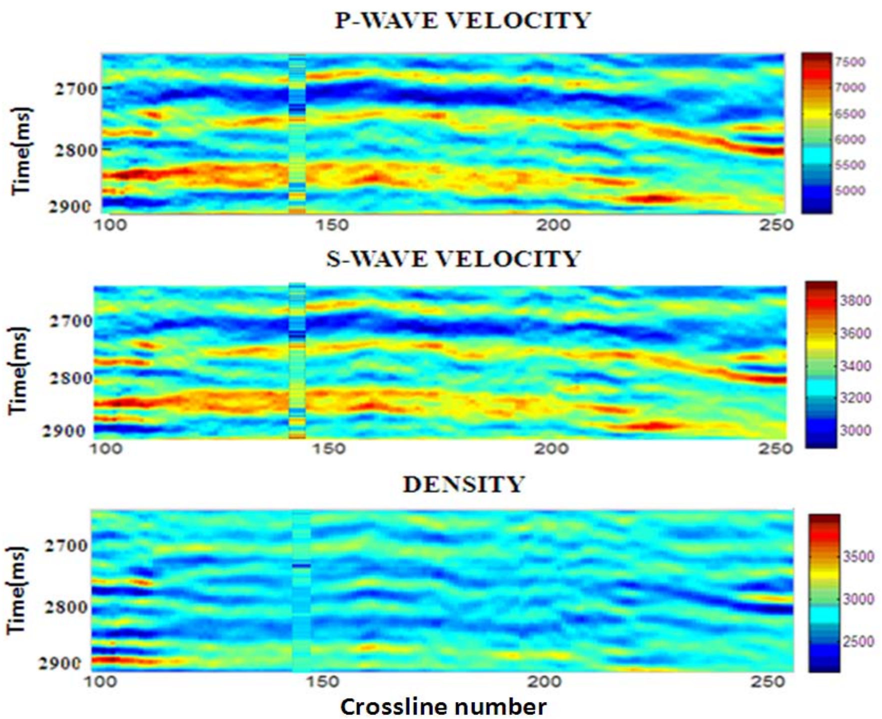

Figure 6: Maxium a posterior inversion result of P-wave velocity, S-wave velocity and Density for inline 209

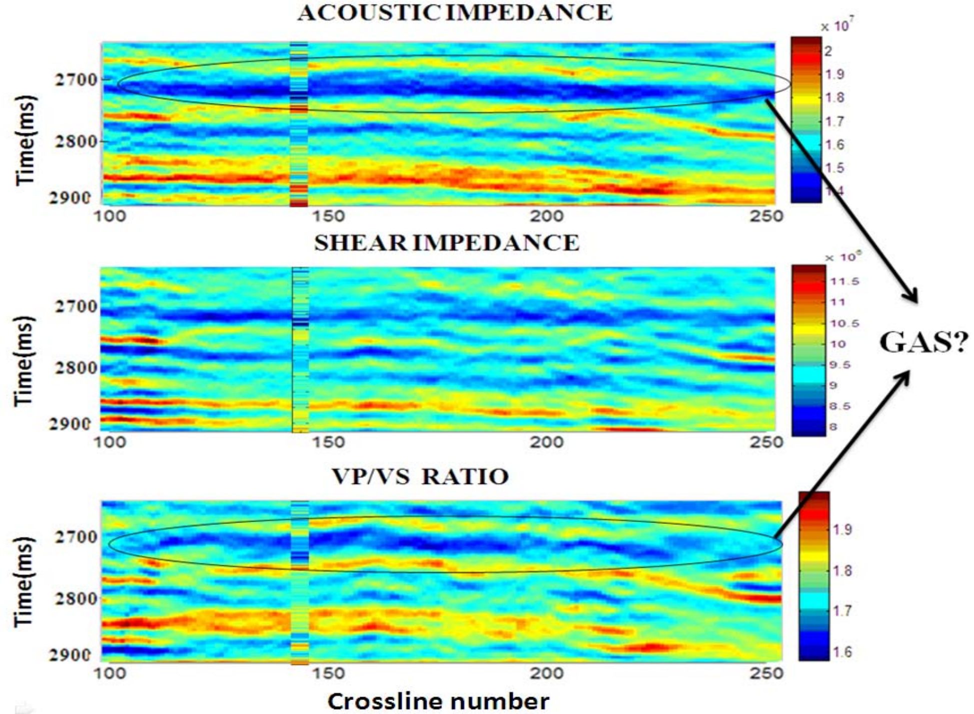

Figure 7: Maxium a posterior inversion result of Acoutisc impedance, Shear impedance and Vp/Vs ratio for inline 209

EDITED REFERENCES

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