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Petrophysical Characterization of Pore Type in Tight Gas Carbonates of Southwestern China

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SUMMARY

Exploration and production in tight gas carbonates reservoir requires a comprehensive petrophysical characterization of rock microstructure in low-porosity and low-permeability tight carbonates. The complex pore system in tight gas carbonate makes pore shape must be taken into account for estimating elastic properties in rock physics modeling, differential effective medium(DEM) theory can be used to study the relationship between changing pore geometries and elastic properties. In this article, detailed rock physics modeling steps was put proposed, and on this basis pore type inversion algorithm was developed according to the concluded velocity-porosity relationship. Finally, Geological knowledge, core data, and well log data are integrated to discuss the pore shape effect on elastic properties of carbonate rocks in tight gas carbonates reservoir of Southwestern China, and the given pore type inversion result fits well with features of pore geometry which was revealed by thin section of cores and FMI image of local area, indicating this method can be can be effective to characterize complexity of pore system in tight gas carbonates.

Introduction

Tight gas carbonates often presents distinguishing feature of low-porosity and low-permeability compared with porous and permeable carbonates, the characterization of tight carbonate reservoirs is challengeable because of heterogeneity and complex pore structure. Pore shape are considered to be key factor which can cause great change for elastic properties in tight gas carbonates. If the elastic properties and behavior of these low-porosity rocks are understood, then seismic response of tight gas carbonates can be well discussed. Proper pore type classification and estimation can help for a better delineating tight gas carbonate reservoir, it's necessary to develop pore type inversion procedure and algorithm based on rock physics modeling in tight gas carbonates.

Pore types classification and Rock physics modeling

The target tight gas carbonate reservoir of well YB1 and well YB2 in Southwestern China consists of heterogeneous dolomite and limestone deposits and occurs at deeper depth ranging from 6,500 to 7,100 meters, with an average porosity of about 3%, and effective permeability of 0~3 mD. To study the effective elastic properties of low-porosity tight gas carbonates, we define the pore type into three categories based on the local geological information, well log data and core data(Figure 1): (1) Reference rock (interparticle pores, α =0.15) which is the most common pore type, (2) Reference rock+ stiff pores(α =0.8, that represent moldic pores and vugs), (3) Reference rock+ cracks (α =0.02, that represent most compliant pores in the system, such as fractures) (Sayers, 2008; Xu and Payne, 2009).

Figure 1 *Photos of rock's cores from tight gas carbonate reservoir of Southwestern China*

DEM provides a tool to calculate the effective bulk and shear moduli for different pores, this model simulates porosities in a composite of two phase by incrementally adding small amount of pores(phase 2) into matrix (phase 1).

$$(1-\phi)\frac{d}{d\phi}[K^*(\phi)] = (K_2 - K^*)P^{(*2)}(\phi)$$

$$(1-\phi)\frac{d}{d\phi}[\mu^*(\phi)] = (\mu_2 - \mu^*)Q^{(*2)}(\phi)$$

With the initial conditions $K^*(0)=K_1$ and $\mu^*(0)=\mu_1$, where K_1 and μ_1 are matrix bulk and shear modulus respectively. K_2 and μ_2 are the bulk and shear modulus of inclusion phase respectively. ϕ is the porosity and $d\phi$ is the small increment in porosity. $P^{(*2)}$ and $Q^{(*2)}$ are the geometrical factors depending on aspect ratio of the elliptical pores (Mavko,1998).
Detailed rock physics modeling steps was given (Figure 2)

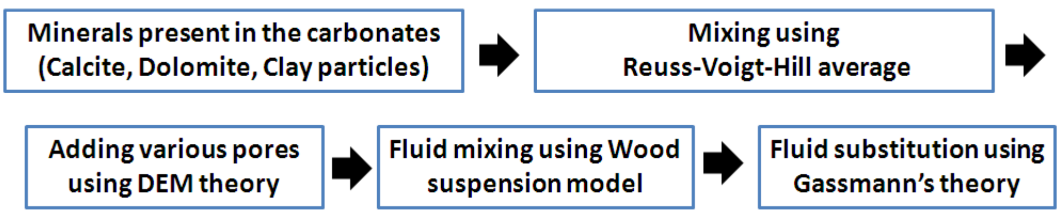

Figure 2 *Detailed steps of rock physics modeling in tight gas carbonates*

Pore shape and mineralogy effect on elastic properties of tight gas carbonates

According to the introduced rock physical modeling method, the calculated P-wave velocity as a function of porosity and pore type can be predicted in reference to the mineral composition of the carbonates rocks, clay content, fluid type, fluid saturation and classification of pore types of the local region. Figure 3 shows well YB1 log data, the shadow zone indicates tight gas carbonates reservoir, there are mainly two kinds of lithology for tight carbonates in well YB1: dolomite and limestone. Figure 4 shows the pore shape effect on P-wave velocity-porosity relationship based on the Well YB1 log data. As expected, for a given porosity, velocity will be relatively higher when the pore types are stiff pores, while velocity will tend to be relatively lower when pore types are cracks.
In the left plot of Figure 4, the mineral present in the carbonates is assumed to be calcite. It is evident that some dolomite data points from tight gas carbonate reservoir in well YB1 are not included in the boundary of P-wave velocity-porosity relationship. Also, for the right of Figure 4, the mineral present in the carbonates is assumed to be dolomite. All of the data points from tight gas carbonate reservoir in well YB1 are scattered in the boundary of P-wave velocity-porosity relationship. However, some pore types of limestone data points in the calcite-based rock physics modeling are interpreted as stiff pores, but interpreted as cracks in the dolomite based rock physics modeling. It can be concluded that rock physics modeling should be locally calibrated based on mineral composition of the matrix.

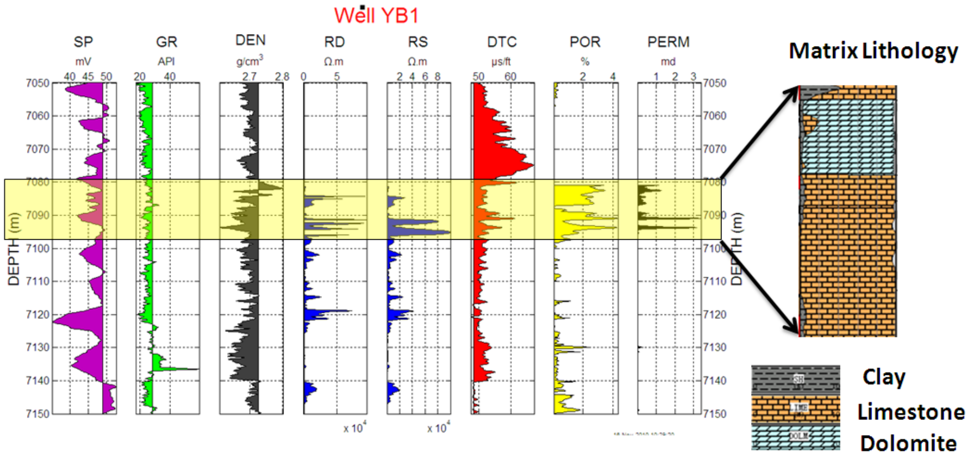

__Figure 3__ Well YB1 log data, shadow zones indicate tight gas carbonate reservoir

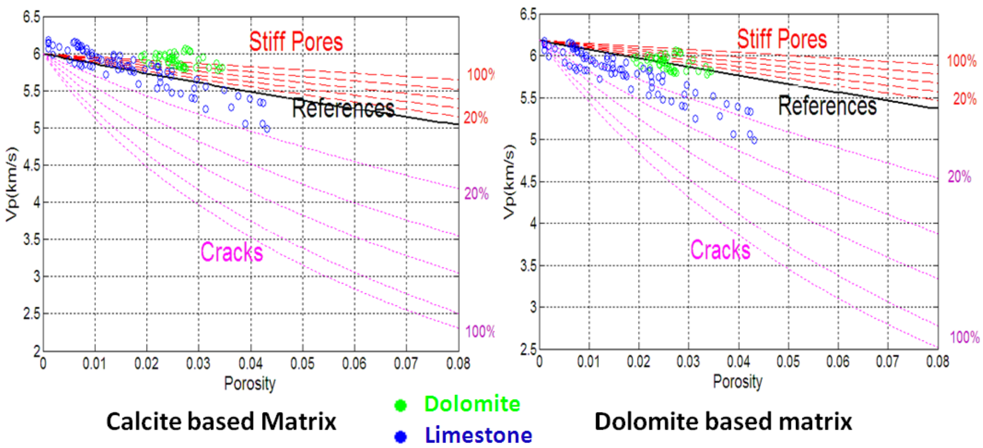

__Figure 4__ Illustration of possible pore type effect on P-wave velocity-porosity relationship, left is calcite based matrix, right is dolomite based matrix, all the data points are from tight gas carbonates in well YB1

This model can be used to invert rounded pores or cracks from P-wave velocity-porosity relationship . For example, in Figure 4, a data point lying on the reference line means that there are no rounded pores or microcracks in the system and all pores are interparticle pores. A data point on the 80% rounded pore line means that 80% of the total pore space is rounded and the remainder is interparticle pores (Xu and Payne, 2009).

Pore type inversion in tight gas carbonates

Pore type inversion means that according to the measured velocity and porosity, we can predict the fraction of different pore types (reference, stiff pores and cracks) in pore space. The main steps for pore type inversion are as follows (Kumar and Han, 2005):

1. Input measured velocity Vp and porosity ϕ_0 from well log data.
2. Assume that only interparticle pore in pore spaces, use DEM theory and modeling method to calculate $Vp_{interparticle}$ given porosity ϕ_0.
3. If measured velocity Vp is greater than $Vp_{interparticle}$, use $\alpha_1 = \alpha_{interparticle}$, $\alpha_2 = \alpha_{stiff}$, $\phi_1 = \phi_0$, $\phi_2 = 0$.
4. Use DEM theory and modeling method to calculate $Vp_{Modeling} = f(K_0, \mu_0, \alpha_1, \alpha_2, \phi_1, \phi_2)$.
5. If $(Vp - Vp_{Modeling})^2 > \varepsilon$?, then $\phi_1 = \phi_1 + \delta\phi$ and $\phi_2 = \phi_2 - \delta\phi$.
6. Repeat step 4 and 5, until $(Vp - Vp_{Modeling})^2 < \varepsilon$?, so the $\phi_{interparticle} = \phi_1$, $\phi_{stiff} = \phi_2$.
7. If measured velocity Vp is lower than $Vp_{interparticle}$, use $\alpha_1 = \alpha_{interparticle}$, $\alpha_2 = \alpha_{crack}$, $\phi_1 = \phi_0$, $\phi_2 = 0$.
8. Use DEM theory and modeling method to calculate $Vp_{Modeling} = f(K_0, \mu_0, \alpha_1, \alpha_2, \phi_1, \phi_2)$.
9. If $(Vp - Vp_{Modeling})^2 > \varepsilon$?, then $\phi_1 = \phi_1 + \delta\phi$ and $\phi_2 = \phi_2 - \delta\phi$.
10. Repeat step 4 and 5, until $(Vp - Vp_{Modeling})^2 < \varepsilon$?, so the $\phi_{interparticle} = \phi_1$, $\phi_{crack} = \phi_2$.

The inverted stiff pores(red), reference pores(black) and cracks(blue) for tight gas carbonate reservoir in well YB1 are shown in left of Figure 5, the right of Figure 5 shows FMI image of corresponding well log section. It's clear to see that there is a huge variation in pore type from sample to sample. Interparticle pores make up large percentage of the pore space in these samples. Pore type inversion result shows that there are some stiff pores at the depth of 7082m, this match well with FMI image which also show stiff pores in the corresponding depth. Also, pore type inversion result shows that interparticle pores and cracks dominate the pore spaces below 7090m, which fits well with clear corresponding fractures in the FMI image.

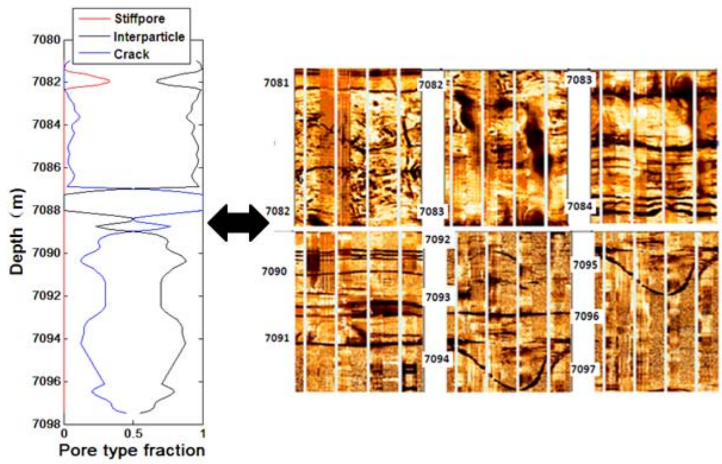

Figure 5 *(left) Pore type inversion result in tight gas carbonates reservoir of well YB1. (right) Corresponding FMI image of pore types*

Pore type inversion for Well YB2 is shown in Figure 6. The inversion area is a tight gas carbonate reservoir which ranges from 6550m to 6590m. The corresponding thin sections of the well logs are also shown in the right of Figure 6. At the depth of 6555.2m, stiff pores are present in the thin section and the inversion result shows that stiff pores make large percentage of pore space in the depth of about 6555m. At the depth of 6561.73m, one can see fractures in the thin section and the pore type inversion result shows that the main pore type here is interparticle pores and cracks. At the depth of 6587.97m, the thin section indicates stiff pores, and it's found that interparticle pores and stiff pores dominate pore space from the pore type inversion result.

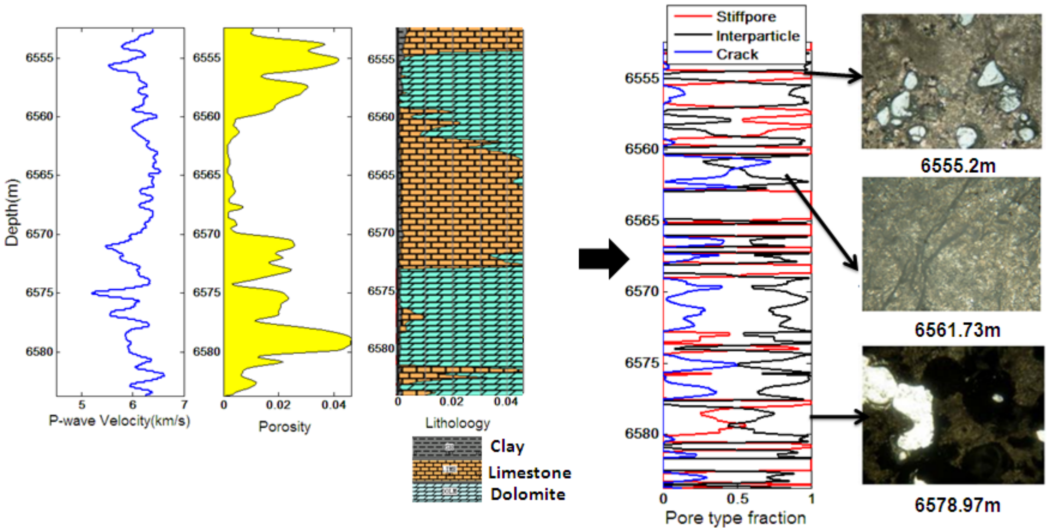

Figure 6 *(left) P-wave velocity, porosity, matrix lithology of well YB2. (right) Pore type inversion result and corresponding thin section of pore types*

Conclusions

In order to have better understanding about petrophysical properties of low-porosity and low-permeability tight gas carbonates of Southwestern China, three kinds of pore types (stiff pores, interparticle pores and cracks) with different aspect ratio are classified. Mineral composition of the matrix and pore geometries has been taken into account to estimate elastic properties, and rock physics modeling shows that stiff pores are less effective to reduce velocities, and in opposite cracks and fractures are more effective to reduce velocities. Algorithm and workflows for pore type inversion was put forward and developed in this study, and the pore type inversion can be effective to characterize complexity of pore system in tight gas carbonates.

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Reference

Colin M. Sayers, 2008, The elastic properties of carbonates, The leading Edge, 27, 1020-1024

Kumar, M., and D. Han, 2005, Pore shape effect on elastic properties of carbonate rocks, 75th Annual SEG Meeting Expanded Abstracts, 1477–1480.

Mavko, G., T. Mukerji, and J. Dvorkin, 1998, The rock physics handbook: Tools for seismic analysis in porous media: Cambridge University Press.

Shiyu Xu et al.2009, Modeling elastic properties in carbonate rocks. The Leading Edge, 28, 66-74