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## Geophysical Pore Type Characterization from Seismic Data in Carbonate Reservoir

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### SUMMARY

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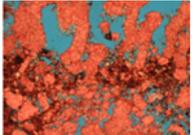
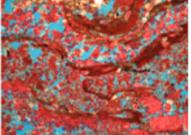
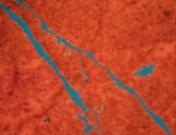
Pore geometry in carbonates control the fluid flow properties and geological story, the purpose of our work is to predict pore type distribution from well observations and seismic data based on geologic understanding of the reservoir. Based on developed rock physics model which can take into account volume fraction of pore type quantitatively, we bridge the three defined geophysical pore type with extracted seismic properties from seismic data. The approach is evaluated on real well log data and seismic data from offshore Brazil carbonate reservoir, we obtain the distribution of reference pores, stiff pores and cracks which can be used to predict reservoir permeability.

## Introduction

In carbonate systems, the combined effect of variations in depositional facies and diagenetic alterations plays a key role in controlling the variations in sonic velocities and acoustic impedance, which makes the seismic response of these rocks hard to understand and interpret. Carbonate pore types are considered the key factor causing significant variations in permeability and elastic properties (Eberli et al., 2003). In this abstract we will discuss how we estimate pore type distributions in a carbonate reservoir from both well log and seismic data, which is critical for reservoir characterization, geologic model building and hence dynamic simulations.

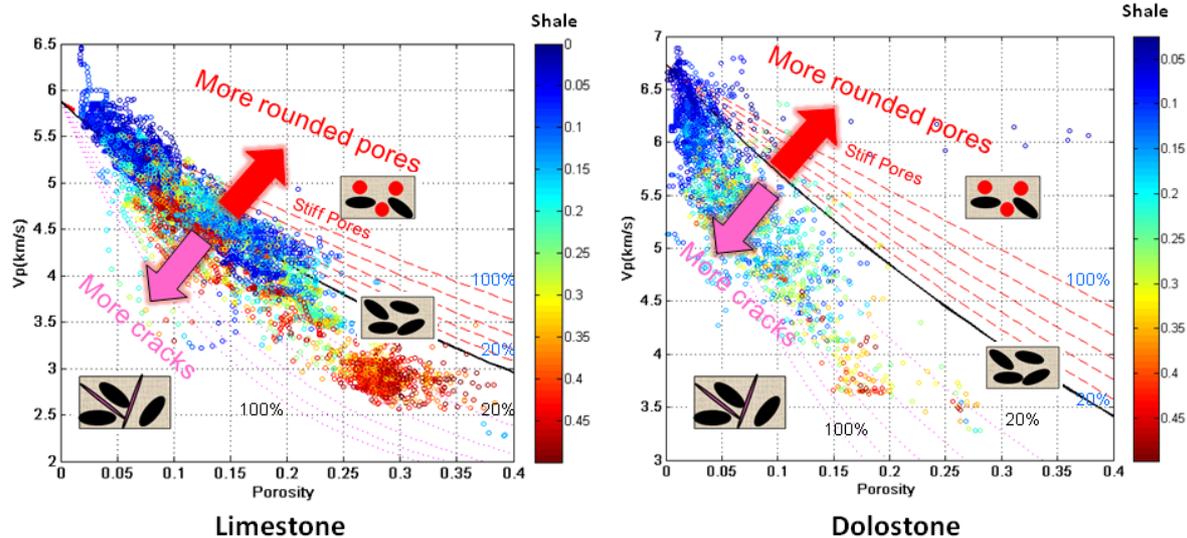
### Geophysical pore type characterization in carbonates

Intense geological processes cause carbonate rocks to develop wide variations in pore types, such as interparticle, intercrystal, moldic, vuggy, intraframe and microcracks. Although this classification is useful for characterizing petrophysical properties, relating these descriptions to a geophysical response is very challenging. Normally, vuggy pores are very rigid and less affected by seismic wave propagation, while cracks are effective to reduce velocities in carbonates. We use three geophysical pore types to abstractly represent seismic velocities in carbonate reservoir rocks as in Figure 1: (1) Reference pores, which mainly consist of interparticle pores and is considered the dominant pore type in carbonate rocks, (2) Stiff pores, which represent moldic and vuggy pores, which are usually formed as a result of dissolved grains and fossil chambers. (3) Cracks, which can occur due differential compaction, faulting and solution collapse in carbonates. (Lucia, 1999; Han, 2004; Xu and Payne, 2009).

	Pore types		
Petrophysical	Vuggy(Moldic)	Interparticle(Intercrystal)	Microcracks
Geophysical	Stiff	Reference	Cracks
AR	0.7-0.8	↔ 0.12-0.15	0.01-0.02
Connectivity	Separate    Touchy	Good	Good
Image			
Pore systems			

**Figure 1** Pore type classification in Carbonates; thin section are from a field offshore Brazil

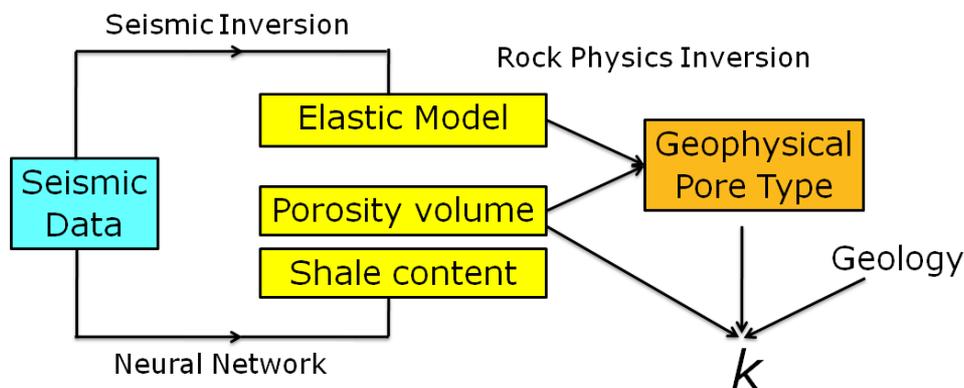
Following Xu and Payne's (2009) rock physics modelling approach for carbonates, we mix minerals present in the rock using Voigt-Reuss-Hill averages. Differential Effective Medium (DEM) scheme is used to calculate the dry effective bulk and shear moduli for different geophysical pore types represented by the pore aspect ratio. Gassmann's fluid substitution is then performed and the final elastic response of the saturated rock is calculated. Combined DEM with Gassmann can be used for the low frequency approximation, because fluid inside the pore space can communicate and fluid may flow from one pore to another, however, no bulk flow can take place (Ruiz, 2009). Another reason for using DEM is because rocks with vuggy pores and moldic pores resemble the physical realization of the DEM. Figure 2 shows the effect of pore types on a P-wave velocity-porosity relationship. As expected, for a given porosity, velocity is relatively faster when pores are stiff (vuggy), while it becomes slower when pores are compliant such as cracks. Most of the data points on this cross-plot are from well-A in a carbonate reservoir offshore Brazil. It is evident that more cracks are expected in the dolostone unit compared to the limestone unit.



**Figure 2** Illustration of possible pore type effects on the P-wave velocity-porosity relationship; left is a calcite dominated matrix; right is a dolomite dominated matrix. All of the data points are from Well-A in a Brazil carbonate reservoir.

### Geophysical pore type inversion from well log and seismic data

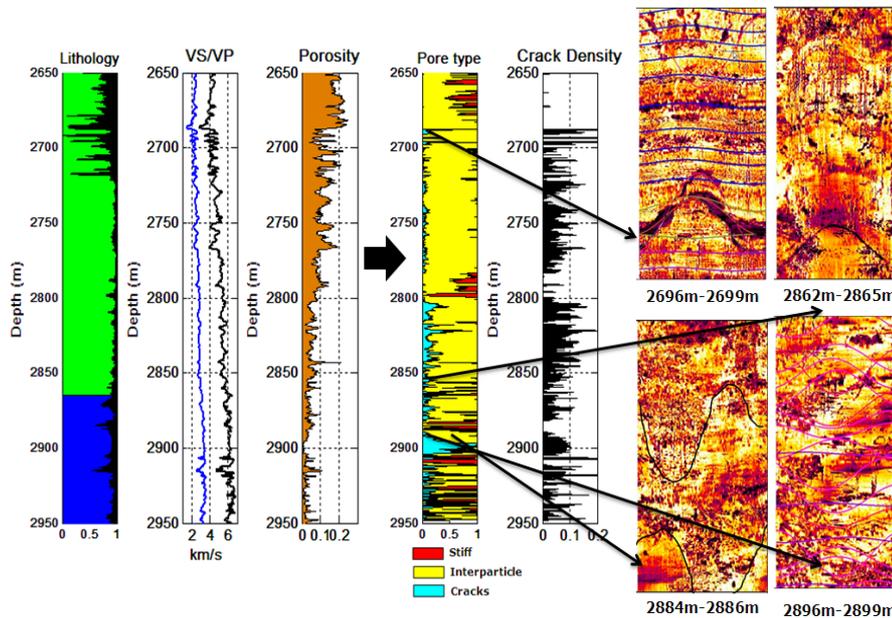
The main objective of this inversion is to predict the volume fractions of the different geophysical pore types from seismic data. If we successfully integrate the pore type inversion results with geologic information and porosity volume, then permeability can potentially be predicted with some empirical relationship (Lucia, 1999). The relationship between the geophysical pore types, the extracted seismic property (elastic model, porosity volume, shale content) and the seismic data are illustrated in Figure 3. The main steps for completing a pore type inversion are summarized by Kumar and Han (2005).



**Figure 3** Schematic illustrations of the relationship between the geophysical pore type, the extracted seismic property, the seismic data and permeability.

Pore type inversion from well log data can be used to calibrate geophysical pore type distribution from seismic. In Figure 4 we show the inverted stiff pores (red), reference pores (yellow) and cracks (blue) for the carbonate reservoir in well-A, where crack density is calculated from crack-induced porosity and aspect ratio. As shown in this figure, we observed a good agreement between the inversion results and those identified by the FMI log in the well. For example, complex fracture network found in OMRI-CAST in 2862-2865m and 2896m-2899m are in good agreement with inverted pore types. Following these results, geophysical pore type inversion from seismic data was performed. Stacked seismic data is shown in Figure 5(a), targeted inversion area is limestone unit and dolostone units which are calibrated by well log and core information. We invert Acoustic impedance from prestacked seismic data, while porosity and shale content are predicted using neural network

from seismic data. All those extracted properties are calibrated with the log response in well A and B. In this case we ignore the fluid effects of the heavy oil due to the similarity of its elastic properties to those of brine. Figure 5(b), 5(c), 5(d) display the geophysical pore type inversion result from seismic data. It is clear to see that reference pores which represent interparticle pores dominate pore space in this interval, while stiffer pores (vuggy pores and moldic pores) are present in the upper limestone unit, which implies that the dissolution is more extensive in this area. Also, the predicted crack density suggests that both the upper limestone unit and the whole dolostone unit are heavily cracked, which could be an indication of a good permeability zone.



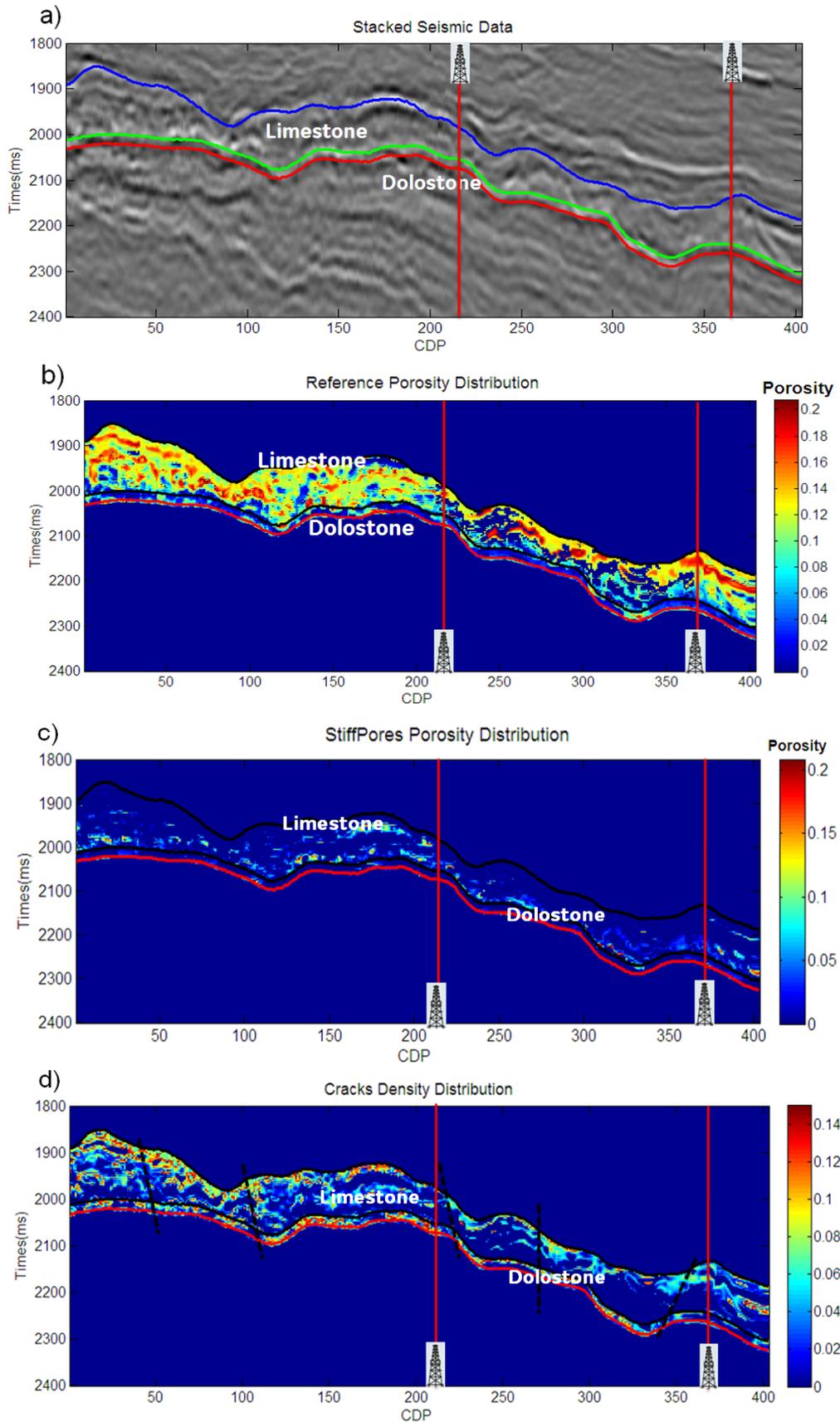
**Figure 4** Well log data in offshore Brazil Carbonate reservoir (left) and the corresponding OMRI-CAST image (right).

## Conclusions

Geophysical pore type inversion from seismic data is possible and can be used to unlock the potential of carbonate reservoirs. We use the rock physics modeling approach that takes into account three defined geophysical pore types and bridge them to the seismic response. The distribution of reference pores, stiff pores and cracks from 2D seismic data was obtained for a carbonate reservoir offshore Brazil, which is useful for predicting reservoir permeability. However, there is always uncertainty associated with geophysical pore type inversion results as it depends on many different factors: The quality of seismic data, number of wells, input AI & porosity volumes, shale content, fluid content ...etc

## References

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**Figure 5** Well log data in offshore Brazil Carbonate reservoir (left) and the corresponding OMRI-CAST image (right).