Deciphering pore-type signatures from acoustic data in carbonates: Equivalent Pore Aspect Ratio approach

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The acoustic properties of carbonate reservoirs are strongly controlled by pore space architecture resulting from both depositional and diagenetic processes. The seismic interpretation and inversion of highly heterogeneous sedimentary systems such as shallow marine carbonate platforms or pre-salt non-marine carbonates requires a quantification of the mineralogic, pore volume, pore geometry and fluid effects on acoustic impedance. A methodology based on a proxy named EPAR (Equivalent Pore Aspect Ratio) is used to deconvolve the mineralogic and pore geometry controls on acoustic properties in carbonate rocks from various depositional and diagenetic settings. The EPAR represents the aspect ratio of pores from an equivalent elastic medium consisting of a non-porous calcitic host with spheroidal inclusions and displaying the same elastic moduli as the actual rock. EPAR parameters are calculated by means of differential (DEM) approach. Equivalent pore aspect ratio are regarded as parameters, that are independent of mineralogy and porosity), and that allow pore type associations to be discriminated but they should not be considered as descriptors of the actual pore shape. Based on the analysis of well logs and laboratory petroacoutic databases from shallow-marine carbonate platforms (lower Cretaceous urgonian platform from South-East France, upper Cretaceous redeposited carbonates from Gargano, Italy) and microbialite reservoirs (lower Cretaceous pre-salt carbonates from Brazilian offshore subsurface and outcrop analogues of various ages and localities), EPAR parameters demonstrated their ability to discriminate the main pore type associations.

Introduction

Rocks usually show a strong correlation between velocities and porosity or geological facies. As a result, the Vp-Porosity or Vp/Vs-Vp laws are often used to interpret the seismic as a porosity or a geological facies indicator of the reservoir. However, carbonate rocks rarely follow a simple relationship. This is due to the complexity of the micro-scale features resulting from the initial sedimentary facies and its subsequent transformation during burial (diagenesis).

In the case of the pre-salt play, the overprint of diagenesis on the initial depositional facies is strong enough to drive a large part of the petro-elastic behaviours. This phenomenon was poorly understood and even less quantified. That is the reason why we opened a new field of investigation called "**seismo-diagenesis**" looking after the petro-elastic signature of diagenesis of the pre-salt carbonate reservoirs.

Seismo-diagenesis was the missing link between carbonate diagenesis and seismic. This new approach is able to explicit (ie. understand and quantify) the impact of diagenetic transformations on the elastic parameters. Therefore, it is now possible to model the seismic response of different geological/diagenetic scenarios of pre-salt carbonates.

Method

The quantitative seismic interpretation of highly heterogeneous sedimentary systems such as pre-salt carbonates requires a multi-scale approach integrating sedimentologic, diagenetic, rock physics and seismic data. On the basis of the integration of well log data and petrographic analysis of thin-sections, the seismo diagenesis approach aims at:

1) quantifying the respective impact of mineralogy, porosity and pore geometry on the acoustic properties of pre-salt carbonates;

2) identifying and quantifying diagenetic pathways for porosity and acoustic property evolution;

3) testing the effect of changes in mineralogy and pore types on the seismic expression of pre-salt carbonates by means of virtual 1D synthetic seismograms.

The computation of effective property models such as Differential Effective Models (DEM) (Cleary et al., 1980; Norris, 1985; Zimmerman, 1991) has been shown to help modelling the velocity-porosity transforms and elastic moduli-velocity transforms, and relating them to pore structure in various marine and continental carbonate settings. As defined by Fournier et al. (2011), the Equivalent Pore Aspect Ratio (EPAR, **Fig.1**) represents the aspect ratio of pores from an equivalent elastic medium consisting of a host with spheroidal inclusions and displaying the same elastic moduli as the actual rock.

In pre-salt carbonates, the EPAR approach is used to deconvolve the mineralogic and pore stiffness controls on acoustic properties. EPAR parameters are therefore regarded as being a quantitative index of the pore stiffness regardless of the total pore volume and the mineralogy. Caution, one should not consider the EPAR as descriptors of the actual pore shape.

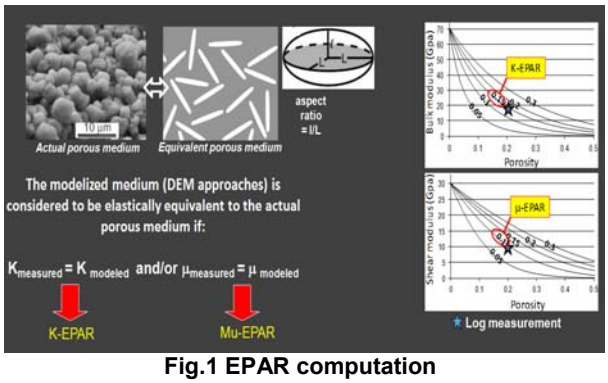

Fig.1 EPAR computation

Example

The idea is to correlate EPAR to the main diagenetic transformations. Once this correlation established it is possible to seismic forward model different diagenetic scenarios and assess their impact on the seismic expression. The general workflow can be defined as follows:

1. Identification of diagenetic pathways on velocity-porosity plots by means of the EPAR approach
2. Computation of modified sonic and density logs for a given diagenetic transformation on all or selected seismo-diagenetic units, based on quantified diagenetic pathways on velocity-porosity plots
3. Computation of 1D synthetic seismograms based on modified sonic and density logs
4. Finally, comparison with actual synthetic seismograms and actual traces

Figure 2 gives an example of a virtual diagenetic transformation consisting in substracting 10% of the intergranular dolomite volume **(**between state 1 and 2). The considered diagenetic transformation results in a decrease in acoustic impedance in all the units highly dolomitized. Such modifications result in synthetic seismograms showing a higher frequency pattern.

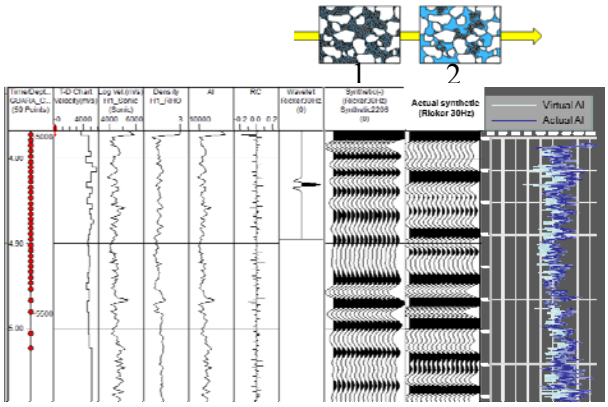

Fig. 2 Substraction of 10% of the intergranular dolomite volume

Conclusions

Seismo-diagenesis was the missing link between carbonate sedimentology/diagenesis and seismic. With the EPAR proxy, it is now possible to model the seismic response of different diagenetic scenarios of pre-salt carbonates (depositional & diagenesis & fluids).

In both exploration and development contexts of the pre-salt carbonate play, the seismo-diagenesis approach could potentially be used to help derisking the reservoir quality prediction and optimize well locations..

References

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