Petroacoustic Signature of Carbonate Rocks Microstructure*

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Abstract

Building a realistic 3D reservoir model requires to integrate all available pertinent data, which include thin sections, core measurements, logs, seismic and production data. The reliability of flow modeling and production monitoring by 4D seismic depends on the consistency of the defined reservoir rock types with the initial 3D seismic data. A large part of hydrocarbon reserves being held in carbonate reservoirs, understanding and overcoming the specific issues raised by carbonate reservoirs represent a major challenge.

Rocks usually show a strong correlation between wave propagation velocities (V_p and V_s) and porosity. The corresponding variation law is used to interpret seismic data in terms of reservoir petrophysical characteristics. However, carbonate rocks do not appear to follow any simple or direct specific relationship. Two limestones of same mineralogy and porosity can have V_p values differing by up to 1,000 m/s. This disparity can be related to different microstructures associated with the sedimentary facies and its subsequent transformation during diagenesis (Eberli et al., 2003; Alvarez, 2007). Carbonates are actually characterized by high diagenesis impact. Due to the resulting complexity and heterogeneity of carbonate microstructure, extracting reliable information on reservoir properties from data other than core analysis remains an issue. Acoustic data have the key advantage of being available at various scales and thus providing insight into the spatial heterogeneity.

Introduction

The objective of this work is to establish correlations between the microstructure and the petroacoustic signature of carbonate rocks. The followed homogenization approach could ultimately allow the computation of an advanced porosity log (and potentially a permeability log) for carbonate reservoirs from density and sonic logs combined with microstructure data deduced from thin sections. The obtained results will be useful to define reservoir rock types to initiate fluid flow modeling and the monitoring of hydrocarbon production through 4D seismic data. The benefit of the proposed approach will be to improve the estimation of pore volumes and the associated recovery.

Discussion

An experimental and modeling workflow has been defined to infer relationships between microstructure characteristics and petroacoustic properties, such as wave propagation velocities and dynamic elastic moduli. The first step consists in a comprehensive experimental characterization of the considered carbonate samples, which involves:

- the description of petrography, diagenetic phases and pore types, through thin section analysis (Hamon and Merzeraud, 2008);
- the determination of the pore size distribution through High Pressure Mercury Injection (HPMI) and Nuclear Magnetic Resonance (NMR) measurements (Vincent et al., 2011);
- petrophysical measurement of the effective porosity and the intrinsic permeability;
- petroacoustic measurement of phase velocities and dynamic elastic moduli using the fluid substitution technique (Rasolofosaon et al., 2008) (see Figure 1).

In a second step, microscanner observation (Youssef et al., 2008) is added to thin section analysis and pore size distribution measurements to extract the characteristics of the carbonate microstructure (see Figure 2 and Figure 3). The representative elementary volume of the samples is then modeled by an assemblage of phases, representing either grains or pores. Each phase is defined by its volume fraction, geometric features (shape, orientation...) and physical properties (elasticity, permeability, etc.). Eshelby-based homogenization schemes are used to compute the elastic moduli and wave velocities (Xu and Payne, 2009). A cement layer coating the grains and/or microporous grains can be considered through this approach. The theoretical velocities are compared to the experimental measurements to invert optimal microstructure parameters (in particular the pore aspect ratio).

Conclusion

When considering a new carbonate formation, the main microstructure characteristics observed on thin sections and the petroacoustic properties deduced from seismic data and/or logs will be used to define a representative micromechanical model, which could then be used to constrain the estimation of the porosity and potentially the permeability.

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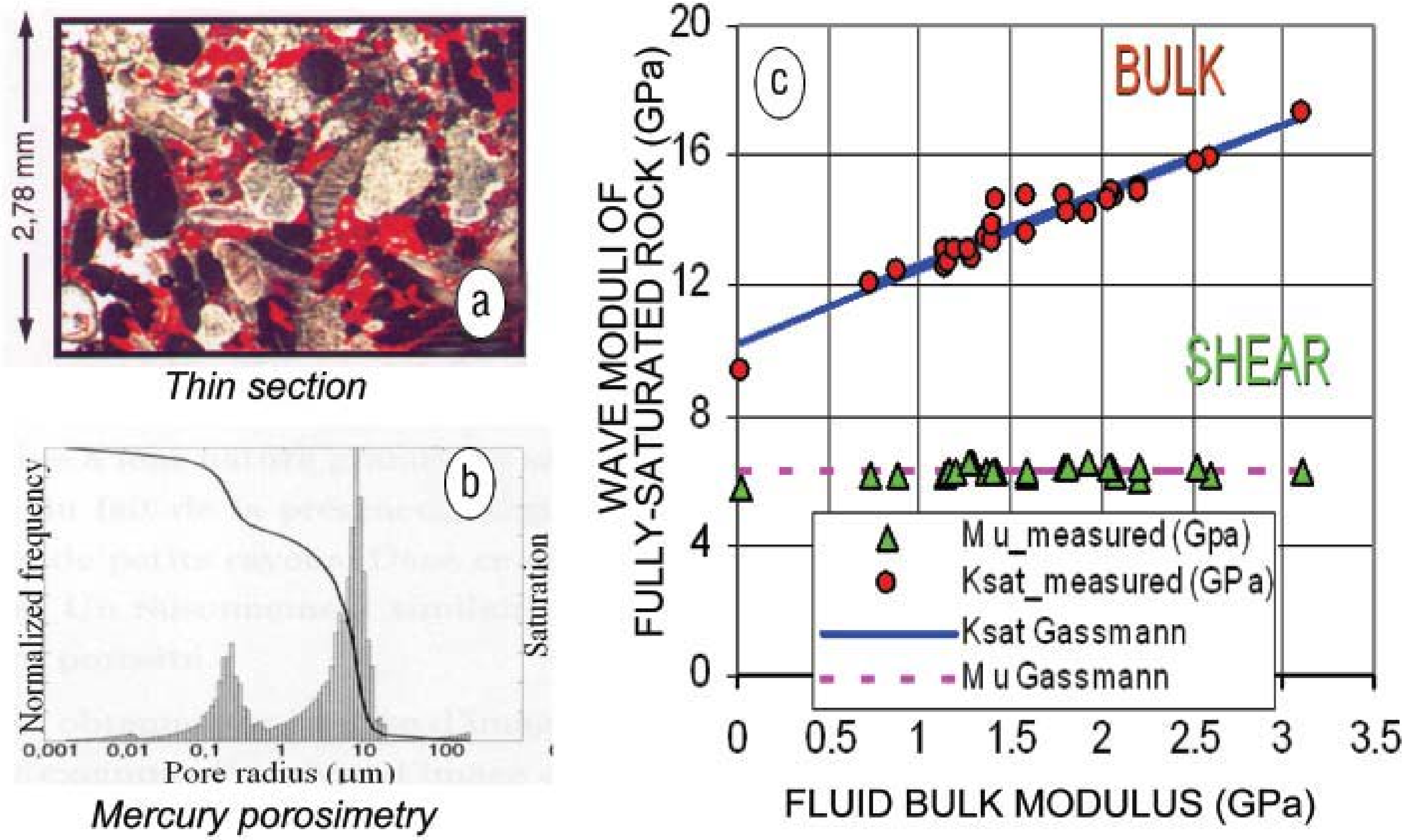

Figure 1. (a) Thin section of Estaillades limestone (porosity ~ 30%, permeability ~ 180 mD. (b) Mercury porosimetry curve (c) Bulk modulus (red circles = experimental data, solid line = Gassmann's theory) and shear modulus (green triangles = experimental data, pink dashed line = Gassmann's theory) of the fully saturated rock as functions of the bulk modulus of the saturating fluid (Rasolofosaon et al., 2008).

Figure 2: Observation of a carbonate sample in IFP Energies nouvelles microscanner.

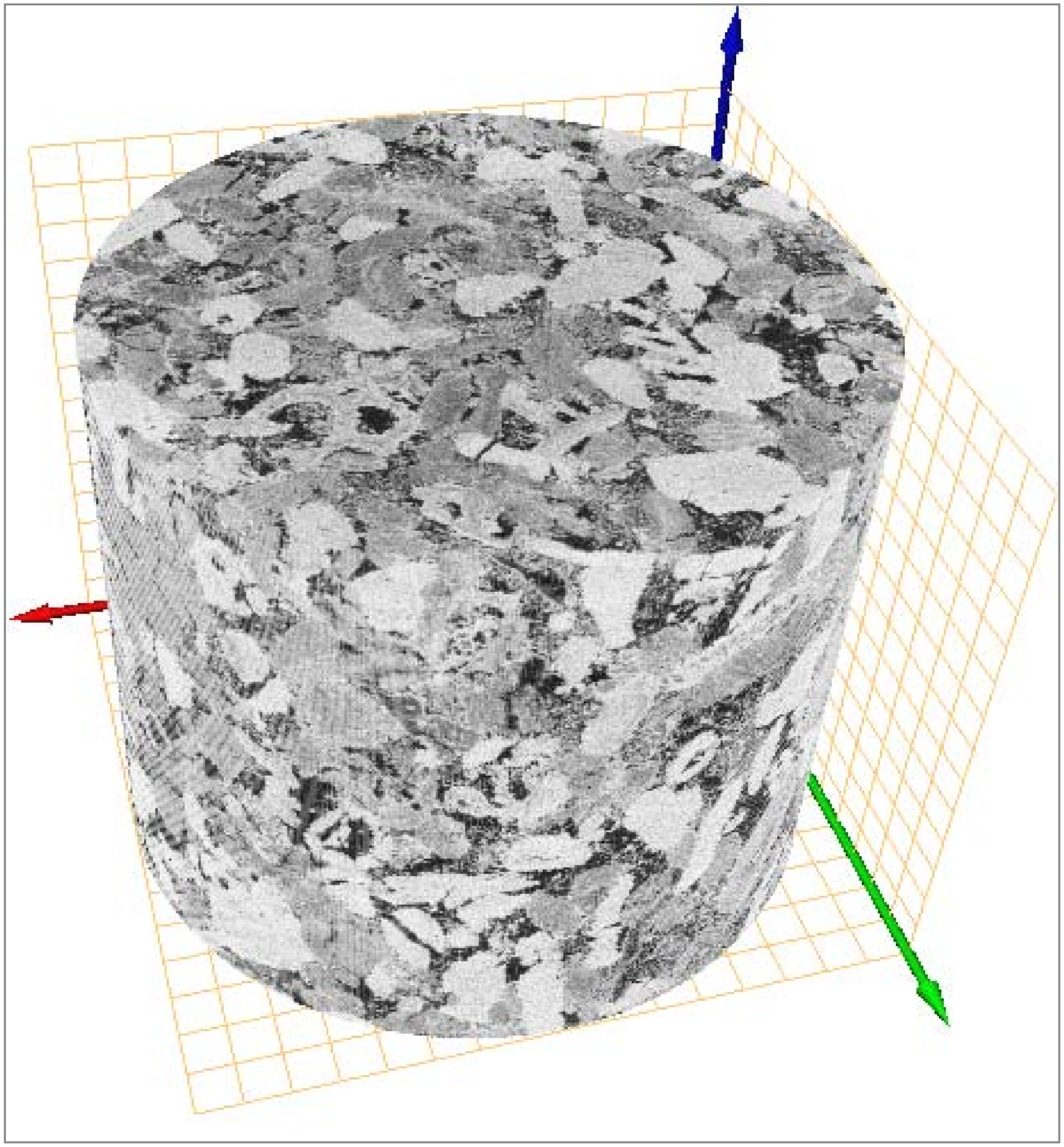

Figure 3: Microscanner image of Estaillades limestone.