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Vug Porosity Estimation using Acoustic Images in Oil or Water-based Mud Systems

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SUMMARY

Many productive carbonates show complex porosity systems with widely varying proportions of primary porosity (from the matrix) and secondary porosity (from vugs and open fractures).

Until now vugs present at the surface of the borehole could be quantified only using micro-resistivity images logged in water based mud. For the first time, Schlumberger will present textural analysis using ultrasonic images. The image analysis, not dependent on a specific type of mud, is based on the variation of acoustic amplitudes within the geological formation.

From amplitude histograms, the vug porosity quantification is then computed through:
- Breakout / Background removal
- Normalization of acoustic amplitude histograms
- Determination of an amplitude threshold that limits host acoustic amplitude of the matrix from lowest acoustic amplitudes for vugs.
- Calibration with the total porosity log.

The technique presented here is applied and validated in a carbonate reservoir of Shell Brazil, logged in a well filled with oil based mud. The new vug porosity (0.2inc vertical resolution) captures better the variation of porosity of the formations than the conventional logs. This paper will also present different applications of the vug porosity:
- To calibrate the volume of macropores derived from NMR.
- To construct a Reservoir Rock classification scheme and lithofacies

Introduction

Many productive carbonates show complex porosity systems with widely varying proportions of primary porosity (from the matrix) and secondary porosity (from vugs and open fractures). Due to the coarse resolution of the conventional porosity logs (density, neutron and sonic), both types of porosity are either under-estimated or overlooked.

In the 1980s, Schlumberger had introduced borehole electrical images logged in water based mud, for the analysis of carbonate porosity systems. From micro resistivity images, vugs present at the surface of the borehole can be quantified (proportion, size and connectedness). This methodology is only valid for electrical images logged in water based mud system. In oil or synthetic muds no reliable method to quantify vug porosity was available until now.

For the first time, Schlumberger will present a potential substitute for the electrical images based on ultrasonic imagers, with little sensitivity to drilling fluids. These acoustic images are currently used for determining open or closed fractures. The image analysis process presented in this paper is based on algorithms that allow quantification of vugs at small scale (5 mm) with full azimuthal borehole coverage. The process is not dependent on a particular tool, and is not specific to mud type.

Vug porosity: Program logic

The method is based on the variation of acoustic amplitudes within the geological formation. Histograms of acoustic amplitudes extracted from ultrasonic images show high values representing the average acoustic amplitudes of the entire matrix of the volume investigated, as well as low amplitudes correspond to low acoustic material such as clays or fluid filled vugs. In carbonates with secondary porosity, the amplitude distribution shows then a bimodal histogram distribution (Facies 1, Fig.1) while homogeneous carbonates show unimodal distributions (Facies 2, Fig. 1).

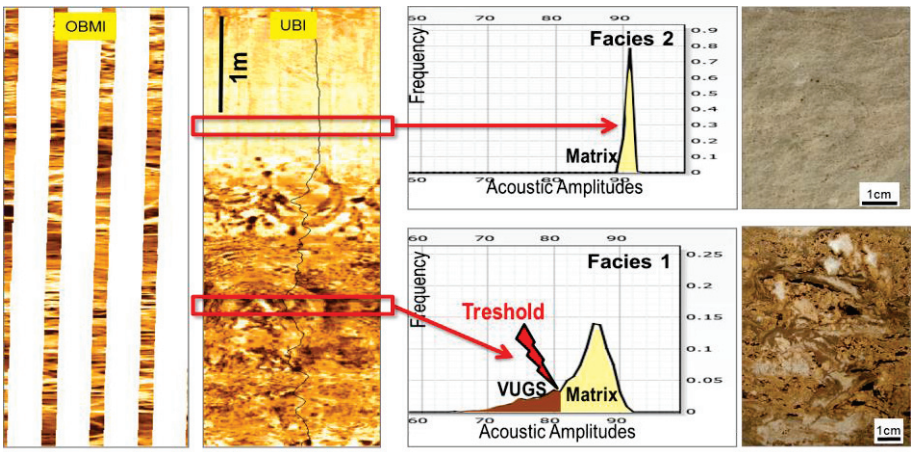

***Figure 1**: Facies 1: heterogeneous carbonate with vug porosity displaying bimodal amplitude histograms. Facies 2: homogenous carbonate with no dual porosity and unimodal amplitude histogram.*

From amplitude histograms, the vug porosity quantification is then computed through:

- Breakout / Background removal
- Normalization of acoustic amplitude histograms
- Determination of an amplitude threshold that limits host acoustic amplitude of the matrix from lowest acoustic amplitudes for vugs and macropores. This threshold is obtained using the ‘’Discriminant Threshold Selection Algorithm’’.
- Calibration with the total porosity log.

Case study

The technique was applied in a carbonate reservoir of Shell Brazil, logged in a well filled with oil based mud. Natural magnetic resonance, or NMR, image logs (acoustic, micro-resistivity logs) and conventional logs were available for the study.

The vuggy porosity extracted from the ultrasonic image shows a good match with the NMR distribution of macro-meso pores as shown in figure 2a (VMacro + VMeso in red and green shadings). Nevertheless, in very limited zones, the computed ultrasonic vuggy porosity is showing a clear discrepancy with the NMR porosity partitioning results (P3A in Fig. 2). Indeed, in these particular zones the ultrasonic image displays a system of interconnected vugs in agreement with side wall core descriptions while NMR is only reading micro-porosity (blue arrow in Fig. 2b).

Careful examination of the NMR T2 distribution and comparison to core of NMR total porosity and density porosity (using variable matrix density from Nuclear Spectroscopy data) shows:

- In some zones differences between NMR and density porosity suggest presence of tar; this has also been seen on cuttings showing strong hydrocarbon indication (Fig. 2b).
- Degradation of oil properties causing a shift of the T2 signal to earlier times
- Vugs observed on the acoustic image can be so large that they are filled with mud, causing an additional shift of the T2 signal (mud T2 signal expected ~10-30 ms).

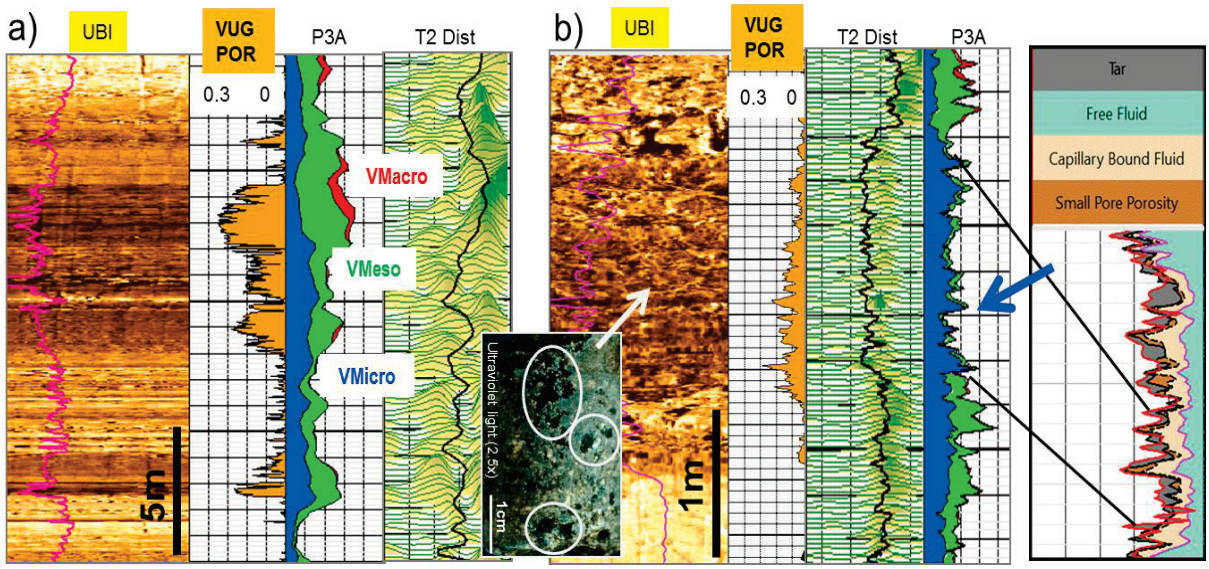

Figure 2: 2a) *Vuggy porosity extracted from ultrasonic image is in agreement with the NMR porosity partitioning P3A, showing high volume of macroporosity (red shading) in front of the highest density of vugs.* ***2b)*** *however some intervals show discrepancy between ultrasonic image vug porosity and NMR VMacro (blue arrow). This is due to the presence of tar or heavy oil filling the vugs (white circles on the core plug).*

Applications and conclusions

The new vug porosity code based on the acoustic contrast of the formation measured by ultrasonic imager is a log of high vertical resolution (raw at 0.2 in vertical resolution) that captures better the variation of porosity of the carbonate formations than the conventional logs. This paper will also present different application of the vug porosity:

- To calibrate and validate the volume of macropores (Vmacro) derived from NMR – Porosity-partitioning.
- To construct a robust Reservoir Rock classification scheme when combined with conventional logs and lithofacies.