Joint elastic-electrical properties as an indicator of carbonate reservoir lithology and quality

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Introduction

Since the early 2000s, there has been increased interest in using marine controlled source electromagnetic (CSEM) surveying to complement co-located seismic surveys for hydrocarbon reservoir exploration, characterisation and monitoring. This has prompted the need for detaled studies of the joint elastic and electrical properties of reservoir and overburden rocks and sediments (e.g. Han et al. 2011) for improved quantitative geophysical interpretation. This is true for both siliciclastic and carbonate reservoir rocks that account for nearly all the world's oil and gas reserves. While the joint velocity-resistivity properties of shaly sandstone reservoirs are closely controlled by shale content (Han et al., 2011), there are no similar laboratory studies for carbonate reservoir rocks. However, Vanorio & Mavko (2011) showed the importance of micrite content for controlling P-wave velocity and transport properties (porosity and permeability) in carbonates.

Here, we study the influence of lithology and microcrystalline calcite (micrite) on ultrasonic velocity and attenuation, and electrical resistivity, of 36 brine-saturated, carbonate rocks comprising 15 dolomites and 21 ooltic limestones, classified according to Dunham (1962).

Methodology

We expanded the carbonate joint properties dataset of North et al. (2012) by measuring the compressional wave velocity and electrical resistivity (expressed as apparent electrical formation factor F*, defined as the ratio of formation resistivity to pore fluid resistivity) of 12 new limestone samples. We used the same combined ultrasonic pulse-echo and electrical impedance tomography measurement system, giving a total of 36 carbonate samples. The samples were brine saturated (35 g/L NaCl), with dimensions 5 cm diameter, 2 cm long. We report ultrasonic results at 700 kHz and electrical resistivity results at 80 Hz.

We adapted method of Sorensen et al.(2015) to classify a set of carbonate into two groups according to the micrite content and distribution. The two groups are carbonate with partial pore filling micrite, and load bearing micrite (micrite that forms part of the load-bearing framework of mineral grains). Figure 1 shows an example optical thin section image with segmentation for micrite content, according to standard image analysis methods; the micrite content results are shown in Figure 2 for all samples. Figure 2 shows apparent formation factor (F*, log scale) against ultrasonic P-wave velocity (V_p) at an effective pressure of 50 MPa for all 36 carbonate samples, colour-coded by micrite content from image analysis. Two groups are indicated as data from North et al (2012)

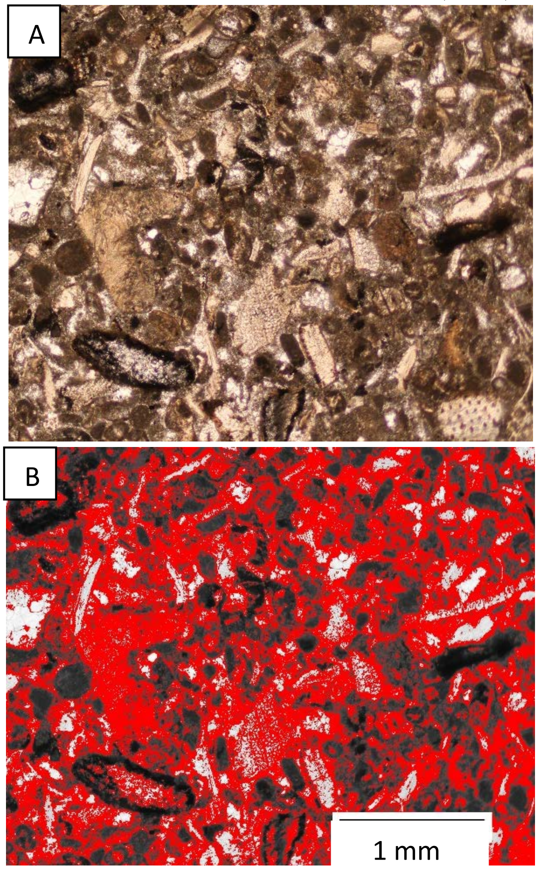

Figure 1. Example segmentation for micrite of a rock thin section optical image for sample S-39446, an oolitic limestone (wackestone). A) Plane-polarized light (B) Micrite segmentation shown in red.

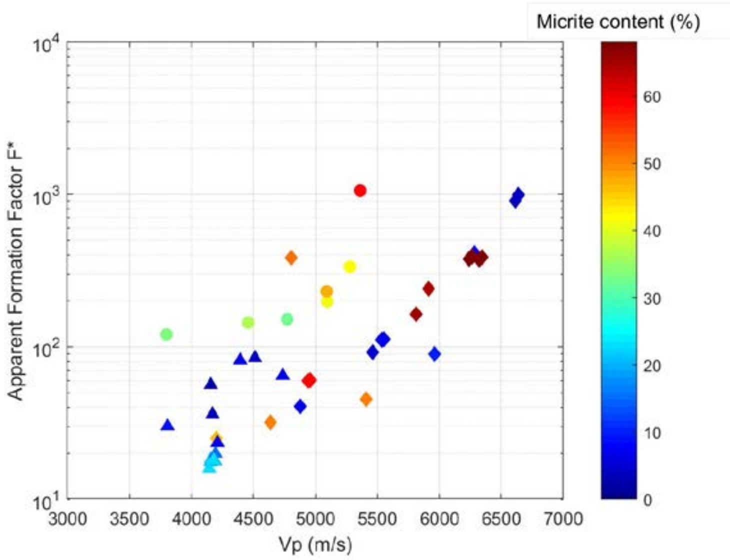

Figure 2 shows apparent formation factor (F, log scale) against ultrasonic P-wave velocity (V_p) at an effective pressure of 50 MPa for all 36 carbonate samples, colour-coded by micrite content from image analysis. Two groups are indicated as data from North et al (2012) as diamond, and the oolitic limestone samples as triangle (load-bearing) and circle as partial pore filling.*

as diamond which is mudstone and grainstone dolomite (single grain size), and the new samples as partial pore-filling micrite (triangle) and load-bearing (circle) and they are oolitic limestone. In general, F* increases with increasing velocity, with an approximately log-linear trend, with increasing micrite content. The dolomite mudstone extending partial pore filling trend and it is less steep than load-bearing trends. The higher micrite contents tend to correspond to higher F* and V_p values.

Conclusions

We compared newly acquired laboratory data of P-wave velocity V_p and apparent electrical formation factor F^* on 12 limestone samples to similar data for 24 samples. The P-wave velocity is approximately positively linearly correlated with F^* on a semi-logarithmic scale, the joint F^*-V_p properties increase with micrite content. The results suggest that such joint properties could be used as a reservoir quality indicator based on micrite, grain size and its distribution (pore-filling or load-bearing).

Acknowledgements

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