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Quantitative microstructure characterization and elastic properties upscaling of carbonate rocks

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Most Rock Physics models commonly used to predict elastic properties rely on a very simplified representation of the pore and grains geometry. Initially developed for siliclastic rocks, they do not apply easily and/or with as much success, to rocks with more complicated microstructure such as carbonates, which exhibit complex relationships between geophysical attributes and rock properties, such as P-wave velocity versus porosity. Furthermore, until recently, most microstructure imaging techniques such as optical microscopy, SEM, X-ray micro-CT, etc., only give a qualitative description of the pore and grain arrangement. Nano-indentation technique is a method that gives quantitative information by mean of local (micrometer size) measurements of elastic moduli. We used this technique to obtain 300 μm * 300 μm maps of Young's moduli (around 1000 data points) of two microporous carbonates of same mineralogy but of two different microstructures. As the size of the indenter tip is much smaller than the characteristic length of the heterogeneities in microstructure, the distribution of the Young's moduli can be deconvolved into its component parts (i.e. phases). SEM imaging of the same areas than the ones mapped by nano-indentation shows correlations between type of micrite and phases of different mean Young's modulus: tight micrites exhibiting a higher Young's modulus (up to 64 GPa) than microporous micrites (as low as 9 GPa). We then investigate different ways to upscale the measurements in order to get the effective bulk and shear moduli, from simply using volume fractions of the different phases, classical Hashin-Shrikman bounds, and Hill average; to using micro-CT imaging and analysis combined with rock physics models. Though more work is still needed to render nano-indentation technique a robust method for rock physics, both on the theory behind and on the upscaling of the measurements, these results that use nano-indentation method in a statistical way are very promising.