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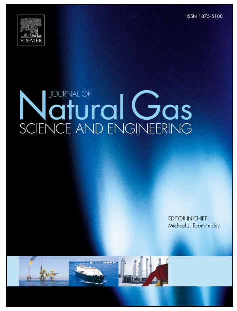

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Statistical grid nanoindentation analysis to estimate macro-mechanical properties of the Bakken Shale

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Abstract

Retrieving standard sized core plugs to perform conventional geomechanical testing on organic rich shale samples can be very challenging. This is due to unavailability of inch-size core plugs or difficulties in the coring process. In order to overcome these issues, statistical grid nanoindentation method was applied to analyze mechanical properties of the Bakken. Then the Mori-Tanaka scheme was carried out to homogenize the elastic properties of the samples and upscale the nanoindentation data to the macroscale. To verify these procedures, the results were compared with unconfined compression test data. The results showed that the surveyed surface which was 300 um x300 um is larger than the representative elementary area (REA) and can be used safely as the nanoindentation grid area. Three different mechanical phases and the corresponding percentages can be derived from the grid nanoindentation through deconvolution of the data. It was found that the mechanical phase which has the smallest mean Young's modulus represents soft materials (mainly clay and organic matter) while the mechanical phases with the largest mean Young's modulus denote hard minerals. The mechanical properties (Young's modulus and hardness) of the samples in X-1 direction (perpendicular to the bedding line) was measured smaller than X-3 direction (parallel to the bedding line) which reflected mechanical anisotropy. The discrepancy between the macromechanical modulus from the homogenization and unconfined compression test was less than 15% which was acceptable. Finally, we showed that homogenization provides more accurate upscaling results compared to the common averaging method.

Keywords: Grid nanoindentation, REA, Deconvolution, Macro-scale homogenization

1. Introduction

The Bakken Formation is one of the largest unconventional shale oil plays in the world. The average recovery factor of the Bakken Formation is approximately 7% which is much lower than the national average level of 30%. This is due to its low porosity and extremely low permeability (Clark, 2009) thus horizontal drilling, combined with hydraulic fracturing, are the two commonly used technologies that are employed to increase the production from the Bakken Formation. Having a good knowledge of the formation's mechanical properties is very important in the placement and design of horizontal drilling and hydraulic fracturing. Reliable estimation of the mechanical properties can improve the success rate of the drilling and production and, eventually, enhance the overall recovery factor. In a routine laboratory analysis, standard static tri-axial lab experiments or dynamic field-scale analysis using sonic logs are normally performed to obtain the necessary rock properties (Shukla et al., 2013). However, obtaining standard sized core plugs from downhole cores would be challenging and, thus, not considered to be ideal for conducting conventional geomechanics testing (Liu et al., 2016). On the other hand, nanoindentation tests, which only need a small volume of rock sample, have proven to be a great success in petroleum engineering applications to investigate the mechanical properties of shale samples (Shukla et al., 2013; Kumar et al., 2012a; Mason et al., 2014).