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Correlating Dynamic and Static Mechanical Properties of Horn River Shale

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Introduction

The Middle and Upper Devonian Horn River shale in Northeast British Columbia is recognized as a major source of natural gas in Canada. The reservoir is comprised of three main units, the Evie and Otter Park membersand the Muskwa Formation . The three units are cumulatively approximately 200 meters thick and are estimated to contain 78 Tcf of recoverable gas reserves (BC Ministry of Energy and Mines, National Energy Board, 2011).

Profitable development of shale resources is directly linked to hydraulic fracturing of the reservoir. The success of hydraulic fracturing operations largely depends on rock mechanical properties (indicative of brittleness), natural fracture network, and in-situ stress conditions (Jin et al., 2015). There are several definitions for rock brittleness available in the literature. Most commonly, rock elastic parameters such as Young's modulus and Poisson's ratio are used to calculate a measure of rock brittleness (Holt et al., 2015). Therefore, it is desirable to understand the distribution of elastic properties in a formation, to be able to identify the sweet spots with regards to rock brittleness.

Sonic logs are commonly used to calculate the dynamic Young's modulus and Poisson's ratio. Dynamic elastic parameters are calculated based on compressional and shear wave velocities (V_p and V_s) in the rock; this type of analysis was carried out for the Horn River shale, reported in Dong et al., (2017). This differs from the static elastic parameters that correlate to a static loading, which is a better representation of the loads encountered during hydraulic fracturing. Geomechanical analyses are typically based on static loads. Static elastic parameters are measured in the lab with a load frame. Static Young's modulus has been generally observed to be lower than the dynamic values in all rock types (Asef and Farrokhrouz, 2017). Since the dynamic elastic parameters are more readily available through logs, it is beneficial to find correlations between dynamic and static mechanical properties. Such correlation facilitates the estimation of static Young's modulus and Poisson's ratio to calculate rock brittleness using logs. This practice has been successfully implemented for sandstones, carbonates, and a few shale formations (Najibi et al., 2015).

Methodology and Results

In this study, static Young's modulus and Poisson's ratio are measured in the lab. The samples are obtained from a core from Horn River shale formation (Tattoo D-A028-F/094-O-10), at different intervals covering the major facies present. The majority of the samples are taken from Otter Park and Muskwa units. The Evie unit in the core under study is thin and contains excessive number of fractures, making it difficult to take intact samples. The specimens are loaded at zero confining stress while measuring axial and lateral strains with high-precision gauges. Uniaxial Compressive Strength (UCS) is measured by increasing the axial load slowly until the sample fails. Static Young's modulus is measured by recording the axial stress and strain, while static Poisson's ratio is measured using the lateral strain. Static mechanical properties are measured both perpendicular and parallel to bedding. Compressional and shear wave velocities are also recorded for each sample prior to the UCS tests. V_p and V_s measurements are used to calculate dynamic Young's modulus and Poisson's ratio using well established theoretical relationships (Najibi et al., 2015).

For each sample, dynamic elastic properties calculated from wave velocity measurements (Dong et al., 2017) are plotted against static mechanical properties. A correlation between static and dynamic elastic properties is presented. Static Young's moduli in our results are observed to be smaller than the dynamic Young's moduli. The difference observed among samples can be attributed to the change in mineralogy and porosity. The lab measurements are upscaled by correlating the wave velocity measurements in the lab and the wave velocity measurements obtained from sonic logs, for the well under study. Therefore, a direct relationship between static elastic properties and the sonic log reading is obtained and presented.

In order to calculate the in-situ brittleness of the formation, static elastic properties need to be evaluated under reservoir stress conditions. The static Young's modulus and Poisson's ratio change with confining stress. Therefore, their in-situ values are different from the measurements using UCS tests at zero confining stress. Subsequently, four samples are placed in a triaxial cell to measure static elastic parameters under several confining stresses ranging from 5 to 35 MPa. Based on the results, a general relationship between static Young's modulus and Poisson's ratio and confining stress is obtained. This relationship can be used to estimate the in-situ static parameters from cheaper UCS tests. The previous analysis using UCS results is updated to provide a correlation between static parameters under reservoir conditions and sonic log measurements. The results facilitate estimation of brittleness parameter for Horn River shale under reservoir conditions, using readily available log data.

Conclusions

Successful hydraulic fracturing is key in developing shale resources. Determining areas of the basin with favorable rock properties such as high brittleness is essential to ensure economic development of Horn River shale play. Static Young's modulus and Poisson's ratio can be used as a proxy for rock brittleness. These parameters need to be measured in the lab, an expensive process largely limited to core availability. Dynamic Young's modulus and Poisson's ratio are typically calculated using readily available sonic logs. It is therefore valuable to investigate the relationship between static and dynamic elastic properties. The relationship between static and dynamic properties is unique for each formation. In this work, we conduct extensive lab tests to determine static Young's modulus and Poisson's ratio across a core from Horn River formation. The compressional and shear wave velocities are also measured in the lab and compared to the values measured by logs. A relationship between static and dynamic elastic properties in Horn River shale is presented. Using triaxial tests, the relationship between static properties and confining stress is investigated. This relationship is subsequently used to correlate the sonic log measurements to the in-situ static Young's modulus and Poisson's ratio. The results of this work allow determination of the distribution of brittleness index across the basin by using sonic logs. Additionally, the results provide more accurate inputs for hydraulic fracturing simulations.

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