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Shale Geomechanics - A Nano-indentation Application

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SUMMARY

Nano-indentation is a technique developed to determine the mechanical properties of small samples. It is based on a hard tip, which is pressed into the surface of a rock sample. The ratio between the applied load and the displacement of the tip into the sample is used to calculate the hardness and Young's modulus. Additionally, the load-displacement plot obtained from nano-indentation measurements can be used to define three areas which describe the plastic work done on the sample and the elastic work done on the sample. This work-of-indentation approach is a good predictor for the brittleness of shale formation.
For the study, core samples were collected from the Toarcian shale formation of the Paris Basin (Couy-1 scientific well) and merged in epoxy resin blocks. First, mineralogical analysis was performed on each block (QEMSCAN analysis) and secondly blocks are used for nano-indentation measurements.
Using nano-indentation, for each subsample the Young's modulus and the hardness are determined. The work-of-indentation approach is utilized in order to predict the brittleness of the samples. Integrating the nano-indentation results with the QEMSCAN data the relation between the mineralogy and the mechanical properties is investigated. Results will presented in details and discussed during the EAGE WS04 workshop.

Introduction

Applications of shale geomechanics include wellbore stability studies, determination of the sealing ability, and maximisation of production from natural fractures. Nowadays, with the increasing oil and gas production from unconventional resources, shale geomechanics have been the focus of renewed attention as they play a key role in hydraulic fracturing operations, which are essential for oil and gas production from shale formations.
The geomechanical behaviour of shales is mainly controlled by the mineralogy and structural properties, as well as the in-situ stresses and the anisotropic and heterogeneous character of the shales. To determine the geomechanical behaviour of shales the mechanical properties, such as the Young's modulus, Poisson's ratio, and fracture toughness, need to be determined. These are mathematically defined properties, describing the response (i.e. deformation) of a material due to applied forces. Besides these properties, the terms brittleness and fracability are often used to describe the tendency of a rock to break under stress, and they are used to predict the geometry and complexity of fracture networks resulting from induced stresses, for example from hydraulic fracturing. The brittleness, however, is not a mathematically defined property and therefore many different methods have been suggested for quantifying the brittleness. One of the most commonly used methods for this purpose is introduced by [1] who proposed three equations for calculating the Brittleness Index from the Young's modulus and the Poisson's ratio.

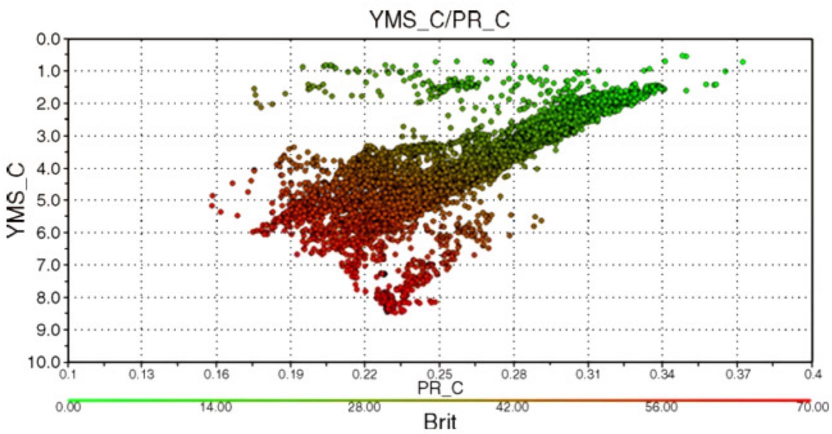

Figure 1 *Plot showing the Brittleness Index as a function of the Young's modulus (y-axis, in mpsi) and the Poisson's ratio (x-axis). The Brittleness Index varies between 0 and 70 percent, with a high Brittleness Index indicating a brittle material, while a low Brittleness Index indicates a more ductile material [1].*

The mechanical properties of rocks are usually determined by lab testing of core samples (e.g. triaxial testing, acoustic analysis). One of the dilemmas in the characterisation of shale formations is the lack of core sample material for the shale intervals. Unlike cores, drill cuttings are collected and preserved for most wells and often cover large intervals of the well trajectory, including the unconventional reservoir rocks. Therefore, methods for determining rock properties from cuttings samples are beneficial, as they provide a fast and cost-efficient way for characterising shales.
In this study, nano-indentation is performed on shale core samples and fragmented shale core samples, in order to determine the Young's modulus and the hardness of the samples, and to predict the brittleness of the shales. Furthermore, the results are used to investigate the relation between the mineralogy and the mechanical properties, the effect of shale anisotropy on the mechanical properties and to define a method for the upscaling of nano-indentation measurements.
The methodology has been developed and tested on two case studies; the Silurian Hot Shales of SW Algeria [2] and the present study in the Lower Toarcian shales of the Paris Basin [3] [4].

Methods

Nano-indentation is a technique developed to determine the mechanical properties of small volumes or samples. The technique is based on a hard tip with known properties, which is pressed into the surface of a sample. The ratio between the applied load and the displacement of the tip into the sample is used to calculate the hardness and Young's modulus of the sample. Additionally, the load-displacement plot obtained from nano-indentation measurements can be used to define three areas which describe the plastic (or permanent) work done on the sample and the elastic work done on the sample. Hay and Sondergeld [5] propose that this work-of-indentation approach is a good predictor for the brittleness of shale formation.
For this study, nine shale core samples were collected from the Toarcian Black Shales of the Paris Basin (Couy-1 well), and were cut into 20 mm cubes. First, QEMSCAN analysis was performed on the samples [6]. For this, each core cube was subsampled three times; one section was cut perpendicular to bedding, the second was cut parallel to bedding whilst the remnant sample was crushed to simulate idealised cuttings material (the third subsample). Each aliquot was then prepared using standard methodologies as a polished epoxy resin block. After QEMSCAN analysis, the polished epoxy resin blocks are used for nano-indentation measurements. The sites for the nano-indentation measurements are selected based on the results of the QEMSCAN analysis.

Results

Using nano-indentation, for each subsample the Young's modulus and the hardness are determined. The work-of-indentation approach is utilized in order to predict the brittleness of the samples. Integrating the nano-indentation results with the QEMSCAN data the relation between the mineralogy and the mechanical properties is investigated. Furthermore, the measurements on the three different types of subsamples (perpendicular to bedding, parallel to bedding, crushed fragments) are used to determine the effect of shale anisotropy on the mechanical properties and to compare analysis of cores with analysis performed on cuttings-sized fragments. Results will be presented in details and discussed during the EAGE WS04 workshop.

Conclusion

The results of this study show definitely that, without recent log, the geomechanical properties of a shale formation (Young's modulus and hardness) can be measured from cuttings using the nano-indentation methodology. This method can also be very useful for geomechanical analysis on core samples damaged during core acquisition, storage or sample preparation (common in shale).

References

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