Geomechanical and Petrophysical Impact of Partial Saturation in Clay-Bearing Shales

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Summary

Partial saturation in conventional reservoirs has a significant impact on rock properties in terms of wave propagation, electrical properties, static geomechanical response and the like. There are also likely to be changes in rock properties for gas shales as a result of changing saturation, especially in clay-bearing gas shales, although understanding the level of impact and development of appropriate rock properties models are at an early stage. There are two important implications for the impact of partial saturation in clay-bearing gas shales, one around field applications and the effects of varied saturation on rock properties and the second around sample preservation for laboratory testing. This talk will look at the impact of water content and partial saturation on geomechanical, rock physics and petrophysical properties of low and moderate clay content shales and how they respond to systematic changes in saturation. Full characterisation in terms of water content, mineralogy and microstructure was performed with testing including dielectric properties, nuclear magnetic resonance, standard and true triaxial testing (Figure 1). Significant differences in behaviour are noted between fully saturated and partially saturated shale properties (Dewhurst et al., 2013), begging the question of "how much clay is enough" in terms of making good rock properties measurements on unpreserved core?

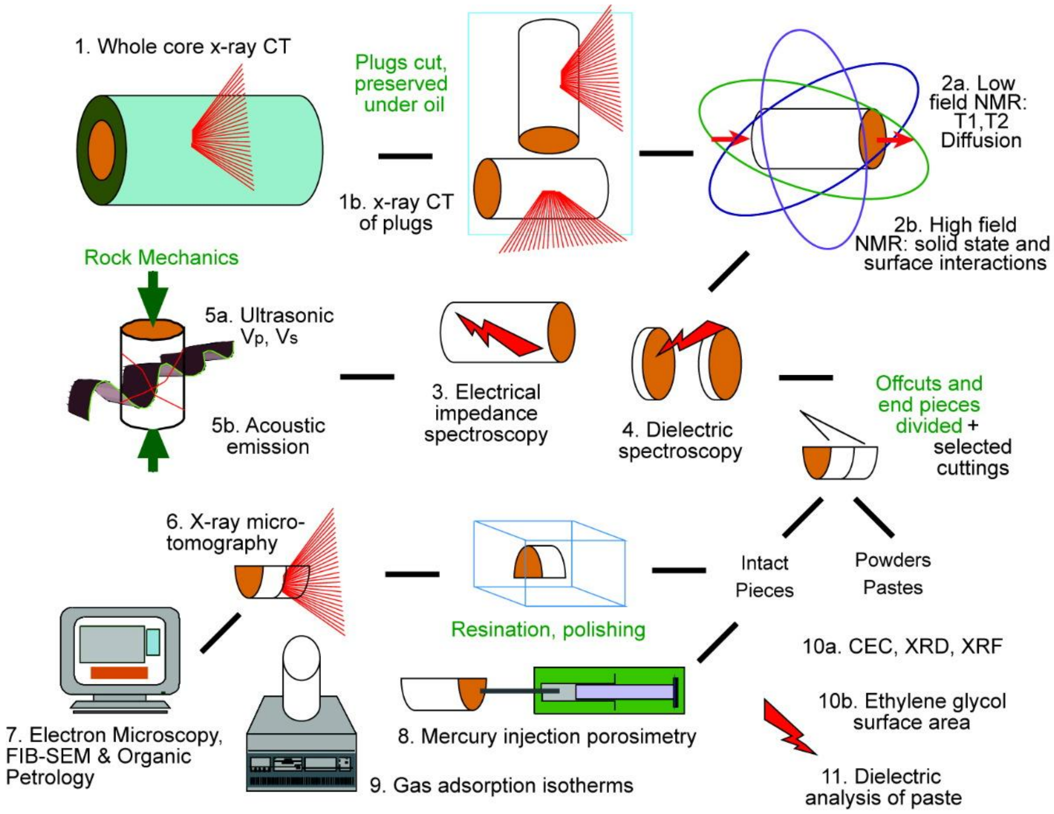

Figure 1. *Shale characterisation workflow for evaluation of links between geomechanics, rock physics, petrophysics and microstructure in these highly anisotropic rocks.*

Introduction

The level of interest in shale properties has rocketed in recent years with the advent of gas shales and the concept of shales as reservoirs. Such gas shales have a wide variety of compositions, from highly siliceous to rich in carbonates to clay bearing and their compositions can exert significant control over their geomechanical properties, especially those relevant to hydraulic fracturing. In addition, it is well known that partial saturation has a large effect on rock physics properties, P-wave velocity for example, in conventional reservoirs but such impact is less well understood in these fine grained shale reservoirs, especially those where some clay minerals are present. Petrophysical properties such as resistivity are obviously impacted by the presence of gas (be that methane in situ or air in laboratory tested samples) and it is well known in both petroleum geomechanics and soil mechanics communities that static geomechanical properties, both elastic and deformational can change significantly as a result of changing water saturation. The development of petrophysical and rock physics models to assess the degree of gas saturation from downhole logs and now more utilised seismic data requires both high quality field data and laboratory measurements. However, poor preservation of clay bearing gas shales has hampered systematic laboratory studies. While the preservation requirement in theory is well known for shales, there appears to be a common belief that as some gas shales are lower in clay than say shale seals or overburden materials that preservation is no longer important. However, significant changes in rock properties caused by partial saturation will totally change rock strength, stiffness, dynamic elastic properties, electrical properties and furthermore may violate assumptions such as constant shear modulus for using Gassmann's equations. This paper will discuss the start of a systematic laboratory campaign to evaluate the impact of partial saturation on shale properties.

Methodology

A number of shale samples of low to moderate clay content (30-50%) were tested for routine physical properties (bulk and grain density, porosity, CEC, SSA), petrophysical properties (resistivity, dielectric constant, water content by NMR), rock physics properties (velocity, anisotropy) and geomechanical properties (Young's, Poisson's, UCS, peak strength, cohesion, friction) under conditions of full water saturation and partial water saturation. Initial tests involved a "quick and dirty" method of drying by placing shale cylinders in an oven at 70˚C for 1-2 weeks. Water content was assessed before and after the tests using NMR and found to decrease from 100% S_w to 40% S_w. Other samples were dehydrated in a more controlled fashion from preserved state using desiccators containing various compositions of salts to give constant relative humidity atmospheres between 29% and 97% RH (Dewhurst et al., 2013).

Results

In general, strength and stiffness of shales were seen to increase with decreasing water saturation. In the example in figure 2 (left), for standard triaxial tests, peak strength, residual strength and stiffness increase 2.5 to 4-fold as relative humidity decreases. True triaxial compressive strength also increases (figure 2, right). Significant increases in stiffness were also noted in true triaxial tests in both cases where $\sigma_2 = \sigma_3$ and where $\sigma_2 > \sigma_3$. The failure mode also changes in true triaxial tests from a single plane at high water saturation, through dual parallel slip surfaces surrounding a regular fracture array at moderate water saturation to multiple through-going fractures at low water saturation (Dewhurst et al., 2013).

Evaluation of dynamic properties also shows significant difference between dried and partially saturated states. P-wave velocity decreases and S-wave velocity increases, the latter significantly by up to ~20% as water saturation decreases. In terms of dynamic moduli, this translates to increases in Young's and shear moduli and a decrease in bulk modulus as water saturation decreases. Dielectric constants drop slightly (~1-2%) at high frequencies (10-100 MHz) but much more significantly (~5%) at 1 MHz as saturation decreases. Conductivity drops across all frequencies by 3-4%.

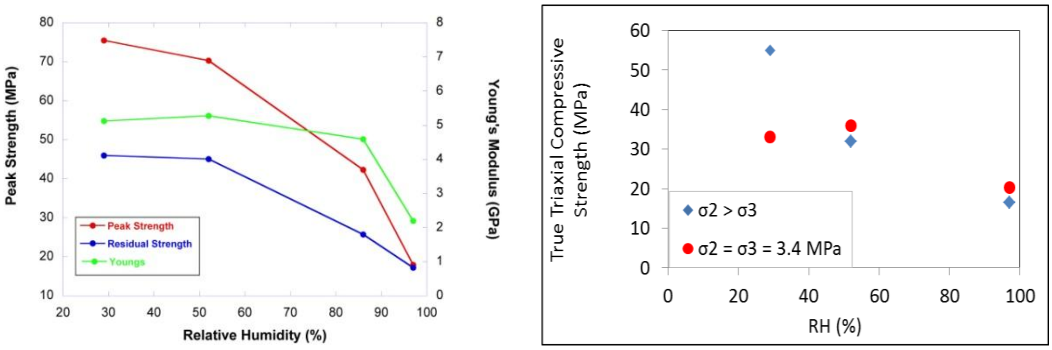

Figure 2 *(left) Shale strength and stiffness generally increases with decreasing relative humidity (saturation) in standard triaxial tests; (right) compressive strength measured in true triaxial tests also increases with decreasing relative humidity.*

Conclusions

Partial saturation has a significant impact on shale properties. Strength and stiffness significantly increase as saturation decreases, dynamic rock properties can change by 15-20% and electrical properties are also impacted. This has implications for both field assessments of gas saturation in shale reservoirs and for laboratory testing of clay-bearing gas shales which are not well preserved.

References

Dewhurst, D.N., Minaeian, V., Delle Piane, C., Josh, M., Esteban, L., Sarout, J. & Clennell, B., 2013, Geomechanics and Petrophysics of Partial Saturation in Shales. Extended abstract for Houston Geological Society Conference on Micro to Macro Geomechanics For Unconventional Resources, Houston, Texas, 2pp.

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