Investigation of elastic weakening and deformation of Bentheim sandstone with water adsorption

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Introduction

Adsorption of small amount of water causes a reduction of elastic moduli in sandstones (e.g., Clark et al., 1980; Murphy, 1982; Knight and Dvorkin, 1992; Pimienta et al., 2014) and deformation in porous materials and rocks (e.g., Gor et al., 2017). This effect is of practical importance for near surface seismic and for applications of conventional rock physics theories, which require measurements of elastic properties of dry rocks. In this work we suggest that these two effects are driven by the change of pressure of fluid adsorbed in small compliant pores. In order to validate this concept, we conduct simultaneous measurements of the elastic moduli and deformation of the Bentheim sandstone with adsorption and desorption of water. From the measured deformation we estimate the magnitude of change in the fluid pressure. Then, in order to support the suggested hypothesis, we compare the variation of the elastic moduli related to the estimated fluid pressure with stress dependencies of the bulk and shear moduli of the Bentheim sandstone measured in a triaxial cell.

Methodology

We conduct measurements on the Bentheim sandstone, nearly isotropic and homogeneous rock composed by 95% quartz, 3% kaolinite, and 2% orthoclase. We regulate the saturation by maintaining the sample in atmosphere with controlled relative humidity (RH). We use a semiconductor strain gauge to measure deformation caused by changes in RH. We measure elastic properties using ultrasonic pulse transmission technique.

Results

The observed strain of the sample during transition from the driest state (RH = 13%) to the wettest state (RH = 97%) is of order of 10^{-4} (Figure 1a). The corresponding change in saturation is from 0.1% to 1-2%. The measured elastic moduli of the sample decrease with increasing saturation exhibiting the difference between the driest and the wettest states of ~20% (Figure 1b).

Discussion

The observed deformation may be caused by change in the pressure of the adsorbed fluid. We estimate the magnitude of the change in the fluid pressure from the measured linear deformation ε as

$$\Delta p_f = 3\varepsilon \,/\, (\, 1/K - 1/K_s \,), \tag{1}$$

where K = 6.9 GPa is the drained bulk modulus of the rock, and K_s = 38 GPa is the bulk modulus of the solid (quartz). From equation (1), we obtain the variation of the fluid pressure with the change of RH (Figure 2a). Here, the reference hydration state, where $\Delta p_f = 0$, is the state with room RH = 46%. If the change in fluid pressure is a reason of observed variation of the elastic moduli, this variation should be consistent with stress-dependency of the elastic moduli of the sandstone measured, for example, in a triaxial cell. Figure 2b shows these moduli plotted against the effective pressure p_{eff}. On the same plot, we show moduli measured during sorption experiment at ambient pressure versus the effective pressure

$$p_{eff} = -\Delta p_f\,. \tag{2}$$

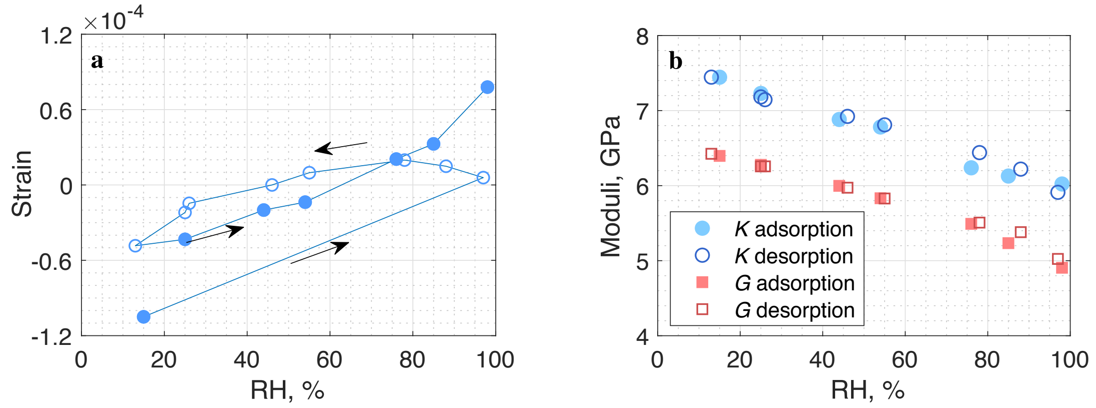

Figure 1: (a) Deformation of the sample versus RH. Black arrows show the direction of the sorption process. (b) Bulk K and shear G moduli dependencies on RH at desorption and adsorption paths.

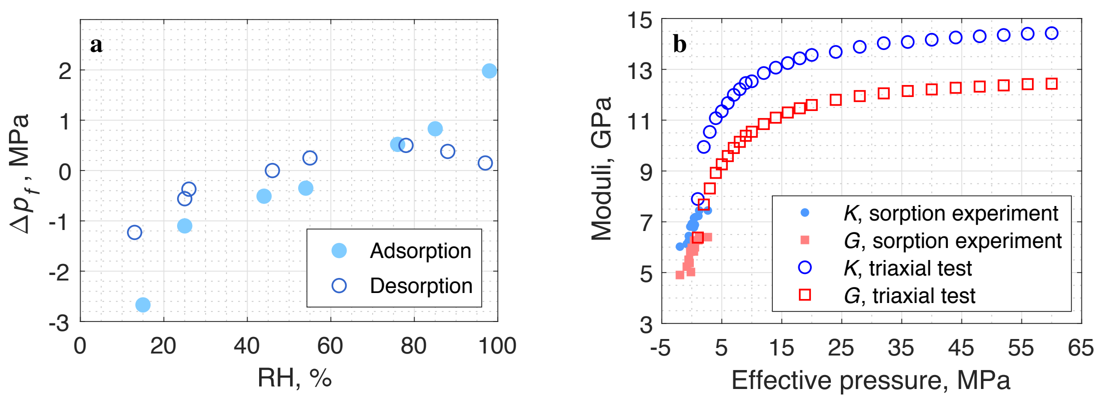

Figure 2: (a) Variations in the fluid pressure as a function of RH estimated from eq. 1. The reference state where $\Delta p_f = 0$ is the state with room RH. (b) Bulk K and shear G moduli versus the effective pressure measured from sorption experiment and triaxial test.

Conclusions

We see that both the bulk and shear moduli obtained from triaxial and sorption experiments show broadly similar trends at low effective pressures. The broad consistency between the two sets of measurements confirms that the moduli variations with RH can be explained by changes in the fluid pressure.

Acknowledgements

This work was partially funded by Curtin Reservoir Geophysical Consortium (CRGC). Alexey Yurikov was supported by Curtin Strategic International Postgraduate Research Scholarship and Australian Government Research Training Program Scholarship.

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