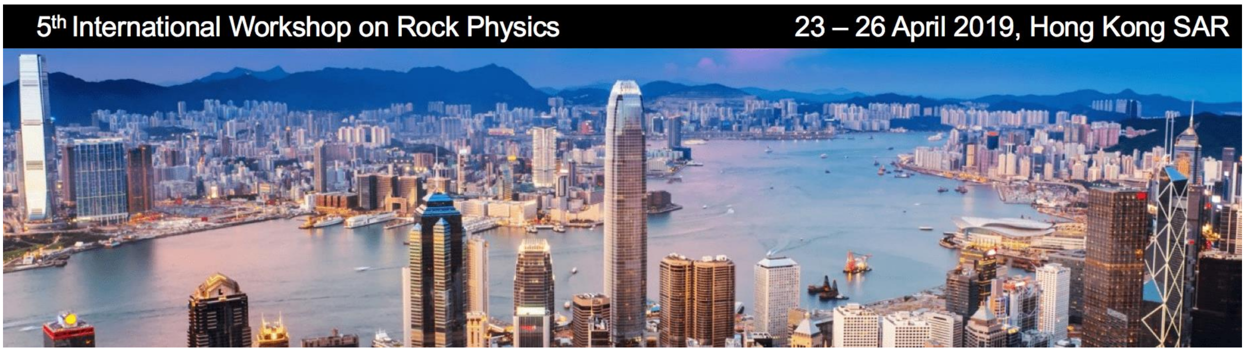

Stiffening by increased testing temperature of dry North Sea sandstones

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Introduction

We designed a triaxial testing program with the intention of investigating temperature effects on static and dynamic stiffness of two sandstones from the deep North Sea Basin. As the North Sea basin is geologically undergoing subsidence, we assume that studied reservoir material has never experienced higher temperature than in situ. We determined static and dynamic E-moduli of investigated material at temperatures of ambient and in situ (170°C), hence envisaging the materials geological temperature history. We show that the material in the dry state is stiffest at in situ temperature and propose that thermal expansion of constituting minerals increase stress in grain contacts when the applied stress is high enough for conversion of thermal strain to thermal stress in the grain contacts, thus leading to higher stiffness. Test results illustrate the importance of temperature controlled experiments.

Material and methods

The investigated sandstones originate from two North Sea HPHT wells (A and B). Drill cores were obtained from 5 km depth at a temperature of approximately 170°C. From each well, eight vertical 1½" plugs were collected as closely as possible with the aim of securing maximum similarity between individual specimens. They were prepared for testing by trimming the length to approximately twice the diameter, and we measured grain density, dry density and N_2 porosity using standard petrophysical procedures. Mineralogy was determined using X-Ray Diffraction (XRD) and Backscattered Electron Micrographs (BSEM) recorded on polished thin sections. BSEM images show A- and B-samples to be quartz dominated sandstone, but with a significantly higher degree of contact cementation in A (Figure 1). Porosity was found to be around 13% and 20% for respectively A and B samples.

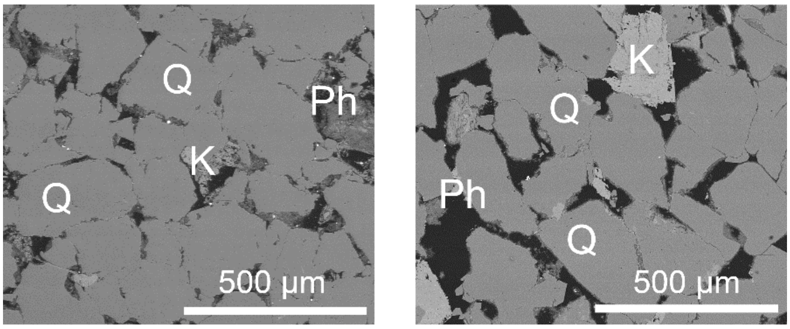

Figure 1: BSEM-images of studied sandstones. Q = quartz, K = feldspar, Ph = phyllosilicate. Left) Thin section of sandstone from well A. Right) Thin section of sandstone from well B.

In the dry state, specimens were placed in a triaxial testing cell designed with temperature control. At ambient or in situ (≈170°C) temperature individual specimens were hydrostatically loaded to stress levels of respectively 0.7, 3, 10 or 20 MPa, where after the confining stress, σ_R, was kept constant and specimens loaded to shear failure by increased axial stress, σ_A. The axial strain, ε_A, was continuously measured. By using stress-strain (σ_A-ε_A) curves, the static E-modulus, E_{sta}, was derived using a running least squares best fit with a length of 5 MPa. Ultrasonic compressional velocity (V_P) and velocity of two perpendicular shear waves (V_{S1} and V_{S2}) in the vertical direction were combined with bulk density to derive dynamic E-modulus, E_{dyn}.

Results and discussion

At ambient conditions we found dynamic E-modulus to be approximately twice the static for sandstones from both A- and B (Figure 2). At in-situ temperature and confining stress levels of 10 and 20 MPa, A-sandstone was found to have significantly higher static and dynamic E-moduli than at ambient conditions. For confining stress of 0.7 and 3 MPa, approximately identical response was found at in situ and ambient temperature for the static response whereas the dynamic moduli were higher at ambient temperature. B-sandstone has lower elastic moduli than A-sandstone, and higher static and dynamic moduli at in situ temperature than at ambient temperature (Figure 2).

For increasing confining stress, a significant stiffness increase is found at in-situ temperature for both static and dynamic moduli. The increased stiffness is interpreted as increased forces in grain contacts because thermal strain created by thermal expansion of constituting minerals is converted to thermal stress but limited to the degree at which the applied stress counteracts expanding thermal strain. Thus, at higher confining stress more thermal strain is converted to thermal stress putting more stress on the cemented connection (grain contacts) leading to overall stiffening of the entire rock frame.

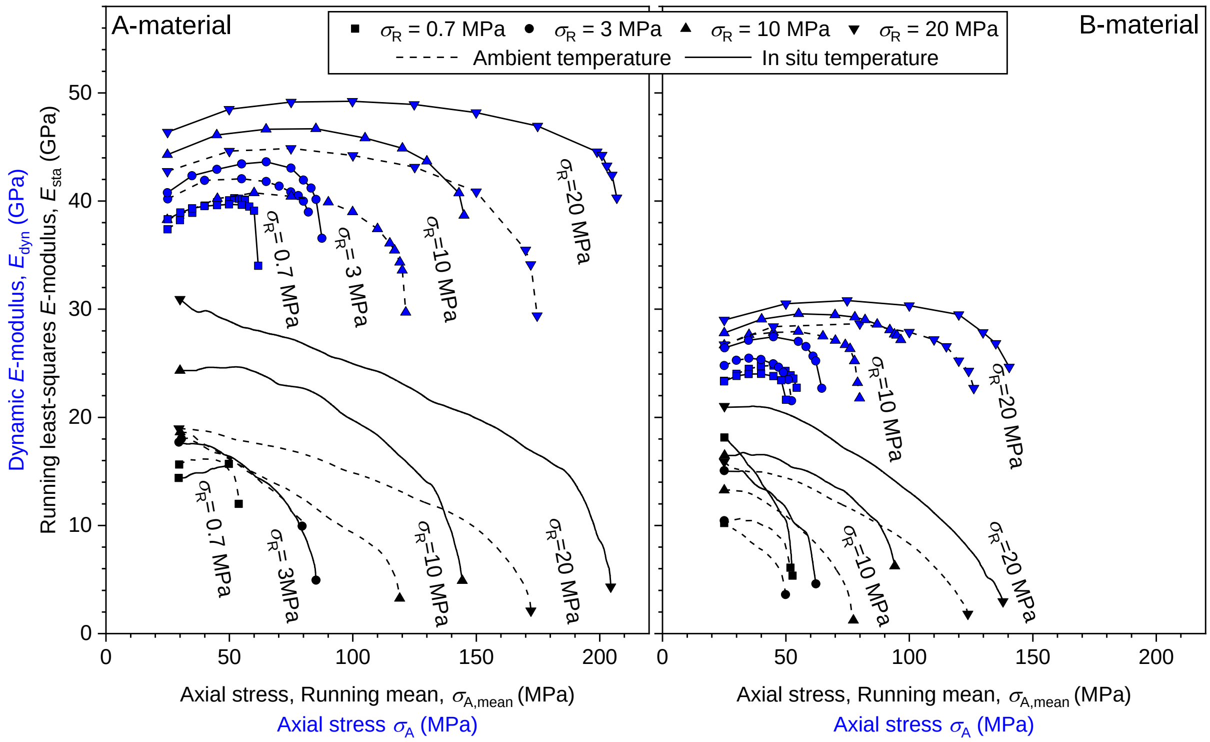

Figure 2: Static and dynamic E-moduli for confining stress of 0.7, 3, 10 and 20 MPa. $\sigma_{A,mean}$ *is the mean stress used in running least squares best fit with a length of 5 MPa.*

Conclusions

We conclude from experimental results that in the dry state, static and dynamic E-moduli are under-estimated when derived from tests at ambient temperature, however more so for increasing stress levels.

Acknowledgements

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