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“Frequency dependent elastic properties of shales – Impact of partial saturation and stress changes”

By

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Venue: E1 #06-06, Executive Seminar Room, Faculty of Engineering, National University of Singapore

Abstract

Shale is the most common constituent of the overburden of conventional hydrocarbon reservoirs. As such, knowledge about the elastic properties of shales is important for interpretation of seismic data. Shale characterisation is further required for addressing cap rock integrity, costly operation problems such as borehole instability during drilling, and as a part of reservoir characterisation (oil and gas shales).

It is known that fluid saturated crustal rocks are dispersive in nature (e.g. Nur and Byerlee 1971). Although techniques allowing for measuring elastic properties of rocks at different frequency ranges are available, they entail many practical issues, and only few groups report on seismic-dispersion measurements. Therefore, analytical descriptions of seismic dispersion often remain theoretical and require experimental verification (e.g. Müller et al. 2010). In the past, seismic dispersion effects were often neglected, but recent studies have revealed significant frequency dependence of elastic properties in some fluid saturated (and partially saturated) rocks.

In this talk, we report on series of laboratory experiments addressing the influence of stress and saturation change on dispersive properties of Mancos shale and Pierre shale I. Different water saturations have been established by exposing the core plugs to different relative humidities (RH) ranging from RH ≈ 11% to RH ≈ 100%. In addition, oven-dry samples were also tested. Samples of different orientations have been used to determine all independent parameters of the shale stiffness matrix. The experiments were carried out in a biaxial compaction cell, allowing for quasi-static deformation and pulse transmission measurements, as well as dynamic elastic-stiffness measurements in the seismic frequency band.

Our experiments reveal frequency dependant stress-sensitivity of the acoustic velocities (Fig. 1 a-b). In general, higher stress-sensitivity was observed at seismic frequencies. However, the measured stress-sensitivity was shale type dependant, direction dependant, and saturation dependant. Large seismic dispersion of up to 50% in vertical Young’s modulus (EV) or 20% in vertical P-wave velocity (VPV) is observed for tested core plugs. Additional water content
causes both strong softening of the shale and high increase of the seismic dispersion. As a result, rock softening with increasing water saturation is observed at seismic frequencies. At ultrasonic frequencies, above certain saturation, dispersion-induced stiffening exceeds the rock softening leading to the complex behaviour of EV as a function of water content (Fig 1 c). P-wave velocity exhibits lowest discrepancy between seismic and ultrasonic frequencies in case of either highly saturated or oven-dry samples, the intermediate states shows that increased water content strongly increases dispersion (Fig 1 d). We think that the observed saturation effects can be attributed to adsorption and capillary effects. Simple poroelastic modelling (anisotropic Gassmann) can fairly well capture the observed phenomena if the adsorption driven frame weakening (e.g. Clark et al. 1980) is taken into account (Fig 1 e-f). However, further work is required in order to fully explain the observations.

Figure 1 – (a,b) Stress-sensitivity of the vertical P-wave velocities of differently saturated Mancos shale and Pierre shale core plugs at seismic and ultrasonic frequencies. (c-d) Dispersion of the vertical Young’s modulus and the vertical P-wave velocity of Mancos shale. (e-f) Anisotropic Gassmann fit of the measured low frequency data after accounting for the adsorption driven frame weakening (Clark et al. 1980).
References


About the speaker

Dr. Szewczyk got his M.S. in condensed matter physics and nanophysics from University of Strasbourg and M.S. in photonics from Wroclaw University of Technology. Afterwards, he joined the Department of Geoscience and Petroleum at Norwegian University of Science and Technology (NTNU), where he received his Ph.D. in rock physics. Currently, he is employed as a postdoctoral researcher at NTNU.

Dr. Szewczyk is an experimentalist interested in many aspects of computational and experimental physics. His career covers different areas of physics. He received a student grant from the European Space Agency, where he was involved in development of the Gran Telescopio Canarias. He was working on molecular dynamic simulations at Institute of Materials Physics and Chemistry in Cronenbourg, and as an experimentalist in the field of biophysics at Institute of Supramolecular Science and Engineering in Strasbourg. Nowadays, Dr. Szewczyk works in the area of rock physics. Together with Dr. Andreas Bauer and Prof. Rune M. Holt, he has set-up the forced-oscillation apparatus allowing to measure the seismic responses of rocks within the laboratory framework. He is mainly interested in acoustic methods and known for his studies of seismic dispersion in shales.

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Location

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