Experimental compaction of dry smectite-silt mixtures

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Summary

This study investigates the effects of smectitic clay on petrophysical and acoustic properties of experimentally compacted dry silt-clay mixtures. Thirteen samples ranging in composition from pure smectite to pure silt were compacted in the Norwegian Geotechnical Institute laboratory under vertical effective stress up to 50 MPa. A systematic increase in compaction (porosity reduction) was found with decrease of smectite in the silt-clay mixtures. Experimental results show that for a given stress compaction decreases and the velocity (both Vp and Vs) increases with increasing smectitic clay percentage in the silt-clay mixtures. It could be explained by the distribution of stresses over the more grain contacts in finer aggregates compared to the coarser aggregates resulting in a less overall compressibility in case of clay-rich samples. These results will have practical implications for rock physics modeling, seismic and well log interpretation.

Introduction

Stress-dependent mechanical compaction plays a dominant role for compacting muds and mudstones that result in significant changes in petrophysics and acoustic properties of mudrocks. The influence of kaolinitic clay in silt-clay mixtures on acoustic and petrophysical properties in synthetic mudstones has been investigated earlier (Mondol, 2009; Fawad et al., 2010). This study demonstrates how the smectite content in silt-clay mixtures affect the petrophysical and acoustic properties as a function of effective stress. The terms “clay” and “silt” in this study are used to refer to a phyllosilicate clay mineral smectite and quartz. Smectite was chosen for this study as it is one of the most common clay mineral found in various amounts in mudstones at shallow depth (less than 60 to 70°C). To quantify the main influences of stress and clay content on rock petrophysical and acoustic properties a series of dry compaction tests were performed at room temperature. Using brine-saturated silt-clay mixtures it may not be easy to isolate the influence of stress and clay content on rock physical properties due to swelling nature of smectitic clay.

Materials and methods

Thirteen oven-dried (60°C for 3–4 days) samples of 100% clay aggregates, 92:08, 85:15, 75:25, 65:35, 58:42, 50:50, 42:58, 35:75, 25:75, 15:85, 08:92 clay-silt mixtures and 100% silt aggregates were prepared in the laboratory by mixing known amount (by mass) of silt and smectite. The measured clay particle size was below 2 µm and the measured silt size was between 4 and 40 µm. The mineralogical composition of the materials was determined by XRD (X-ray diffraction). The clay composition was mainly smectite (89%), cristobalite (9%), and quartz (2%), whereas the silt composition was about 100% quartz. The density of smectite measured in the laboratory at 60°C was 2.613 g/cc (Mondol et al. 2007). The experiments were performed at room temperature using a high stress uniaxial oedometer equipped with acoustic measurement transducers. The sample height was accurately measured and monitored throughout the experiments using two linearly variable displacement transducers (LVDT). The vertical stresses and vertical strains were measured continuously during the tests. Change in porosity as a
function of effective stress was computed from the change in the sample height/strain (Figs. 1a and 1b). Uncertainties in velocity were ±21 m/s for Vp and ±8 m/s for Vs (Mondol et al. 2008).

Figure 1. Experimental mechanical compaction of dry smectite-silt aggregates under uniaxial compression strain. Strain (a) and porosity reduction (b) as a function of vertical effective stress up to 50 MPa are shown.

Results

Results are presented here for various ratios of smectitic clay-silt aggregates mechanically compacted to 50 MPa effective stress. The change in porosity and acoustic velocities (both P- and S-wave) as a function of clay percentage (Vcl) under given vertical effective stress are illustrated in Figure 2. A gradual increase of porosity with increase in clay percentage was observed under corresponding stress (Fig. 2c), whereas both P- and S-wave velocities generally increased with increase in clay content (Figs. 2a & 2b). The local variations of velocities (especially Vp at high stresses documented in the Fig. 2a) demonstrated that the velocity is not only a function of porosity but also fabric. This is demonstrated by the fact that the highest velocities were measured in 25:75 and 15:85 silt-clay mixtures having a higher porosity than the other matrix supported samples.

Figure 2. Clay percentage (Vcl) versus porosity and acoustic velocities (both P- and S-waves) colour coded with effective vertical stress. Porosity values increase with increase of clay content (c) and also Vp and Vs generally increase with increasing clay content (a and b), however drop slightly in pure clay.
The P- and S-wave velocities in the silt-clay compaction tests increase with increasing porosity (Fig. 3) at corresponding stresses, however this porosity increase is mainly a function of increasing clay percentage (Figs. 3a & 3b). The dry clay-silt aggregates clearly demonstrate that smectitic clay-silt ratio has a systematic control on compaction i.e. reduction of porosity (Fig. 1b) and increment of ultrasonic velocities (Figs. 2a and 2b). In order to generalize and quantify the combine effect of stress and clays (their type, amount, distribution and interaction with brine) on rock properties in natural sediments more experiments of well-characterized mudstones are warranted.

**Figure 3.** Porosity plotted against (a) P-wave velocity and (b) S-wave velocity color coded with vertical effective stress. The arrow shows increasing direction of smectitic clay content.

**Conclusions**

Experimental mechanical compaction of dry smectite-silt aggregates provides useful information about petrophysical and acoustic properties of silt-clay mixtures. Experimental results show that for a given stress compaction decreases (i.e. porosity increases) and the velocity increases with increasing smectitic clay percentage in a silt-clay mixture. It could be explained by the distribution of stresses over the more grain contacts in finer aggregates compared to the coarser aggregates resulting in a less overall compressibility in case of clay-rich samples. The experimental results are valuable but have restricted quantitative application due to its idealized synthetic compositions as well tested under dry condition compared to the brine-saturated natural mudstones. In spite of the limitations, still the results are of intrinsic value in the interpretation of well log data as well as contributing towards our understanding of the relationships between seismic and petrophysical properties of smectite-dominated mudstones, enhancing the accuracy and reliability of the interpretations.
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References


