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Modelling of effects of parameters of shales on anisotropic elastic properties

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Introduction

Anisotropic elastic properties of seal shales are important for understanding of shale compaction trends, improved seismic to well tie, non-hyperbolic moveout correction, and serve as a baseline for predicting properties of organic-rich shales (source rocks). However, no predictive models of elastic properties of shale have been developed so far due to a multiparametric nature of such modelling problem and the fact that effects of some parameters of shales are poorly understood. The large number of parameters required for prediction of elastic properties of shales stems from multicomponent nature of these rocks, as shales are composite media comprising clay particles of different mineralogy and silt. The complexity of the system is complemented with the pores of micro- to nano-scale, which shape and orientation is poorly understood.

Data and Methodology

In this study, we use the experimental results of Beloborodov et al. (2017) to understand the parameters that affect elastic properties of shales and to establish a predictive modelling workflow. The experimental results provide all five independent elastic constants measured during compaction of two artificial shale samples A0100 and A2080 with the solid phase comprised of 100% kaolinite, and 80% kaolinite with 20% quartz, respectively. The porosity of the samples is controlled during compaction. First, we invert the elastic properties of an individual kaolinite particle applying effective medium theories to the experimental data obtained at the maximum compaction state, where orientation distribution function (ODF) of clay particles is known from neutron diffraction measurements (Beloborodov et al., 2016). Second, we perform a forward modelling, where we take into account the effects of different parameters of shales changing as a result of compaction. Namely, we account for (Step 1) the effect of reorientation of particles (changes in ODF) due to compaction, (Step 2) the effect of porosity reduction and (Step 3) the effect of silt fraction. Finally, (Step 4) the resultant misfits between the modelled and experimental moduli are taken into account by attributing these misfits to changes in the properties of contacts between particles. The relationship between the properties of these contacts and of contacts in natural shales is shown.

Results

Figure 1 shows variations of anisotropic parameters ε and δ from properties of kaolinite particles (thin solid lines) via clay polycrystal stage (dotted lines), porous clay stage (dashed-dotted lines) and porous and silty shale stage (dashed lines) to the final stage (thick solid line) that takes variations in properties of discontinuities into account. The anisotropic parameters do not change significantly after reorientation of clay particles is taken into account (after Step 1). Taking ODF into account affects the anisotropic parameters differently: ε drops from the values above 0.4 to the ~0.2, and δ increases from -0.4 to about 0.1. The shear $s_n B_T$ and normal $s_n B_N$ compliances of contacts and their ratio B obtained in this study (Step 4) is shown in Figure 2 in comparison with the results obtained for natural shales. These values are similar, but the shear compliance in the artificial samples is one order of magnitude higher than in natural shales, and the ratio B is generally one or two orders lower. This difference can be explained by better consolidation of clay particles in natural shales.

Conclusions

A new methodology of modelling of anisotropic properties of shales has been suggested. This methodology has allowed separating effects of multiple parameters that shape elastic properties and anisotropic parameters of shales. We show that anisotropic parameters ε and δ, which are the most important parameters for seismic data processing and interpretation, can be reliably estimated from the ODF of clay platelets.

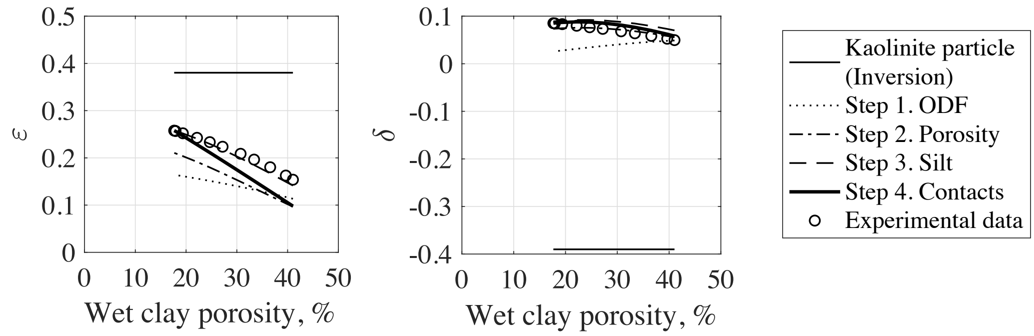

Figure 1: Anisotropic parameters ε and δ measured and modelled for the sample with 80% kaolinite and 20% quartz.

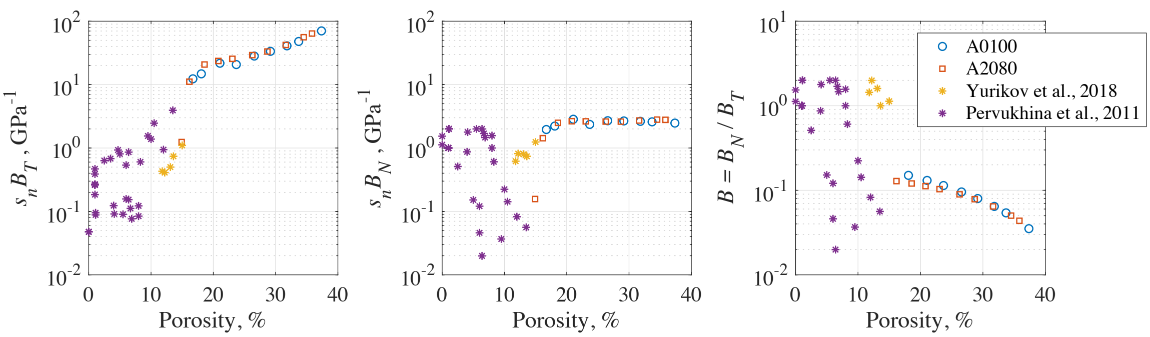

Figure 2: Comparison of compliances of contacts in artificial samples A0100 and A2080, Opalinus shale from Yurikov et al. (2018) and other natural shales from Pervukhina et al. (2011).

References

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