Computation of anisotropic elastic moduli for muscovite and clay minerals

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Summary

The elastic properties of muscovite and clay minerals are vital for a variety of applications in both conventional and unconventional shale characterization. The orientation distribution of the mineral platelets significantly affects the elastic velocities and its anisotropy. We use the orientation distribution data from published literature to relate the maximum platelet pole density to the median orientation angle τ with respect to the bedding plane. This is then used in a heuristic approach to model bedding-normal anisotropic elastic moduli and P- and S-wave velocities of zero-porosity clay aggregates as a function of the median orientation angle.

Introduction

Shales (or mudrocks) are heterogeneous rocks composed of dominantly clay and mica minerals. The anisotropy of these mudrocks can be a combined effect of kerogen laminations, crack alignment (Vernik and Liu, 1997) and clay platelet preferred orientation (Sayers, 1994).

The orientation of clay mineral is generally expressed in the terms of MPD (maximum pole density) in m.r.d. (multiples of random distribution) (Wenk, 1985). A higher value of m.r.d. signifies a higher degree of preferred orientation. In this study, we have used Orientation Distribution Functions (ODF) data from X-ray goniometry for different shales to devise a relationship between P- and S-wave velocities for zero interparticle porosity minerals to their preferred orientation. We then compute elastic tensors for the most common shale minerals such as muscovite, illite and illite/smectite aggregates.

Methodology

The methodology used in this study consists of mainly three steps:

1. Use the theoretical approximations to constrain the isotropic elastic moduli of bonded muscovite composite with random platelet orientation.
2. Replace conventional method of describing platelet orientation distribution strength with an equivalent one for our modeling purposes.
3. Finally, we propose a heuristic elliptical function relating the principal TI elastic moduli of zero-porosity muscovite/clay composites to their orientation strength.

Results

Muscovite is a phyllosilicate mineral from the micas group. Its chemical composition is given by the formula: $KAl_2(AlSi_3)O_{10}(OH)_2$ (Rieder et al. 1998). Using the measured five independent C_{ij} tensor elements, the mineral density and Thomsen parameters for TI medium, the isotropic moduli of the muscovite aggregate with random crystal orientation, zero porosity, and zero crack density is computed. The results for the P-wave and S-wave moduli are M_H = 104.7 GPa, G_H =

35.2 GPa, respectively. The isotropic velocities are V_P = 6.10 km/s and V_S = 3.54 km/s. Fixing the end points of the bedding-normal and bedding-parallel stiffnesses in the modulus versus DMO-angle 2τ space, we devise a heuristic elliptical function that describes variation of velocities w.r.t. platelet orientation as shown in Figure 1a.

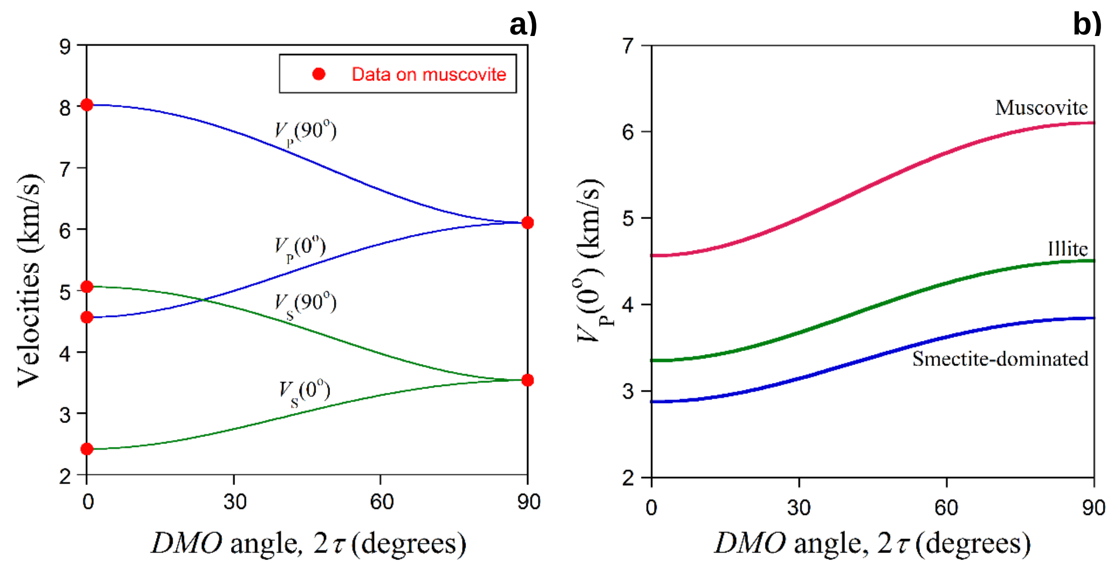

***Figure 1** a) Bedding-normal and bedding-parallel velocities of P- and S-waves vs. the DMO angle using the elliptical functions for muscovite b) bedding-normal velocities of P-waves versus the platelet orientation strength for muscovite, illite, and smectite-dominated clay aggregates.*

Using experimental data and semi-empirical relationships along with the help of shale RPM templates described in Vernik (2016), we apply this methodology to compute the elastic moduli for illite dominated clay and illite/smectite dominated clay composites using the elliptical functions. Figure 1b shows bedding-normal velocity variations for different DMO angles and it can be observed that the values decrease from muscovite to more hydrated illite and smectite-dominated clays.

Due to space restrictions, the entire methodology and observations are not shown here.

Conclusions

We have shown that the orientation distribution data can be related in a heuristic way to model the anisotropic elastic moduli for zero-porosity mineral aggregates as a function of median orientation angle. The results and methodologies shown for muscovite can also be extended for other clay minerals such as illite and illite/smectite. We found that the bedding-normal moduli and mineral density of muscovite are significantly greater than those of illite, whereas the respective moduli of illite/smectite-dominated clay composite are significantly smaller than those estimated for illite-dominated clays.

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