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Rock-Physics Models - A Tutorial

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Summary

The purpose of this presentation is to demonstrate some of the uses of rock physics in the interpretation workflow with an emphasis on how some of the different types of models are built, what information is needed, and where different model types might be relevant. While no equations are discussed, references are provided for those seeking more details.

Introduction

Rock physics deals with the relationships between geological properties and geophysical observations. In practice, this means that geophysical observations can be predicted or interpreted in terms of rock properties by building a model of the rock that is consistent with the known data. Testing how different fluid saturations affect log velocity, modelling the magnitude of impedance change for a steam flood, and interpreting inversion results as changes in mineralogy and porosity are all examples of uses for rock physics.

As outlined by Reine (2017), rock physics can be broken down into the modelling of four different components: 1) minerals, 2) fluids, 3) the rock frame, and 4) how the parts are assembled. In this tutorial presentation, I go through the different components following Reine (2017), showing additional examples of data and outcomes.

Minerals

At the most basic level, the elastic properties of a rock are driven by those of the minerals of which it is composed. It is intuitive, for example, that a block of calcite is expected to be more stiff than a block of clay. The properties of various minerals most typically encountered in exploration geophysics have been measured in the lab and tabulated in useful summaries (e.g. Mavko et al., 1998; Avseth et al., 2005) (Figure 1).

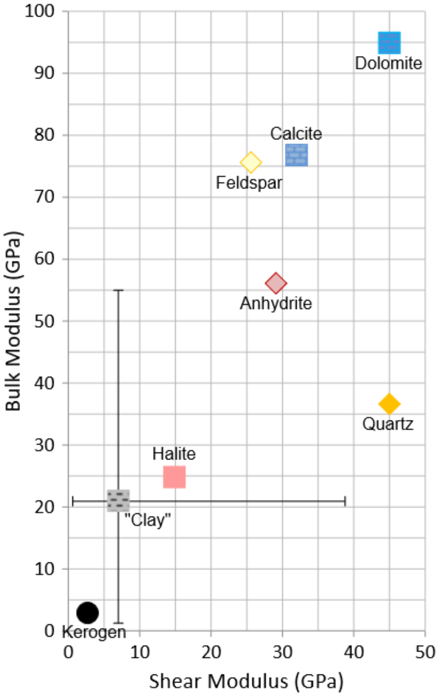

Figure 1. *Elastic properties of select minerals.*

For creating a rock-physics model, information on the mineralogy of the rock is valuable. This can come in different forms. The most detailed data is from XRD or XRF analysis, which indicates the types of minerals and their percentages. If these data aren't available, however, petrophysical calculations or even geological knowledge of the area can be used in its place.

Fluids

While mineral properties define the solid portion of the rock, the porous nature of rocks means that the fluid component must also be considered. As it is the most directly related to the economics of exploration, modelling changes in the fluid type or saturation is a common application of rock-physics.

Compressible fluids (i.e. gas) result in a rock that is much softer than one filled with less compressible fluids (i.e. water). However a continuum of fluid properties exists (Figure 2).

Fluid properties are most often modelled using empirical relationships between reservoir parameters and elastic properties (Batzle & Wang, 1992; Han & Batzle, 2000a,b). Because of this link, the critical data for fluid modelling includes reservoir-fluid parameters such as temperature, pore pressure, oil API, gas-oil ratio, gas gravity, and water salinity. These properties have economic significance and the measurements are therefore frequently available for rock-physics modelling.

Rock Frame

Knowing the mineral and fluid properties of a rock allows one to establish the upper and lower bounds of the rock properties, but where the actual properties lie within those bounds depends largely on how the rock is constructed. If a sandstone is unconsolidated or cemented, the stiffness of the rock will be different (Dvorkin & Nur, 1996). Low-porosity rocks (Xu and White, 1995) and rocks with isolated fractures or dissolution porosity (Xu and Payne, 2009) are different still.

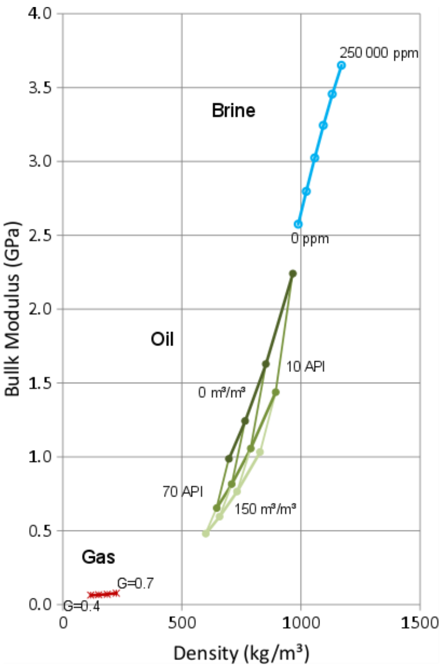

Figure 2. *Elastic properties for a range of reservoir fluid parameters.*

Each of these different rock types has its own theoretical models describing the elastic properties based on the architecture of the rock. This is often what is considered to be 'rock-physics modelling', but is still just one component of the process. Using different models typically introduces parameters that are difficult to measure empirically. Calibration with known data is an important step to properly establish these unknowns.

Assembly

Assembling the different parts of the model accounts for the stiffening of the rock frame due to the presence of fluids. Conventionally, the Gassmann equations (Gassmann, 1951) are used to calculate the saturated elastic properties, where the shear component is unaffected by the fluids. To model heavy oils, this approach is often insufficient to match the observed data. Methods that account for the shear strength of bitumen (Ciz & Shapiro, 2007) are used instead.

When all of the parts of the model have been assembled, it is often useful to go back and recalculate the model for different versions of the parameters. For example, depending on the geological factors that are of interest, one could calculate the elastic properties for a range of porosities and clay volumes. When arranged on a crossplot, this allows the systematically varying models to be arranged into a grid. Figure 3 shows such a grid using MuRho and density, where the red lines have constant clay content and the blue lines have constant porosity. Shown here with well data for further calibration, these templates are more useful when applied to seismic data, where the geological conditions were previously unknown and can now be interpreted.

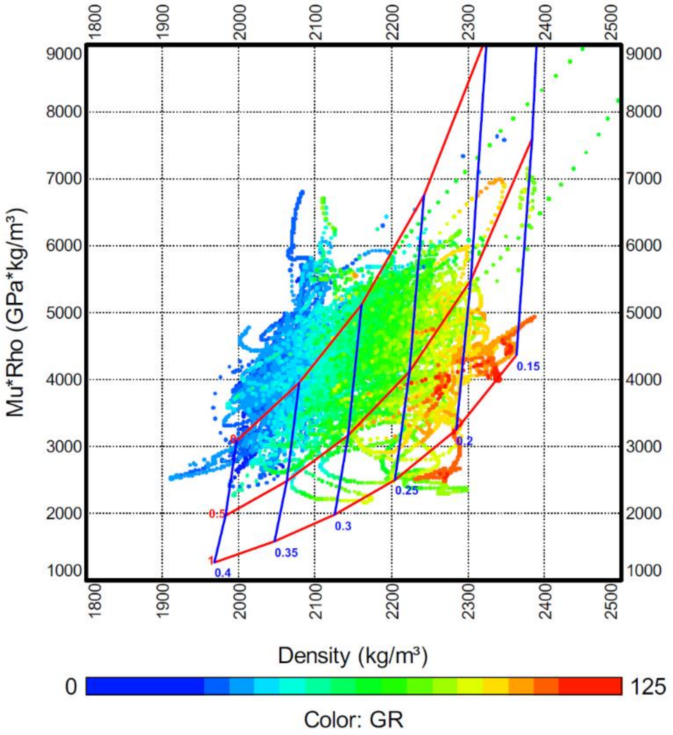

Figure 3. *A rock-physics template displayed on a crossplot of MuRho vs. density. The intersection of the lines of constant clay content (red) and lines of constant porosity (blue) each represent an individual rock model. When applied to seismic-inversion data, the template provides a useful means for geological interpretation.*

Conclusions

Rock-physics modelling is a crucial tool for interpreting seismic data. Among other uses, it can be used to model different fluid saturations in a well log, determine the feasibility of detecting a time-lapse result, or provide a quantitative means to interpret a seismic inversion. By understanding the components of creating a rock-physics model, the process is de-mystified and an improved relationship is obtained with the geological significance of the work.

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