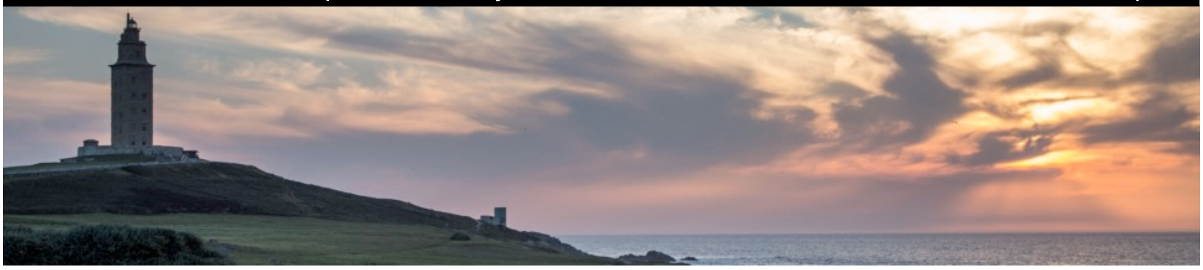

Predicting well-log Thermal Conductivity from sonic velocities: a rock physics investigation

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Introduction

Knowledge on heat transport properties are required for applications such as underground nuclear waste disposal, CO_2 storage, or exploration and exploitation of geothermal reservoirs. In low permeability rocks, one of the key properties governing heat transfer is the effective thermal conductivity (Clauser, 2011). Since accessing directly and accurately the in situ Thermal Conductivity (TC) is challenging, this property is either (i) measured on extracted cores samples (e.g. Esteban et al., 2015); or (ii) estimated using semi-empirical models. While these models are based on physical considerations, the effects of microcracks – or soft porosity - on thermal properties are often disregarded. Yet, microcracks strongly affect the rocks dependence to stress conditions (Walsh, 1965), and the TC largely depends on the confining pressure applied to the rock (e.g. Linn et al., 2011). Comparing published datasets of elastic and thermal properties measured on samples of Berea sandstone, Pimienta et al. (2014) showed that the pressure dependence of these two physical properties was very similar. They attributed this pressure dependence to the presence of microcracks and open grain contacts, and they derived a micromechanical model to infer the TC of clean sandstones from Elastic Wave Velocities (EWV) and porosity measurements.

The aim of this work is to extend this pore-scale laboratory approach and model to larger scales by using the well-log sonic EWV and porosity (i.e., two standard data acquisitions from well logging) to infer TC. Further, the different assumptions made on the presented model will be discussed, e.g. in the light of our knowledge of the frequency dependence of elastic properties.

Methodology

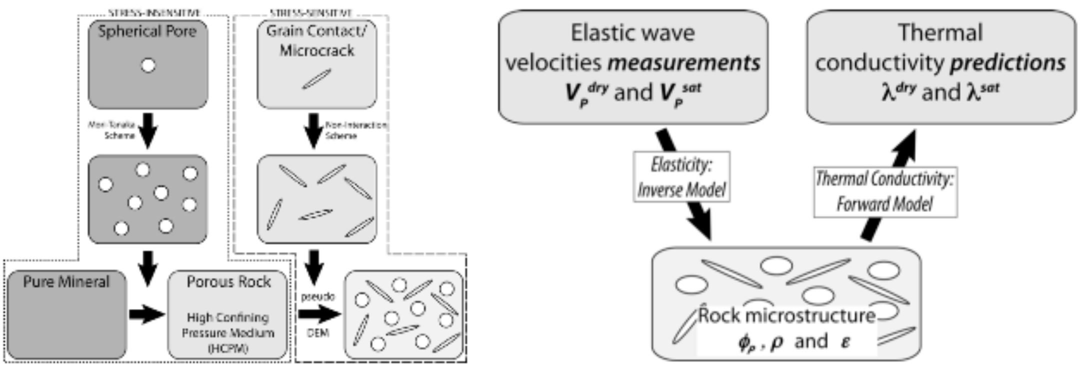

Figure 1. Principle of the pore-scale modeling approach using effective media theories (left), with the same assumptions for TC and EWV; and (right) methodology for TC predictions (after Pimienta et al, 2014).

The methodology for TC prediction (dry and/or water-saturated sample state) follows a two-step procedure (Fig. 1) : (1) the P-wave velocity and porosity measured from well log are data input to invert some rock microstructural parameters, including microcrack density and length-to-width microcrack aspect ratio, using an effective elasticity model, and (2) these inverted parameters are then used to predict TC by forward modelling.

Results & Discussion

We applied this TC prediction methodology in a relatively clay-free sandstone formation from Mena-Murtee well, Darling Basin (New South Wales, Australia) from reported (Bell & Knight, 2014) well-log sonic P-wave velocity ranging between 2 and 6 km/s and neutron porosity ranging from 5% to 45% assuming no clay minerals influence (Fig. 2). The TC results show a continuous increasing trend (dry and saturated state) with depth up to 1.2 km, then reach a maximum of ~ 5.6 $W.K^{-1}/m^{-1}$ and ~ 6.5 $W.K^{-1}/m^{-1}$ in dry and water-saturated conditions respectively (Fig. 2). Those results are matching the TC measured on cores retrieved from Mena-Murtee well (e.g., Esteban et al., 2015). Two extreme crack aspect ratio values, representing typical ratios observed in sandstone reservoirs, were tested and led to a positive TC offset of ~ 0.4 $W.K^{-1}/m^{-1}$ for both dry and water-saturated states from low to high crack aspect ratio. Such microcracks aspect ratio could be independently assessed (e.g. microscopy imaging) to improve the TC predictions. The TC prediction however relies on several assumptions: (i) the rock is composed of only quartz mineral in this study; (ii) the pore media is only filled with air or water; (iii) the unrelaxed – high frequency – regime. The relative effect of such assumptions will be thoroughly discussed.

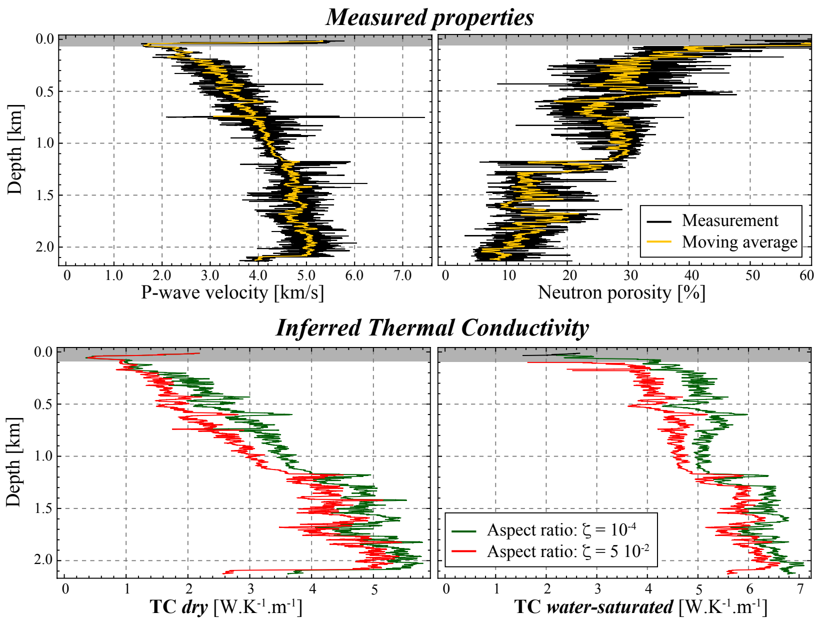

Figure 2. TC prediction for either dry (bottom left) or water-saturated (bottom right) sandstone formations along Mena-Murtee well, using sonic P-wave velocity (top left) and neutron porosity (top right). Low value (red curve) and high value (green curve) of microcrack aspect ratio were tested to model TC.

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