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Shales physical properties and anisotropy: Micromechanical modelling and tri-axial experiments

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Clayrocks and shales represent approximately two-third of all sedimentary rocks on Earth's upper crust. For instance, in oil and gas drilling operations, shales constitute 80% of the drilled sections, mainly because they overlie most hydrocarbon bearing reservoirs. Also, due to their very low permeability, several countries are considering clayrocks as a possible confining host lithology for radioactive waste deep burial. Beyond these practical aspects, it is also well-known that clays play a significant role in fault ruptures because of their lubricating properties. In fact, lubrication and thermal fluid pressurization control faults rupture. Adsorbed water and water expelled from the clay structure may cause both/either increased lubrication and/or local excess pore pressure. Furthermore, it is typically observed that clay content and degree of fabric development do increase closer to the fault core, i.e., more stratified clay minerals near the gouge zone, which in turn increases their anisotropy. Also, damage usually accumulates during: (i) fault growth from process-zone deformation associated with propagation of fault tips; (ii) progressive deformation associated with stress cycling due to displacement on non-planar and segmented faults; and (iii) stress cycling from repeated passage of propagating slip events. This analysis suggests that, in a wide range of applications, clayrocks water content, damage extent and anisotropy constitute the significant parameters to be explored and understood.

The present research work combines an experimental approach (laboratory measurements) to a theoretical approach (micromechanical modelling) in order to assess the evolution of clayrocks microstructure under tri-axial stresses, representative of in situ conditions. The main purpose of this type of approach is to understand clayrocks behaviour in response to external perturbations in terms of the evolution of its microstructure, water content, damage extent and anisotropy.

The experimental setup developed by the rock physics group at the Ecole Normale Supérieure allows for the continuous and simultaneous measurement of five different elastic wave velocities and two directions of strain (axial and circumferential), on the same cylindrical rock sample. The main outcomes of these experiments are: (i) identification of the whole tensor of elastic moduli of the transversely isotropic clayrock from the elastic wave velocity measurements; (ii) assessment of the evolution of these moduli under tri-axial loading; (iii) assessment of the evolution of the elastic anisotropies of this clayrock under loading. This last point allows us to use the anisotropy of the dynamic properties of this rock as an indicator of the evolution of its microstructure. Indeed, the experiments have been designed in such a way that they allow for the distinction between: (i) the intrinsic elastic anisotropy of the solid phase forming the rock; and (ii) the anisotropy induced by the presence of the porosity.

An original micromechanical model is developed in order to assess the relative impact of these sources of elastic anisotropy. Indeed, this type of theoretical approach takes into account both sources of anisotropy, i.e., intrinsic and microstructure-induced, as our laboratory experimental data, or reported data in the literature suggest. This effective medium model is able to describe macroscopic properties of the rock in terms of its microscopic specificities by means of a homogenization procedure based on Eshelby's theory. It relates explicitly rock porosity to pores density, aspect ratio and fluid compressibility. This original tool leads asymptotically to a more classical damage model based on phenomenological considerations, taking into account rock intrinsic anisotropy though.