**SHAKAS Alexis** (2017): Characterizing fracture aperture and transport dynamics with hydrogeophysics. Theoretical and experimental advances

Abstract

Fractures are ubiquitous in the Earth's crust. From the scale of a few cm to several km, fractures can act as conduits or barriers to fluid flow and play a major role in several processes and applications, including groundwater extraction, contaminant migration in fractured rock, underground storage of disposed nuclear waste and sequestration of carbon dioxide, as well as geothermal heat migration. A fracture's geometrical properties such as aperture variations along its plane influence fluid flow and transport within. Nevertheless, it is a challenging task to statistically characterize aperture variations of a single fracture because these are self-affine; a property that implies similar patterns over several spatial scales. Classical hydrological tests are spatially sparse and do not provide direct information about aperture variations. This limitation can partly be overcome by hydrogeophysics, which combines geophysical methods with hydrological experiments. Here, we present experimental and theoretical advances on the use of ground penetrating radar (GPR) alone and also combined with push-pull tests for improved fracture aperture characterization. On the theoretical aspect we used analytical solutions to develop a modeling framework that simulates GPR reflections from fractures with heterogeneous aperture distributions, embedded in a uniform rockmatrix. In the presence of aperture heterogeneity in a single fracture, we demonstrate that classical aperture-inference approaches that rely on uniform fracture properties lead to biased estimates of mean aperture. The modeling framework is suitable for GPR use in fractured rock but is also suitable for other applications such as fracture imaging in concrete. On the experimental side, we present the first experiments in which the migration of a saline tracer is imaged during a push-pull test. The GPR data are informative about the dynamics of the tracer plume and the nature of the fractures involved in the experiment, but also highlight density effects that hinter our ability to infer natural flow dynamics and processes, such as ambient flow. We address the density issue by introducing a neutrally-buoyant, yet electrically conductive tracer, which consists of ethanol mixed with a saline tracer. A comparison of results from the two types of tracer tests demonstrates that the addition of ethanol diminishes the density effect; we therefore suggest that neutrally buoyant tracers should be used in hydrogeophysics. Finally, we introduce a fully coupled model that can simulate the combined experiments. The coupled model can be applied within a Markov-chain Monte-Carlo inversion of the data from the combined experiment to infer a fracture's geometric properties.

Key words: Hydrogeophysics, GPR, push-pull, fractures, density.