Identification of 3D fracture distribution and fracture connectivity by combined Ground Penetrating Radar imagery and tracer tests at the Äspö Hard Rock Laboratory, Sweden

Justine Molron[a*], Niklas Linde[b], Ludovic Baron[b], Diane Doolaeghe[a], Johanna Ragvald[c] , Peter Andersson[c], Jan-Olof Selroos[d], Tanguy Le Borgne[e], Caroline Darcel[a] and Philippe Davy[e]
(* = presenting PhD student, subsequent authors optional)

[a*] Itasca consultants s.a.s, 64 Chemin des Mouilles, 69130 Écully, France
[b] Université de Lausanne, UNIL, Lausanne, Switzerland
[c] Geosigma AB, Stockholm, Sweden
[d] Svensk Kärnbränslehantering AB, SKB, Solna, Sweden
[e] Géosciences Rennes, OSUR, CNRS, Université de Rennes 1, Rennes, France

Keywords: fractures, GPR, Geosciences

Abstract:
Predicting flow and transport properties of fractured rock masses is a major challenge in a large number of hydrological and geotechnical applications. A common approach is to derive Discrete Fracture Network (DFN) models from fracture mapping in the field and core mapping, as well as from hydraulic and tracer tests. The present work aims ultimately at conditioning DFN models to geophysical data (Ground Penetrating Radar – GPR). The application in mind relates to safety assessments of nuclear waste repositories; specifically, the conditioning is aimed at improving DFN models at scales from a few to tens of meters around the canisters containing the spent nuclear fuel. All GPR and auxiliary experiments were completed at the Äspö Hard Rock Laboratory in Sweden, in a test tunnel (20 m long, 4 m wide and 4.5 m high) located 410 m below the sea level. The tunnel floor is flat and the main rock types are granite, diorite and granodiorite. The first field campaign aimed at imaging the 3D distribution of the main open fractures at the site using 160 MHz, 450 MHz and 750 MHz antennas providing investigation depths of 10 m, 8 m and 5 m, respectively. The imaged diffractors and reflectors were grouped into three zones ranging from, supposedly, more permeable to less permeable regions and one borehole was drilled in each zone (BH1 to BH3). Based on the drilling, core log data and hydraulic tests, the most transmissive borehole agreed with the GPR classification, while the most permeable 1-m section (2.23E-10 m2/s) encountered was found in the region with the least GPR reflections. The few open fractures encountered (five 1-m sections had detectable flow rates out of 27) have very small apertures and it seems that filled fractures with larger apertures are responsible for the stronger GPR reflections at the site. To infer fracture connectivity patterns, we conducted surface GPR surveys during tracer test injections. Because of the saline formation water, we injected deionized water to achieve an electrical contrast together with Uranine and Rhodamine tracers for solute transport testing purposes. The injection took place in the middle borehole BH2 between 3.2-3.7 m depth with withdrawal in either borehole BH1 (3-6 m) or BH3 (4-5 m). Despite a pressure difference exceeding 40 bar, the injection rate was 10 mL/min only. For this reason, the injection was pursued for 24 hours (accumulated injected volume of 10 to 13 L) to increase the chances of observing a GPR time-lapse signature. The mass recoveries in the experiments were 20 to 30 %. These hydrogeophysical data will be further processed and used to reduce uncertainties and improve conditioning of site-specific hydraulic DFN models.