Advancing field methods for GPR monitoring of flow channeling in fractured rock

George Tsoflias[1], Matthew Becker[2], Matthew Baker[1] and Chris Perll[1]
tsoflias@ku.edu, matt.becker@csulb.edut, mpbaker@ku.edu, perll@ku.edu
[1] The University of Kansas, Lawrence, KS, United States
[2] California State University Long Beach, Long Beach, CA, United States

Fractures control the flow of fluids in rocks with important implications for groundwater resources, contaminant transport, geothermal resources, sequestration of carbon dioxide, and the development of unconventional hydrocarbon resources. However, fractured rocks exhibit heterogeneous hydraulic properties that are difficult to characterize using conventional hydraulic testing methods. Flow channeling caused by fracture aperture variability is known to result in preferential pathways of rapid contaminant transport in aquifers and poor sweep efficiency in geothermal reservoirs. The hydrologic community has recognized the need for imaging flow channeling in the field.

We present results of ongoing research on the development of GPR reflection methods for remote imaging of the channeled path of tracer transport. Time-lapse GPR experiments were conducted at the Altona Flat Rock fractured sandstone field site using surface reflection to image a water saturated subhorizontal bedrock fracture at a depth of 7.6 m below surface. Forty-eight three-dimensional (3-D) multi-polarization GPR grids were acquired, each covering approximately a 100 m^2 area at a 0.25 m x 0.5 m trace spacing. Radar data were acquired at 50 MHz and 100 MHz frequencies using broadside and cross-polarized dipole antenna pairs oriented parallel and orthogonal to the survey grid lines. Dipole flow hydraulic tests established by re-circulation of saline traced formation water between injection and pumping boreholes were used to set-up controlled flow of variable salinity tracers and variable direction hydraulic gradients.

Analysis of the radar data indicates that aperture variability and flow channeling introduce significant polarization effects to the scattered radar wavefields that need to be accounted for in order to quantitatively relate GPR reflection response to fracture aperture and tracer concentration. Increasing water salinity along flow channels results in increasing polarization differences on the recorded signals. Therefore, in addition to full-resolution 3-D acquisition and processing, multi-polarization surveying is necessary for imaging flow channeling and monitoring tracers in subhorizontal fractures.

Preliminary comparison of GPR reflection amplitudes between background clean water (9.3 mS/m) and traced water of 200 mS/m, 400 mS/m and 700 mS/m fluid electrical conductivity under East-West oriented dipole flow showed overall reflection strength increase with increasing fluid electrical conductivity. Amplitude differencing between each of the saline tracer tests and background reveals 1 m to 1.5 m wide flow channels trending across the survey area and the flow dipole field. The spatial scale of these channels corresponds roughly to hydrodynamic dispersivity measured from interwell saline tracer breakthrough. Ongoing data analysis is evaluating the use of GPR for imaging in the field, for the first time, flow channeling resulting from varying orientation hydraulic gradients.