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GPR borehole reflection experiments constrain fracture geometry in a crystalline rock aquifer, Ploemeur, Brittany, France

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Fluid flow in fractured crystalline aquifers is mainly controlled by the geometry and connectivity of permeable fractures. Deterministic imaging of individual 3D flow paths between boreholes in fractured rock is so far not possible using either geophysical or hydrological data. At a hydrogeological research site in Ploemeur, France, we explore the utility of combining Ground Penetrating Radar (GPR) data collected within boreholes with single- and crosshole flowmeter data to stochastically invert for possible fracture distributions. Previous hydrological and borehole logging indicate that the water flow at the site is mainly focussed in a few fractures. Here we focus on the analysis of single- and crosshole GPR reflection data and to what extent interpreted reflectors can be correlated with available hydrologic and borehole logging data.

GPR data were acquired using 100 and 250 MHz antennas along 4 neighbouring wells (70-100 m deep). The surrounding rock matrix in the depth range of interest (40-100 m) consists of intact granite with a high electrical resistivity. Consequently, GPR signal attenuation is weak and large reflection coefficients are expected to occur mainly at rock-fracture interfaces. Multifold singlehole GPR data were collected in common offset gathers every 0.25 m using 16 (4) different offsets for the 100 (250) MHz antennas. To separate the reflected energy from direct waves and source-generated noise, we subjected the data to a processing scheme that included bandpass and eigenvector filtering, muting, prestack Kirchhoff time migration and stacking. The signal-to-noise-ratios were much improved compared to a traditional single-offset section. The final stacked and migrated sections clearly image several fracture zones and individual fractures (dipping 40-90°) located at 2-20 m radial distance away from the boreholes. We can correlate GPR reflections with most hydrologically important fractures that intersect a borehole at steep angles. Reflections originating from adjacent boreholes allowed us to redefine the well geometry that was originally obtained from borehole deviation logging. This new geometry was then used for crosshole GPR reflection data processing and traveltime inversion for which these new constraints were absolutely vital. The crosshole GPR data were collected in common source gathers. Transmitted and reflected signals were enhanced using the same prestack processing scheme as applied for the singlehole data. The final stacked and non-migrated sections image reflections and diffractions that originate from subvertical to subhorizontal dipping reflectors. Traveltime tomography revealed similar velocity ranges as those observed for the direct waves of the singlehole data, thereby supporting the borehole geometry used.

By comparing the interpreted single- and crosshole GPR sections we construct a distribution of reflectors that correspond to fractures with certain possible geometries (distance to the borehole, dip, minimal length, dip direction). This allows us to significantly reduce the model space of possible fracture geometries. The resulting probabilistic distribution will be used to invert hydrological data (flowmeter and tracer test data). The static GPR experiments will be complemented with time-lapse GPR measurements to be carried out during saline tracer injection tests in hydrologically conductive fractures. These data will provide additional constraints on the geometry of preferential flow paths between the boreholes.