Tracking Fluid Flow with 4-D Ground Penetrating Radar (GPR) in a Fractured Carbonate Reservoir

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Fractures represent important fluid conduits in carbonate reservoirs. Currently characterization of fluid flow mostly relies on laboratory sample measurements, upscaling and modeling. For the first time high-resolution 4D GPR allows visualization and quantification of fluid flow within a 20x20x10m fractured carbonate volume. We performed a time-lapse, 3D Ground Penetrating Radar (GPR) field experiment before and after a controlled water infiltration to determine the influence of fractures and deformation bands in a porous matrix on fluid flow.

The data were collected in Madonna della Mazza limestone quarry on the inner part of the Majella anticline (Italy). The survey area is in the center of the quarry floor where previously acquired 3D volumes reveal orthogonal clusters of deformation bands and fractures. A temporary polyethylene pond of 4 m diameter was sealed to the quarry floor and 3000 liters of water were infiltrated over 30 hours. As soon as there was no more standing water, the pond walls were removed and the first post-infiltration GPR survey was acquired. Overall, sixteen 3D GPR time-lapse surveys were performed with centimeter precise repeatability: 2 surveys before and 14 surveys after the water infiltration monitoring fluid flow over a period of 5 days.

The momentary wetting and draining fronts of the evolving water bulb can be resolved by the sensitivity of the GPR signal to changes in subsurface water content. Amplitude differences and event time shifts between repeat surveys visualize the wetting fronts and the preferential pathways of the fluid flow at 5 cm resolution within the 20x20x10m data volume. By extracting the intrinsic time shifts between time-lapse data volumes and using the Topp petrophysical transfer function we can quantify the watercontent changes over time and space. With a semi-transparent rendering of the watercontent change volume over the regular 3D GPR data, the hydraulically most active fractures and deformation bands can be identified together with estimates of fluid transport within these zones.