

4D GPR FOR QUANTIFICATION AND CHARACTERIZATION OF FLUID FLOW IN FRACTURED CARBONATES

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PROJECT OBJECTIVES

- Calculate volumetric water content changes and visualize wetting/drainage zones as the response to a controlled infiltration experiment in fractured carbonates.
- Compute flow rates within porous matrix and quantify influence of faults and deformation bands on flow.
- Relate flow parameters to geology: faults, deformation bands, stratigraphy, petrophysics of rock matrix.
- Compare results with Miami Oolite infiltration experiment.

PROJECT RATIONALE

Characterization of the parameters controlling fluid flow mostly relies on 0.01-0.1 m scale laboratory measurements, upscaling and modeling. To visualize and quantify fluid flow at a more realistic scale of 1 to 10 m we monitor in-situ fluid flow in response to a controlled water infiltration experiment at an outcropping fractured carbonate reservoir analog. 4D GPR is used in this study to quantify local water content changes, delineate wetting and drainage zones and determine the influence of faults and deformation bands and stratigraphy on fluid flow (Figure 1). Characterizing the dynamics of fluid flow in a porous matrix is possible because of variations detected in the GPR response between time-lapse data (Truss et al., 2007). Quantification of fluid flow within a network of faults and deformation bands helps in perfecting flow models and residual fluid recovery.

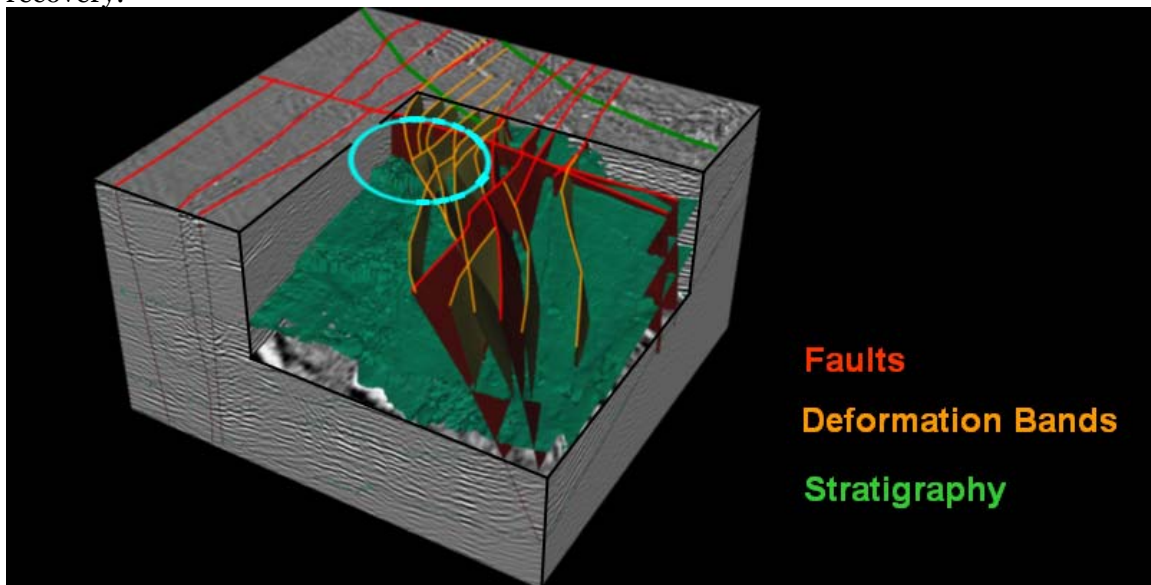


Figure 1. Three dimensional interpretation of the main geological features within the 3D GPR volume. The blue circle indicates the area where a 4 m diameter pond was installed.

APPROACH

4D GPR field data acquisition

Data were acquired at the Madonna della Mazza quarry. This quarry is cut into a sequence of Upper Cretaceous rudist grainstones (Orfento Formation) located in the Majella anticline in southern Italy. We chose the infiltration area where previously acquired 3D GPR surveys revealed the coexistence of dipping layers, faults, and deformation bands in a high porosity matrix. Average porosity and permeability are 30% and 300 mD respectively. 3000 l of water were infiltrated over 30 hours from a temporary pond with 4 m diameter installed on the quarry floor. The timelapse dataset consists of 16 repeated 3D GPR surveys (2 before and 14 after the infiltration) monitoring a 20x20x10 meter rock volume over 5 days. A 3D rotary laser positioning and guidance system coupled with a 200 MHz GPR system achieved high resolution 3D data quality and centimeter precise repeatability between surveys.

4D GPR processing method for quantification of in-situ water content changes

Event time shifts and amplitude differences between repeated surveys are related to subsurface water content changes. Figure 2 shows how GPR reflection travel timeshifts are extracted from survey pairs with a 3D warp algorithm, followed by quantification of volumetric water content changes with the Topp petrophysical transfer function (Topp et al., 1980). For a selection of infiltration stages, volumetric water content changes have already been computed with an accuracy of 1%. Results show that the momentary wetting and drainage progress faster in undisturbed host rock, compared to strata containing deformation bands (Fossen et al., 2007). We also observe how gravity driven transport of water, occurring in the initial stages of the experiment, shifts to a capillary driven transport mechanism within 12 hours.

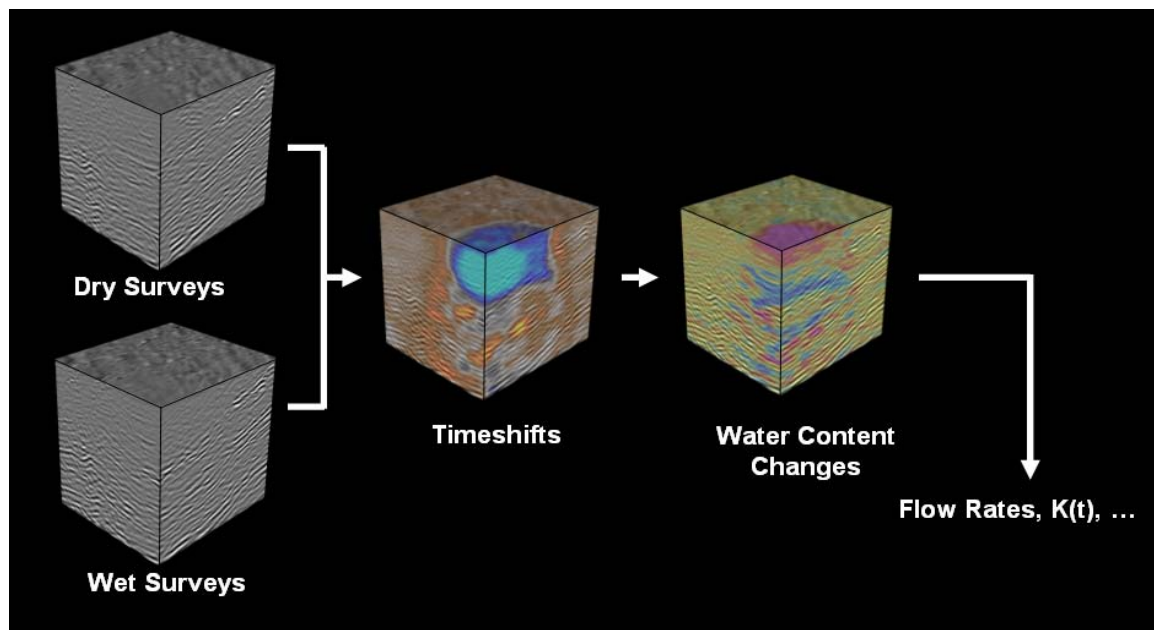


Figure 2. 4D GPR Processing workflow: Warping extracts the time shifts between pairs of time-lapse volumes. Application of the Topp petrophysical transfer function yields volumetric water content changes over time.

KEY DELIVERABLES

- *Computation of water content changes over time intervals ranging from 2 hours to 5 days after start of infiltration:* Preliminary results of water content changes suggest that such data allows the behavior of the infiltrated water mass to be described over time and space. This unique dataset will be used to reach a comprehensive visualization and quantification of fluid flow dynamics with unparalleled accuracy.
- *Comparison of flow behavior in the fractured carbonates of the Madonna della Mazza quarry with results from a similar infiltration experiment in undisturbed oolitic grainstone.* A previous GPR time-lapse experiment was performed in Pleistocene Miami Limestone. 3200 liters of water infiltrated strata with porosities ranging from 20-50% and permeabilities up to 1 Darcy (Grasmueck et al., 2007). Water propagated preferentially along dipping cemented shell hash layers, causing an asymmetric wetting bulb. There are also indications of local breakthroughs across stratigraphic boundaries likely caused by dissolution features. The comparison of the two infiltration experiments allows an assessment of the role of sedimentary structures versus structural deformation features on fluid flow.
- *Comparison of 4D GPR derived flow parameters with petrophysical plug measurements and thin sections.* In order to comprehensively capture the flow behavior of the rudist grainstone facies from the plug to the meter scale, plugs from various stratigraphic intervals will be analyzed for their porosity, permeability, velocity, and electrical resistivity.
- *Integrate Geophysical, Geological and Petrophysical Results.* The water content change volumes, propagation rates, quantification of fluid mass balance, conventional 3D GPR data and rock sample measurements characterize the stratigraphic-structural-hydraulic relationships at the Madonna della Mazza Quarry. This pilot project develops tools and workflows applicable to other outcropping reservoir analogues where a precise understanding of flow processes is needed.

REFERENCES

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