Intergration of 3D GPR and Outcrop Analysis of Solution Enhanced Fractures and the 3D Visualization of Karst Cavities by GPR (Cassis, France)

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Rationale

Characterizing fracture patterns of reservoirs in the subsurface is a challenging task that requires a good understanding of the 3D geometry and distribution of the fractures as well as the processes controlling the distribution of fractures. Fracture characterization in outcrops relies mostly on scan line measurements to capture the properties of fractures including the type, orientation, length, aperture, spacing, density and fracture termination. The inability of this technique to visualize and analyze the fracture in three dimensions, however, limits the fracture characterization using this method. Likewise the 3D distribution of karst cavities is not discernable in outcrops but is of paramount importance for fluid flow in the subsurface. This study takes advantage of newly developed high precision and high resolution 3D GPR (Grasmueck et al., 2005) to image in 3D both fractures and the karst cavities in the shallow subsurface.

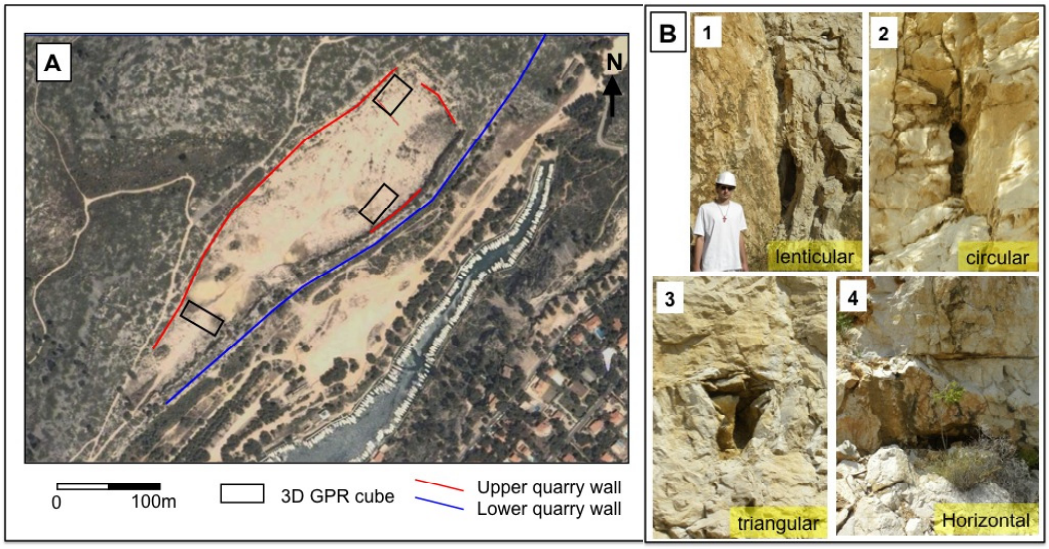

Figure 1. (A) Aerial view of the Solvay quarry near Cassis. The quarry is approximately 500m long and 100 – 200 m wide. Three 3D GPR cubes were acquired in key locations and fracture analyses were performed along the quarry walls. (B) Karst of various size and shape are observed in the outcrop mostly along fracture and bedding planes.

Scope of Work

Late Barremian shallow-water carbonates strata in the quarry located near Cassis,

France are dissected by four families of steep mostly open fractures. Many fractures are solution enhanced and karst cavities form along the fracture and bedding planes (Figure 1).
The geometry, the character and the distribution of the fractures in three dimensions are investigated in an integrated method of outcrop and 3D GPR analysis. Likewise the distribution of the karst cavities in outcrop has been documented. The next step is the integration and correlation of the different data sets to produce a comprehensive 3D characterization of the fracture and karst network (Figure 2). In addition, a stratigraphic, diagenetic and petrophysical analysis will be performed to assess the controlling factors for fracture and karst formation.

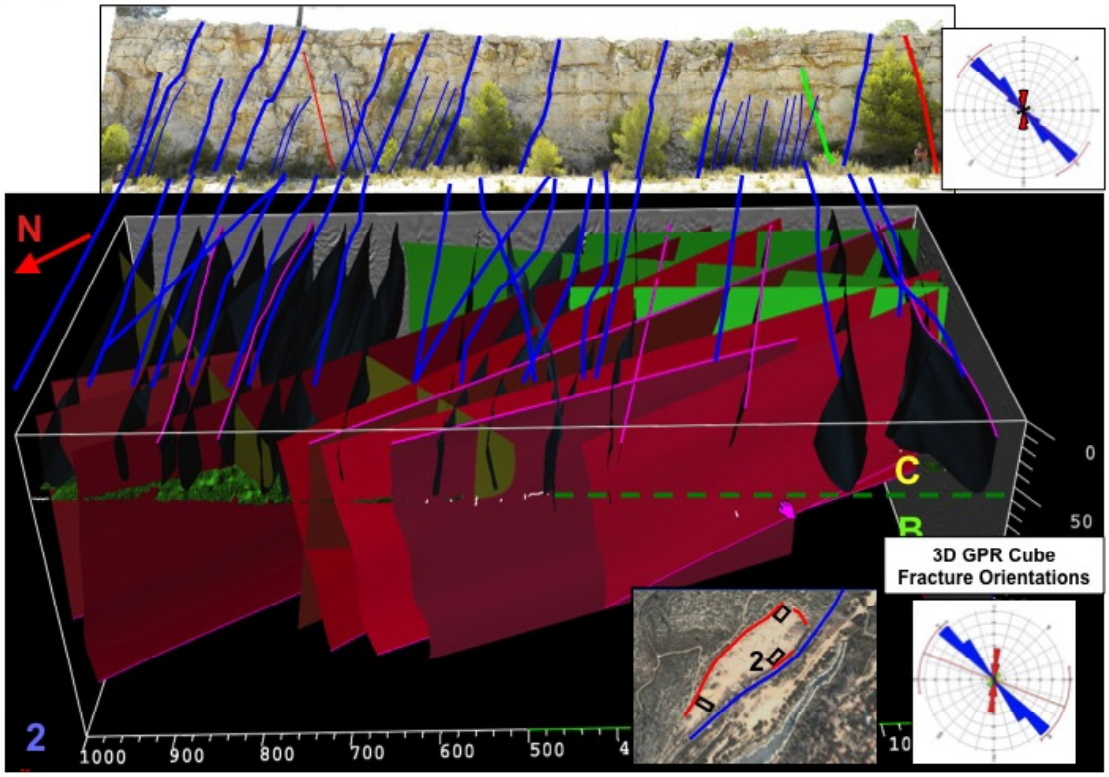

Figure 2. Comparison between fractures in 3D GPR cube 2 and the adjacent quarry wall. There is an excellent match in the orientation and the density of the fractures.

Method

Conventional scan line method is used to assess the fracture properties and 2D distribution along the quarry walls, whereby the fracture type, position, orientation, length, aperture, spacing, termination and density are recorded. Three 3D GPR cubes at key locations record the fractures and karst features in the subsurface. A processing and interpretation workflow is developed to isolate both the fractures and karst in the GPR data. Landmark 3D modeling software and its attributes are used to visualize the fractures, stratigraphy and karst features (Figure 2).

The stratigraphic sections are divided into sequence stratigraphic units surfaces correlated into the GPR data (Coll et al., 2009). Thin sections provide relevant facies and diagenetic information of the strata. Petrophysical measurements, including porosity and

both compressional wave and shear wave velocity give indications of the stiffness variations in each stratigraphic unit. Stable isotope analyses of the speleothems within the karst cavities will help assess how many different karst episodes produced the observed karst.

Key Deliverables

1. Visualization and quantification of 3D distribution of the fractures and karst in the GPR cubes.
2. Integrated outcrop-subsurface structural analysis and a comparison of the outcrop versus the GPR analysis.
3. Analysis of karst features, including their distribution in three dimensions, the timing of the karstification, and their relationship to the fractures.
4. Quantitative assessment of the karst volume within the GPR volumes.
5. Static reservoir model that takes into account the stratigraphic, fracture and karst information and the matrix porosity and fracture/karst porosity.

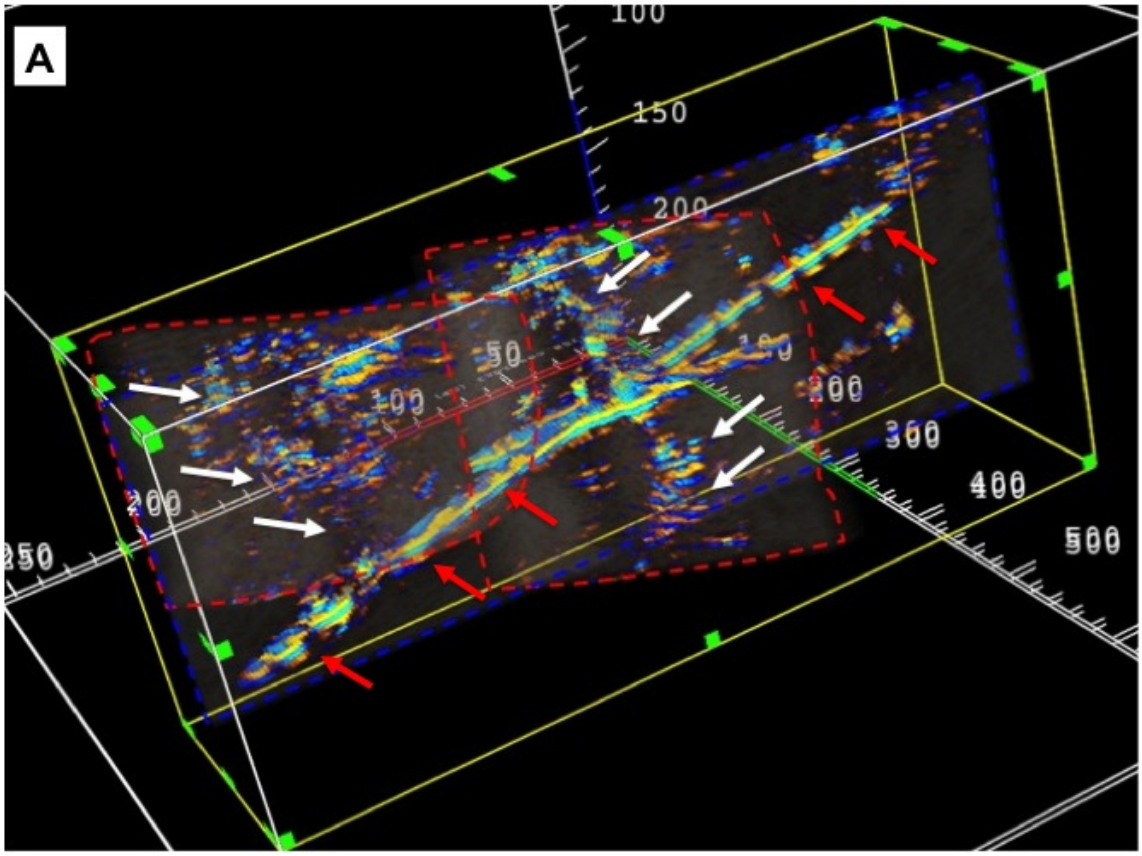

Figure 3. The fractures and karst are high-amplitude features in the GPR volumes. A semi-transparent amplitude rendering of the fracture planes displays the stratigraphic boundary (red arrows) and the karst feature (white arrows). We will develop a workflow to visualize and quantify the karst in 3D.

Expected Results

The results of this research are expected to provide a workflow for an accurate technique to characterize solution-enhanced fractures and associated karst in the outcrop

and the shallow subsurface. In addition, this data set will for the first time image the 3D distribution of fractures and the associated karst, which will allow answering questions in regards to the mutual relationship between the two processes. A good understanding of the 3D geometry and distribution of the fractures and karst will allow us to make a more comprehensive reservoir characterization of fractured limestone reservoirs.

References

Coll et al., 2009, Integration of GPR, LIDAR and conventional outcrop data for accurate multi-scale geometry in fractured reservoirs. CSL Prospectus 2009.

Grasmueck, M., Weger, R., and Horstmeyer, H., 2004, Full-resolution 3D GPR imaging. Geophysics, v. 70, p. K12–K19.