Project Objectives

The overall goal of this project is to produce a comprehensive fracture and deformation band analysis including preferential flow paths of the Cretaceous reservoir analog in the Madonna della Mazza quarry in the Maiella Mountains, Italy. This analysis will include the following tasks:

1. High-resolution 3D visualization of the strata, fractures and deformation bands using 3D Ground Penetrating Radar (GPR).
2. Integration of structural information into stratigraphic and petrophysical characterization
3. 3D fracture analysis of GPR cube using Antracking™
4. 4D GPR experiment to track and quantify fluid flow within the strata, fractures and deformation bands
5. Simulation model of the GPR volume, using a HAVANNA/ECLIPSE simulation and comparing it with the fluid flow experiment

Background and New Opportunities

This collaborative project has its foundation in the 2008 acquisition of high-resolution 3D GPR data in the Madonna della Mazza quarry. The quarry in the northeastern limb of the four-way closure Maiella anticline is a popular site for detailed structural- and fracture analysis of the Upper Cretaceous strata (Orfento Formation) and serves as an analog for mildly deformed Cretaceous hydrocarbon reservoirs.

Figure 1: (A) Part of line drawing of deformation bands on the quarry floor by Tondi et al. 2006. (B) Aerial photograph of the same area; 20 m x 20 m wide. (C) Horizontal slice at 40 cm depth through one of the 3D GPR volumes displaying the deformation bands in great detail. The yellow arrow represents the direction of GPR data acquisition.
Tondi et al. (2006) conducted a detailed analysis of the quarry’s structural features, documenting at least six sets of deformation bands that are produced either by compaction and shear strain localization, or through stylolites formed by pressure solution and subsequent shearing of these stylolites. In 2008 we tested if these deformation bands can be imaged with the GPR. Indeed, the 3D GPR surveys accurately image fractures and deformation bands in the subsurface (Figure 1). This visualization of the deformation bands gives the opportunity to investigate several fundamental aspects structural deformation at the 1-10 scale in carbonates. For the first time, the curvature and 3D geometry of the deformation bands can be analyzed and cross-cutting relationships of the different generations can be seen in space. In addition, the GPR cubes with their stratigraphic and structural information can be used as input cubes for fluid flow modeling. Finally, a fluid infiltration experiment and subsequent repeat GPR surveys can track and quantify the fluid flow in the strata, thus providing important information on the permeability characteristics of and across the deformation bands.

**Scope of Work for the Individual Tasks**

*3D visualization of the strata, fractures and deformation bands:* Six different GPR volumes using three different antenna frequencies (100 MHz, 200 MHz and 250 MHz) were acquired on the main level of the quarry (26 x 64 m). These volumes will be further processed and attributes (i.e. semblance and coherence attribute) will be applied for enhancing the visualization of fractures and deformation bands.

*Integration of structural, stratigraphic and petrophysical data:* For a comprehensive characterization of the deformed strata the stratigraphic heterogeneities and their petrophysical properties will be integrated. Petrography analysis from thin section and SEM will provide information of the diagenesis of the strata. Digital image analysis will quantify the porosity structure of the matrix. The petrophysical analyses of the matrix and deformation bands will include porosity, permeability and sonic velocity.
3D fracture analysis of GPR cube using Antracking™: This task will be performed in collaboration with Brita Graham-Wall and Paul Gillespie. The 3D analysis of the deformation bands using Petrel will provide a statistical analysis and will be used for a comparison with the outcrop-based analysis.

4D GPR experiment to characterize fluid flow: For detecting and quantifying fluid flow at the 1-10 m scale we will perform time-lapse Ground Penetrating Radar (GPR) experiments for tracking of infiltrated water at different time scales. GPR is very sensitive to changes in subsurface water content, and can therefore be used to monitor wetting and drying events in the unsaturated zone. If a 3D GPR survey is repeated with identical geometry (Grasmueck and Viggiano, 2007) changes in the GPR signatures must be due to the movement of water within the subsurface. Automated extraction of time shifts between time-lapse 3D GPR surveys and application of the Topp petrophysical transfer function (Topp et al., 1980; Huisman et al., 2003) yields the in-situ water content changes between repeat surveys. The water content change volumes are co-rendered as a semi-transparent attribute together with the regular 3D GPR data. Thus the most active flow zones can be identified and inferences can be made which stratigraphic and structural elements act as baffles or preferential flow paths. In our previous 4D GPR experiments within the Miami Oolitic Limestone, mass balancing has shown that volumetric water content change estimates from the 4D GPR method are accurate within a few percent. By decreasing the time interval between repeat surveys to 3 hrs the momentary wetting and draining fronts of the evolving water bulb could be resolved.

Figure 3: Location of the proposed ponded infiltration experiment on the Tondi et al. (2006) map (blue square). The larger stippled square is the footprint of the repeat 3D GPR surveys. To avoid GPR antenna surface coupling artefacts we will construct a temporary pond using white plastic sheets (see inset). After all water has infiltrated, the pond walls are removed and the first post-infiltration GPR survey can be recorded.
Flow simulation model of the GPR volume: This task will also be performed in collaboration with Brita Graham-Wall and Paul Gillespie. It is planned to use a HAVANNA/ECLIPSE simulation but other simulations might also been used. The model geometry will be based on the 3D structural interpretation of the GPR surveys. The initial flow model will be populated with flow properties based on rock sample and plug measurements. This model is also used to help design the 4D GPR experiment (time interval between repeat surveys and amount of water to infiltrate). Once the 4D GPR data are acquired, flow simulation and GPR derived water content change volumes can be compared for an update of the flow simulation model.

Key Deliverables

- A comprehensive data set consisting of high-resolution GPR volumes, displaying the geometry of deformation bands and strata in three dimensions.
- A stratigraphic and diagenetic analysis of the rudist grainstone facies in the quarry, including quantitative digital image analysis parameters of the pore structure.
- Petrophysical measurements of the matrix and the deformation bands.
- 4D GPR volumes that visualize the progress of wetting fronts, pinpoint the preferential pathways, and quantify the fluid mass balance over time.
- Flow simulation cubes for comparison with the 4D GPR cubes.

Expected Results

The results of this multifaceted collaborative research effort is expected to provide new and insightful information of the role of deformation bands on the fluid flow behavior in Cretaceous rudist reservoirs.

References