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GPR investigations in galleries buried inside a karstified limestone formation

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A large scientific program of geophysical investigations is presently performed inside the Low-Noise Underground Laboratory (Laboratoire Souterrain à Bas Bruit / LSBB, Rustrel, France) which is an decomissioned underground missile control center, buried in a karstified limestone formation.
One of the goals of this project is the understanding of the water circulation inside the structure. This experimental site offers a unique opportunity of perfoming measurements within an unweathered limestone massif.
The tunnel has been dug in lower cretaceous limestone which is characterized by a low clay content, high electrical resistivity. The dip is around 25 degrees and vertical faults locally affect the structure. The studied zone is located in south-eastern France (Provence) and is characterized by a mediterranean climate with long dry periods and strong, short events of rain. This phenomenon induces large variations of water content within the karstified limestone from dry to saturated conditions.
Analysis of the spatial and temporal variations of the water flow in a karstified limestones needs to define the geological context and the adequate geophysical methods. GPR offers a good tradeoff between resolution and ease of use on one hand and investigation depth on the other hand.
We present some GPR profiles which have been acquired in April 2008 after a quite long and strong period of rain, inducing a complete water saturation inside the karstified massif. We used several RAMAC shielded antennas from 100 to 500 MHz.
The longest profile is around 600 m long, with a 20 cm spacing, running from a raw to a concrete gallery. These data sets are characterized by a very good signal to noise ratio and a signal penetration, up to 18 meters.
Signal processing includes very low frequency filtering, amplitude compensation, keeping lateral relative attenuation and ringing suppression. Final sections includes migration and time to depth conversion or depth migration. The estimated resolution is centimetric to decimetric and matches the required geologic accuracy.
These data allow us to accurately map the stratigraphy of the surrounding rocks across the concrete walls of the tunnel.Using thes results the location of 5 vertical drillings has been determined. Future acquisition including standard borehole measurements (gamma-ray, resistivity, sonic, etc ...) will be performed in the boreholes as well as GPR vertical profiling and surface to borehole measurements.
In order to monitor the water content, 50 meters of the raw gallery have been investigated with multi offset 250 Mhz shielded antennas. Using this data set, we obtain a detailed 2D velocity model down to 10 to 12 meters. The minimum offset of the data is 18 cm, using a single 250 MHz RAMAC antenna up to 9 meters using the transmitter of a shielded antenna and the receiver of an other one. We compare pre stack depth migration approach and DMO/NMO velocity analysis. First results show that the velocity range from 6 to 8 cm/ns. Porosity can be estimated from GPR velocity : in the usual frequency radar range and for good dielectric material, the radar wave velocity can be approximated by a relation depending only of the wave velocity in free space and the dielectric constant of the investigated medium. This dieclectric constant is itself strongly dependant of the volumetric water content in the medium. The estimation of water content is finally estimated using the usualy well-known polynomial function proposed by Topp.
Future GPR acquisitions, including measurements along the 3 available kilometers of gallery, should be performed during this year, in order to compare the 2D velocity model determined with data acquired when water conditions are dry. This comparison will allow us to compare the water spatial distribution of water containt variations and, finally, to better characterize the karstified context of this massif.