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Petroacoustic characterization of fractured and weathered limestone from the O-ZNS Critical Zone Observatory

Abdoul Nasser Yacouba¹, Céline Mallet¹, Jacques Deparis², Philippe Leroy², Gautier Laurent¹, Mohamed Azaoural^{1,2}, and Damien Jougnot³

¹Université d'Orléans, CNRS, BRGM, ISTO, UMR 7327, F-45071, Orléans, France

²BRGM, Orléans, France

³Sorbonne Université, CNRS, EPHE, UMR 7619 METIS, F-75005 Paris, France

In a context of energy transition and water resources crisis, studying the fluid flow in the critical zone appears to be a major issue. The O-ZNS (Observatory of transfers in the Vadose Zone, Orleans, France) site has been designed for the development of innovative tools that can characterize and monitor the dynamics of the vadose zone (VZ). The geological structure of this VZ is composed mainly by a lacustrine limestone formation located between 10 and 20 m-deep, characterized by multiscale heterogeneities (facies variations, presence of cracks, fractures, pores, cavities and karstification). In order to predict fluid flow, heat transfer, and aquifer recharge through this VZ, the limestone heterogeneities have to be integrated into geological concepts and numerical models.

This study is a key part of the O-ZNS project, as it aims at (i) understanding and classifying the microstructural and petrophysical properties at laboratory scale; (ii) predicting these properties through quantitative geophysical parameters and; (iii) developing new geophysical interpretations through coupled approaches.

From well logs analysis of O-ZNS site, we collected limestone samples from four main facies (with four samples per facies). We performed a state-of-the-art petrophysical characterization including connected and total porosity, density, and permeability measurements. Then we carried out acoustic measurements on dry and water-saturated plugs (2.5 and 4 cm diameter) with P- and S-waves at two frequencies 0.5 and 1 MHz.

The measurement results show a large dispersion of the petrophysical properties. For example, connected porosity ranges from 4 to 12 %, and density from 2,3 to 2,5 g/cm³. This dispersion of petrophysical properties is interpreted in terms of heterogeneity of the type of porosity (micro to cm pore size, presence of cracks and fracture) and mineralogy. However, it appears that the deepest facies (located at the aquifer level) is more homogenous and shows the highest porosity. This is consistent with directly observed (micro)structure from 3D sample and well scans.

Acoustic velocity results show coherent values for fractured limestone rocks. The different facies show dispersion, such as V_p varying from 4950 to 5600 m/s for the shallowest facies at 9 m-deep.

Here also, the deepest facies appears to be the most homogeneous with the lowest velocities (around 4875 m/s). Thus, velocities are consistent with the petrophysical measurements and one can draw a simple relationship between the porosity, density and acoustic velocities. However, other petroacoustic relationships are necessary to better discriminate between each facies and therefore predict their microstructure and transport properties.

The following step of this work is to add electric measurements and develop petro-acoustico-electrical models and enhance our capacity to upscale these properties from the laboratory to the field.