Combining Ground-Penetrating Radar profiles with geomechanical and petrophysical in situ measurements to characterize sub-seismic resolution structural and diagenetic heterogeneities in porous sandstones (Northern Apennines, Italy)

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Deformation bands and structurally-related diagenetic heterogeneities, here named Structural Diagenetic Heterogeneities (SDH), have been recognized to affect subsurface fluid flow on a range of scales and potentially promoting reservoir compartmentalization, altering flow paths, influencing flow buffering, and sealing during production. Their impact on reservoir hydraulic properties depends on many factors, such as their permeability contrast with respect to the undeformed reservoir rock, their anisotropy, thickness, geometry as well as their physical connectivity and arrangement in the subsurface. Deformation bands offsets (from a few mm to 20-40 mm) and diagenetic heterogeneities (carbonate nodules) dimensions (from 0.2 to 15 m in length; from 0.1 to 1.0 m in thickness) make them SDH below seismic resolution.

We used Ground Penetrating Radar (GPR) for detection and analysis of the assemblage “deformation bands - carbonate nodules”, in high-porosity arkose sandstone of the Northern Apennines (Italy). Petrophysical (air-permeability) and mechanical (uniaxial compressive strength) properties of host rock, deformation bands, and calcite-cement nodules were evaluated along a 30-meters thick stratigraphic log to characterize the permeability and strength variations of those features. 2D GPR surveys allowed the description of the SDH spatial organization, geometry, and continuity in the subsurface. The assemblage “deformation bands – nodules” decreases porosity and permeability and produces a strengthening effect of the rock volume, inducing a strong mechanical and petrophysical heterogeneity to the pristine rock. Different textural, petrophysical, and geomechanical properties of deformation bands, nodules, and host rock result in different GPR response (dielectric permittivity; instantaneous attributes). We show that GPR can be useful to characterize variations in petrophysical and geomechanical properties other than characterize the geometry and spatial distribution of flow baffles and small-scale flow barriers in the subsurface such as deformation bands and cement-nodules. GPR showed its worth as a high-resolution and non-invasive tool to extend outcrop information (petrophysical and geomechanical data) to 3D subsurface volumes in a way to reconstruct realistic and detailed outcrop analogues. Such potential could be critical in assisting and improving the characterization of SDH networks in the study of faulted aquifers and reservoirs in porous sandstones.