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The influence of hydrocarbons in changing the mechanical and acoustic properties of a carbonate reservoir: implications of laboratory results on larger scale processes

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Understanding hydraulic and mechanical processes that acted in reservoir rocks and their effect on the rock properties is of a great interest for both scientific and industry fields. In this work we investigate the role of hydrocarbons in changing the petrophysical properties of rock by merging laboratory, outcrops, and subsurface data focusing on the carbonate-bearing Majella reservoir (Bolognano formation). This reservoir represents an interesting analogue for subsurface carbonate reservoirs and is made of high porosity (8 to 28%) ramp calcarenites saturated by hydrocarbon in the state of bitumen at the surface.
Within this lithology clean and bitumen bearing samples were investigated. For both groups, density, porosity, P and S wave velocity, at increasing confining pressure and deformation tests were conducted on cylindrical specimens with BRAVA apparatus at the HP-HT Laboratory of the Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Rome, Italy.
The performed petrophysical characterization, shows a very good correlation between Vp, Vs and porosity and a pressure independent Vp/Vs ratio while the presence of bitumen within samples increases both Vp and Vs. P-wave velocity hysteresis measured at ambient pressure after 100 MPa of applied confining pressure, suggests an almost pure elastic behaviour for bitumen-bearing samples and a more inelastic behaviour for cleaner samples. Calculated dynamic Young's modulus is larger for bitumen-bearing samples and these data are confirmed by cyclic deformation tests where the same samples generally record larger strength, larger Young's modulus and smaller permanent strain respect to clean samples. Starting from laboratory data, we also derived a synthetic acoustic model highlighting an increase in acoustic impedance for bitumen-bearing samples. Models have been also performed simulating a saturation with decreasing API° hydrocarbons, showing opposite effects on the seismic properties of the reservoir respect to bitumen.
In order to compare our laboratory results at larger scale we selected 11 outcrops of the same lithofacies of laboratory samples both clean and bitumen-saturated. Fractures orientations, from the scan-line method, are similar for the two types of outcrops and they follow the same trends of literature data collected on older rocks. On the other hand, spacing data show very lower fracture density for bitumen-saturated outcrops confirming laboratory observations.
In conclusion, laboratory experiments highlight a more elastic behaviour for bitumen-bearing samples and saturated outcrops are less prone to fracture respect to clean outcrops. Presence of bitumen has, thus, a positive influence on mechanical properties of the reservoir while acoustic model suggests that lighter oils should have an opposite effect. Geologically, this suggests that hydrocarbons migration in the study area predates the last stage of deformation giving also clues about a relatively high density of the oil when deformation began.