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Mechanical compaction, microstructures and physical properties in two highly porous carbonate rocks

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Recent field observations documented that fault development in high porosity carbonates can occur through the growth and coalescence of mm to cm scale deformation bands. In order to investigate the micromechanics underlying the development of compaction localization in high porosity carbonate rocks, we conducted a systematic experimental study on two very porous grainstones from Majella mountain (Central Appenines, Italy) and Saint Maximin sur Oise (France) with porosities of 30% and 35%, respectively. Hydrostatic and conventional triaxial experiments were performed on samples of 20 mm diameter and 40 mm length in nominally dry conditions. The samples were deformed at room temperature, constant strain rate and at confining pressures between 3 and 50 MPa. The microstructure of intact and deformed samples was characterized using mercury porosimetry, specific area measurements and petrophysical attributes like AMS (anisotropy of magnetic suceptibility) and APV (anisotropy of P wave velocity) have been estimated. Microstructural observations and chemical analyses were also performed through a state of the art high resolution thermal field emission scanning electron with resolution up to 1.5 nm designed to collect electrons from the gun more efficiently than traditional SEM. The analysis of intact samples revealed that Saint Maximin grainstone contained a significant amount of Si and Al, while Majella grainstone is mainly made of $CaCO_3$. Our new mechanical data showed that both rocks are relatively weak and confirmed that porosity played a major role in the strength of porous carbonates. Under hydrostatic conditions, the onset of grain crushing and pore collapse occurred at confining pressures of 17 MPa for Majella and 37 MPa and Saint Maximin. Shear-enhanced compaction and a wide variety of failure modes were observed with increasing confining pressure in both rocks. Compactive shear bands developed in both grainstones at low confining pressures. These compactive bands were always oriented at low angles and typically had a thickness of a few grains. Extensive grain crushing and pore collapse were observed inside the compactive shear bands, while significant less damage was visible on the host rock. A different spatial distribution of damage was found by increasing confining pressures. Cataclastic flow was the main mechanism in Majella grainstone, while compaction localization was a persistent pattern in St. Maximin even at relatively higher pressures. In most cases, subhorizontal bands developed in this rock at confining pressures above 10 MPa. The geometric attributes of these bands have been compared with recent observations of compaction bands in porous sandstones.