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Micromechanics of inelastic compaction in micritic and allochemical limestones

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Previous studies on the transition from brittle faulting to cataclastic flow in carbonate rocks revealed that while compact carbonate rocks display appreciable dilatancy when undergoing cataclastic flow, inelastic compaction was observed in their more porous counterparts. In their compactive behavior the porous carbonate rocks are more akin to porous siliciclastic rocks such as sandstone. Whilst for sandstone the micromechanics of inelastic compaction and cataclastic flow have been studied extensively, little is known about these processes in porous limestone.

To fill this gap we performed experiments on Tavel, Indiana and Majella limestones with respective porosities 10-14%, 16-18% and 31%. Tavel limestone is a micritic limestone with a small number of sparry grains embedded in a microcrystalline matrix. Indiana and Majella limestones are allochemical limestones. In Indiana limestone allochems (fossils, ooids and peloids) form some 65% of bulk volume. In Majella limestone the allochems (represented by rudist fragments) have grain size somewhat smaller than that in Indiana limestone and form about half of the bulk volume. Samples of the three rocks were deformed in a conventional triaxial apparatus at confining pressures up to 150 MPa. Samples were loaded to various stages of deformation and microstructures associated with the damage evolution were investigated using optical and scanning electron microscopy. For a reference, a study on an intact sample and a sample deformed under hydrostatic conditions was also performed on each rock.

Despite the phenomenological similarities between cataclastic flow in siliciclastic rocks and porous carbonate rocks, we showed that the micromechanics can be very different. In a clastic rock such as sandstone, inelastic compaction derives primarily from grain crushing initiated by stress concentrations at grain contacts that induce cracks to radiate in a conical pattern towards the interior of the impinging grains. In contrast, inelastic compaction in the micritic Tavel limestone is associated with pore collapse that seems to initiate from stress concentrations at the surface of an equant pore, which induce a ring of localized cataclastic damage in its periphery. Damage appeared to develop preferentially around the macropores. While our observations for Indiana and Majella limestones suggested that the micromechanical process is qualitatively similar, they also showed that the spatial distribution of damage in the allochemical limestones can be complicated by its uneven partitioning among the allochems, micrite and sparite. In Indiana limestone, many allochems remain relatively intact even after the cement has undergone significant microcracking and fragmentation, with the implication that significant strength contrast exists between the allochems and cement. In Majella limestone, the asymmetry in damage intensity is not as pronounced, suggesting a less pronounced mechanical contrast between rudist shells and cement. In the three limestones, significant mechanical twinning was observed in samples deformed to relatively high level of non-elastic strain. Motivated by the microstructural observations a new model has recently been developed, that treats a limestone as a dual porosity medium, with the total porosity partitioned between macroporosity and microporosity.