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Micromechanics of dilatancy and compaction in basalt

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Understanding how the strength of volcanic rock varies with stress state, pressure and microstructural attributes is fundamental to understanding the mechanics of faulting in volcanic areas. This is particularly important for example in the context of Mt Etna volcano edifice, made from a pile of lava flows affected from repeated episodes of localized deformation leading to the formation of eruptive fracture systems that fed lava flows.
In this study we investigated the micromechanics of deformation and failure in basalt, focusing on Mt Etna's basalt. Several blocks were sampled from a quarry on the western flank of the volcano. The basalt is made of mm-sized phenocrystals of pyroxene, olivine and feldspar in a fine-grained groundmass. Our samples covered a porosity range between 4 and 16%. Microstructural observations of the intact material revealed the presence of thin cracks (probably formed during the rapid cooling of the lava) and variable concentrations of quasi-spherical voids formed during degassing.
We performed 23 conventional triaxial experiments on water saturated samples in drained conditions at confining pressures between 20 and 160 MPa and with 10 MPa of pore pressure. In this pressure range, dilatancy and brittle faulting were observed in all samples with porosity less than 5%. Shear-enhanced compaction was however observed at effective pressures as low as 80 MPa in samples of 8% porosity. Our new mechanical data also revealed the complex impact of the phenocrystal concentrations on mechanical strength of basalt from Mt Etna.
We also performed 20 uniaxial compression tests on the whole porosity range. We observed that the UCS of Etna basalt decreases by more than a factor 5 when porosity increases from 4 to 16%.
Systematic microstructural analysis performed on deformed samples revealed that in the tight end-members, stress-induced microcracks and their coalescences predominately occurred in the grand mass and were probably responsible of the development of dilatancy and shear localization. This scenario is well captured by the sliding wing crack model. The more porous basalt could however be treated as a dual porosity medium made up of macropores isolated in an effective medium containing preexisting microcracks. At high effective pressures, shear-enhanced compaction was therefore the results of cataclastic pore-collapse as it has been recently observed in porous limestone and tuff.