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Compaction localization in porous limestone studied by 4D synchrotron X-ray imaging

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An understanding of the failure and strain localization in a porous rock is of fundamental importance in poromechanics and rock physics. Confined compaction experiments on porous limestones and sandstones have revealed a broad spectrum of failure modes. Techniques such as acoustic emission location and velocity tomography provide kinematic information on the partitioning of damage and localization of strain. Complementary observations on deformed samples using microscopy and Computed microTomography (microCT) can also be used to image microscale damage and its distribution. Only by synthesizing such measurements on multiple scales could one infer the multiscale dynamics of compaction localization.
Located at the European Synchrotron Radiation Facility (ESRF beamline ID19), the HADES rig is a miniature triaxial rig that is transparent to the high flux of X-rays produced by a synchrotron, which allows direct in situ 3D imaging of the whole rock sample as it is subjected to increasing differential stress, at confinement up to 100 MPa and pore pressure up to 100 MPa. With a spatial resolution of 6.5 microns, the microCT data provide an integrated perspective of the spatiotemporal evolution of damage and strain localization on scales ranging from grain to continuum.
We conducted an experiment on a sample of Leitha grainstone, a carbonate of middle Miocene age from the Vienna Basin (Austria) with an initial porosity of 27%, in nominally dry conditions at a confining pressure of 20 MPa. With increasing differential stress, the sample strain hardened and two distinct yield points can be identified in the stress-strain curve. Given the relatively simple mineralogy (100% calcite) the CT images can readily be segmented into solid grains and pore space. The spatiotemporal evolution of local porosity and damage were analyzed at multiple scales. At an intermediate scale of 10 voxels (65 microns), the time-lapse microCT images reveal the strain partitioning associated with the first yield point and development of strain localization with the second. The latter development of three discrete compaction bands is the first unambiguous observation of such a bifurcation phenomenon in a porous carbonate rocks. The CT data on the voxel scale elucidate in refined details the nucleation and propagation of a discrete compaction band under quasi-static loading, as well as the micromechanical processes, which in the past can only be inferred from a synthesis of kinematic observations of AE activity and post-mortem observations of microstructure and damage.