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Microfracture evolution leading to catastrophic failure observed by hearing and seeing

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Catastrophic failure is a critical phenomenon present in Earth systems on a variety of scales, and is associated with the evolution of damage leading to system-size failure. Laboratory testing of rock failure permits characterization of fracture network evolution at the micro-scale to understand the interaction of cracks, pores and grain boundaries to an applied stress field, and the relationship between deformation and seismic response. Previous studies have relied on acoustic emissions (hearing) or X-ray imaging (seeing) to study the process of localization, which involves spontaneous self-organization of smaller cracks along faults and fractures on localised zones of deformation. To combine hearing and seeing of the microscopic processes and their control of system-sized failure, a novel x-ray transparent cell was used for deformation experiments of rock samples, which permits integration of acoustic monitoring with fast synchrotron x-ray imaging. To increase temporal characterization of damage beyond the temporal resolution of the fast 3D synchrotron system, acoustic emission (AE) feedback control was used to regulate the applied stress and slow down the deformation processes. As a result, there is increased temporal resolution of the incremental deformation between successive x-ray scanned states allowing synchronized comparison of acoustic emissions to x-ray scans. Here, we present the seismic analysis used to characterize the velocity evolution of the rock samples, and the location and characteristics of individual AE events in relation to microscopic deformation processes. Time-lapse velocity measurements are linked to internal stress changes and structural damage corresponding to seismic and aseismic deformation processes, while acoustic emissions are a direct indication of local cracking. We show that we can successfully locate AE events in 3D using only two sensors on either end of the sample, based on ellipsoid mapping, and x-ray image to event correlation. We explore temporal and spatial statistics of AE signatures and how those are linked to the strain field in the samples measured with incremental digital volume correlation between pairs of recorded x-ray tomograms. The direct observation of AE and X-ray images enables quantification of relevant seismic (local cracking leading to AE) to aseismic (elastic loading and silent irreversible damage) processes, with information extracted over fine temporal resolution throughout the deformation

process through the AE-feedback control.