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Space and time damage evolution during the prenucleation of shear failure in rocks

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Precursory signals to large earthquakes include foreshocks, increase or decrease of seismic velocities, or variations of the chemistry of spring waters. As stresses build-up at depth before rupture, these precursors may have different origins, from the formation of microfractures, to creep in the nucleation zone, or modifications of flow paths. However, these precursors are not observed for all earthquakes, making challenging their use to predict their occurrence. On the one hand, rocks show various degrees of heterogeneities at the microscale; on the other hand similar stress-strain curves are measured when approaching rupture under compression in laboratory experiments: an elastic domain is followed by a deviation from elasticity as stress is increased towards failure. Based on these field and laboratory observations, the question arises then why, despite similar stress-strain curves, rocks may show different precursors before failure. We have performed a series of laboratory experiments where various rocks (limestone, sandstone, monzonite, marble) where deformed until shear failure at conditions relevant for earthquake nucleation. Using an X-ray transparent triaxial rig installed at the European Synchrotron, the evolution of damage (microcracks, fractures, pore collapse) before failure can be imaged in-situ by X-ray microtomography. We show that, before failure, the density of these damage events can either increase, decrease, or remain constant. The reason is that two mechanisms are competing at the microscale: the formation of microcracks that decreases rock density due to dilatancy, and the collapse of pores or voids that increases rock density towards failure. The competition between these two mechanisms depends on the nature of the host rock and controls how seismic velocities and fluid flow paths evolve prior to failure. These data show, for the first time with high time and space resolution, the nature of the precursory signals before rupture, with implications on the search of earthquake precursors.