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Time dependent evolution of elastic properties in fault damage zones: Insights from experiments in Carrara Marble

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The slip behaviour of faults is controlled by the mechanical properties of the surrounding rocks. Mechanical properties of fault rocks are time-dependent, and can vary rapidly during and after earthquakes, due to damage creation, healing or fluid flow. Variations in elastic properties of damaged rocks over the seismic cycle are expected to impact the deformation around fault zones and its surface manifestations, notably in the early post-seismic stage.
In particular, seismological studies have shown that seismic wave velocities (and therefore elastic moduli) tend to drop during earthquakes and recover in the post-seismic period (e.g., Froment et al., 2014). While a growing number of geophysical studies report such time-dependent variations, the underlying physical mechanisms remains poorly understood.
In order to constrain the microscale processes responsible for time-dependent variations in elastic properties of damaged rocks, we conducted experiments to simulate damage generation and recovery under controlled laboratory conditions. Specifically, we investigated the evolution of elastic wave velocities following deformation episodes in Carrara Marble under constant stress conditions. Dry Carrara Marble cores were deformed in the ductile regime (Pc = 40 MPa) up to 3% axial strain. After deformation, samples were held at constant stress conditions for extended periods of time (5-8 days) whilst continuously recording volumetric strain and seismic wave velocities. The velocity data were used to invert for microcrack densities using an effective medium approach. Finally, thin sections were produced to characterise the microstructures after recovery.
During deformation, elastic wave speeds decreased with increasing strain by more than 30% of the value for the intact rock due to the formation of distributed microcracks. Under constant hydrostatic pressure, wave speeds progressively recovered 12–40% of the initial drop, depending on the applied confining pressure. Tests performed under nonhydrostatic (triaxial) stress conditions during recovery showed some time-dependent creep deformation together with very significant recovery of wave velocities.
The recovery is interpreted as a progressive reduction in crack density within the sample. The process is highly dependent on confining pressure, which favours it. We propose that the driving process for wave speed recovery is the time-dependent increase of contact area between microcrack surfaces due to the formation and growth of asperity contacts increasing the elastic moduli of the medium.
Our study shows that the elastic properties of damaged rocks recover by up to several tens of percent over a few days after deformation, even under constant stress conditions. The timescale and amplitude of recovery measured in our experiments are consistent with seismological observations.