Seismologic estimates of energy flow during dynamic rupture: Benefits of laboratory settings to understand up-scaling processes

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Understanding the mechanisms that describes how stored elastic strain energy feeds dynamic rupture on faults and in rock is not well understood. Over the last decades, phenomenological models have developed a framework that describes how the available energy flows into energy sinks, such as, anelastic processes (friction, damage, and plastic strain) and radiated waves. Feedback between the source and sinks determines characteristic of rupture growth that are quantified in terms of source properties. Seismological studies have – through a myriad of assumptions – been able to use simplified spectral models to estimate source properties from the radiated waves. These estimates have been useful in determining dynamic source properties for smaller to moderate-sized earthquakes that are not well-constrained due to frequency limitations of seismic instruments and wave propagation effects.

In this study, we further extend the lower end of seismologic observation to the laboratory-scale. We detail critical methodologies that allow for the correct calculation of source extent parameters, i.e. magnitude, source radii, stress drop, radiated seismic energy and fracture energy, using both P and S waves in the laboratory setting. We compare the source parameters from 16 studies that employ similar methods at scales ranging from laboratory to mining to natural scales. At first glance, event magnitude ($-9 < M_w < -7.5$) and corner frequencies (f_{cP}, f_{cS}) were found to scale to natural earthquakes and scale independence in stress drop ($\Delta\sigma$) was also observed. However, the typical empirical scaling relationship between coseismic slip and fracture energy ($_c \propto u^{nG}$; $nG = 1.28$) appears to breakdown with relationships estimated for the mining- ($nG = 1.86$) and laboratory-scales ($nG = 2.33$).

We propose that this break in scaling may be related to the level of rock volume that is available as an energy sink during the dynamic rupture process. It may be that ratio of surrounding volume of host-rock (that stores energy) to the volume of sinks differs from scale to scale. We offer two physical explanations for this: (1) the volume of energy sinks increases in the presence of off-fault structures and fault core damage, which may differ from lab-to-mining-to-natural settings and (2) temperature-driven mechanisms, such as anatomizing shear bands with limited Hertzian damage, could increase the volume of energy sinks available for rupture in hotter environments. More complex rupture simulations, which take into account both off- and on-fault anelastic processes might be useful in reconciling the break in scale observed here. Improving our understanding of energy feedback related to dynamic ruptures processes will help to better constrain seismic hazard (e.g. GMPEs) and can be useful in engineering activities where induced or triggered earthquakes are present.