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# Imaging damage zones and fault growth processes with high-precision relocations of earthquake sequences.

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The architecture of fault damage zones combines various elements. Halos of intense fracturing forms around principal slip planes, possibly resulting from the shearing of slip surface rugosity or from dynamic stresses caused by earthquake ruptures. Splays forming off the tips and off the edges of a growing fault result in larger scale fracture networks and damage zones. Faults also grow by coalescence of en-echelon segments, such as Riedel fractures in a shear zone, and stress concentration at the steps results in linking damage zones. We show that these various elements of a shear-crack system can be recognized at seismogenic depth in earthquake sequences. Here we examine high-precision, absolute earthquake relocations for the Mw5.7 Magna UT, Mw6.4 Monte Cristo CA and Mw 5.8 Lone Pine CA earthquake sequences in 2020. We use iterative, source-specific, station corrections to loosely couple and improve event locations, and then waveform similarity between events as a measure for strongly coupling probabilistic event locations between multiplet events to greatly improve precision (see presentation EGU21-14608, and Lomax, 2020). The relocated seismicity shows mainly sparse clusters of seismicity, from which we infer multi-scale fault geometries. The uncertainty on earthquake locations (a few hundred meters) is typically larger than the width of halo damage zones observed in the field so that it is not possible to distinguish small aftershocks that could occur on a fracture within the halo or on a principal slip plane.

The relocated Magna seismicity shows a west-dipping, normal-faulting mainshock surface with an isolated, mainshock hypocenter at its base, surrounded up-dip in the hanging wall by a chevron of complex, clustered seismicity, likely related to secondary fault planes. This seismicity and a shallower up-dip cluster of aftershock seismicity correspond to clusters of background seismicity. The Lone Pine seismicity defines a main, east-dipping normal-faulting surface whose bottom edge connects to a steeper dipping splay, surrounded by a few clusters of background and reactivated seismicity. The space-time relation between background seismicity and multi-scale, foreshock-mainshock sequences are clearly imaged. The Monte Cristo Range seismicity (Lomax 2020) illuminates two, en-echelon primary faulting surfaces and surrounding, characteristic shear-crack features such as edge, wall, tip, and linking damage zones, showing that this sequence ruptured a complete shear crack system. In this example the width of the damage zone increases toward the earth surface.  Shallow damage zones align with areas of dense surface fracturing, subsidence and after-slip, showing the importance of damage zones for shaking intensity and earthquake hazard.

For all three sequences, some of the seismicity clusters delineate planar surfaces and concentrate along the edges of the suspected main slip patches. Other clusters of seismicity may result from larger scale damage associated with splay faults, en-echelon systems and linking zones, or with zones of background seismicity reactivated by stress changes from mainshock rupture. These types of seismicity and faulting structures may be more developed in the case of a complex rupture on an immature fault

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Lomax (2020) The 2020 Mw6.5 Monte Cristo Range, Nevada earthquake: relocated seismicity shows rupture of a complete shear-crack system. https://eartharxiv.org/repository/view/1904