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Principal Slip Zones in Carbonate: Microstructural Characterization and Implications for the Seismic Cycle

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Main shocks in central Italy, such as the L'Aquila Mw 6.3 earthquake on 6 April 2009, and associated foreshock and aftershock sequences, often nucleate within, and rupture through, carbonate-bearing rocks within the upper-crust. One way to understand the mechanical behaviour of such rocks during the passage of earthquake ruptures is to study the Principal Slip Zones (PSZs) of exhumed faults. The PSZs are thought to accommodate a majority of displacement during individual earthquake slip events, and potentially contain a rich variety of information about earthquake-related processes and, more generally, deformation mechanisms throughout the seismic cycle. At present, however, there are no reliable microstructural or geochemical indicators of seismic slip in carbonate rocks.

We present detailed field and microstructural observations of the PSZs of large-displacement, seismically active normal fault zones in the central Apennines of Italy. The fault zones are exhumed from <3km depth and cut 3-5km thick sequences of platform limestone. Samples were collected from individual PSZs containing polished slip surfaces with both small (centimetres to metres) and large (metres to hundreds of metres) displacements, including the main PSZ that defines the active Quaternary fault scarp. Small displacement slipping zones are characterized by typical cataclastic fabrics, including angular grains cross-cut by brittle fractures, and a gradual decrease in grain-size towards the polished slip surface. In contrast, large-displacement slipping zones always contain a continuous, texturally-distinct layer up to 2-3mm in thickness that lies immediately beneath the polished slip surface. This layer is itself internally zoned; up to 6 distinct zones can be present, each between 200-300μm in thickness, and recognized on the basis of grain-size, colour, and textural variations. In some cases, the zones developed at the expense of one another. 100-200μm-thick, syn-tectonic calcite veins suggests fluid involvement in faulting. Some of the zones display compelling microstructural evidence for fluidization. For example, relatively large host rock clasts appear to have impeded movement of smaller clasts only on their up-dip side, resulting in imbrication much like that observed during bedload transport at the base of river systems. On their down-dip side the presence of small piles of clasts suggests a decrease in energy and settling towards the base of a fluid medium. Commonly, the zone closest to the polished slip surface contains sub-spherical grains consisting of a central (typically angular) clast surrounded by a cortex of ultra-fine grained calcite. The cortex can display concentric or lensoid internal laminations and appears to have developed by progressive aggregation of matrix material. The sub-spherical grains closely resemble those produced in fluid-saturated high-velocity friction experiments, and other humid high-energy environments such as ignimbrite flows and the basal décollements of mega-landslides.

We suggest that the microstructures observed in the texturally-distinct layers adjacent to high-displacement slip surfaces result from transiently high fluid pressures and fluidization of fault rock materials, possibly during the passage of seismic ruptures. Future work will include precisely determining the mineralogy and structure of the slip surfaces using XRD, TEM and EBSD analyses, and comparing the natural slip-surface microstructures to those produced experimentally over a wide-range of slip speeds and normal stresses. For the latter, we will use the recently installed high-velocity rotary shear apparatus at INGV in Rome.