Fossil Earthquakes in Limestone? Natural "Clast-Cortex Grains" and Constraints from Low- to High-Velocity Friction Experiments

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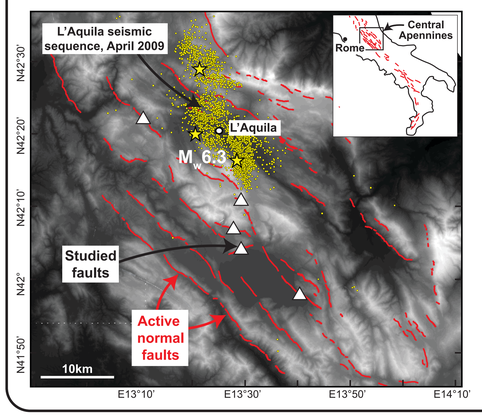
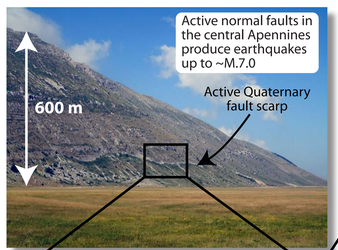
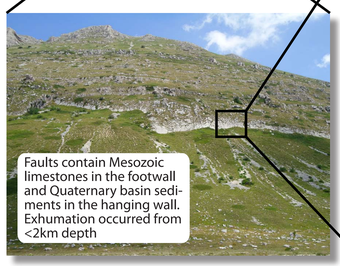
1. Introduction

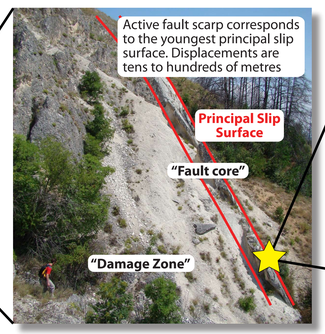
Many destructive earthquakes in Italy, and in other areas of central Europe, nucleate within and propagate through carbonates. During individual ruptures, a majority of displacement is accommodated by thin "principal slip zones". We are studying the principal slip zones of seismically active normal faults in the central Apennines, and comparing the natural microstructures to those produced in deformation experiments to gain a better understanding of fault mechanics.

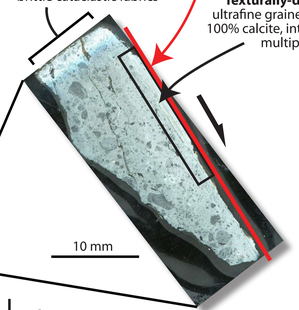




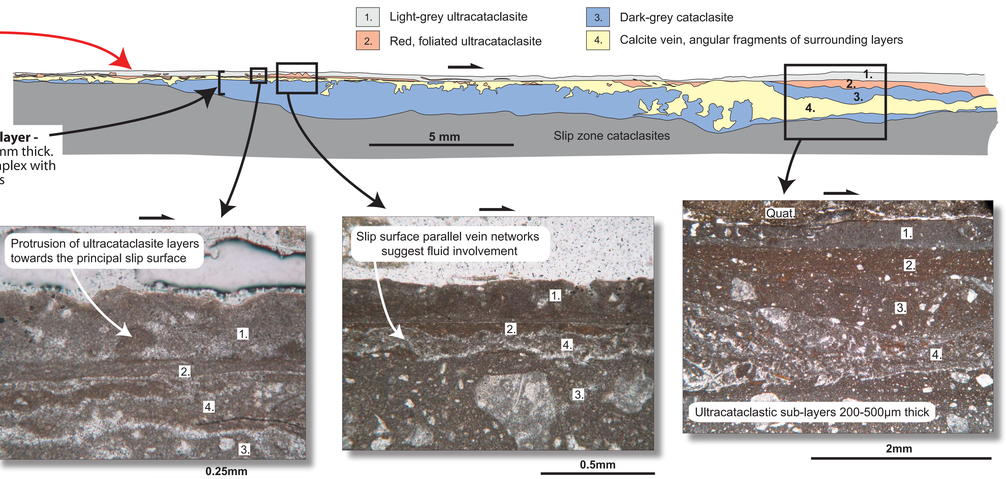


The principal slip zones and principal slip surfaces are exposed along active Quaternary fault scarps that have been exhumed from <2km depth. Surface grooves and slickenlines on the slip surfaces suggest minimal erosion. Despite the relatively wide "fault core - damage zone" structure, on the order of metres to tens of metres, we find a high level of microstructural complexity within a few millimetres of the principal slip surfaces. Such complexity includes a texturally-distinct slip layer <5mm thick (see right), evidence for fluidization of ultracataclasites, and in some cases formation of rounded 'clast-cortex grains' (see lower left).



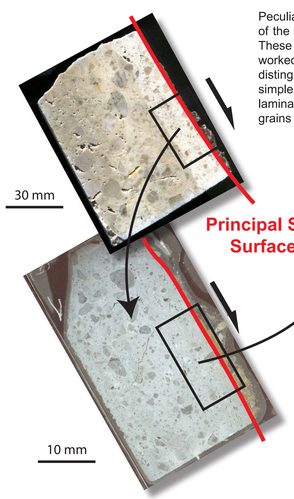


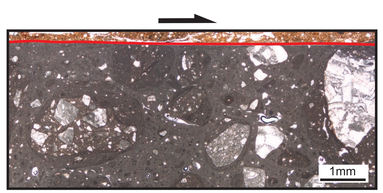
2. Microstructure of Principal Slip Zones in Limestone - ultracataclasite sub-layers

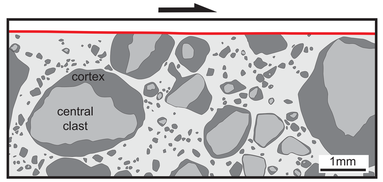


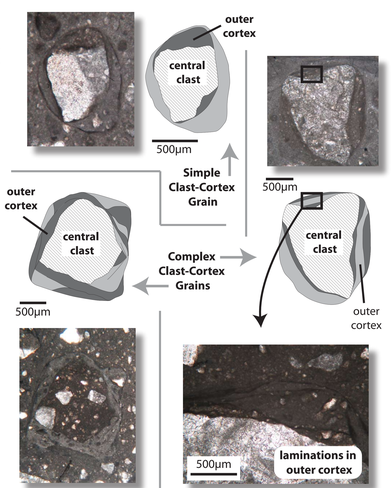
3. Natural Clast-Cortex Grains - fossil earthquakes in limestone?

Peculiar rounded grains up to 3 mm in diameter are found within the slip zones of some of the normal faults. They are not found elsewhere within the fault core or host rock. These "clast-cortex grains" consist of a central (often angular) clast of host rock or reworked cataclasite, surrounded by an outer cortex of fine-grained material optically indistinguishable from the calcite matrix. Some examples of clast-cortex grains are simple, whilst others are more complex and consist of an outer cortex with multiple laminations. Preliminary rotary-shear friction experiments (see right) suggest that such grains may develop during shearing of gouge layers at seismic slip velocities (>1 m/s).



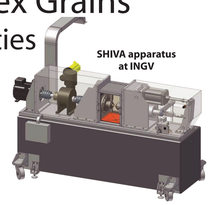


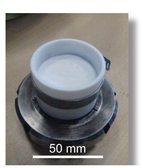




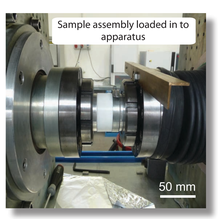
4. Experimental "Clast-Cortex Grains" - produced at seismic slip velocities

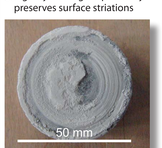
To recreate the natural slip zones, a series of experiments have been initiated using SHIVA at INGV in Rome. 2mm thick layers of water-saturated calcite gouge were deformed at a constant normal stress of 1.5 MPa and slip rates of 1mm/s - 6.5m/s. At slip speeds <10cm/s the gouge layer is crosscut by riedel shears, and has μ of 0.4-0.7. At slip speeds >40cm/s (seismic speeds) the gouge layer shows dynamic weakening and a steady-state μ of 0.1-0.3. The gouge contains a zone of localized slip at the boundary with the rotary column. Inside this zone, simple clast-cortex grains are formed, raising the possibility that such grains may be a useful indicator of seismic slip in limestones.

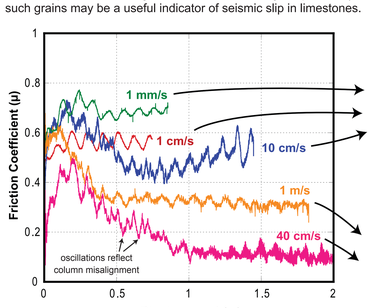


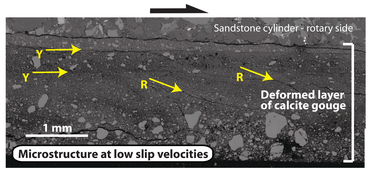


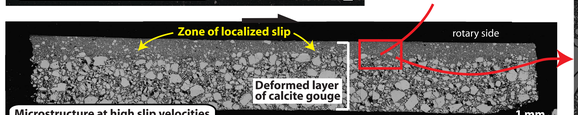
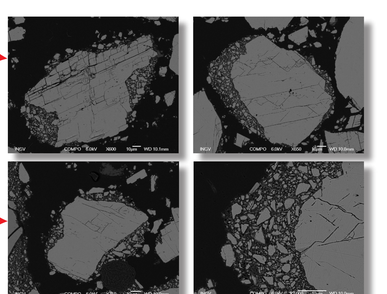
2mm thick layer of calcite gouge confined using teflon rings











Simple Clast-Cortex Grains produced in localized slip layer at high slip velocities (>40 cm/s)