T13A CC: 516 A Monday 1330h

Visualizing the Evolving Fault Zone I

(joint with G, S, MR)

Presiding: **J F Hazzard,** University of Toronto**; K Mair,** University of Edinburgh

T13A-01 1335h INVITED

Defining the mechanical fault

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Simply defined, a fault is a fracture on which slip is localized during an earthquake. However, as the number of studies on fault zones grows, so too does our understanding of the complexity of fault structure and evolution. We examine the structure and evolution of faults related to the Landers and Hector Mine ruptures in the Mojave Desert, within the eastern California shear zone. Following both the Landers and Hector Mine earthquakes, we used trapped waves to delimit a 100-200 m wide zone of highly damaged rock and found significant velocity and shear modulus reduction within this zone to at least 5 km depth. In addition, we tracked the healing of these fault zones. Our study of both fault zones showed an increase in velocity in the years following the mainshocks. The Hector Mine earthquake shook and re-damaged the Landers fault zone resulting in a temporary reversal of healing. InSAR and shear-wave anisotropy studies complement the refraction wave studies by providing a regionally extensive view of the deformation field. Anisotropy studies show rotation in microcrack orientation along strike of the Hector Mine earthquake and also variable distribution of crack density. Post-seismic InSAR images indicate poroelastic rebound is a major player in the deformation fields following both the Landers and Hector Mine earthquakes. Localized zones of post-seismic deformation detected by InSAR correspond to regions of high crack density and velocity reduction observed by anisotropy and trapped wave studies. While we see healing of the fault zones within the first few years after rupture, long-term reduction in the fault-zone rigidity is evident from coseismic InSAR images spanning both the Landers and Hector Mine earthquakes. We see strain localized on compliant zones of nearby unbroken faults, i.e., the Pinto Mountain, Calico and Rodman faults, indicating that active fault zones are probably permanently softer than the surrounding more intact rock.

T13A-02 1355h

Comminution characteristics of quartz in natural and experimental faults; Implications for brittle shear localization

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We studied a number of faults in weakly cemented Aztec sandstone (92.6% quartz, 6.1% clay, 1.2% K-feldspar; well/sub-rounded grains; mean grain size 330μm; porosity 17-24%) from Valley of Fire (VOF) State Park in Nevada, USA, with true displacements 1.5 to150 cm. The deformation is typically asymmetric core/damage zone type microstructure with fault core thickness varying between the samples from 2 to 50mm. Digital optical and SEM images were used to obtain PSD, and fractal dimension (D) of the comminuted quartz with $\sim$4μm particle segmentation resolution. A shape descriptor algorithm (POL) was used for quantifying particle angularity. The VOF results were compared with those of quartz and feldspars in simulated Westerly granite gouge (WG) sheared at 25MPa pressure. Compared to WG samples of similar displacement, typical VOF fault gouge appears to be less isotropic and includes larger and more survivor particles. The incidence of D values >2.58 seems to correlate with shear localization microstructures regardless of total displacement on the faults. There is considerable reduction in particle angularity with increased displacement in the VOF samples, and higher D values correlate well with lower POL numbers, i.e. comminution results in rounding of quartz particles. Similar correlation of D and POL values is found for the quartz fraction in the WG samples in which feldspar particles become more angular with increased shear displacement. The results provide a tentative basis for relating the evolution of particle geometry to angle of internal friction in active bands within the fault gouge. Our observations support a model in which an episode of displacement on the fault initially generates series of dilatant oblique shears (e.g. a stack of R-shears). The dilatant shears should occur with diminishing frequency as further comminution reduces the band thickness via packing density increases. This process tends to lower the angle of internal friction by reducing the magnitude of dilatational component of friction, and is probably associated with the onset of localization of deformation in a shear-parallel orientation. Our data suggests that the proposed microstructural transition from R to Y shears might be affected, among other probable factors, by fracture properties of mineral constituents.

T13A-03 1410h

Comparative Laboratory and Numerical Simulations of Shearing Granular Fault Gouge

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Laboratory studies of granular shear zones have provided significant insight into fault zone processes and the mechanics of earthquakes, including important contributions to our understanding of earthquake nucleation, the seismic-aseismic stability transition, dynamic rupture, and fault interactions. Numerical simulations using particle dynamics methods can offer unique views into deforming fault zones, particularly regarding the micromechanisms of deformation in shearing materials. Recently, significant advances in our understanding of granular shear have been gained by integrating these two approaches to better model the frictional behavior of tectonic faults. We describe a series of comparative laboratory and numerical experiments of granular shear carried out under identical initial and boundary conditions, using idealized granular materials, i.e., glass beads and rods. Phenomenologically, the two sets of experiments are very similar, demonstrating shear strength fluctuations that can be related to variations in particle size distribution, shear zone thickness, and imposed normal stress. Observed discrepancies in absolute shear strength and stress-strain behavior, then, allow us to calibrate and update the numerical interparticle contact laws to gain improved fits to the laboratory results. The numerical simulations serve to clarify the active deformation processes, demonstrating the role of shear localization, and partitioning between deformation mechanisms, including grain boundary sliding, rolling, and changes in particle size distribution. This integrated study offers great promise to improve our understanding of fault mechanics and earthquake physics. We describe results of the combined study and development of the next generation of particle-based numerical models, including realistic, physico-chemically based contact laws.

T13A-04 1425h

Visualising stress-chain morphology during granular shear

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Active faults often contain distinct accumulations of granular wear material. During shear, this granular material accommodates stress and strain in heterogeneous manner that may influence fault stability. We present new work to visualise evolving stress distributions during granular shear. Our 3D numerical models consist of granular layers subjected to normal loading and shear, where gouge particles are simulated by individual spheres interacting at points of contact according to simple laws. During shear we observe the transient microscopic processes and resulting macroscopic mechanical behaviour that emerge from interactions of thousands of particles. We track particle translations and contact forces to determine the nature of internal stress accommodation with accumulated slip for different initial configurations. We view model outputs using novel 3D visualisation techniques. Our results highlight the prevalence of transient force or stress chain networks that preferentially transmit enhanced stresses across our layers. We demonstrate that particle size distribution (psd) strongly controls the nature and persistence of the stress chain networks. Models having a narrow (or relatively uniform) psd exhibit localised stress chains with a dominant orientation, whereas wider psd models show diffuse stress chain webs that take a range of orientations. First order macroscopic friction, is insensitive to these distinct stress chain morphologies, however, wider psd models with diffuse stress chains are linked to enhanced friction fluctuations i.e. second order macroscopic effects. Our results are consistent with predictions, based on recent laboratory observations, that stress chain morphologies are sensitive to grain characteristics such as psd. Our numerical approach offers the potential to investigate correlations between stress chain geometry, evolution and resulting macroscopic friction, thus allowing us to explore ideas that heterogeneous stress distributions in gouge material may exert an important control on fault stability and hence the seismic potential of active faults.

T13A-05 1440h

POST-TERMINAL COMPRESSIVE DEFORMATION OF ICE: FRICTION ALONG COULOMBIC SHEAR FAULTS

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Coulombic shear faults characterize terminal failure when polycrystalline ice Ih is rapidly loaded under a moderate degree of confinement. Post-terminal deformation occurs through frictional sliding along the shear fault. To examine this latter stage of deformation, experiments were performed on freshwater S2 ice at -10o C. The ice was proportionally loaded biaxially across the column-shaped grains along a variety of all-compressive loading paths at four sliding velocities (8*10-1, 8*10-2, 8*10-3 and 8*10-4 mm/s.). At higher velocities sliding was noisy and the process exhibited velocity weakening. At a lower velocity sliding was quiet and fault healing occurred. The two kinds of sliding are indicative of brittle-like (at higher speeds) and ductile-like (at lower-speeds) behavior. At each velocity Coulomb's law describes the relationship between the shear strength of the fault and the normal stress across it, both at the onset of sliding and once sliding has progressed a few millimeters. The friction coefficient decreases with increasing velocity in a manner similar to that seen by Kennedy et al. (2000) in ice-on-ice experiments, but is higher by about a factor of two to four depending upon the sliding speed, owing perhaps to a greater degree of roughness.

T14A CC: 516 A Monday 1530h

Visualizing the Evolving Fault Zone II

(joint with G, S, MR)

Presiding: **J F Hazzard,** University of Toronto**; K Mair,** University of Edinburgh

T14A-01 1530h INVITED

Use of 2D and 3D Imaging Techniques to Understand Fracture Growth

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The monitoring of acoustic emissions (AE) is a valuable tool for studying the brittle fracture process in rock. With the improved characterization of transducer response, researchers are able to apply a broad