MULTI-SCALE EXPERIMENTAL INVESTIGATION OF SLIDING FRICTION

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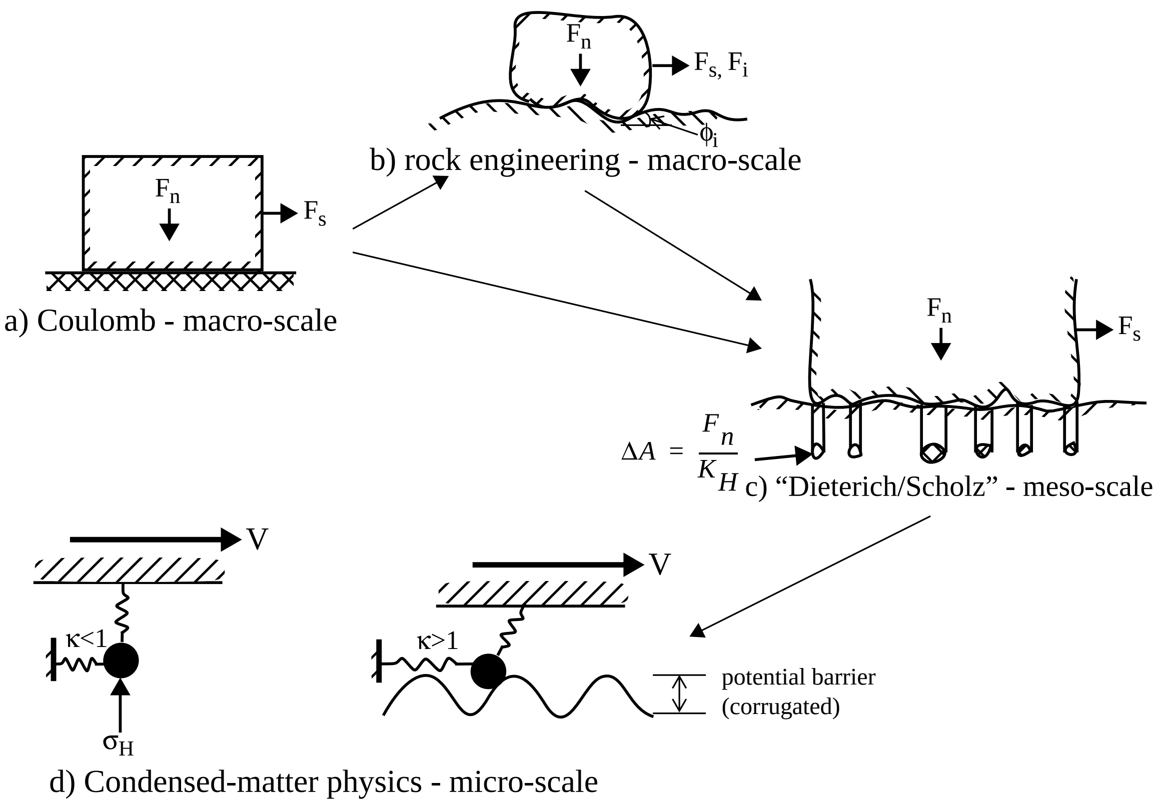
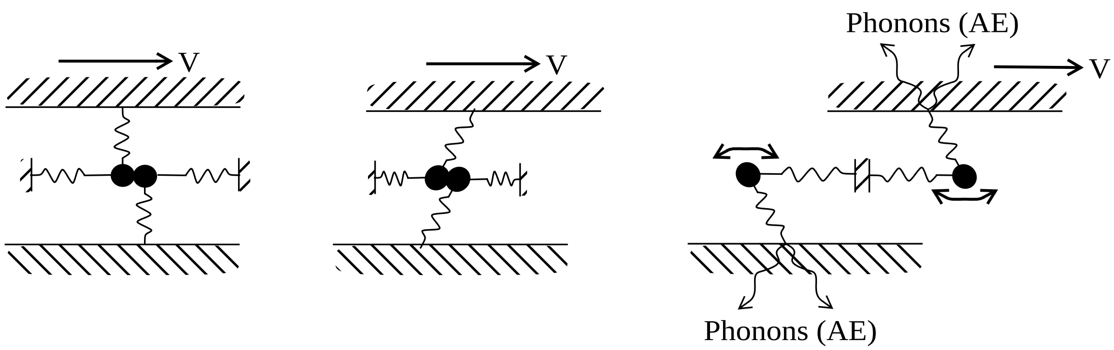
A. PROJECT SUMMARY:

We are proposing an experimental investigation into the fundamental mechanisms responsible for sliding friction. Engineers have always relied on rate- and state-dependent constitutive models. These empirical models, from Da Vinci (1490) to Dieterich (1999), allow matching and prediction of bulk behaviors. As well as these model work, they are still behavioral criteria - curve-fitting that tells nothing about the actual physical mechanisms that result in frictional resistance to sliding. Recently, there have been significant advances by the condensed-matter physics community in formulating a theoretical mechanism responsible for frictional resistance to sliding. These models have enormous constitutive power, explaining behaviors from angstrom scale to kilometers-long earthquake dislocations, and provide a theoretical framework for understanding material creep as well as self-healing slip on the San Andreas fault.



Models of multi-scale sliding friction. Macro- and meso scale models are behavioral criteria that accurately predict behavior on that scale. The micro-scale model posits a physical mechanism.

Since there has been little direct experimental proof that the posited fundamental physical mechanisms indeed are at work (attractive as the theory might be), the PIs propose to leverage their experimental and interpretive ability to image these micro-mechanisms. Given that the fundamental kinematics of frictional junctions results in production of phonons (vibrational, hence acoustic, energy), the PI's expertise in quantitative acoustic emission and waveform inversion make them uniquely able to image these kinematics. They have developed surface and embeddable sensors proven capable by NIST of measuring picometer displacements from 10 kHz to 1 MHz to within 3 dB. Studies show that the dynamic record transduced by these sensors match the theoretical kinematic waveforms remarkably well, allowing whole-waveform inversion for source kinematics rather than single-point moment tensor inversion Combining these sensors and the proven wave propagation expertise of the co-PI into a well-constrained experimental program insures success.



Cartoon of localized friction at the nano-scale. Notice the "stick-slip" motions at the localized junctions.

The results of this project will further science and engineering on several levels. Fundamental understanding of the physical mechanisms behind sliding friction, leading to improvement of basic understanding of the physical world. This will help refine current empirical understanding of friction and allow great improvement in mechanical design from nanomachines to sub-kilometer-scale structures. In addition, fundamental questions about kilometer-scale earthquake source mechanisms will be answered, in particular the issues surrounding the notion of self-healing slip. In turn leading to understanding of the earthquake dislocation mechanism, and ultimately improved seismic safety.

EXPERIMENTAL PROGRAM

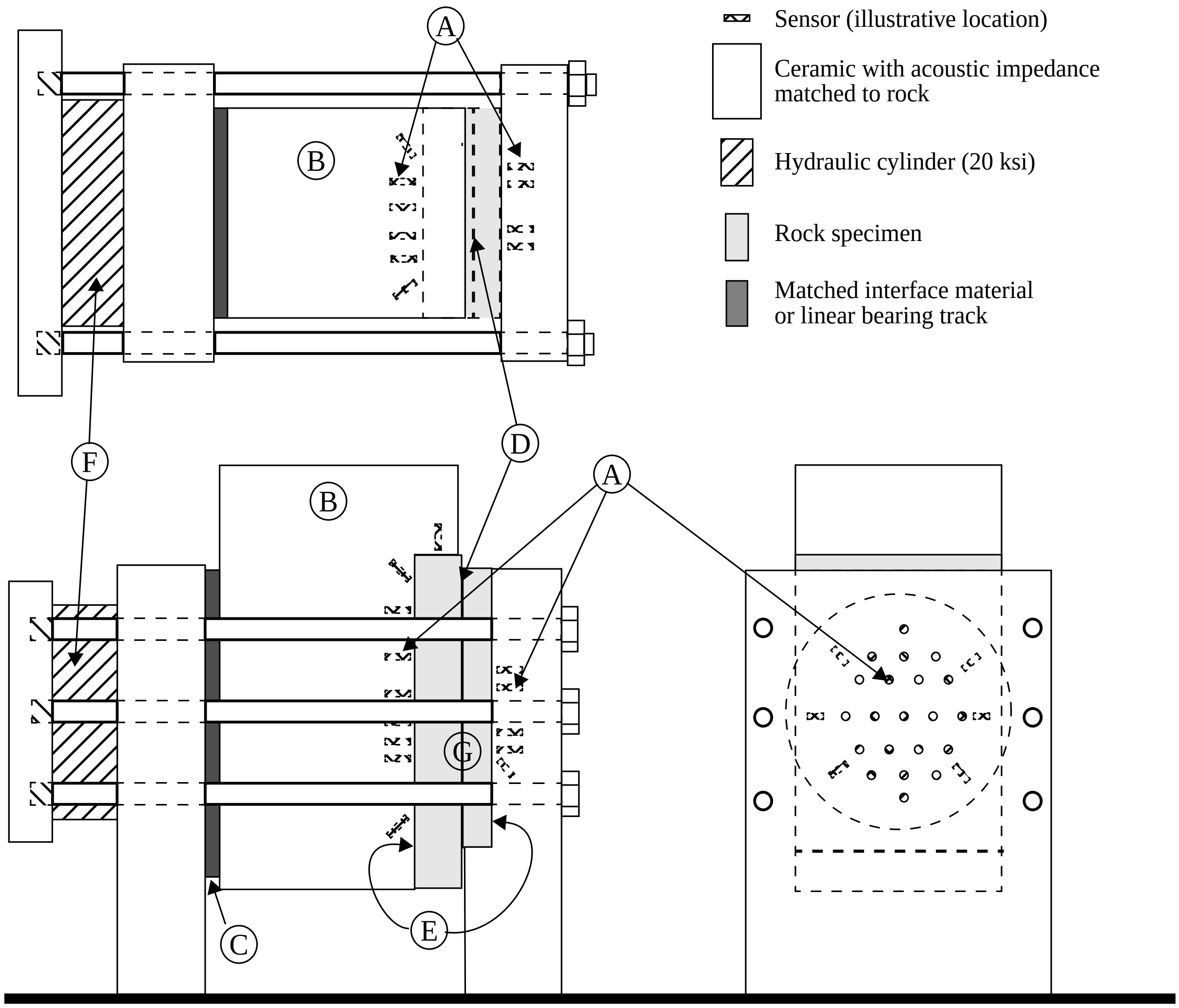
Theory shows that vibrational displacements are the result of frictional sliding, therefore quantitative AE and careful invasion with respect to wave propagation theory is the optimal technique to image sliding mechanisms. We propose to make a detailed kinematic map of frictional mechanics on several orders of scale:

(1) the actual motions which make up localized junctions [sub-Å];

(2) the kinematics of the junction seen as a "unit" [μm];

(3) the interactions of junctions, and self-organization into elastic coherence lengths [μm-mm];

(4) the repetition of organization of critically-sized domains (ξ) on a macro-scale [mm-m].



Ⓐ Wide-band high-fidelity acoustic emission sensors embedded into impedance matched backing blocks B and B`

Ⓑ Specimen mobile backing block made from ceramic with an acoustic impedance matching the rock specimens used

Ⓒ Spacer made from material with a shear stiffness equal to that of the rock interface being tested. This spacer is the matching half of the interface being tested to eliminate moment on test surface D.

Ⓓ Rock interface being tested.

Ⓔ Flat ground back surfaces of rock specimen bonded to ceramic backing blocks with adhesive layer << wavelength in thickness.

Ⓕ Normal force actuator. Force will be supplied by hydraulic cylinder, or stacked piezoceramic actuator if faster response and higher stiffness is needed.

Ⓖ Non-contact differential sensors to measure gross motions directly at the interface.

A schematic diagram of the proposed experimental testing fixture. Specimens to be tested are estimated to be about 300 mm long and wide.