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Electrical Potentials Observed During Frictional Stick-Slip – A Semiconductor Mechanism

J.R. Leeman[1], M.M. Scuderi[1], C. Marone[1], D.M. Saffer[1]

[1] Department of Geosciences and Energy Institute Center for Geomechanics, Geofluids, and Geohazards, The Pennsylvania State University, University Park, Pennsylvania, USA

Electromagnetic phenomena are commonly reported during and after large earthquakes. Various lines of evidence including charring of plant roots, magnetic remnant signatures in pseudotachylite, and visible earthquake lights indicate a strong electrical potential separation during co-seismic rupture. Suggested explanations have included triboelectricity, piezoelectricity, and streaming potentials. The "semiconductor effect", or migration of electron holes, has been proposed as an alternative explanation and studied extensively in solids. We present evidence of a similar migration effect in a granular material that exhibits repeated frictional stick-slip events under a variety of conditions.

Soda-lime glass beads were sheared in a double-direct shear configuration in a biaxial loading frame. Glass beads exhibit consistent, repetitive stick-slip and rate/state friction effects that are similar to rock. Layers of 5 mm thickness were sheared under a constant normal load of 4MPa, at load point velocities of 1, 30, and 100 μm/s. This was done for mono-disperse particle size distributions of 100-150 μm and 420-500 μm. Tests were conducted at room humidity, at 100% humidity, and under submerged conditions. During shearing, the electrical potential of the surface was monitored relative to the system ground with a non-contact electrostatic volt meter (ESVM) manufactured by Trek Incorporated.

During stick-slip events, we observe electrical potential anomalies that appear to be related to failure of force chains supporting the shear load. Two distinct types of behavior are delineated by the attainment of steady state frictional sliding. In the pre-steady state phase, as shear stress is increasing, layers are observed to charge during stick-slip and the potential of the entire system rises. When shear stress rises to the level of steady state frictional sliding, the system begins to discharge, with superimposed anomalies characterized by potential drops of several volts that coincide with stick-slip failure. This behavior is consistent at both 1 and 30 μm/s loading velocity. At a load point velocity of 100μm/s, the anomalies exhibit sharp potential spikes on the order of 20 volts coincident with stick slip failure events with gradual charging between events. Experiments conducted under 100% humidity and submerged conditions showed no associated electrical anomalies.

We interpret that the observed signal is a convolution of two effects: charging of the forcing blocks and anomalies associated with the stress state of the material. Charging of the blocks is accomplished by grain movement along the boundaries during initial arrangement of force chain networks. Anomalies associated with the material originate from electron holes produced when peroxy

links are broken. The defects then propagate away from stressed regions during loading, separating charge. A return current results in a potential drop as a semi-homogeneous stress state is attained after failure of the force chain network. Electrical anomalies during material failure could potentially be used to remotely monitor stress states and cracking during the inter-seismic stage of the seismic cycle. Potential changes could result in detectable low-frequency signals that may signal the early stages of failure, providing a modest warning of the event.