Electrical Anomalies Observed During Frictional Stick-Slip in Granular Materials

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Introduction

We present data from double direct shear experiments on granular synthetic fault gouge in which the electrical potential difference between the gouge layers and system ground was monitored with a no-contact electrostatic voltmeter. Data were obtained for different humidity conditions, loading velocities, and particle size distributions. We find that electrical potential varies systematically during repetitive stick-slip frictional sliding. Careful measurement shows that observed electrical signals are not influenced by other external factors (i.e. apparatus and environment).

Potential Causes of Electrical Charge

Piezoelectricity - Charges resulting from strain of certain materials. Geologically, quartz is a piezoelectric mineral, but it is generally randomly oriented. In bulk, opposing charges would cancel.

Streaming Potential - Preferred dissolution of ions results in a charged fluid and material surface. High electrical conductivity of brines generally makes this potential very small, even over large distances.

Material A / Material B

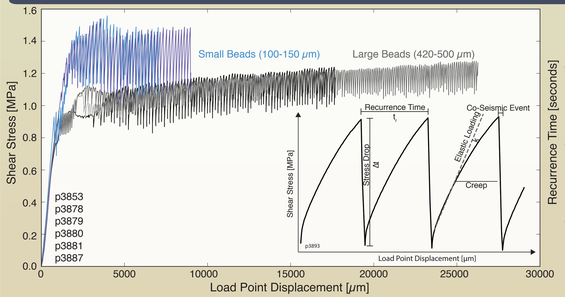
Triboelectricity/Contact electrification - Potentials resulting from contact of different materials or charges generated during frictional rubbing and fracture processes.

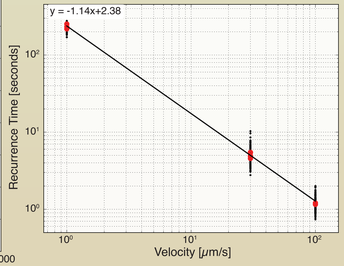
P-hole and Pair Theory - Positive charge holes and pairs of these holes produce current flow during the stressing and straining of material. Can be connected to peroxy links in silicate rocks.

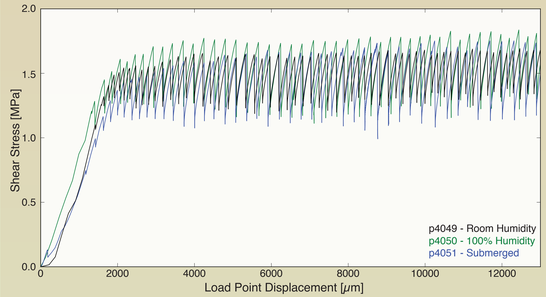
Potential Effects of Electrical Charge

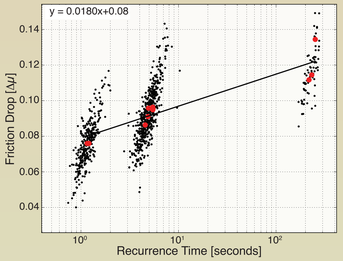
- Coronal Discharges and Earthquake Lights
- Magnetic and Radio Perturbations
- Pre-Seismic Thermal Anomalies
- High Remnant Magnetization in Pseudotachylite Veins
- Anomalous Biological Effects/Behavior
- Ionospheric Perturbations

Stick Slip Events





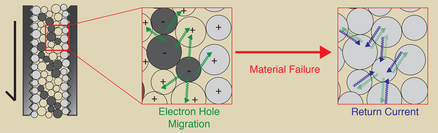




Electrical Mechanism

Hypothesis of Electrical Mechanism

1) As shear load is applied, force chains form to support the load. This is a 'fragile system' configuration.
2) Small piezoelectric charges result from grain stressing.
3) Deformation of contact junctions within force chains streams electron defects, making highly stressed regions negatively charged.
4) Force chains fail and stress drop occurs. Return currents neutralize contact junctions.
5) Acoustic wave passage aids migration of positively charged holes.



Stick slip events are characterized by a period of elastic loading followed by elasto-plastic deformation and pre-seismic creep. At failure, shear stress rapidly drops. The failure then is arrested and elastic loading begins again.

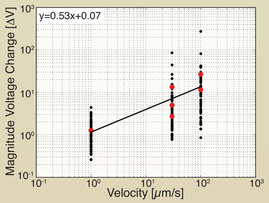
Though electrically identical, the larger beads were weaker and presented smaller stress drops than experiments with smaller beads at the same boundary conditions.

Experiments at 100% humidity were slightly stronger than room humidity experiments with larger stress drops. Submerged experiments, where the entire sample was placed in DI water, show higher stress drops than room humidity experiments, but approximately the same peak shear stress.

Number of Experiments Conducted

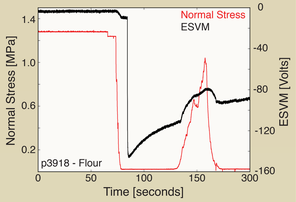
Loading Velocity	Room	100% Humidity	Submerged
1 μm/s	3	0	0
30 μm/s	8	3	2
100 μm/s	2	0	0

Conclusions



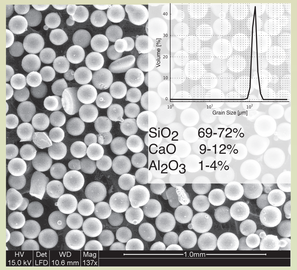
The magnitude of voltage change that is co-seismic appears to be positively correlated to the load point velocity and inversely correlated to the recurrence time. Most voltage changes at 100 μm/s are positive spikes possibly pointing to the importance of acoustic activation at different velocities.

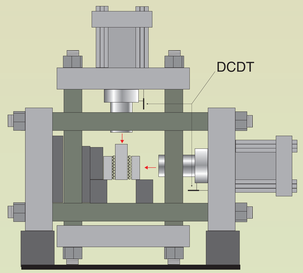
After shearing was complete and shear stress was removed the normal load was cycled. The voltage follows the stress curve with a delay and smoothing imposed. Positive changes with reapplication of stress support the hypothesis of the electrical mechanism.



- Long term trends suggest charging of the forcing blocks combined with high frequency, stress induced anomalies related to stick-slip events.
- 100% humidity and submerged experiments showed no repeatable electrical signal suggesting that charge is rapidly equalized by a conductive layer of fluid on the surface of the particles.
- Reversal of electrical signal as the system reaches mechanical steady state is unexplained.
- Direct contact methods monitoring current required to keep the system at ground potential will allow a charge balance to be calculated in future experiments.

Materials and Methods





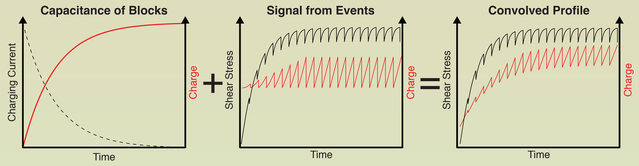
Mechanical and Material Parameters

We shear soda-lime glass beads in a double direct shear configuration exposed to room humidity, 100% humidity, and submerged in de-ionized water. Plexiglass forcing blocks were used to electrically insulate the granular material from the loading frame. The surface of the blocks is roughened to reduce edge effects. Two grain size distributions 100-150μm (pictured) and 420-500μm were tested at room humidity conditions. All experiments were conducted with 5mm thick layers at 4MPa normal stress. Load point velocity was set to 1, 30, or 100 μm/s, remaining constant for the duration of the experiment. Electrical charge was monitored with a non-contact electrostatic volt meter (ESVM) manufactured by Trek Inc.

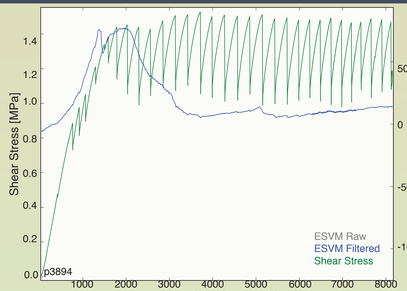
Electrical Charge Monitoring

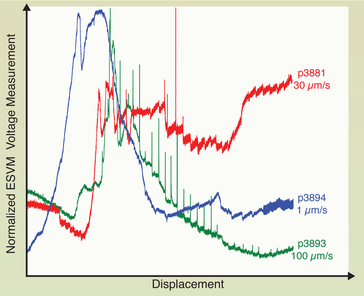
- Monitor surface potential of beads with respect to system ground
- Measurement accomplished by measuring AC signal resulting from electromechanical oscillation of a capacitive probe. When probe voltage matches the surface voltage the AC component is extinguished.
- Capable of -2kV to +2kV measurement.
- All data recorded at 24-bit resolution.
- Several positions attempted with similar results.

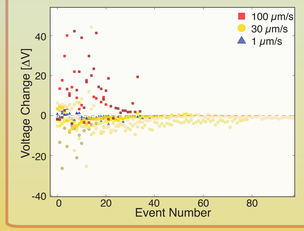
Electrical Profile

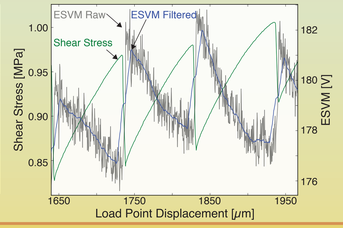


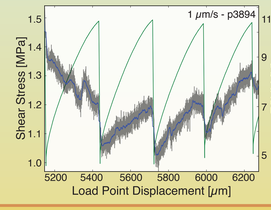
- Charging of the plexiglass forcing blocks follows a capacitor charging profile.
- Voltage changes associated with stick-slip events are semi-stochastic.
- Superposition of two signals gives final voltage profile.
- Sign change possibly associated with the blocks becoming charged.

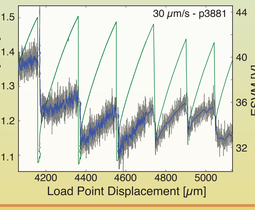


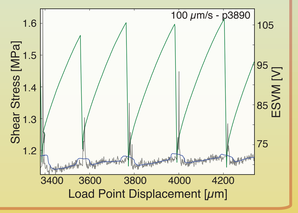












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