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Comparison of the electrical response of dry rocks as a function of uniaxial stress

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A set of nominally dry rocks (gabbro, granite, limestone, marble, and sandstone) were subjected to asymmetric loading as shown in Figure 1 according to [1]. This load was applied with a 60T hydraulic press, across approximately 40 cm^2 producing compressive stress levels well below the yield or breaking point of each sample. A set of precision platens made from 1018 low carbon steel were used to transmit the uniaxial compressive stresses from the press to the sample, using insulators made from ultra-high molecular weight (UHMW) polyethylene [2] to electrically isolate the rock sample. The photograph shows the laboratory setup with white granite held between the platens and a pair of 0.25 mm thick insulators. The samples were carefully cleaned with acetone, and then self-adhesive copper electrodes were applied to the endfaces of the sample as shown. Care was taken to burnish the copper tape and solder wire pigtails to obtain a consistent electrical contact with all samples.

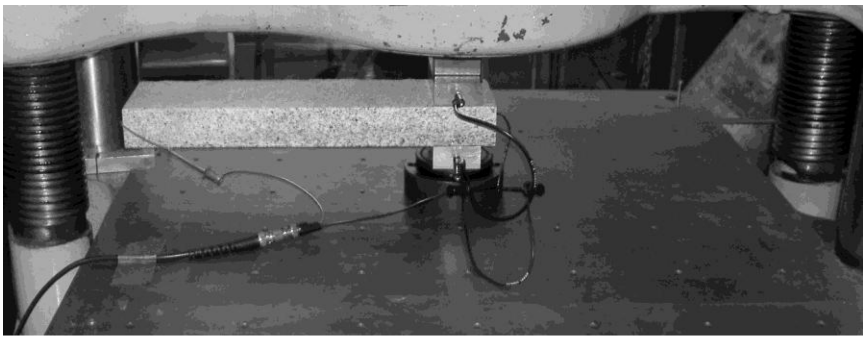

Figure 1. Experimental setup showing platens, insulators, sample and spherical bearing.

The electrical current and EMF were monitored using a Keithley 617 instrument, which can operate in picoammeter or electrometer modes. A WinTel PC running LabView data acquisition software samples the instruments at a 0.5 second rate via the GPIB bus and records the electrical measurement along with the force value, which is converted to units of stress.

A preloading or pedestal stress level of 5.5 MPa was applied from which the stress was increased to 22.25 MPa during the loading cycle. Initially the 5.5 MPa pedestal stress held for 100 seconds and then increased to 22.25 MPa where it was held for 100 seconds before returning back to the pedestal stress. Stress rate is on the order of ~5MPa/sec but since the machine is manually controlled it there is some uncertainty in the rate and exact stress levels. Each sample was tested with a minimum of four load cycles, having ~200 second periodicity.

The results are summarized in Table I, where the first column is a name of the experiment, and the next two columns attempt to summarize the currents measured between the pedestal and the maximum stress levels. The last two columns are for voltage measurements for the same sample, with the same protocol as the current measurements. Baseline values for current and voltage I_{DC} and V_{DC} are the average baseline values where the baseline is constant or quasi-static, and are estimates where the baseline is decaying as is the case for marble. The baseline signal is driven by sample self-potentials and does not provide much meaningful information.

The ΔI and ΔV values in the table summarize the stress-dependent electrical response for the different rock samples. These data represent a repeatable effect over three or four consecutive load cycles, for a stress increase of Δs = 16.7 MPa from 5.5 to 22.25 MPa. In general, the offsets and transients (for current) and offsets (for voltage) are reversible when S returned to the pedestal stress.

Table I. Summary of responses for dry rocks for increasing Stress ΔS = +16.7 MPa.

Run No. Description	I_{DC}	ΔI	V_{DC}	ΔV
49 Gabbro, fine-grained	+40 pA	–15 pA	+60 mV	–20 mV
50 Marble, white	–0.5 pA	nil	~ –150 mV ‡	+10 mV
51 Granite, light brown	–7 pA	-0.3 pA	–23 mV	+5 mV
52 Sandstone, barea	–7 pA	+1 pA	–10 mV	~ +15 mV
53 Granite, white	–5 pA	–10 pA	–35 mV	–35 mV
54 Limestone	0.0 pA	–1.0 pA	+10 mV	–105 mV
55 Granite, westerly	+10 pA	nil	+70 mV	–5 mV

‡ Large and slowly decaying baseline

Regarding the electrical current response to stress: with the exception of the sandstone, all of the samples showed a negative-going offset for current, and three samples showed no stress-dependent effect within the limits of the experiment (estimated to be ~ 1 pA). All samples showed the alternating transients that are characteristic if the experimental setup at the beginning and end of each load cycle [1]. When measuring current, offsets from the sample were very easy to discern from the experiment artifacts.

Regarding the voltage response to stress: voltage offsets arising from the sample are summed with the voltage offset due to deformation of the polyethylene insulators. This makes voltage measurements less reliable. There was also a richer variety of transients observed such as unipolar, bipolar and more complex transient dynamics. Limestone was the only sample tested with no voltage transients although this particular rock had a major calcite inclusion in the sample, and white granite tended to have the least stable voltage and current values.

In conclusion, six different rock samples were tested in as nearly identical conditions as possible. The current and voltage responses observed were much smaller than previously reported [3], presumably due to improved experimental procedures. If the results are representative, i.e. if we have measured what we think we measured and have not been mislead by unknown/unrecognized sources of variation due, for example, to the design of the experiment or systematic errors, then these results appear to establish an upper bound on the magnitude of a p-hole effect, if it exists. We note that the response for rocks with the suspected largest semiconductor properties (gabbro, granite) is the same as those (limestone, marble) without expected semiconductor properties, although the values for marble were below the noise. Run 54 for limestone had –1 pA response for the repetitive 16.7 MPa load increase and decrease. Run 49 gabbro and three types of granite (51, 53, and 55) showed negative-going or zero current dependence as a function of stress, all of which would be expected to be positive with respect to the baseline, if the currents are assumed to be linear with stress according to the p-hole theory. Thus, for these particular samples, the results are not in agreement with those predicted for hole-dominant charge carriers activated by increasing stress. Experiments with different contact electrodes and lower pedestal stress levels are planned to further validate these observations.

References

[1.] R. Dahlgren, V. Vanderbilt, M. Johnston, G. Carlson, R. Nakaba, and F. Freund, Characterization of the electrical response of geological samples as a function of uniaxial stress, EMSEV meeting, 2012.

[2.] Saint-Gobain, Norton™ Ultra High Molecular Weight Polyethylene Film, 2007.

[3.] F. Freund, Stress-activated positive hole charge carriers in rocks and the generation of preearthquake signals, Electromagnetic Phenomena Associated with Earthquakes, M. Hayakawa, ed, 2009.