GENERATION OF MEASURABLE CURRENT CAUSED BY LUNAR IMPACTS. W.A. Hollerman[1], C.A. Malespin[1], R.J. Moore[1], and P.J. Wasilewski[3], B.W.S. Lau[4], F.T. Freund[4,5], [1]Department of Physics, University of Louisiana at Lafayette, P.O. Box 44210, Lafayette, LA 70504, hollerman@louisiana.edu , [3]Astrochemistry Branch, Code 691, NASA Goddard Space Flight Center, Greenbelt, MD 20771, Peter.J.Wasilewski@nasa.gov, [4]Carl Sagan Center, SETI Institute, 515 N Whisman Road, Mountain View, CA 94043, [5]NASA Ames Research Center SETI Institute, MS 242-4, Moffett Field, CA 94035, ffreund@mail.arc.nasa.gov

Introduction: On Earth, various electrical and electromagnetic phenomena have been reported prior to or concurrent with earthquakes such as resistivity changes, ground potentials, electromagnetic (EM), and luminous signals [1]. Doubts have been raised as to whether these phenomena are real and indeed precursory. One of the reasons for uncertainty is that, despite decades of intense work, there is still no physically coherent model how these signals can be generated.

Using low- to medium velocity impacts to measure electrical signals with microsecond time resolution, it has been observed that when cylinders of dry gabbro and diorite cores are impacted at relatively low velocities, ~100 m/s, highly mobile charge carriers are generated in a small volume near the impact point. They spread along the cylinder axis, causing electric potentials that exceed +400 mV, EM in the 5-20 kHz range, and light emission caused by corona discharges [1]. As the charge cloud spreads, the conductivity of the rock momentarily increases. When a dry granite block is impacted at higher velocity, ~1.5 km/s, the propagation of the P and S waves can be registered through the transient piezoelectric response of quartz. After the sound waves have passed, the surface of the granite block becomes positively charged, suggesting activation of the same charge carriers as during low-velocity impact experiments, except that now the charge cloud expands from within the bulk.

The observations are consistent with positive holes, e.g. defect electrons in the O^{2-} sublattice, traveling via the oxygen 2p-dominated valence band of the silicate minerals. Before activation, the positive holes lay dormant in the form of electrically inactive positive hole pairs (PHP), chemically equivalent to peroxy links, $O_3X/^{OO}\backslash XO_3$, with $X=Si^{4+}$, Al^{3+}, etc [1,2]. PHPs are introduced into the minerals by way of hydroxyl, O_3X–OH, which nominally anhydrous minerals incorporate when crystallizing in H_2O-laden environments.

The fact that positive holes can be activated by impacts suggests that they are activated by deviatoric stress. Depending on how the charge carriers can flow out of the stressed rock volume, they will form rapidly moving or fluctuating charge clouds that may account for earthquake-related electrical signals and EM emission. Wherever such charge clouds intersect the surface, high electric fields build up, causing electric discharges and earthquake lights [2,3].

Lunar Rocks: Lunar rocks are widely believed to be bone dry and never "saw" any water. The argument is based on the observation that lunar rocks do not contain any detectable O_3X–OH nor even H, except for implanted solar wind. However, it can be shown that O_3X–OH in igneous rocks undergo a redox conversion upon cooling that converts O_3X–OH pairs into positive hole pairs (our peroxy) plus molecular H_2. At first the H_2 go interstitial, but over time, they will diffuse out of the rocks. Hence, the idea that the O_3X–OH content is equivalent to dissolved H_2O content is wrong. This point is important for the Moon because, if lunar rocks ever contained O_3X–OH, they would be the source of $O_3X/^{OO}\backslash XO_3$ and, hence, capable of activating PHP and of generating positive hole currents during impacts.

Experimental Data: Research to date shows that PHPs are activated by acoustic/seismic waves of sufficiently large amplitude. Impact experiments were conducted at NASA Ames and NASA Goddard.

Low Velocity Impacts: Impacts with 3-6 mm diameter steel projectiles at speeds of ~100 m/s indicate that positive charge carriers are generated in a relatively small volume around the impact point [2]. From there the charges spread into the rock at about 200 m/s.

Ames Vertical Gun Range. Measurements at NASA Ames were conducted at the Ames Vertical Gun Range (AVGR), a 0.30 caliber two-stage light gas and powder gun that can launch projectiles up to 0.5 to 7 km/sec. Impacts with a 5 mm Al sphere at 1.5 km/s into a 25 x 25 x 20 cm^3 block of granite show that PHPs are activated by the P or S wave within the entire volume [3]. After the near-instant activation we see a redistribution of the activated positive charge carriers within 2-3 msec building-up a surface charge.

Goddard One State Gas Gun. Measurements at NASA Goddard were conducted using a one-stage gas gun. At a barrel length of about 10 m the gun can fire 63.5 mm (2.5 inch) diameter sabots with masses from 90 g to 1.2 kg to a maximum speed of about 1 km/s. The sabot can carry a smaller projectile which impact the rock samples after the sabot has been stopped by a sabot catcher consisiting of a 20 mm (0.75 inch) thick steel plate with a 32 mm (1.25 inch) hole. The Goddard gun has a large compartment and a 1.6 m (64 inch) wide, nearly 4 m (12 feet) long catch tank, which we used to set up large rock samples. The assembly can be pumped down within 1-2 hrs to less than 1 torr for a given test shot. Approximately four to eight shots are feasible per day.

Goddard Example Data. The goal of the Goddard experiments was to obtain data from which we can derive the threshold of the energy of the acoustic or seismic waves to activate positive hole charge carriers. An example is shown in Figure 1. Shots were fired at 150 mm (6 inch) long granite cylinders equipped with six capacitive sensors along the axis and one a Cu contact on the end. A 6.3 mm (0.25 inch) steel ball bearing hit the face of the granite cylinder at a speed of about 350 m/s. The first two capacitive sensors show a near-instant activation of the positive charges, indicating that the acoustic/seismic waves had enough energy in the first 75 mm (3 inch) of the rock cylinder to break the peroxy bonds and activate positive hole charge carriers. Beyond 75 mm a positive charge cloud travels at approximately 200 m/sec through the rock leading to a series of voltage maxima and minima [4].

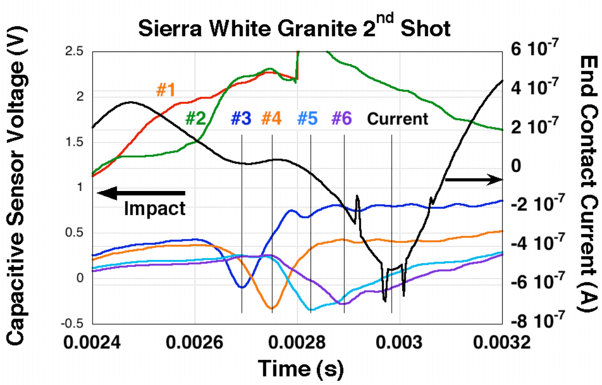

Figure 1. Example results from a NASA Goddard impact test showing the propagation of PHPs through a 150 mm granite cylinder.

Relevance to Lunar Exploration: Our work indicates that electric currents can be generated under a variety of conditions relevant to the moon. For instance, during impact events, either meteorite impacts or human-made impactors such as the LCROSS mission, will probably lead to substantial electric pulses. The P and S waves propagating outward from the point of impact at velocities around 6 and 3.4 km/sec respectively, will be followed by a charge cloud propagating at a much slower speed, on the order of 200 m/sec. This moving charge will be attenuated by the polarization field that will build up concurrently. Additional attenuation is expected on the basis of loss and scattering mechanisms, which have not yet been studied in detail.

During its outward propagation, the charge cloud will emit a low frequency EM signal that could probably be recorded by an approprate antenna on the spacecraft in lunar orbit. Furthermore, given the high surface potentials measured during impact experiments at NASA Goddard (see Fig. 1), we have to consider other emission processes arising at the lunar surface.

One possibility are electric discharges, which have been recorded in air [1] and might also occur in vacuum, if the surface potentials exceed certain ionization thresholds. Such discharges would manifest themselves in EM emission in the low frequency radio frequency range.

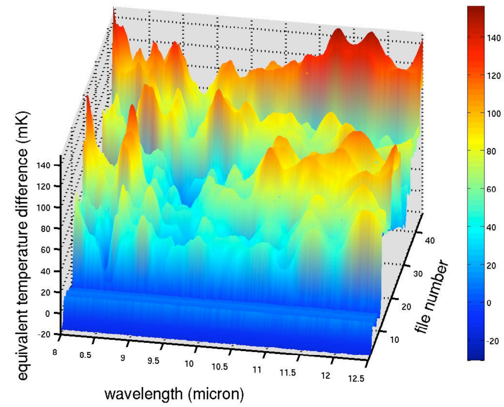

Figure 2. Excess IR intensity emitted during stressing a rock (anorthosite) 50 cm away from the surface from which the IR emission is measured [5]. Intensity is plotted against wavelength with the y axis being the time axis (36 min) of increasing stress application.

A further possibility is stimulated infrared emission in the form of a series of narrow bands beginning at 930 cm^{-1} (10.7 micron) and extending to lower energies (longer wavelength) in 50-60 cm^{-1} increments. These "cold" emission band in the thermal infrared window (for 300 K emission) arises from the recombination of positive hole charge carriers at the surface and the radiative decay of the vibrationally highly excited O-O bonds [5].

Figure 2 shows the excess IR intensity emitted from a rock that is being stressed 50 cm away from the surface from which the IR emission is measured. The sequence of narrow bands that appear within seconds is most clearly seen at the beginning of stressing.

Conclusions: Understanding the electrical properties of igneous rocks, in particular gabbro and anorthosite, when deviatoric stresses are applied, opens opportunities for novel experiments on the moon that have never before been proposed.

References:

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