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Natural Hazards and Earth System Sciences
Discussions

Interactive comment on "Pre-earthquake magnetic pulses" *by* J. Scoville et al.

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We thank referee 2 for a detailed commentary.

First, regarding the discussion of Dahlgren, et al. (2014), the situation has progressed somewhat since its initial publication. A recent experimental study published in the Journal of Asian Earth Sciences (Scoville, et al., 2015) found that with a nominally equivalent experimental setup, some of the results in Dahlgren, et al. (2014) could not be reproduced. Specifically, the polarity (sign) of electrical currents agreed with those previously reported in the literature and contradicted the findings and conclusions of Dahlgren, et al. We hope to include this and other NHESS-D comments from the discussion of Dahlgren, et al (2014).

The rock-stressing experiments presented in Scoville, et al. (2015) also contain data

directly relevant to the phenomenon of unipolar pulses. By applying a rapid (approx. 1ms) impulse to a rock tile, a predominantly unipolar pulse of current is consistently observed. The broadening of the 1ms impulse to a 3-6ms current pulse indicates that diffusion is taking place as the charge carriers drift through the rock, a behavior that is characteristic of semiconductors. This is the phenomenon that originally allowed Haynes and Shockley to confirm the drift-diffusion dynamics of semiconductors.

Moreover, since currents are the sources in a magnetic field, unipolar current pulses should be accompanied by unipolar magnetic pulses, as modeled in the present manuscript. Figs 14a-e from Scoville, et al. (2015) are attached, showing the result of five experiments producing current pulses. The predominantly unipolar nature of these current pulses resembles the predominantly unipolar magnetic pulses described by the model of our manuscript. We would like to make note this behavior in the section summarizing experimental results.

In response to the numbered points raised by referee 2:

1. Regarding "The incidence of these pulses increased as the day of the earthquake approached", details can be found in Bleier, et al. (2009). Figure 4 shows that the pulse count in the three weeks preceding the Alum rock earthquake, the pulse count was much higher than any other 3-week period from 2006-2007. Moreover, after the earthquake, the pulse count immediately falls back to normal levels. Bleier, et al. (2009) also notes that there were no nearby lightning strikes at corresponding times, and that in comparison to the PC3 and PC4 geomagnetic pulsations, these localized unipolar pulses were much stronger, longer, and could not be seen at locations far from the EQ epicenter.

2. Noted, the figures should be numbered in the order they are referenced in the text.

3. 5m-7 is a typographical error, one of three that were introduced during the typesetting process, it should read $5\text{x}10^{-7}$ m. Also, "Vasileskaet al" should be "Vasileska, et al." and 'V' should appear in bold italics on the first line of equation 1.

4. This is just mathematical formalism for the space-time domain on which the partial differential equations are to be solved. In this case, Omega represents a region of three-dimensional real Euclidian space. Crossing this with the time interval (0, T) gives the four-dimensional space-time that forms a coordinate space over which the equations are defined.

5. This particular surface (a flattened teardrop shape) was chosen somewhat arbitrarily to avoid spherical symmetry. Perfect spherical symmetry could lead to cancellation of fields, but in practice this is impossible to achieve with surfaces that are carved out of discretized rectangular grids. The shape of the source volume in the rectangular grid seems to make very little difference – a tetrahedral source volume produces nearly the same result – although the signal strength is increased with a larger source volume.

6. The fact that very slow (nearly DC) variations in the magnetic field can pass through the earth is the basis for magnetotelluric surveys. Ultra-low frequency radio waves are also used for "through-the-earth" radio communications in mine shafts due to the fact that lower frequency waves can penetrate the earth much more effectively than more conventional radio frequencies. This behavior is typical of most materials: the characteristic depth of penetration of an EM wave (the "skin depth") typically scales as $\sqrt{\frac{2\rho}{\omega\mu}}$ where ω is the (angular) frequency, ρ is the resistivity, and μ is the magnetic permeability.

7. In general, the VAN method seems consistent with an underlying flow of positive holes along a preferred direction, such as along a vein or dyke of mafic rock. This allows charges to propagate far from their source (the stressed volume) without dissipating significantly, which, in turn, allows sufficient number of charge carriers to accumulate and generate a surface potential. This potential, to the extent that it is primarily electrostatic, doesn't involve enough current to generate large magnetic fields. It could, however, in highly energetic circumstances. The phenomenon of 'earthquake lights' could result from such a preferred direction of current flow in conjunction with a high

level of current, e.g. stimulated by an S-wave.

8. We will review the references provided and comment. I note in passing that 1) Plastic deformation of individual crystal grains in most cases would require very high levels of stress/temperature and 2) Several experimental validations of the crack dislocation model seem to employ marble samples. Marble is one of the few rocks that does not exhibit a significant positive hole effect, due to its calcite structure. Positive holes (and their accompanying semiconductor effects) are most prominent in igneous rocks. Hence, electrical activity in marble samples could be expected to follow a different pattern than in most igneous rocks.

Best regards, John Scoville

References

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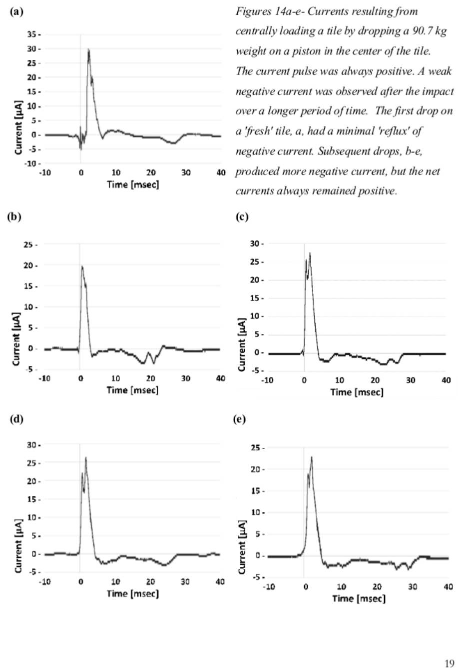

Fig. 1. Figs. 14a-e from Scoville, et al. (2015)