MACROSCOPIC ELECTRIC CHARGE SEPARATION DURING HYPERVELOCITY IMPACTS: POTENTIAL IMPLICATIONS FOR PLANETARY PALEOMAGNETISM. D. A. Crawford and P. H. Schultz, Department of Geological Sciences, Brown University, Providence, RI 02912.

The production of transient magnetic fields by hypervelocity meteoroid impact has been proposed to possibly explain the presence of paleomagnetic fields in certain lunar samples as well as across broader areas of the lunar surface[1-6]. In an effort to understand the lunar magnetic record, continued experiments at the NASA Ames Vertical Gun Range allow characterizing magnetic fields produced by ∼5 km/s impacts of 0.32-0.64 cm projectiles over a broad range of impact angles and projectile/target compositions [7-10]. From such studies, another phenomenon has emerged, macroscopic electric charge separation, that may have importance for the magnetic state of solid-body surfaces. Adushkin and Soloviev observed this phenomenon during explosive cratering experiments[11,12] but the magnetic consequences of macroscopic electric charge separation (as opposed to plasma production) during explosion and impact cratering have not, to our knowledge, been explored before now. It is straightforward to show that magnetic field production due to this process may scale as a weakly increasing function of impactor kinetic energy although more work is needed to precisely assess the scaling dependence.

The original intent of our experiments was to assess the character of purely electrostatic signals for comparison with inferred electrostatic noise signals acquired by shielded magnetic sensors buried within particulate dolomite targets (Fig. 1). The results demonstrated that electrostatic noise does affect the magnetic sensors, but only at relatively short distances (< 4 cm) from the impact point (our magnetic studies are generally performed at distances greater than ∼5.5 cm [7-10]). However, to assess models for magnetic field generation during impact, measurements are needed of the magnetic field as close to the impact point as possible[9,10]; hence, work with an improved magnetic sensor design is in progress. In this paper, we focus on electric charge separation during hypervelocity impacts as a potential transient magnetic field production mechanism in its own right.

![Fig. 1 Setup used for the measurement of macroscopic charge separation during the exploratory hypervelocity impact experiments reported here. Each electrode consists of an aluminum plate with a 5-cm hole to allow passage of the projectile through the upper electrode and to insure that no early-time interaction occurs between the projectile and lower electrode. Ongoing experiments with greater electrode coverage are being performed to better identify the charge distribution in space and time for various projectile and target materials.](image)

Adushkin and Soloviev measured electric fields produced by electric charge separation during explosive cratering experiments in dry and wet soil[11,12]. They obtained an empirical relationship between electric charge (q), explosive charge (W) and crater diameter (D) of the form: \( q = 2.92 \times 10^{-4} W^{0.65 \pm 0.05} = 7.2 \times 10^{-4} D^{2.04 \pm 1} \) (MKS) [11,12]. The latter relationship can be transformed using the scaling relations for hypervelocity impacts (5 km/s, terrestrial gravity) into dry sand [13] to obtain a relationship between electric charge and equivalent projectile kinetic energy (E) of the form: \( q = kE^{\alpha} = 5.5 \times 10^{-7} E^{0.56 \pm 0.03} \) (MKS). For comparison, an \( \alpha \)-value of 0.67 implies that charge production is a contact phenomenon proportional to the projectile area whereas an \( \alpha \)-value of 1.0 implies that charge production is proportional to projectile volume (at constant impact velocity). Similar empirical relationships can be derived from charge collection data that were obtained during hypervelocity impact experiments into dolomite targets (Fig. 2). The relationship between electric charge \( q_1 \) collected on the lower electrode (see Fig. 1) and projectile kinetic energy (E) fits an expression of the form: \( q_1 = 5.5 \times 10^{-12} E^{0.93 \pm 0.09} \) (MKS). A similar relationship derived from data acquired by the upper electrode is of the form: \( q_2 = 5.4 \times 10^{-9} E^{0.63 \pm 0.14} \) (MKS).

A first-order estimate of the average azimuthal magnetic field \( B \) (in Tesla) produced by vertical transport of charge \( q \) during vertically incident hypervelocity impacts can be represented by an equation of the form:

\[
B(x') = 2 \times 10^{-7} \frac{q}{x' L \Delta t} = 2 \times 10^{-7} \frac{kE^{\alpha}}{x' L \Delta t}
\]  

(1)
where $x'$ is dimensionless length, $L$ is the dimensional length scale (in meters), $\Delta t$ is the length of time (in seconds) during which charge transport occurs, $k$ and $\alpha$ are empirical constants (as shown earlier), and $E$ is projectile kinetic energy (in Joules). There are two potential length scales for this problem: projectile radius ($L = R_p$) or crater radius ($L = R$). To simplify matters, we consider projectiles with equal velocity and density impacting a single planet; hence, the length scales can be written in terms of projectile kinetic energy [13]: $L = R_p \propto E^{0.33}$ or $L = R \propto E^{0.26-0.28}$. Likewise, there are several potential time scales bracketed by two extremes: projectile penetration time ($\Delta t \propto R_p \sqrt{\rho} \propto E^{0.33}$) and crater formation time ($\Delta t \propto E^{0.13-0.14}$). Of particular interest is the case where charged impact products possess a velocity independent of the length scale ($\Delta t \propto L$). In any case, the azimuthal magnetic field of this first-order model can be written in the form:

$$B(x') = \frac{k}{x'} E^{-\beta}$$

(2)

where the constants of proportionality have been absorbed into $k$, $\alpha = 0.53-1.02$, the empirical exponent shown earlier and $\beta = 0.39-0.67$, depending on the particular combination of length and time scales. For instance, if the transient magnetic field strength experienced by target material near the crater rim is of interest, then the crater radius would be an appropriate length scale. Furthermore, if the charged impact products expand at a scale-independent rate (e.g., entrained within the expanding vapor/plasma plume), then an appropriate value for $\beta$ would be $0.52-0.56$; hence, the magnetic field experienced by target materials near the crater rim ($x' \sim 1$) would scale as a weakly increasing function of impactor energy for most of the experimentally derived $\alpha$-values. Clearly, better estimates of $\alpha$ and $\beta$ are required if reasonable extrapolations of this process to larger scales are to be made. Ongoing experiments are being performed that will hopefully improve the precision of the empirically derived $\alpha$ and $\beta$-values and lead to a better understanding of the process.