ISOLATING THE RICOCHET-INDUCED VAPORIZATION PROCESS. P.H.Schultz[1], S. Sugita[2], C.A. Eberhardy[1] and C.M. Ernst[1] , [1] Brown Univ. Dept. of Geol. Sci.. (Providence, RI 02912, peter_schultz@brown.edu); [2]Univ. of Tokyo, Dept. of Complexity Sci. and Eng. (Hongo, Bunkyo-ku, Tokyo 113-0033, JAPAN).

Introduction: Impact vaporization is not simply the result of shock effects. Previous experimental studies document multiple components reflecting the effects of jetting, shock, ricochet, and shear [1]. As a result, separate components of vapor can be observed and measured by imaging [1], electrostatics [2], and spectroscopy [1,3,4]. Peak shock pressures decrease with decreasing impact angle (from the horizontal), yet impact vaporization increases by three orders of magnitude from 90^o to 30^o [1]. Such enhanced heating is not confirmed, however, by theoretical computations [5]. Consequently, new laboratory experiments were designed in order to isolate the contribution of impactor failure and post-contact shear to the vaporization process as a possible explanation for the discrepancy.

Experimental Strategy: Experiments were performed at the NASA Ames Vertical Gun Range. Pyrex projectiles were launched at 30^o into calcium carbonate powder at 5.4 km/s. But in order to isolate the controlling processes, the carbonate powder was restricted to a 100µm layer covering one-half of a copper block. Impact points were selected such that the first contact occurred either in the carbonate or exposed copper half of the target. This strategy isolated the jetting phase produced at first contact from vaporization created later by the projectile ricocheting and impacting downrange [see 6].

Impacting the copper surface first removed any carbonate vapor from first-contact processes. Hence, any vaporization must originate from the ricochet component striking the carbonate veneer downrange (i.e., a *Ricochet-Coupled Impact*, or RCI). Impacting the carbonate half removed vaporization produced by the downrange ricochet component (i.e., a *Partially Couple Impact*, or PCI). Impacts that coupled both the first contact and ricochet components produced a *Fully Coupled Impact* (or FCI). In all experiments, the copper was milled such that the initial target surface was flat and continuous.

High-speed 0.35m spectrometers captured the vapor phases [7]. A six-channel photo-diode simultaneously recorded the evolution of the blackbody temperature [see 8]. Four telescopes isolated areas on the target from above, each covering a field of view (FOV) 2 cm across. The first area (A) was slightly offset downrange from the impact point. The second area (B) was positioned downrange at a distance of 6 cm (just off the target surface). The third (C) and fourth (D) spots were focused downrange (12 and 18 cm, respectively) in order to isolate slower moving vapor components from the jetting phase. Pyrex projectiles ensured catastrophic failure and minimized competing contributions to the spectra.

Exposure times of about 15-17 µs further allowed temporally resolving different components by subtraction. Region D could record only the jetting phase, whereas C captured both the jetting (15 –18 km/s) and vapor components traveling downrange at velocities at least 6-7 km/s. Region B recorded downrange vapor phases moving at least 3-4 km/s.

Results: The 100µm-thick layer of carbonate was sufficient to prevent significant vaporization of the copper substrate (30^o impact angle). The spectral content of the vapor depended significantly on the target configuration. The projectile impacted the carbonate layer first in two experiments: one (E-I) struck the surface six projectiles uprange from the exposed copper; the other (E-II) hit less than 3 projectile diameters away. The E-I configuration produced jetting and vapor from both first-contact (jetting) and post-contact (ricochet) processes, i.e., it was fully coupled (FCI). The latter configuration (E-II) restricted contributions to the spectra primarily from the first contact since most of the ricochet encountered the exposed downrange copper surface (i.e., a PCI).

The exposure times (5µs to 20µs) for the FCI experiment E-I isolated vapor phases traveling downrange at 15 to 18 km/s in the view area farthest downrange, i.e., the jetting component. View Area C (13 cm from impact) captured *both* the jetting phases and any moderate-velocity downrange vapor (~ 8 km/s). View Area B missed the jetting phase (had already passed the FOV before the exposure began) but captured moderate-velocity vapor phases and ricochet debris. Lastly, Area A (slightly downrange from the impact point) largely recorded cooler vapor and target heating (blackbody).

As would be expected from the FCI, the intensity of C far exceeded D because it recorded both the jetting phase and any downrange vapor component. Instead of emissions, however the spectra were dominated by absorptions (CaO). At this location, the vapor had expanded above the heated portion of the heated projectile ricochet debris (blackbody component).

The PCI (E-II) configuration produced jetting (Fig. 1) from the carbonate veneer at first contact but reduced any vapor generated from the ricochet component over the 2.8µs to 20µs exposure times. As a result, view areas C and D had nearly identical spectra. Area B exhibited a slightly reduced blackbody (relative to the FCI), but the earlier trigger also allowed capturing a portion of the initial jetting phase.

The experiment designed to isolate the ricochet-coupled impact (RCI) revealed dramatic differences (Fig. 2). The downrange view area (D) captured the jetting created only by ricochet impacts that scoured the downrange calcium-carbonate layer. In contrast with either the FCI or PCI configurations, the RCI-jetting component exhibited both CaO and CO bands downrange (D) with minimal contributions from blackbody sources. This became more evident in C, which captured vapor components traveling downrange with velocities greater than 6km/s. Because the intensities in C far exceeded D, the component in C must include significant vapor phases traveling between 6 km/s and 13 km/s, a component also contributing to B.

Vapor produced in the ricochet-coupled experiment (RCI) is characterized by co-existence of Ca, CaO, and CO. Temperature measurements using a six-channel photo-diode system [8] revealed that the spatially integrated (wide field of view) temperature for the RCI exceeded 6000^{o}K, whereas the PCI and FCI exhibited lower temperatures (5000^{o}K and 3300^{o}K, respectively). These differences reflect the impedance at first contact. Spectral measurements demonstrate that the blackbody component is largely near the point of impact. Consequently, the recorded temperatures are documenting the important role of the thin carbonate veneer (~ 0.1% of the projectile diameter) in reducing the coupling to the target and impactor, as previously demonstrated in other studies [9].

Summary and Implications: Experimental design has allowed isolating the ricochet contribution to the vaporization process. While jetting dominates the impact "flash" [3], impactor ricochet plays the controlling role for impact-generated vapor. This latter component contributes to vapor traveling at maximum velocities comparable to the sum of the ricochet velocity (approximately the initial impact velocity) and the vapor expansion velocity of carbonate vapor (observed to be about 2.5 km/sec; see [1]). The carbonate vapor comprising the jetting phase is dominated by ionized gas [4], whereas the ricochet vapor contains both atomic (Ca, Na) and molecular (CaO, CO) emissions. Conclusions previously drawn about the reduced melting/vaporization at lower impact angles [10] may reflect an inadequate accounting for the fate of the impactor and its contributing role in the impact process.

References:

[1] Schultz P.H. (1996) *JGR* 101 (E9), 21117. [2] Crawford D. and Schultz P. H. (1999) *Internat. J. of Impact Engineering (23), 169-180.* [3] Sugita S. and Schultz P. H. (1999) *JGR* 104 (E12) 30825-30845. [4] Sugita S. and Schultz P. H. (2003) *JGR* 108 (E8), 5051. [5] Pierazzo E. and Melosh H. J. (1999) *Earth Planet. Sci. Lett.*, 165, 2,163-176. [6] Schultz P. H. and Gault D. E. (1990), *GSA Bull. 247*,239-261. [7] Eberhardy C. A. and Schultz P. H. (2003) *LPS XXXIV*, Abstract #2039. [8] Ernst C. M. and Schultz P. H. (2004), this volume. [9] Schultz P. H. (2000) *LPS XXXI*, Abstract #2071.

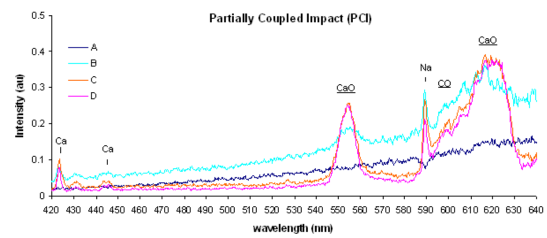

Figure 1. Spectra from a "Partially Coupled Impact" created by impacting a carbonate layer uprange but preventing the ricochet from hitting the carbonate downrange. View areas C and D recorded jetting produced only from the first-contact (no ricochet) into the carbonate. Different viewing positions represented by (A, B, C, D) as described in the text

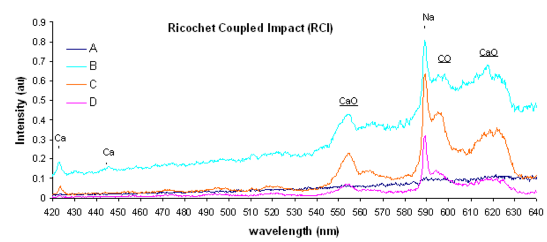

Figure 2. Spectra from a "Ricochet-Coupled Impact" created by allowing only the projectile ricochet to strike the carbonate layer. All emissions were created by ricochet-generated processes and resulted in reduced jetting (D) but significant vaporization (C and B). Additionally, the ricochet produced vapor containing CO, Ca, and CaO emissions. Different viewing positions represented by (A, B, C, D) as described in the text.