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Model for upper atmospheric aggregation of ash following hypervelocity impact events

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Introduction: Accretionary lapilli (AL) have been found in hypervelocity impact crater ejecta deposits and are similar to volcanically produced AL [1]. The initial conditions of ejection from an impact crater are vastly different than ejection from a volcano, particularly regarding the mass of ejecta and the velocity of ejection. Thus, some models of AL formation may not apply to impact ejecta. We propose an upper atmospheric aggregation model. A numerical model is herein described

Numerical model: Re-entry is modeled using the 3D hydrocode SOVA [2], using mainly its “dusty flow” subroutines. Particles are treated as solid non-deformable; they move through the atmosphere and exchange momentum and energy. Radiative, conductive, and convective heat transfer are included. Details of the procedure may be found in [2].

Initial mass flux of ejecta, velocities, and re-entry angles are derived from crater-forming models. The power law SFD N>m$\sim$m-b is used with the exponent b of 0.8 and 0.9. The largest fragment for a given distance can be deduced from observations. The smallest fragments are $\sim$10 μm in diameter.

Results: During re-entry, particles decelerate due to drag, heating the atmosphere, and the atmospheric gas heats particles via conduction, convection, and radiative transfer. Additionally, shock waves are generated. Intensity of these processes depends on the total mass and velocity of ejecta, but also on the ejecta SFD.

Particles of varying sizes were modeled. Large particles penetrate to low altitudes, maintaining temperature. Small particles decelerate at high altitudes, have elevated temperatures, and heat the atmosphere to T> 600 K. These particles can release water from pores or, in some cases, from mineral structures. Cold particles entering later may be coated by this water, permitting aggregation and pushing other particles to lower altitudes. Substantial mixing of particles at temperatures and densities suitable for AL formation remains as long as ejecta are arriving at the top of the atmosphere, i.e. within a few minutes. When the flux ceases, the cloud becomes stratified with the largest particles at the bottom and the smallest at the top. At approximately the same time, shock waves reflected from the surface stir the cloud again, strongly affecting the smallest particles, which may be thrown away from the site back to high altitudes (see [3]).

At distances 400 – 1600 km from the crater (velocities 2-4 km/s), conditions are suitable for AL formation. Closer to the crater, low temperatures and a deficiency of small particles prevent aggregation. At larger distances, re-entering particles are melted. A downrange direction is preferred for AL formation.

Discussion: Conditions in a re-entering ejecta cloud are similar to pyroclastic density currents, allowing formation of AL. AL within “fallback” ejecta deserve separate consideration (e.g., [4]). Likely, multiple processes occur following impact events that permit aggregates to form. Modeling of particles’ interaction on a microscopic scale is our challenge for the future.

References: [1] Cannon W.F. et al. (2010) GSA Bulletin, 122, 50-75. [2] Shuvalov V. (1999) Shock waves 9, 381-390. [3] Artemieva N. and Morgan J. (2009) Icarus 201, 768-780. [4] Stoeffler D. et al. (2013) Meteoritics & Planet. Sci. 48, 515-589.