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The descent of hypervelocity impact ejecta through planetary atmospheres

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New high-resolution imagery of planetary surfaces and continuing studies of distal ejecta deposits on Earth yield information about how distal impact ejecta vary on different planets. Variations in ejecta deposit distribution and the properties of individual ejecta particles can be attributed to differences in the formation and transport of particles from the impact event, as well as differences between the atmospheres through which the particles descend. Although it is fairly simple to calculate how a single particle falls through an atmosphere, the arrival and deceleration of many hypervelocity particles is more complex and involves a large quantity of energy, requiring a numerical treatment of the ejecta-atmosphere mixture. Here we examine the effect of atmospheric structure on ejecta-atmosphere interactions and implications for the deposition of distal ejecta on different planetary bodies.

Ejecta descent through an atmosphere was modeled using a two-phase fluid flow code, which accommodates diffuse particle transport through a fluid medium from the free molecular to continuum flow regimes. A range of initial atmospheres are considered, including that of the modern and Archean Earth, Mars, and Venus. Assumed to behave as an ideal gas, the initial model atmosphere is isothermal with a pressure gradient that decays exponentially upwards as a function of the atmospheric scale height. For these simulations, which are not tied to specific impacts, the ejecta phase is approximated as identical basaltic spheres, which reenter the atmosphere at a constant flux and at speeds not exceeding the planet's escape velocity.

The particles decelerate through the upper atmosphere, become hot, heat the surrounding gas via friction, and radiate their remaining heat as thermal radiation. The altitude at which the particles reach their fall velocities has a linear dependence on atmospheric scale height and a logarithmic dependence on surface pressure. The numerical models show that the upper atmospheres of the modern Earth, the Archean Earth, Mars, and Venus all respond to the injection of high speed impact ejecta in the same general way, with predictable dependences on both the ejecta fallback and the initial atmosphere properties. In denser atmospheres with larger scale heights, such as Venus, the ejecta reach their fall velocities at higher altitudes and experience longer total fall times at lower settling velocities. In contrast, in thin atmospheres, such as Mars, the particles are able to penetrate deeper into the atmosphere and fall much more quickly to the surface. The denser atmospheres also inhibit instability initiation, although any lateral spreading (e.g., due to winds, inhomogeneous initial ejecta distributions) is enhanced by the longer fall times. For identical reentry scenarios, the atmospheres reach similar temperatures for Earth, Mars, and Venus, although the altitudes affected vary due to the different deceleration distances. The fate of the heat radiated from the hot ejecta also varies: increased greenhouse gas contents of the Archean Earth, Mars, and Venus (as compared to the modern Earth) lessen any thermal effect at the surface.