ON THE FORMATION OF CONTIGUOUS RAMPARTS AROUND MARTIAN IMPACT CRATERS. Peter H. Schultz, Lunar and Planetary Institute, 3303 NASA Road 1, Houston, TX 77058 and D. E. Gault, Murphys Center of Planetology, Box 833, Murphys, CA 95247.

Martian impact craters display a great deal of variety in ejecta facies that depends on size, location and elevation (e.g., see 1 and 2). The presence of even a very tenuous atmosphere can affect the ballistic trajectories of sufficiently small ejecta (3,4). This process can be demonstrated from laboratory scales (5) to large explosive events (6). The NASA-Ames Vertical Gun Range (AVGR) provides a unique facility for systematically investigating the effects of an atmosphere on impact cratering over a wide range of conditions that theoretically should have applications at much broader scales (7). We report here the parameters that control the development of contiguous ejecta ramparts observed at laboratory scales and their implications for formation on Mars. It must be stressed that we are considering the simple contiguous rampart (Fig. 1) and not the lower relief ramparts at the terminii of multiple flow lobes.

Conditions for rampart formation: Ejecta ramparts are produced in compacted pumice targets over a wide range of impact velocities and atmospheric densities but within a restricted range of atmospheric pressures. The pumice targets are composed of shards (80% smaller than 120μ; 30% smaller than 40μ). Even for very different atmospheric densities (argon, carbon-dioxide, helium, or nitrogen) ramparts consistently begin to form near 0.06 P_0 (P_0 = 760 mm, Hg) but disappear above 0.4 P_0 for velocities from 0.1 to 6.5 km/s. The rampart boundary (r) increases with increasing atmospheric pressure: from 1.5 R (crater radius = R) at 0.06 P_0 to 2.0 at 0.25 P_0 for 0.635 cm spheres with velocities of 2 km/s. Above 0.4 P_0 the rampart is heavily degraded by radial scouring. Ramparts are also produced in fine-grained sand (No. 140-200 targets) and increase in range with increase in P. Post-formation crater collapse, however, prevents direct comparison with craters in compacted pumice (No. 140-200 sand has grains of which 80% are smaller than 145 μ and 30% smaller than 100 μ).

Analysis of high-frame rate photography suggests that a rolling motion of air occurs behind the leading ejecta curtain with outward flow at the base and return flow above. Ramparts are believed to be produced by erosion and terminal deposition associated with this rolling motion. To test this idea and to determine the effect of fine-grained material buried beneath coarse-grained material, we placed a layer of No. 20 sand (80% finer than 800 μ and 30% finer than 650 μ) over the compacted pumice. Impacts into only No. 20 sand did not produce ramparts. Under vacuum, impacts into sand-over-pumice targets resulted in normal-appearing bowl-shaped craters and ejecta facies with mixing of pumice and sand in the ejecta curtain. From 0.05 to 1 P_0, however, a nested crater was produced with the pumice ejecta separated from sand ejecta. Cross-sections revealed that the outer "rim" was not uplifted but was an accumulation of No. 20 sand. Striations on the exposed pumice surface around the inner crater in pumice suggest lateral erosion of the sand layer. Impacts into targets with the pumice-over-sand (No. 20 sand) produced bowl-shaped craters without ramparts. But, impacting a sand target thoroughly mixed with dry pumice ($\sim$20%) produced a contiguous rampart. An experiment also was performed where progressively finer sands (No. 20,30, and 140-200) were nested inside each other with compacted pumice at the impact point. This experiment was designed to see if rampart development was an early or late-time process. A normal-appearing crater resulted without a rampart. Finally, we simulated a layered atmosphere by forming a layer of CO_2 vapor above the target and found that such conditions encourage rampart formation.

On the basis of these tests, rampart development depends on atmospheric pressure and grain size in the target. The rampart appears to be a late-stage process that does not depend on heating of the atmosphere or target by the impact event or the presence of volatiles. Finally, only a fraction of the target needs to have a fine-size component. Such results suggest that ramparts develop by air flow in response to the outward moving wall of ejecta in an atmosphere.

Evolution of the Ejecta Curtain: Individual frames from the high-frame rate photographs were digitized with a vidicon camera. Each imaged frame was digitally subtracted from the preceding frame, thereby leaving only those components of the ejecta curtain that have moved in the selected time interval. Frame pairs were selected with the same time difference (5msec) but each pair was selected a factor of two farther into the sequence. The first pairing permits comparison of accelerations, whereas the latter selection permits calibrating curtain advancement as power-law growth. Figure 2 illustrates the results for three different atmospheric conditions. Increased atmospheric pressure results in increased distortion of the ejecta curtain with bowing below and constriction above. This technique reveals that the base of the ejecta curtain at 1 P_0 outpaces the curtain at near vacuum conditions for the same impact velocity (at the target). Such a basal expansion is not equivalent to the base surge observed around explosion craters, a process involving gravity collapse of fine debris buoyantly lofted in a hot cloud. The basal expansion in the impacts occurs without significant atmospheric heating. Comparisons of the different experiments reveal that distortion of the curtain is influenced by atmospheric density and ejecta size. The degree of curtain distortion at 0.9 P_0 of He resembles 0.06 P_0 in air, whereas the degree of distortion at 0.25 P_0 in CO_2 resembles about 0.4 P_0 of air. The degree of curtain distortion for No. 140-200 sand targets in 0.5 P_0 in air resembles the results for pumice targets near 0.3 P_0.

Concluding remarks: We must stress that we are not proposing atmospheric pressures and ejecta sizes comparable to laboratory conditions. Scaling relations suggest that comparable phenomena should occur

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for larger size ejecta and lower atmospheric pressures for larger impacts (7). Such analysis suggests that craters with contiguous ramparts may represent relatively low velocity impacts in lithologies with lower volatile content than craters with highly fluid ejecta facies. Increased volatile content will decrease ejecta sizes by comminution (4,8) and by aerodynamic break-up (4,5), thereby increasing the lateral extent of the rampart. If the impact velocity or volatile content is sufficiently high, the energy trapped in the ejecta cloud results in long run-out flows or radial scouring (4). Thus, volatile content in the martian regolith is considered sufficient but not necessary to produce the variety of observed morphologies.

References

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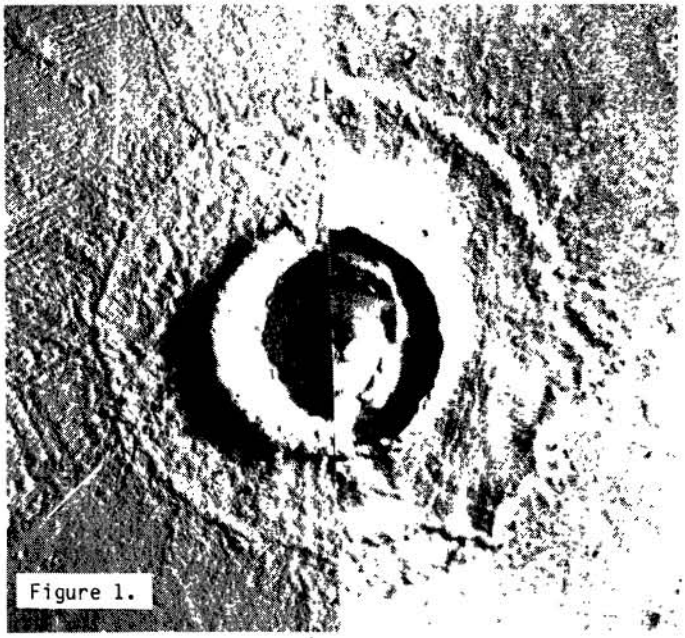

Figure 1.

Comparison of contiguous rampart-bordered crater produced in the laboratory (left half) and on Mars (right half). Laboratory conditions involved 5.3 km/s impact by 0.635 cm aluminum sphere into compacted pumice under 1.90 mm (Hg) of argon. Martian impact crater is 12 km in diameter (Viking 10A61).

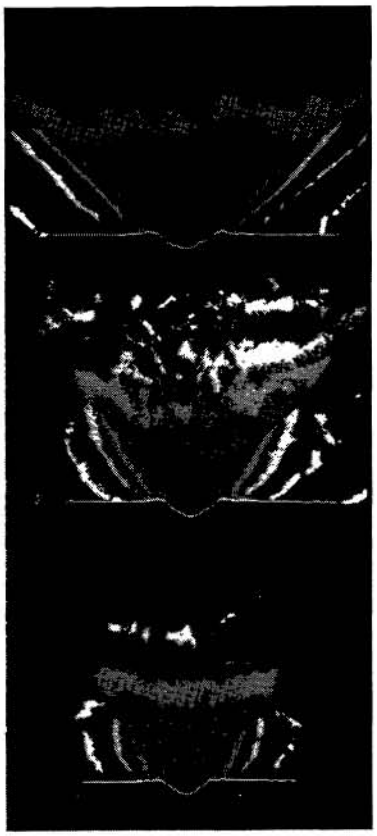

Figure 2.

Ejecta curtain development for different atmospheric pressures (0.12 P_0, 0.5 P_0, and 1.0 P_0 air). Impact velocities correspond to 1.48, 1.78, and 1.99 km/s (top to bottom). Width of curtain slices indicates relative expansion within 5 milliseconds. Slices are shown with outer curtain at 7.5, 15, 30, 60, and 120 ms from time of impact. Even at lower impact velocities, base of ejecta curtain under high atmospheric pressures out distances curtain under low pressures. Note that last time slice for 1.0 P_0 is beyond the limits of the image.