Inferences from Martian Craters Formed by Low-angle Impacts

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A typical hypervelocity impact of an asteroid or comet into the surface of an airless body like the moon will produce a hole in the ground surrounded by the material ejected from the hole. There is a fairly regular exponential drop off in ejecta thickness away from the crater rim, and generally the crater and ejecta are radially symmetric. In the presence of a dense atmosphere, such as occurs on Venus, the material ejected from the crater gets caught up in a turbulent cloud and is emplaced in something akin to pyroclastic flows. On Mars, crater ejecta occurs in formations known as "ramparts" that clearly have flowed across the surface. There has been some dispute about the details of the flow mechanism and whether the fluidizing agents are subsurface volatiles or the Martian atmosphere. The properties of craters formed from low-angle (with respect to horizontal) impacts may shed some light on the issue. For craters in a dry vacuum setting there is a consistent progression in ejecta planform and crater shape with decreasing impact angle. Below about 45 degrees the ejecta starts become asymmetric, with less ejecta in the uprange direction. Starting at angles of ~20 degrees, an area uprange of the crater develops that has no ejecta (a "forbidden zone"). As the impact angle becomes more oblique, the amount of ejecta downrange decreases. Between 5 and 10 degrees there is an abrupt transition to a complete lack of downrange ejecta (a second forbidden zone). At the lowest impact angles the crater becomes elliptical with a major axis along the impact trajectory. On bodies with a dense atmosphere asymmetries in the ejecta blanket show up in craters formed from much higher-angle impacts. The turbulent clouds that emplace the ejecta carry downrange momentum from the impactor, so a downrange forbidden zone never develops. Although the ejecta for Martian craters have clearly experienced flow, the ejecta patterns for the craters formed by low-angle impacts are very similar to those on the moon. This suggests that on Mars the ejecta are emplaced ballistically (as in a vacuum), and then some modest flow occurs, probably due to the presence of volatiles within the target materials.