Martian Rampart Craters: Morphologic Clues for the Physical State of the Target at Time of Impact.

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From the return of the first Viking Orbiter images of martian impact craters it was evident that the morphology of the ejecta blankets surrounding these craters was different from their lunar and mercurian counterparts insofar as much of the ejecta appeared to have been emplaced by surface flow (Carr *et al.*, 1977). Over the last ten years, considerable debate has focused on the possible cause(s) for this ejecta fluidization and flow. Possible forms that the fluidizing medium may have taken include water ice or liquid water within the target material (Carr *et al.*, 1977; Boyce, 1979; Johansen, 1979) or atmospheric gases interacting with suitable particle sizes within the ejecta curtain (Carr *et al.*, 1977; Schultz and Gault, 1979; Schultz, 1986). Indeed, Schultz (1986) draws attention to the fact that the fluidized ejecta facies only indicate fluid-like emplacement, and laboratory experiments (Schultz and Gault, 1981, 1984) have shown that rampart-bordered ejecta facies and ejecta flow lobes can develop without the presence of water.

A ground water system has been proposed for Mars on a global scale (Carr, 1979; Clifford, 1986), and it is believed likely that such a system would influence the occurrence and physical state of impact crater ejecta. A major difficulty in correlating these inferences about ground volatile content with the observed properties of crater ejecta blankets lies in knowing the extent to which the ground water system (the deep megaregolith) was filled. Many of the large outflow channels seen on Mars may have formed through the eruption of ground water under pressure from the megaregolith beneath the permafrost, which is estimated to have been about 1 km thick (Carr, 1979). Carr (1986) concluded that the megaregolith below this permafrost layer, planetwide, might contain no less than the equivalent of a water layer 350 meters thick, while Clifford's (1986) calculations of outgassed H_2O on Mars would suggest that if more than a few percent of the quantity of water required to saturate the pore volume of the cryosphere were present, then a sub-permafrost water system of substantial proportions would result. After saturation of the pore volume of the cryosphere, the equivalent of an additional 100 meters of H_2O inventory would be sufficient to create an acquifer nearly 4.3 km deep. This small volume of water is all that is required to produce this acquifer because the predicted pore volume at depth is very low (Clifford, 1986). It is further predicted that much of the water originally at depths of less than 1 km would remain *in situ* for most of martian history (Fanale *et al.*, 1986), thus constituting a possible method for fluidizing impact crater ejecta.

Because of the importance that the presence of liquid water, liquid brines, or ground ice close to the surface would hold in global models of volatile abundance and physical state (e.g., Fanale and Jakosky, 1982; Fanale *et al.*, 1986), more precise observational information is needed to help constrain these theoretical models of volatile distribution and state. One approach to identifying both the former presence (or absence) and physical state of subsurface volatiles in the martian past comes from their inferred influence in controlling the morphology of rampart craters and crater ejecta blankets. Key testable morphologic indicators are thought to be the identification (or lack thereof) of melt water channels and small-scale topography on the surface and edges of the ejecta blankets, and the degree of stability of the parent crater walls (Mouginis-Mark, 1986). Diagnostic features are likely to be physically small in size (probably less than a kilometer in extent) and so have not previously been considered either in global studies of rampart craters (e.g. Johansen, 1979; Horner and Greeley, 1986) or cratering models (e.g., Schultz and Gault, 1984; Schultz, 1986). The current research therefore attempts to describe morphologic features seen in very high resolution (8 to 17 meters per pixel) Viking Orbiter images of crater ejecta blankets and interiors, in order to constrain the most likely target properties at the time of crater formation.

The Viking Orbiter image data set contains approximately 400 frames at a spatial resolution of better than 10 meters per pixel, and 2,200 frames at a resolution of better than 20 meters per pixel, for which the atmosphere was either clear or only slightly obscured (J. Zimbelman, pers. comm. 1986). A search is being conducted of all these images and so far has revealed several examples of both interior and exterior features of impact craters that bear on the nature of the ejecta fluidizing medium. Preliminary observations and speculations on the physical state of the martian regolith at the time of crater formation are as follows:

1) The ejecta lobes retain much of the small-scale structure that was produced during ejecta deposition. Radial striations, pressure ridges and the sharp distal ramparts are all well preserved on craters ranging in size from 4.5-26 km in diameter. The general absence of remobilized materials as a consequence of water sapping from the emplaced ejecta suggests that the lobes possessed appreciable mechanical strength at the time of their emplacement and that the liquid water content of the flows was very low. No evidence to support the proposal by Woronow (1981) that the ejecta contained 16 to 72% water has been found.

2) For two ejecta deposits within the basin Schiaparelli that have been partially eroded, it is evident that large blocks were transported within the ejecta flow, and that some of these blocks were most likely ice-rich. Subsequent melting or ablation of this ice has led to collapse of the ejecta deposit in isolated places to form features similar to terrestrial kettle holes.

3) The same eroded ejecta blankets reveal that flow striations extend through the thickness of the ejecta deposit, rather than simply being superficial features. This would imply that the ejecta flow was non-turbulent, akin to poorly fluidized terrestrial pyroclastic flows.

4) Most of the crater interiors studied to date reveal few signs of melt water release or the abnormal amounts of slumping that would be expected if the rim material were water-rich.

5) Rare examples of surface flow can be found both on the ejecta deposits and crater inner walls. In the case of a small crater southwest of Bakhuysen, it is believed that this surface flow was made possible due to the formation of this small crater on the ejecta blanket of Bakhuysen. For the crater Cerulli, no obvious explanation for the unusually volatile-rich wall material presents itself, but it is clear that extensive surface flow, expressed by numerous small channels on the wall and continuous ejecta blanket, took place following the formation of the crater.

It should be remembered that only a very small number of craters, all in a narrow latitude band (predominately in the southern hemisphere) have been included in this investigation, primarily due to the sparse coverage of the high resolution Viking Orbiter images. Individually, the above observations do not argue convincingly for a single set of properties for the target material or the derived ejecta; small volumes of liquid water, larger volumes of ice, or purely atmospheric effects could all be used to explain ejecta fluidization. Taken together, however, it is believed that the observational data supports the notion that ice, rather than water or atmospheric effects, dominated both the emplacement process and the mode of ejecta fluidization for the majority of rampart craters studied here. By implication, ice must have been present in the target rocks in significant amounts (a few to perhaps 10 volume percent?) at the time of impact. The surface channels (both on the ejecta blankets and within craters) and kettle holes argue against atmospheric effects dominating ejecta fluidization, while the stability of small-scale topography and only the rare occurrence of surface channels indicates that liquid water was not commonly associated with the ejecta.

As a topic for future investigation, numerical models need to be developed to determine the effects of different volumetric amounts of ice that would have to be entrained within the ejecta to produce the observed morphologies. At the present time the high mechanical strength of ejecta lobes, as demonstrated by up to several tens to hundreds of meters of relief on the lobes and ramparts, would suggest that the volumetric amount of ice that was incorporated within the ejecta was quite low. Quantitative estimates for the volume of ground ice are needed, but currently estimates appear consistent with the regolith/atmosphere models proposed for Mars and can explain the observed landform morphology.

Clearly, however, the observations presented here only pertain to a very small number of fresh cratérs that by chance were imaged at very high resolution by the Viking Orbiters. While these craters provide an insight into the physical state of the target material for these random areas, image resolution is inadequate to draw firm conclusions on volatile state for most of Mars. As a result, it is concluded that the identification of small-scale features diagnostic of water sapping and ejecta remobilization on crater ejecta blankets constitutes one of the many interesting experiments that could be conducted with the sub-meter resolution camera planned as part of NASA's Mars Observer Mission.

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