**SUBSURFACE VOLATILE RESERVOIRS: CLUES FROM MARTIAN IMPACT CRATER MORPHOLOGIES.** N. G. Barlow, Dept. Physics, University of Central Florida, Orlando FL 32816, USA (ngb@physics.ucf.edu).

**Introduction and Background:** The existence of the fluidized ejecta morphologies surrounding most fresh impact craters on Mars was suggested in Mariner 9 imagery but their prevalence across the planet was not recognized until Viking Orbiter. The two major theories to explain the formation of these fluidized morphologies (also called lobate or rampart morphologies) are (1) impact into and vaporization of subsurface volatiles [1] and (2) atmospheric entrainment and emplacement [2, 3]. In the 9.5 years since the 4th International Conference on Mars, substantial progress has been made in understanding the environmental conditions which produce the different types of fluidized morphologies. Both the subsurface volatile and atmospheric entrainment mechanisms appear to play a role in the formation of these morphologies. However the latitude-diameter dependence found for single lobe and multiple lobe morphologies [4] and the regional variation in the distribution of double lobe [5] and multiple lobe [6] morphologies indicate that impact into subsurface volatile reservoirs is the dominant mechanism for formation. As a consequence of these results, several studies have been conducted to determine the areal and vertical distribution of subsurface volatiles (probably $H_2O$, either pure or in brines) on Mars [4, 5, 7, 8]. Until seismic and/or electrical conductivity experiments are performed *in situ*, impact crater morphologies will be the dominant means by which we determine the distribution of subsurface water and ice on Mars.

**Morphologies:** Mouginis-Mark [9] classified martian ejecta morphologies into six categories: single lobe (SL), double lobe (DL), multiple lobe (ML), radial (Rd), diverse (Di), and pancake (Pn). SL craters have a single lobe of fluidized ejecta surrounding the crater while DL craters are surrounded by two complete lobes, one superposed on the other. Multiple lobe craters consist of three or more partial to complete lobes. The Rd morphology consists of linear streaks of ejecta radiating outward from the crater and bear some similarities to the ballistically-emplaced ejecta blankets surrounding lunar and mercurian craters. The Di morphology consists of radial ejecta superposed on a lobate morphology, and the Pn morphology is characterized by the crater and ejecta being on a raised pedestal above the surrounding terrain, likely the result of erosion. These six classes have been the basis of most subsequent ejecta classifications utilized in studies of how the ejecta morphologies may reveal information about the distribution of subsurface volatiles [4, 7, 8].

**Distribution of Ejecta Morphologies:** Barlow and Bradley [4] performed a global study of how specific ejecta morphologies depend on crater diameter, latitude, and terrain. The study only included craters larger than 8-km-diameter. Results of that study included: (1) SL morphologies dominate over the entire planet and are prevalent surrounding craters between 8 and 20 km diameter near the equator (±30°) and around craters of larger diameter closer to the poles; (2) ML morphologies primarily are found surrounding craters between 20 and 45 km diameter near the equator; (3) Rd morphologies are found only around very large craters (typically >50-km-diameter), but are seen surrounding smaller craters on the flanks of the large Tharsis shield volcanoes; (4) DL morphologies are primarily found surrounding craters 8-50 km in diameter in the 40°N-65°N latitude range; (5) Di morphologies primarily occur along the highlands-plains dichotomy boundary, particularly between 330°W-350°W longitude zone. The Pn morphology tends to occur around craters <8-km-diameter and thus the statistics were too poor in the Barlow and Bradley study to draw any conclusions regarding these craters.

Based on the latitude-diameter results, Barlow and Bradley computed excavation depths of craters displaying different morphologies and compared the results with the theoretical distribution of subsurface volatiles based on geothermal considerations [10, 11]. A strong correlation was found for the occurrence of SL, ML, and Rd morphologies with changes in the physical state of subsurface volatiles. Geothermal models suggest that ice should be stable close to the surface across the entire planet, at least within the excavation depths of the SL morphology craters. Within the equatorial region, the geothermal gradient indicates that liquid reservoirs may exist within 1.5-2 km of the surface, within the excavation ranges of the larger ML craters. Most geothermal models indicate that below approximately 3.0-4.0 km depth (at least in the equatorial region) the substrate becomes depleted in volatiles, consistent with the excavation depths reached by Rd morphology craters. DL morphologies have previously been suggested to form by impact into layered targets where the layers have varying concentrations of volatiles--the strong concentration of DL morphologies in the northern plains where ancient oceans or lakes may have deposited sediments is consistent with this idea. A recent MGS MOLA analysis by Head et al. [5] finds that DL morphologies are strongly concentrated in topographic depressions which show geomorphic evidence that they once contained lakes.

More recently Barlow and her colleagues [6] have been investigating whether regional variations in ejecta morphology occur. We have divided the planet into 10°x10° latitude-longitude regions and have looked at the numbers of craters displaying specific ejecta morphologies. We again find that SL morphologies dominate over the entire planet, but that ML, DL, and Rd morphologies do display regional variations. Although our current analysis only includes the equatorial region of the planet (±30°), we have found that the ML morphology displays concentrations in three major regions: (1) 0°-25°N 315°W-10°W, corresponding to the Arabia Terra region of the ancient heavily cratered highlands; (2) 15°S-30°S 65°W-85°W, the Solis Planum area south of Valles Marineris; and (3) 5°S-20°S 155°W-175°W, corresponding to the region surrounding the Mangala Valles system of outflow channels. DL morphologies are found in higher concentrations in the region bounded by 20°N-30°N 50°W-90°W, corresponding to the depositional regions of several outflow channels which could have easily produced layered target material. Rd morphologies not associated with large impacts are rare--the only regional concentrations found for this morphology are in the Tharsis region where the Rd morphology dominates for craters near the tops of the big shield volcanoes.

We also have begun investigations to determine if regional variations occur in the onset diameters of craters displaying different ejecta morphologies. Koroshetz and Barlow [12], using Viking Orbiter imagery, found smaller onset diameters for SL morphology craters in the Solis Planum region south of Valles Marineris (20°S-30°S 50°W-90°W), one of the same regions where [6] found a higher concentration of ML morphologies. Koroshetz and Barlow propose that the uplift of the Tharsis Bulge, directly west of this region, caused the water table in this area to tilt and the water flowed into a topographic depression south of Valles Marineris. The higher resolution MGS MOC data are revealing that previous thoughts about lower-limit cut-off diameters for the SL morphology may simply be the result of Viking Orbiter resolution. Our current studies are beginning to incorporate MGS data to test this possibility. MOLA data also is being incorporated into these studies since it will provide valuable information about how elevation affects ejecta morphology.

**Modeling:** The major step remaining to understand what the ejecta morphologies are telling us about the distribution of subsurface volatiles on Mars is modeling to determine how much volatile concentration is needed to produce the observed morphologies. Most previous studies which have tried to determine the depth to subsurface volatile reservoirs based on ejecta morphology cut-off diameters have assumed that as soon as any volatiles are reached, the associated ejecta morphology forms. In reality, one would expect that some higher volatile/target concentration is necessary for formation of the ejecta morphologies.

Ivanov and colleagues [13, 14] have been using information on the runout distance of fluidized ejecta blankets to model the material properties of these features. They have modeled the flow using Bingham rheology and have demonstrated that martian fluidized ejecta display characteristics between those of dry rock avalanches and water-saturated debris flows on Earth. However, the studies do not yet address the variations in ejecta morphologies or the variations in properties such as sinuosity which are found to occur between the different fluidized morphologies [15].

**Future Work:** Our ability to read the clues from impact crater morphologies and determine what they tell us about subsurface volatile reservoirs on Mars has advanced considerably since the last Mars Conference but much work remains to be done. Our current efforts are focused on incorporating new information from MGS MOC and MOLA data as well as utilizing the modeling results from Ivanov and colleagues to better constrain the depths to the subsurface volatile reservoirs.

**References:** [1] Carr M. H. et al. (1977) *JGR*, *82*, 4055-4065. [2] Schultz P. H. and Gault D. E. (1979) *JGR*, *84*, 7669-7687. [3] Barnouin-Jha O. S. and Schultz P. H. (1998) *JGR*, *103*, 25739-25756. [4] Barlow N. G. and Bradley T. L. (1990) *Icarus*, *87*, 156-179. [5] Head J. W. et al. (1999) *LPS XXX*, Abstract #1352. [6] Barlow N. G. et al. (1999) *LPS XXX*, Abstract #1679. [7] Costard F. M. (1989) *Earth, Moon, and Planet*, *45*, 265-290. [8] Demura H. and Kurita K. (1998) *Earth Planets Space*, *50*, 423-429. [9] Mouginis-Mark P. (1979) *JGR*, *84*, 8011-8022. [10] Fanale F. P. (1976) *Icarus*, **28**, 179-202. [11] Clifford S. M. (1993) *JGR*, *98*, 10973-11016. [12] Koroshetz J. and Barlow N. G. (1998) *LPS XXIX*, Abstract # 1390. [13] Ivanov B. *A.* (1996) *Astronomisheskii Vestnik*, *30*, 36. [14] Ivanov B. A. et al. (1997) *LPS XXVIII*, 637-638. [15] Barlow N. G. (1994) *JGR*, *99*, 10927-10935.