**DISTAL FLOWS ASSOCIATED WITH SOME OF THE BEST-PRESERVED CRATERS ON MARS: IMPLICATIONS FOR EXTENSIVE IMPACT-RELATED LANDSCAPE MODIFICATION.**

J. M. Burley[1], L. L. Tornabene[1], G. R. Osinski[1], J. A. Grant[2], M. R. El-Maarry[3], and other members of the HiRISE and CaSSIS Teams [1]Institute for Earth & Space Exploration/ D. Earth Sciences, Western University, London, ON, Canada (jburley6@uwo.ca), [2](grantj@si.edu), [3](mohamed.elmaarry@ku.ac.ae)

**Introduction:** Since the identification of additional and extensive continuous deposits beyond what is generally considered to be the continuous ejecta blanket of martian, lunar, and venusian impact craters [1], distal modification phenomena within this extended region has been a topic of growing interest, particularly on Mars. Until recently, surface flow features within this region had only been observed around one large crater (D >100 km) on Mars, Hale Crater [2-5], but have since been recognized around some of the best-preserved craters as small as 6-km in diameter [6].

Based on a global database of the best-preserved craters on Mars [7], we have identified additional candidates with extensive distal flow features around them for study. Recent coverage by high-resolution datasets of these craters, and their surroundings, are just beginning to provide the means to determine the origin and nature of these observed distal landscape modification features. Characterization and detailed mapping of them are necessary to place constraints on the emplacement mechanisms (dry vs. wet) involved and to determine the implications for widespread impact-related landscape modification on Mars. This abstract summarizes and highlights recent findings from our ongoing global survey and characterization of these features using CTX [8], HiRISE [9], CaSSIS [10], and THEMIS [11 data. For the sake of brevity, we focus on the observations of one unnamed ~9.5-km diameter crater, located in Noachis Terra (-29.405°N, 351.319°E).

**Methodology:** Additional craters were identified here by extending and completing the global survey based off the crater-related pitted material database of [7], which are consistent with representing the majority of the best-preserved craters on Mars, which is needed to establish as to whether or not the modifications are wide-spread. Nearly global CTX coverage provided the means to assess around which craters flows were present and identify target features for follow up with both HiRISE and CaSSIS image requests necessary for verification and investigation.

*Individual Crater Assessment:* Distinct regions of modification were mapped in all directions from the candidate crater to a distance of 15 crater radii; mapped facies included the readily observable layered continuous ejecta blanket, distal flows and other surface morphologies circumferential to said blanket, and regions of exposed/unmodified target terrain. Surface feature properties including distribution, stratigraphic relations, and morphology were assessed through mapping. Using stereo-derived DTMs, including those we processed ourselves [12], we provide morphometric constraints on whether a viscous/kinematically-fluidized vs. gravity driven dry emplacement mechanism best explains these features. Slope maps were derived via ArcGIS Pro [13]. Deposit slope profiles were then compared to thresholds provided for gravity dominated dry flow models for Mars [14] to see

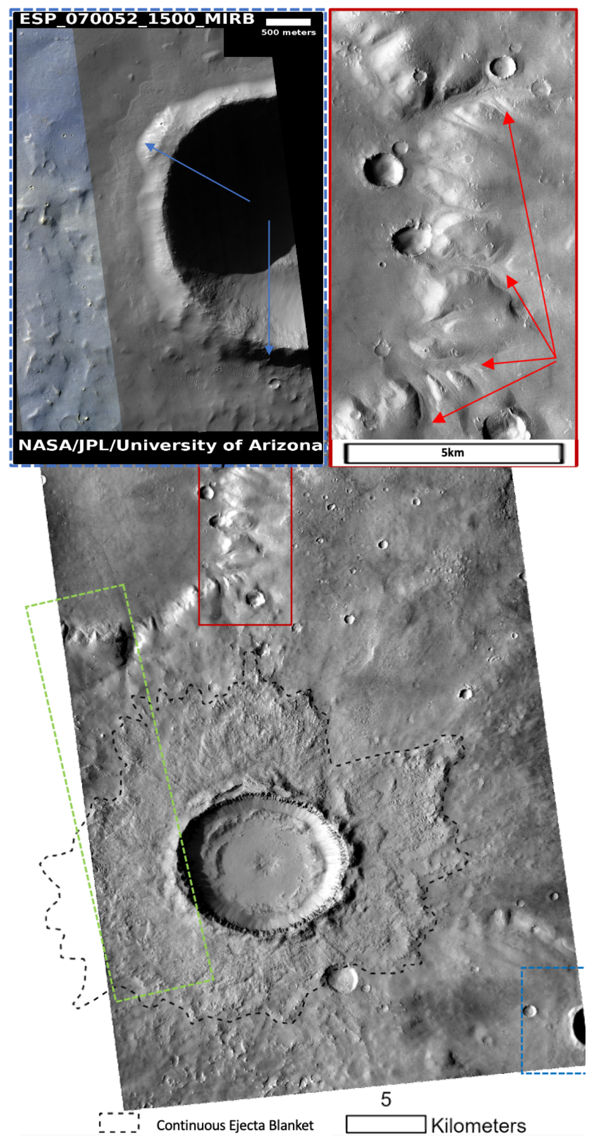


*Figure 1. HiRISE ID: ESP_070052__1500 crop **A** (blue box, Flow Type 2), CTX ID: B06_011818_1506 context map with crop **B** (red box, Flow Type 1), footprint for CaSSIS ID: MY35_011122_211_0 **C** (green box). Candidate crater location: -29.405°N, 351.319°E.*

if the features consistently matched one regime vs. the other.

**Observations:**

*General morphology*: **Fig. 1** shows context for the well-preserved unnamed crater in Noachis Terra and highlights the associated surface modification features that lie beyond the outermost layered ejecta rampart (dashed-line). A zone of morphologically muted target terrain is observed over a large radial area beyond the layered ejecta, not only for this example, but notably for all 31 candidate craters assessed to date. In this distal modification region, particularly where slopes are low and there are few catchments, the terrain is notably smoothed/muted and more devoid of superposed craters when compared to the older underlying and surrounding target surface. The extent of this affect is generally constrained to between ~7-10R from the center of the well-preserved crater.

Within this region, we identify what appears to be two distinct flow morphologies depending on the preexisting topography that is encountered. ***Flow-type 1*** (**Fig. 1**; A) are generally observed closer to the source crater particularly where pre-existing positive relief topographic features occur. Type 1 exhibits preferential accumulation of material at the base of obstacles and only on the side of the obstacle facing the well-preserved crater. Deposit volumes are also observed to visually reduce when moving from the side of the obstacle that directly faces the well-preserved crater (i.e., normal to the crater) to a point where the deposits are notably absent on the opposing side of the obstacle). ***Flow-type 2*** (**Fig. 1**; B) are generally observed where steep preexisting slopes associated with negative relief topography occur. In the example provided in **Fig.1**, the occurrence of the flow is associated with a larger, substantially degraded preexisting crater just to the north of the well-preserved crater. The results of our global survey reveal thirty-one candidate craters (D ≈3-58km, 24°N to 35°S) that possess readily recognizable and verified flow features (n = 14) with the remaining candidates still awaiting coverage with HiRISE to verify them.

*Morphometry*: Thus far, slope profiles from both flow types 1 and 2 have included values exclusively <25º and are observed in locations where pre-existing topographic slopes and catchments would permit the concentration of free-flowing surface materials.

**Discussion, Conclusions & Future Work:** Preferential deposition of materials on crater-facing slopes around topographic obstacles circumferential and in proximity to the best-preserved crater in the region (i.e., flow-type 2) provides strong evidence of a relationship between the impact event and the origin of these deposits. Furthermore, this flow behavior in particular strongly suggests that the deposits are emplaced through ground-flow mechanisms and not aerial deposition. However, whether distal flow deposits are directly-related (extended ejecta flow) or indirectly (e.g., mobilization/modification of target materials through impact generated surface winds and/or released volatiles) remains to be established and has consequences for interpreting the results of our slope analysis. Considering previous morphometric characterization of gravity-dominated martian dry flows found values exclusively ≥28º [14], we consider similar processes (i.e. seismic shaking or passive talus accumulation) to be unlikely drivers here. If the flows associated with these terrains are directly a consequence of the well-preserved crater, they would have a velocity-component imparted by the impact event and slopes < 25º could be consistent with either dry or viscous flow [14].

Considering the current distribution of verified candidate craters, this modification process appears far more geographically ubiquitous than previously reported, potentially being a global phenomenon on Mars.

Constraining whether the radially expansive impact deposits and flows here observed are A; primarily dry, albeit potentially melted/thermally modified [15], atmospherically fluidized [16] target materials akin to terrestrial Pyroclastic Density Currents (PDC's), B; a slurry of target volatiles and hot dry materials (like the PDC-analogous deposits mentioned above) similar to terrestrial lahars, C; thinly distributed impact melt and/or viscous ejecta, or D; some combination, is also currently under investigation.

**References:** [1] Ghent et al (2010) *Icarus, 209*, 818–835. [2]Collins-May et al (2020) *JGR, 125.* [3] El-Maarry et al (2013) *Icarus, 226*, 905–922. [4] Grant and Wilson (2018) *Meteoritics*, 53, 839–856. [5] Jones et al. (2011) Icarus, 211, 259–272. [6] Tornabene et al. (2019) *Mars 9.,* Abstract# 2089. [7] Tornabene et al. 2012. *Icarus, 220*. [8] Malin et al. (2007) *JGR, 112*, 1–25. [9] McEwen et al. (2010) *Icarus, 205.* [10] Thomas et al. 2017. *SSR, 212.* [11] Christensen et al. 2004. SSR. 110, 85–130. [12] Beyer et al. (2018) *Earth and Space Sci. 5,* 537–548. [13] Esri Inc. (2020). ArcGIS Pro (Version 2.9). *tool-reference/spatial-analyst/slope*. [14] Atwood-Stone and McEwen (2013) *GRL, 40,* 2929–2934. [15] Svetsov and Shuvalov (2019) *Meterorics, 54,* 126–141. [16] Dufek et al (2015). *Pyroclastic Density Currents, Ch.35,* 617.

**Acknowledgments:** We thank the spacecraft & instrument engineering teams for the successful completion of the instruments. CaSSIS, a project of the University of Bern, is funded through the Swiss Space Office via ESA's PRODEX programme. Instrument hardware development was supported by the Italian Space Agency (ASI), INAF/Astronomical Observatory of Padova, & the Space Research Center (CBK) in Warsaw. Support from SGF (Budapest), the University of Arizona (Lunar & Planetary Lab) and NASA are also acknowledged. The lead author acknowledges support from Tornabene's funding from the CSA's Planetary and Astronomy Missions Co-Investigator programme (19PACOI07) and the Canadian NSERC Discovery Grant programme (06418-2020 RGPIN).