Comparing the Morphology of Impact Craters on Mars in Different Target Lithologies

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Introduction

NASA's Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission to Mars landed on western Elysium Planitia on a basaltic lava plain (Golombek et al., 2020; Warner et al., 2022). The primary goal of that mission was to measure the interior structure of Mars using a seismometer. Shallow (10-m-scale) seismic data determined that there is an anomalous low-velocity layer under the basaltic surface at the landing site that could denote clastic material (Figure 1). Clastic rocks are of interest for Mars exploration due to their association with water & sedimentary processes (e.g., fluvial-lacustrine). The primary goal of this research is to compare the morphometry of impact craters at InSight to locations of similar age and known clastic and basaltic lithologies on Mars to determine if craters at InSight excavated clastic rock. This is done by examining the relative resistance to erosion of the ejecta, noting that clastic rocks erode faster than basaltic rocks under Mars surface conditions.

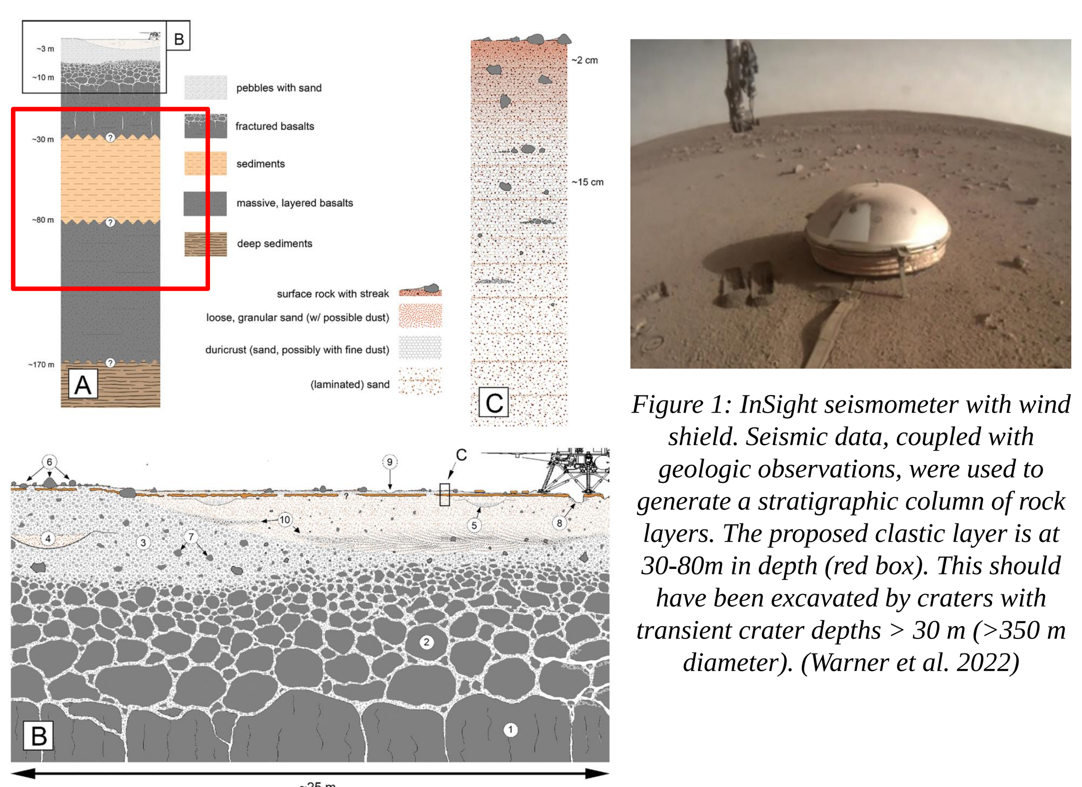

Figure 1: InSight seismometer with wind shield. Seismic data, coupled with geologic observations, were used to generate a stratigraphic column of rock layers. The proposed clastic layer is at 30-80m in depth (red box). This should have been excavated by craters with transient crater depths > 30 m (>350 m diameter). (Warner et al. 2022)

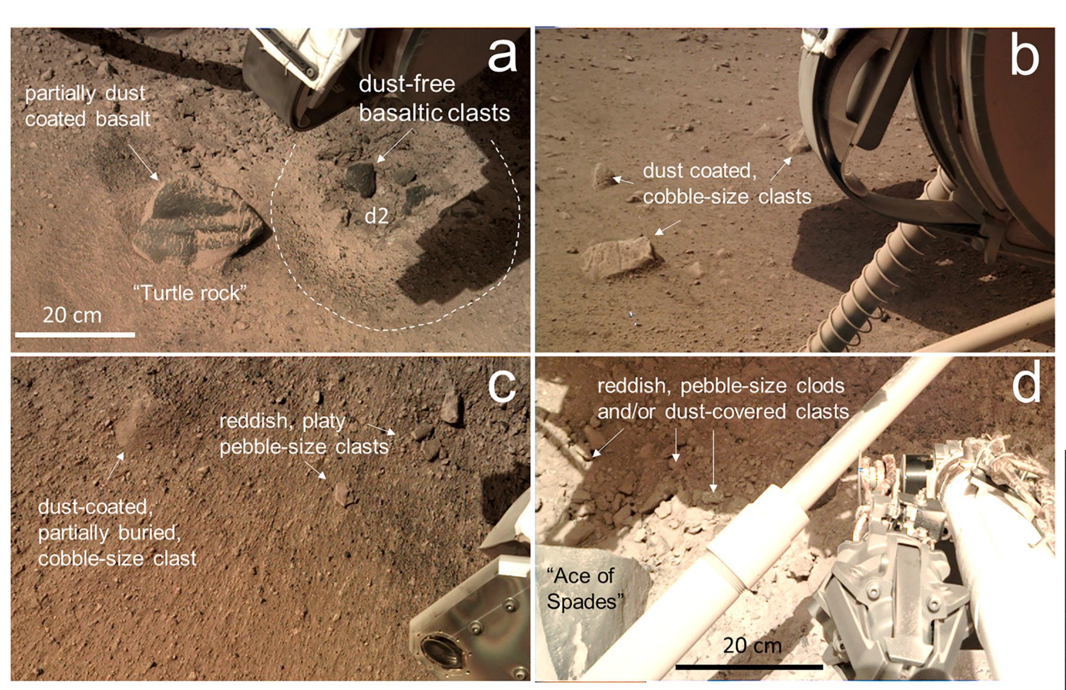

Figure 2: InSight landed on a regolith-covered basaltic lava plain. Note in the lander-based images above the dark-gray, finer-grained, angular clasts of basalt that dominate the surficial regolith. The fine-grained regolith here is ~3 m thick and overlies fractured basalts at depth. Images from Warner et al., 2022.

Methods

High Resolution Imaging Science Experiment (HiRISE) imagery and 1 m digital elevation models (DEMs) were downloaded from https://www.uahirise.org to evaluate crater morphometry in two and three dimensions (e.g., ejecta & cavity volume) (Figure 3). Pristine impact craters were chosen from basaltic and clastic control locations on Mars (Figures 4 – 7) and processed through ArcGIS Pro.

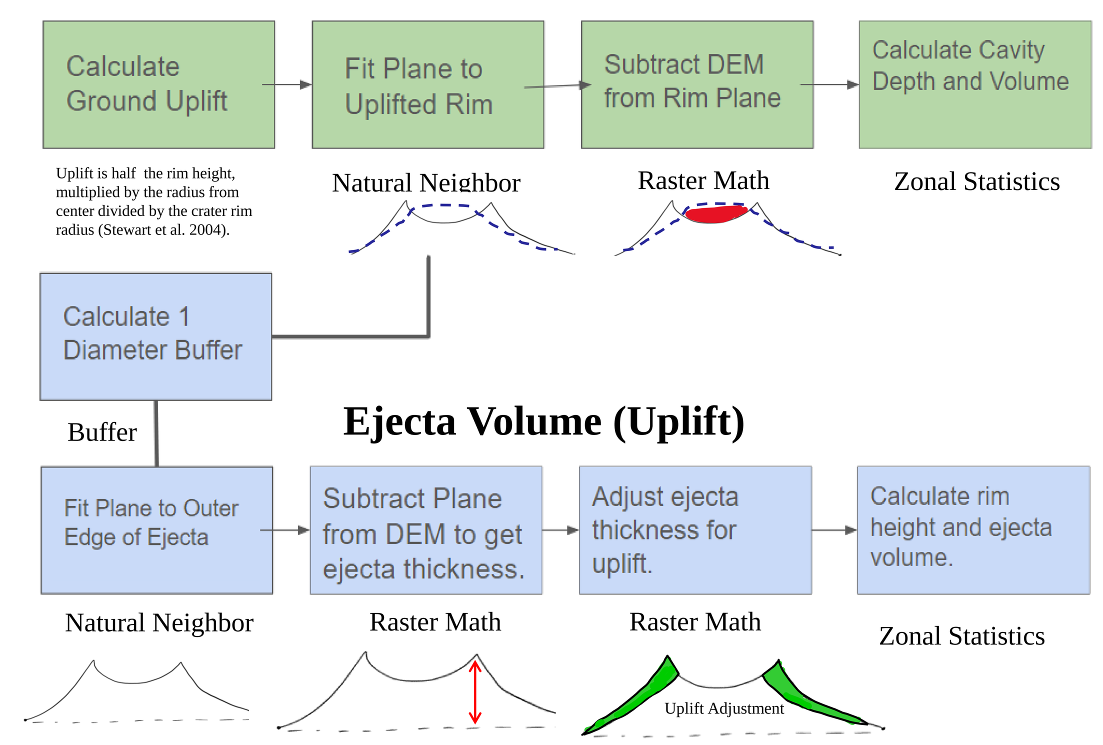

Figure 3: Generalized procedures in ArcGIS Pro for calculating the volumes of crater cavities and continuous ejecta blankets. Cavity and ejecta volumes were calculated accounting for the uplift of the terrain during the excavation stage of the impact (Stewart et al., 2004).

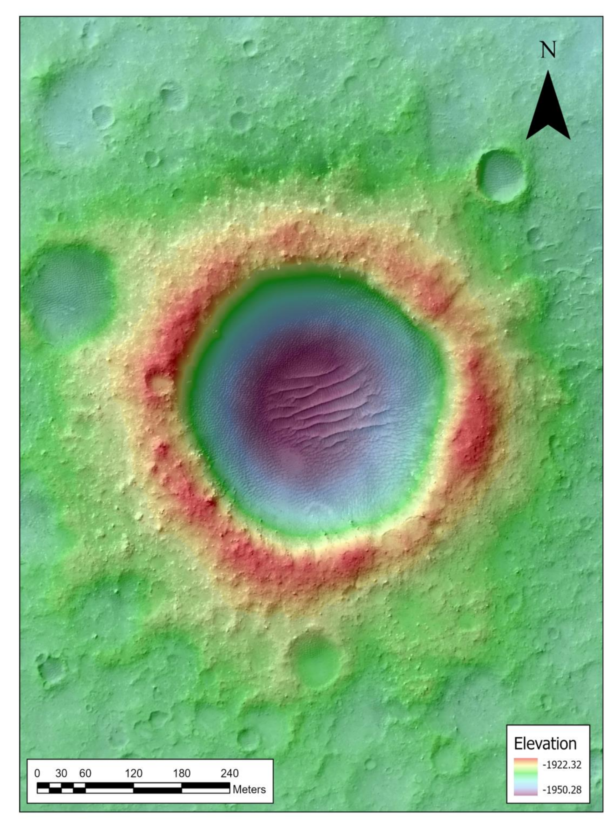

Figure 4. Fresh crater within the Gusev Crater plains, a known basaltic lava plain. The surface is approximately 2.2 Ga in age (Wilson et al. 2021). Gusev was visited by the Spirit Rover from 2004 – 2010. Fresh craters here have continuous, elevated rims, minor sedimentary infill (eolian), and continuous, rocky ejecta comprised of angular basaltic blocks.

Figure 5. The fresh crater from Elysium Planitia at InSight. The surface is approximately 1.7 Ga in age (Warner et al. 2022). The surface of the InSight landing site is dominated by basaltic lava with the possibility of clastic rocks at depth (the hypothesis we are testing here). Fresh craters have continuous, elevated rims, minor sedimentary infill (eolian), and continuous rocky ejecta previously interpreted to be angular basaltic rocks (Figure 1).

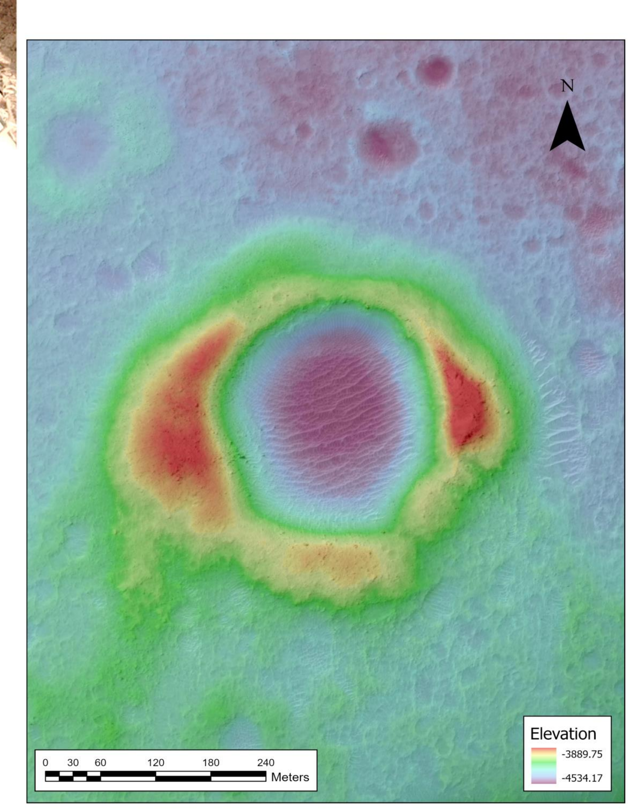

Figure 6. Fresh crater impacted into sedimentary rocks of fluvial-lacustrine origin on the floor of Gale Crater. The surface is approximately 2.1 Ga in age (Martin et al. 2017). Gale Crater is the current exploration site of the Curiosity rover. Fresh crater rims are often discontinuous here. Crater floors are partially infilled by eolian material and the continuous ejecta is less distinct.

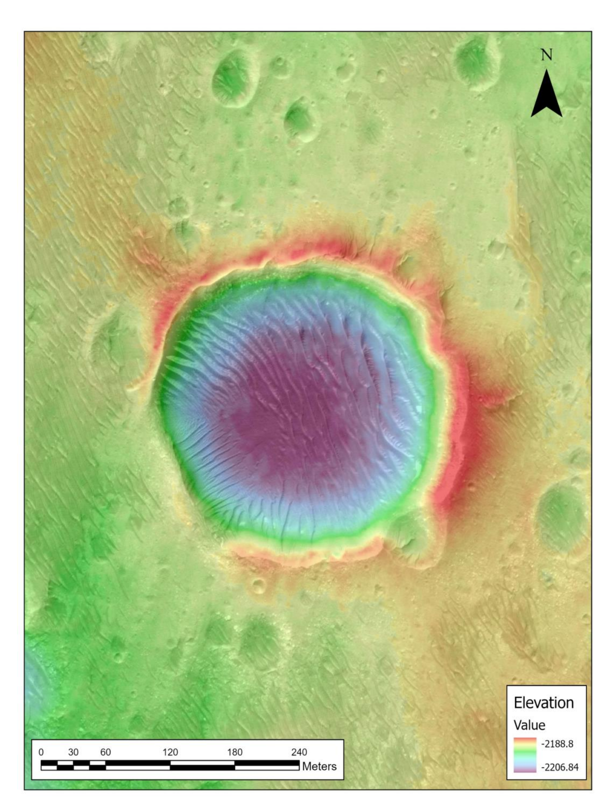

Figure 7. Fresh crater impacted into sedimentary rocks of fluvial-lacustrine origin on the floor of Holden crater. The surface is approximately 1.8 Ga in age (Grant J., Wilson S, 2011). Holden Crater has been a candidate landing site for multiple rover missions. Fresh crater rims are discontinuous, crater floors are infilled with eolian sediment and the continuous ejecta is not distinct.

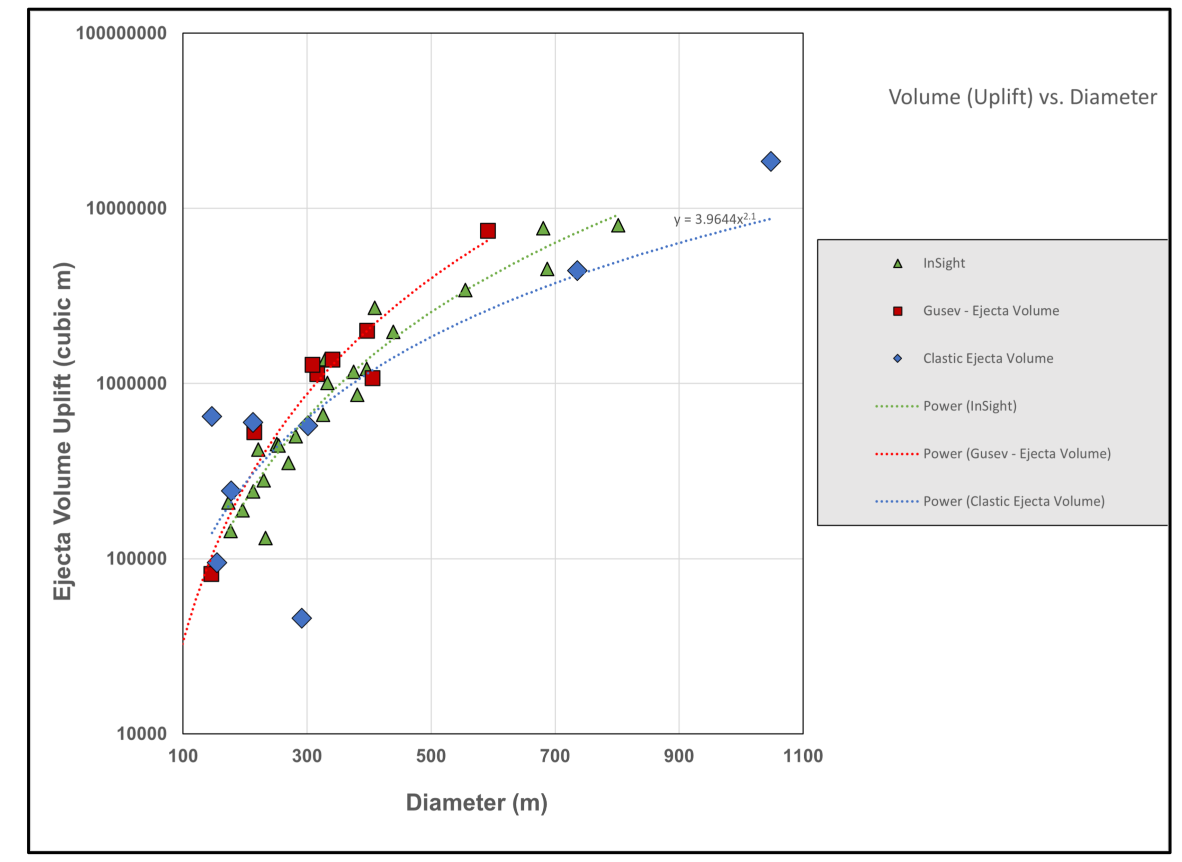

Figure 8. Comparing ejecta volume to diameter conveys that Gusev craters, impacted into resistant basaltic bedrock, retain a large amount of ejecta volume at a given diameter when compared to clastic rocks and InSight.

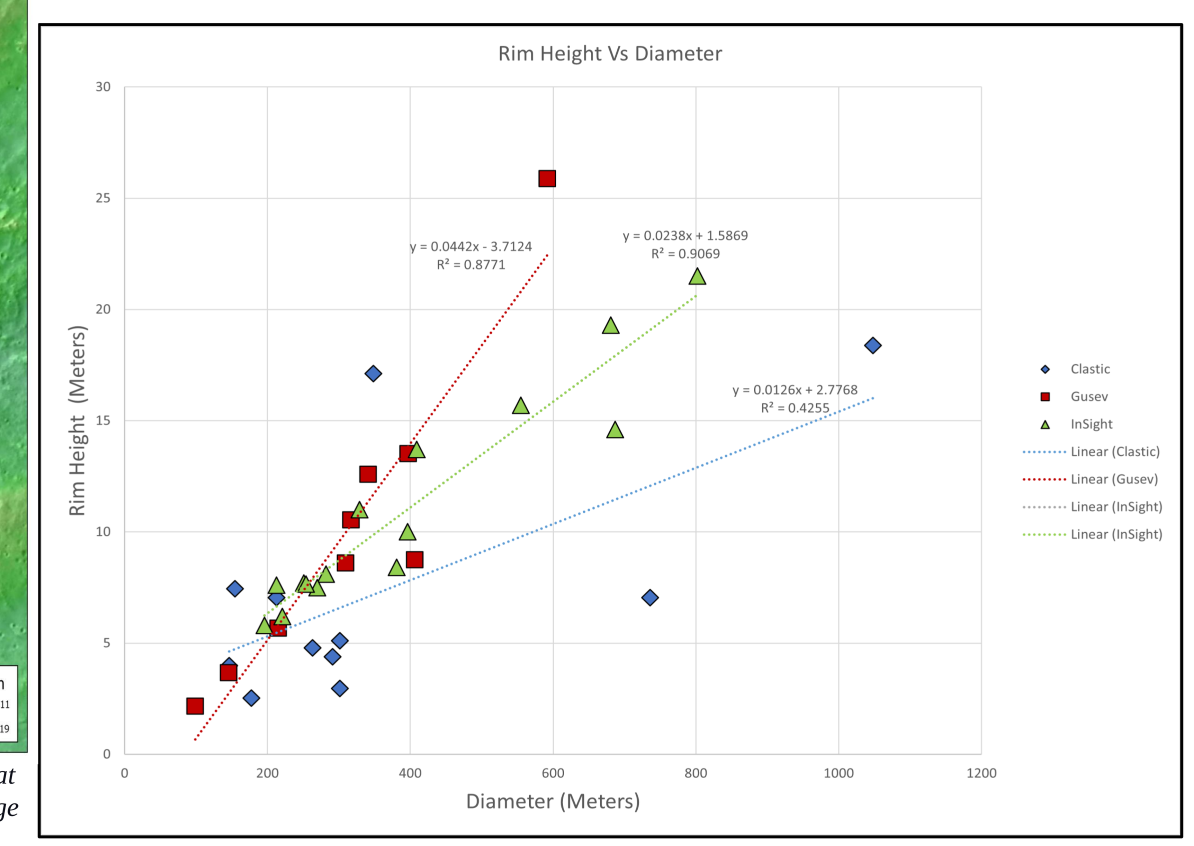

Figure 9. The ratio of rim height to diameter conveys that Gusev craters hold higher rims relative to diameter than clastic rocks and InSight. Denoting that crater rims of clastic material and InSight craters are smaller in rim height despite being similar in size. Outliers in the clastic data may be pedestal craters or craters impacted onto elevated surfaces. Pedestal craters are generated when less resistant rocks surrounding the crater are preferentially eroded, leaving an unusually elevated rim. This is a common phenomenon on clastic target terrains.

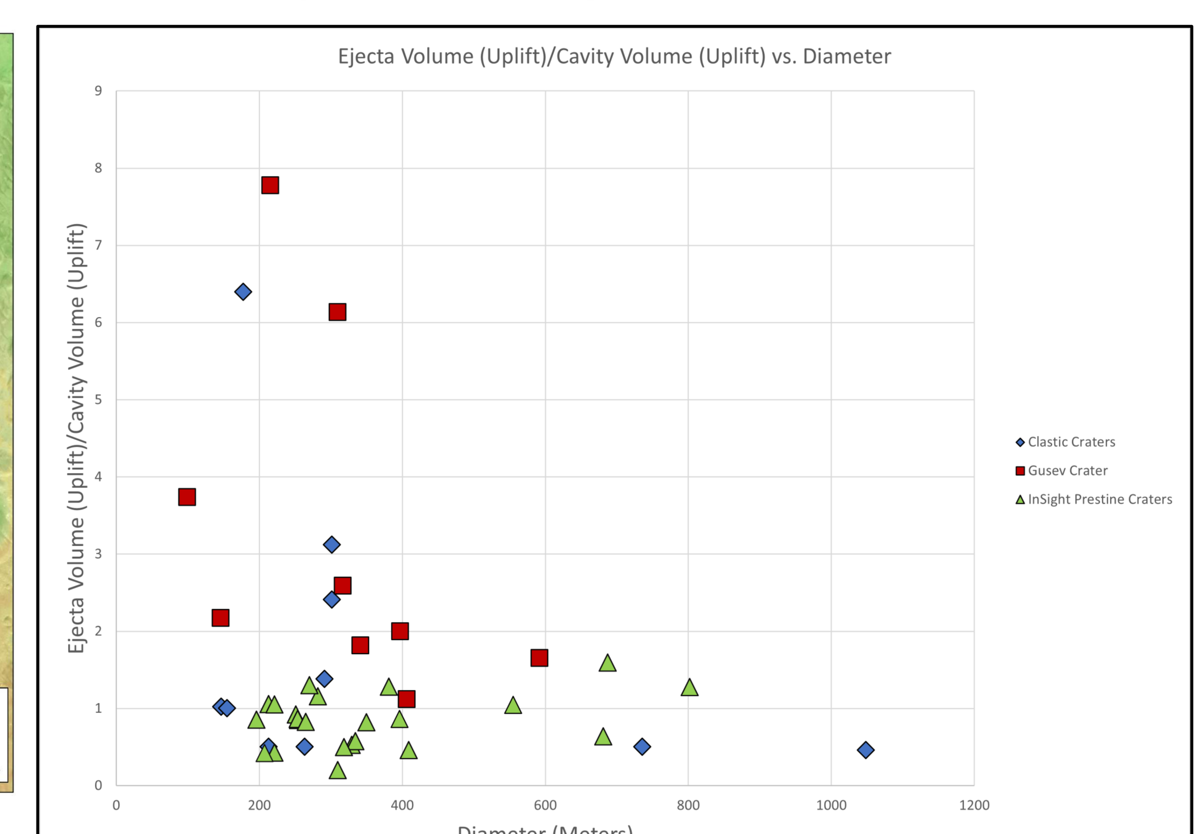

Figure 10. Ejecta volume to cavity volume ratio comparing the relative degradation state of the two morphometric parameters. InSight craters have a near 1 to 1 proportion of ejecta volume to cavity volume when compared to diameter. While Gusev and clastic craters have a more varied relationship between ejecta and cavity volume. A higher relative ejecta volume might indicate increased resistance of the ejecta to erosional surface processes, preferential infilling of the crater by sedimentary materials (eolian sediments), or suggest a pedestal crater origin (likely for clastics)

Results & Discussion

The data indicate that impact sites with more weathering-resistant rocks upheld a more pristine nature with elevated rim heights and higher ejecta volumes compared to craters of similar diameter at localities of clastic target rocks. Gusev, a known basaltic region has craters with notable pristine rims and well-defined ejecta blankets (Figures 4, 8, 9). InSight craters fell consistently between that of the known basaltic rock and that of the recorded clastic sediment. This indicates the possibility that the stratigraphy in the region has a mixture of basaltic and clastic rock (Figures 5, 8, 9). Impact sites in clastic sediment had far more eroded rims despite being of similar ages and diameters to that of the other recorded impact sites (Figures 6-9). Ejecta volume normalized by cavity volume, when compared to diameter (Figure 10), conveys a more proportional 1 to 1 connection for InSight craters, while other localities show both higher and lower relative volumes. Craters with relatively elevated ejecta volumes compared to the crater cavity may be filling at a disproportional rate compared to ejecta erosion. Alternatively, their ejecta may be more resistant to erosion or the craters may have a pedestal crater origin. Craters at the Gusev plains have elevated rim heights compared to other localities. Relatively higher ejecta volumes therefore suggest ejecta resistance and/or higher rates of crater filling. Craters impacted into clastic rocks also may show elevated ejecta volumes and likely have a pedestal origin.

Conclusion

More data would need to be collected to further refine statistics, however, based on preliminary findings, there are important morphometric differences between fresh impact craters that impacted basaltic rocks and clastic rocks. The continuation of this study should focus further on the notion that InSight likely contains a combination of clastic rocks beneath volcanic material based on its distribution of data between that of the volcanic Gusev plains and that of the clastic craters. Identification of clastic rocks is significant for Mars due to the implication of sedimentary processes that are often tied to water. Given the relatively youthful age of the terrain at InSight (1.7 Ga) (well after the early warmer-wetter Mars phase) identification of clastic rocks might imply relatively late aqueous processes on the northern plains of Mars.

References and Acknowledgements

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