AN IMPACT CRATER ORIGIN FOR HOMESTEAD HOLLOW, THE INSIGHT LANDING SITE ON MARS

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Introduction: The Interior Exploration using Seismic Investigation, Geodesy and Heat Transport (InSight) mission to Mars landed on an Early Amazonian-age basaltic lava plain in Elysium Planitia at 4.502°N, 135.623°E [1]. Post-landing observations from the onboard cameras (IDC and ICC) revealed that InSight landed on a smooth, sand to pebble-dominated surface (Fig. 1). The surface corresponds with a 27-m-wide, ~0.3-m-deep, quasi-circular depression informally named Homestead hollow (Fig. 2). Beyond the hollow, the landscape shows a higher abundance of cobble-size materials with the occasional boulder. The lack of similar cobbles within the hollow suggests that it is a location of preferential accumulation of windblown fines [2]. Here, we test the impact crater origin of Homestead hollow and other hollow-like landforms at the landing site. We hypothesize that the morphometry of the hollows should be consistent with a degradational continuum that includes fresher craters. An impact origin for Homestead hollow has important implications for the depth of loose material beneath the lander, the near surface stratigraphy, and degradation history of the landing site.

Methods: All impact craters and hollows with diameters ≥ 20 m were mapped within a ~21 km² region centered on InSight using a single HiRISE image (~25 cm/pixel) and 1 m DEM. Each mapped crater or hollow was classified based on its observed state of preservation from Class 1 (most pristine) to 8 (hollows). Class 7 are the most degraded craters for which an impact origin is not ambiguous. Craters in the region degrade slowly (10² to 10⁴ m Myr⁻¹) through a combination of filling, rim reduction, rim slope decline, and rim backwasting [3]. Morphometric characteristics of all Class 1 to 8 were measured using the DEM. Crater diameter, depth, rim height, rim slope, floor slope, rim curvature (derivative of rim slope), and floor curvature were measured for each crater following a semi-automated approach in ArcGIS described by [3]. Slope and curvature are calculated over a 2 m baseline.

Results: The total number of craters in the 21 km² region (including Class 8 hollows) is 2,260. The craters range in diameter from 20 m to 272 m. The average depth (d) to diameter (D) ratio of Class 2 craters (there are no Class 1 craters) is 0.059 (σ = 0.020), Class 6, 7, and 8 have a d/D of 0.029 (σ = 0.010), 0.020 (σ = 0.0079), and 0.016 (σ = 0.0061), respectively. Class 8 hollows have a d/D ratio that is consistent with progressive depth-related degradation from Class 7. The freshest craters are shallower than pristine models (d = 0.20D) [4] suggesting early-stage degradation, likely by eolian infilling [3].

The average rim height (h) to diameter (D) ratio for all Class 2 craters is 0.031 (σ = 0.014). The mean h/D values for Class 6, 7, and 8 are 0.025 (σ = 0.013), 0.018 (σ = 0.011), and 0.013 (σ = 0.0098). Class 8 hollows generally preserve a rim and are more degraded than Class 7.

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Destruction of a crater rim and filling of the crater interior by local debris and externally-derived materials (e.g. eolian sediments and ejecta) results in a reduction in rim slope and floor slope over time [3,5,6]. Class 2 rim structures hold maximum slopes near the angle of repose for loose sand and pebbles at ~30° to 40°. As the craters degrade through Class 6 to 7, the maximum slopes decrease but a broad range of values exist, spanning 4° to 30°. Class 8 hollows show a similar range in maximum slopes but tend to be most similar to, if not more degraded than, the Class 7 variety.

The mean floor slope for Class 2 craters is 10° (σ = 2.3). Maximum slopes approach 30° to 40°, consistent with observations of trapped eolian bedforms that approach the angle of repose [3]. By Class 5, bedforms are planed off and are replaced by a smooth interior fill. The mean floor slope of the smooth fill for Class 7 craters is between 3° and 5° while the Class 8 interiors range from 2° to 4°.

Hillslope curvature tracks the evolution of a crater rim from its initial convex-up form. The mean rim curvature values for all craters in this dataset, including the hollows, are mostly positive, consistent with an overall convex-up hillslope morphology. The average value for rim curvature for Class 2 craters is 0.10 m² (σ = 0.047). By comparison, the Class 6, 7 and 8 average values are 0.032 m² (σ = 0.025), 0.013 m² (σ = 0.019), and 0.0050 m² (σ = 0.014), respectively. The reduction in curvature, but maintenance of the convex-
Mean floor curvature values are all generally negative for all classes indicating a concave-up morphology that is consistent with a bowl-shaped interior form. The morphologically more-pristine classes exhibit lower, negative interior curvature values relative to the more degraded classes, which is indicative of progressive filling and flattening of the bowl-shape. The interiors of Class 8 hollows have a near zero, but still mostly negative average curvature and are similar in form to Class 7 craters.

**Discussion and Conclusions:** The morphometry of Class 8 hollows indicate that they are part of a continuum of crater rim degradation and infilling, likely by eolian materials and a combination of slope debris and ejecta. Class 8 hollows are more-degraded than Class 7 craters and are morphologically distinct depressions on the landscape (some with elevated rims). We therefore conclude that Class 8 hollows, and by extension Homestead hollow, are degraded craters. From the size frequency distribution of all Class 1 to 8 craters in the landing site we estimate a maximum retention age of ~400 to 700 Myr for Homestead hollow. The morphometry data, coupled with the retention ages, confirms that the rate of crater degradation, which includes infill plus rim height destruction, decreases by two orders of magnitude from $10^2$ m Myr$^{-1}$ to $10^4$ m Myr$^{-1}$ over 400 to 700 Myr. However, the rate of rim height reduction (i.e. erosion rate) only decreases from $10^3$ m Myr$^{-1}$ to $10^4$ m Myr$^{-1}$. This suggests that early stage infilling slows down over time as the crater becomes less of a sediment trap to windblown sand and as mass wasting diminishes during slope decline. A convergence of the degradation rate with the rim erosion rate occurs by Class 5, which for Homestead hollow-size craters, have a maximum retention age of ~50 Myr. This suggests that infilling was negligible for the bulk of the hollow’s history and that most of the degradation was accompanied by slow rim destruction. The fill at Homestead hollow has been stabilized for several hundred million years and has facilitated the formation of a centimeters-thick duricrust, which was identified in the pits excavated by the retro-rockets [1].

Assuming 20% widening of Homestead hollow during degradation [3] and a pristine d/D ratio of $d = 0.15D$ [3], it would have originated as a ~22 m diameter crater with a pristine depth of ~3.3 m. The current maximum depth of the hollow is ~0.3 m. This suggests ~3 m of total degradation. The rim height of Homestead hollow is variable, but typically near zero. The pristine rim height of a hollow of this size is ~0.7 m [3]. The 3 m of proposed degradation cannot be accounted for solely by rim erosion. We therefore estimate ~2 to 3 m of loose, sedimentary fill inside the hollow. The stratigraphy is consistent with the results of the HP$^{3}$-SEIS hammering experiment that detected a low velocity zone in the upper 1 m of the surface beneath the lander [8,9]. InSight rests on the northwest margin of the hollow where the fill is likely shallower than the maximum thickness of ~3 m. A higher seismic wave velocity zone is indicated below 1 m. The velocity values are inconsistent with solid bedrock and are likely the result of a transition from fill to underlying rockier materials, possibly a coarser regolith.