STRATIGRAPHY AND GEOLOGIC HISTORY OF THE INSIGHT LANDING SITE, MARS.

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Introduction: The Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission to Mars landed on a Hesperian to Early Amazonian age, regolith-covered, basaltic lava plain, dubbed Smooth Terrain, in western Elysium Planitia [1]. The lander rests within a ~27-m-diameter, degraded impact crater called *Homestead hollow*. Understanding the local stratigraphy has implications for shallow seismic velocity measurements from the mission's Seismic Experiment for Interior Structure instrument (SEIS) [2], thermal conductivity and soil porosity estimates from the Heat Flow and Physical Properties Package (HP^3) [3], and thermal inertia and conductivity measurements from the onboard Radiometer (RAD) [4,5].

Here, we describe the local stratigraphy beneath the lander by synthesizing previous pre-landing orbital observations with new data from the High-Resolution Imaging Science Experiment (HiRISE) [6] and lander-based imagery from the Instrument Deployment Camera (IDC) and Context Cameras (ICC). The orbital HiRISE images, at ~25 cm/pixel, were used to describe the meter-scale stratigraphy using the morphology and depths of excavation of nearby rocky ejecta craters (RECs). HiRISE data, including 1 m digital elevation models (DEMs), were also used to describe meter-scale stratigraphic characteristics exposed along the Hephaestus Fossae fracture system (~900 km northwest of InSight) that dissects a regolith-covered, Early-Amazonian age basaltic lava plain that is analogous to the Smooth Terrain at InSight [7] (Fig. 1). IDC images show up to ~12 cm of the regolith exposed in pits and depressions that were excavated by the lander's retrorockets, as well as within the hole made by the HP^3 mole. The orbital and *in-situ* observations are interpreted within the context of plausible degradational mechanisms that shaped *Homestead hollow*.

Summary of Stratigraphy and Events: Our multi-scale stratigraphic model for the InSight landing site is bulleted in sequence from oldest to youngest here.

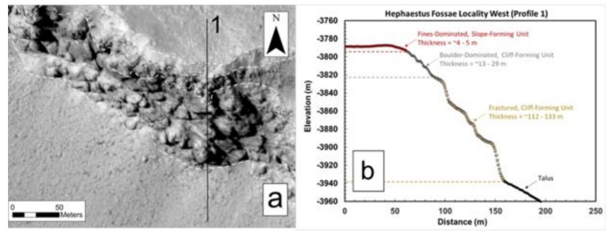

Fig. 1: (a) Hephaestus Fossae exposure (HiRISE image ESP_052638_2020). (b) Topographic profiles reveal stratigraphic variations and thicknesses beneath Early Amazonian age lava plains. The stratigraphic sequence is consistent with an impact comminuted lava plain with a regolith capped by ~5 m of loosely-consolidated fines overlying up to ~29 m of brecciated and fractured bedrock.

(1) Sedimentary rocks containing phyllosilicates, were deposited mostly in the Noachian in western Elysium Planitia at depths ≥170 m [8,9].

(2) Landscape degradation, including Early Hesperian-age volcanic resurfacing, occurred immediately after 3.6 Ga, indicated by a roll over in the size frequency distribution of craters on the Smooth Terrain at diameters <2 km [7]. This was followed by resurfacing of the landscape by effusive volcanics in the Early Amazonian at ~1.7 Ga. The total thickness of the basaltic lava, including Hesperian age materials, is ~170 m [7,8,9]. Emplacement of Early Amazonian lavas was preceded or interrupted by deposition of clastic materials of unknown origin at depths between 30 m and 75 m [10].

(3) Regolith at the landing site was produced by impact gardening and eolian modification, including infilling of impact craters with sand, from ~1.7 Ga [11,12]. The maximum thickness of the total column of regolith is likely ~10 to 30 m, based on comparisons to Hephaestus Fossae (Fig. 1). RECs and nested craters that are (order of) 10 m in diameter at the landing site indicate a boulder-free, fines-dominated, loosely consolidated regolith down to a depth of ~3 m. The resulting time-averaged regolith production rates are (order of) 10^{-2} to 10^{-3} m/Myr.

(4) The *Homestead hollow* impact occurred in the Middle Amazonian at ~400 to 700 Ma [11]. The target

material was a moderately mature regolith that included blocky (10's of cm) impact ejecta from older neighboring ~100-m-scale craters. The pristine crater was ~ 22 to 25 m diameter, ~3 m deep with a ~0.7 m high rim.

(5) *Homestead hollow's* interior filled with sand to pebble-size materials, derived from mass wasting of interior crater slopes and eolian deposition. Slope-derived materials are not observed from the lander as the crater is now nearly filled but likely thin towards the crater interior and inter-finger with eolian sands. Deflation and ongoing impact gardening, largely by 10 cm to 1-m-scale craters, helped to reduce the rim height of the crater to near zero. Granule to cobble-size clasts are both scattered on the sand-dominated surface of *Homestead hollow* and embedded in a sand matrix in the pits beneath the lander (Fig. 2). The bulk of crater degradation occurred within ~50 Myr of formation during the Middle Amazonian at a degradation rate of 10^{-2} m/Myr [11].

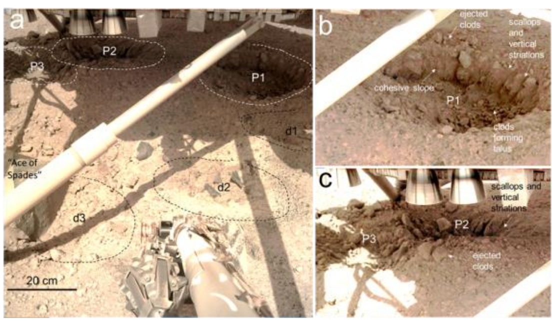

Figure 2: IDC images taken beneath the lander on Sol 18. (a) The pits and depressions were excavated by the lander's retrorockets. P1 (b) and P2 (c) are the largest and deepest pits. P1, the deepest pit, is ~50 cm in diameter and ~12 cm deep. The pit walls are vertically striated and steep (up to 65°) and expose an up to ~10-cm-thick cohesive duricrust. The floor of each pit contains reddish, pebble-size clods of material that broke off the steep pit walls. Dark-gray pebbles of likely basaltic composition are visible within the matrix of fine sand.

(6) A younger 100-m-diameter crater known as *Sunrise crater* impacted ~400 m to the east of *Homestead hollow*. Ejected boulders did not make it to the hollow. However, smaller clasts from Sunrise may be present inside of the hollow fill. The size frequency distribution of craters at a similar state of degradation at the InSight landing site [11] suggest that Sunset crater is Middle to Late Amazonian in age or ~300 ± 50 Ma.

(7) The degradation rate at *Homestead hollow* slowed to 10^{-4} m/Myr and less than 1 m of crater filling occurred over the next few hundred million years [11,12]. Interior eolian bedforms that are today common in fresher impact craters in the region stabilized and flattened in *Homestead hollow*, forming the smooth, sand-dominated surface that is seen from the lander.

(8) *Homestead hollow* impact crater was at or near equilibrium with the surrounding terrain throughout the Late Amazonian. The last ~10's of cm of rim deflation and fill occurred at incredibly slow rates (10^{-4} m/Myr) [11]. Stability of the soil over this time potentially promoted the long-term exchange (order of ~100 Myr) of small volumes of atmospheric water vapor within a sand/dust mixture producing a ~10 to 20 cm-thick cohesive duricrust that is visible as a more resistant unit within the pits (Figure 2) and HP^3 mole hole.

(9) An occasional impact provided a coating of loose, sand, granules, and pebbles that now caps the surface of *Homestead hollow*. Sand and granules are infrequently mobilized by modern winds across the crater interior [13,14]. The combined processes produced a 1 to 2 cm thick surficial layer of loose material that caps the cohesive duricrust.

(10) A secondary crater from the Corinto impact, dubbed *Corintito*, impacted near the southern edge of *Homestead hollow* between 0.1-1 Ma and 2.5 ± 0.2 Ma [15]. The impact exposed the upper tens of centimeters of the fines-dominated regolith.

(11) InSight landed on 26 November 2018.

Conclusion: While the stratigraphic model above is specific to this location on Mars, the overall processes and basic stratigraphic architecture are likely similar across all Hesperian to Amazonian-age lava plains that have experienced limited surface modification by impact, eolian, and gravity-driven processes. The InSight landing site is morphologically and chronologically similar to other lava plains on Mars, including the Gusev cratered plains, Hesperia Sinai and Solis Plana, and Syrtis Major [16,17]. In all cases, these regolith covered basalts have surfaces that are dominated by sand, with low rock abundance and smooth surfaces. The stratigraphy at InSight therefore represents a type example of a regolith-covered basaltic surface on Mars.

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