PROBING THE REGOLITH AT THE INSIGHT LANDING SITE USING ROCKY EJECTA CRATERS.

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Introduction: The Interior Exploration using Seismic Investigations, Geodesy, and Heat Transport (InSight) mission to Mars landed on an Early Hesperian-age [1] smooth lava plain in western Elysium Planitia at 4.502°N, 135.623°E [2, 3]. Pre-landing orbital investigations of the landing ellipse indicated that the general region is capped by an up to 17 m thick regolith that was produced by impact gardening and eolian re-working [4]. However, from an analysis that spanned the entire landing ellipse of the onset diameter of rocky ejecta craters (RECs), the morphometric characteristics of 40 to 80 m diameter nested craters, and the depth to diameter ratios of 10-m-scale pristine craters, the upper 2 to 5 m of the regolith column was found to be composed of loosely-consolidated granular materials [5-7]. The regolith at these depths should be relatively free of large, boulder-size rocks. Below these depths, rockier materials are likely.

The stratigraphy of the upper few meters of the regolith column will soon be tested by the Heat Flow and Physical Properties Package (HP^3) onboard InSight [8]. This percussive mole is designed to acquire a global heat flux measurement by penetrating a loosely-consolidated, granular regolith that is free of >10-cm-diameter rocks. The desired depth of penetration is 3 to 5 m. Here, we evaluate the local stratigraphy of InSight's specific landing location to revise regolith thickness estimates prior to HP^3 operation. We revisit the onset diameter at which craters excavate rocks across the region as well as at the landing site.

Previous Evaluation of Rocky Ejecta Craters (RECs) in the Landing Ellipse: At diameters (D) > 200 m, all fresh craters in the final landing ellipse of InSight have rocks that are visible at HiRISE resolution (0.25 m pixel^{-1}) throughout the entirety of the continuous ejecta [4-7]. This suggests impact into bedrock. Depth of excavation relationships indicate that materials in the continuous ejecta are sourced from 0.1 times the transient crater diameter, which is ~0.84 the final diameter [9]. Using this relationship, the depth to bedrock is ≥ 17 m for 200 m diameter craters.

At diameters between 60 and 200 m, fresh craters also always exhibit ejected rocks (Fig. 1a). Craters as small as 40 m (Fig. 1b) sometimes exhibit ejected rocks. However, the ejecta for these smaller craters generally have a lower rock abundance and the extent is discontinuous around the crater [7]. While these observations indicate the presence of rockier material at depths that are within the range of HP^3 penetration (~3 to 17 m), the lower rock abundance and irregular distribution suggests that the excavated unit has a lower volume of rock-bearing material. This is consistent with a vertical transition from bedrock into coarse breccia that contains loose, meter-size rocks. Observations along an exposure within the Hephaestus Fossae fracture system (~1,000 km NW of the InSight landing site) (Fig. 2), suggest that the stratigraphy of an impact-gardened basaltic lava plain transitions vertically from fractured bedrock to a meters-thick basal regolith layer of coarse breccia [4,5]. Above the breccia, is a progressively finer, meters-thick soil.

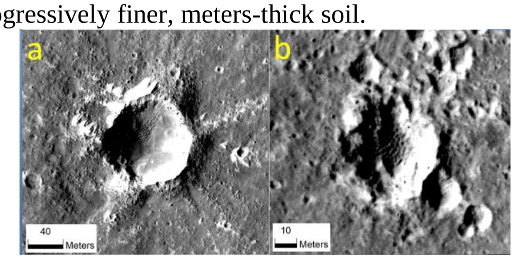

Fig. 1: HiRISE image ESP_036761_1845 showing a ~100 m diameter REC (a) that is 370 m east of the lander and a ~45 m diameter REC (b) that is 320 m to the southwest.

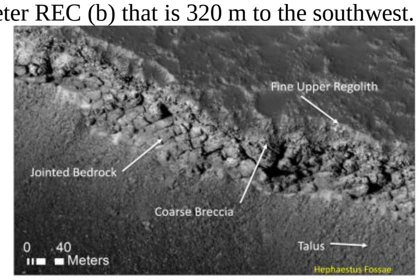

Fig 2: Stratigraphic exposure along the Hephaestus Fossae fracture system showing the stratigraphy of the regolith on a basaltic lava plain (HiRISE image PSP_002359_2020).

Fresh craters in the landing ellipse with D <40 m almost always lack rocks that are visible in HiRISE, consistent with impact into a relatively rock-free, surficial soil. These craters are classified as non-rocky ejecta craters (NRECs). Ejected block size relationships indicate that the largest ejected rock for small 10-m-scale craters should be visible in HiRISE [10]. Therefore, the lack of meter-size rocks around these small craters implies that excavation did not reach a rock-bearing unit.

Regolith Thickness at the Landing Location: A complete REC and NREC map was constructed for the final landing ellipse prior to landing to evaluate the possibility for local variations in regolith thickness that may be relevant for HP^3 operations [6]. To constrain the thickness of the surficial, rock-free portion of the regolith, a REC and NREC contour map was generated using a dataset of all 30 to 60 m diameter craters in the ellipse (straddling the typical onset diameter for ejected rocks). Each crater was converted to a point and a kernel density map was produced in ArcGIS. For the REC map, the excavation relationship [9] was used to determine the depth to the rockier material and the maximum thickness of the rock-free regolith. The NREC contour map was used to identify the minimum thickness of the rock free regolith.

The two excavation contour maps were used together to bound the actual thickness of the rock free regolith. This was done by performing a 3D Delaunay Triangulation using all RECs and NRECs and their associated excavation depths. Craters were used to construct a triangular network where the three closest craters of the same classification (RECs or NRECs) defined the vertices of each triangle and triangles of RECs and NRECs do not cross. Figure 3a illustrates the triangular network for the NRECs. The data indicate that approximately 86% of the landing region must have a rock-free regolith that is <3 m thick. Only in small regions, mostly to the east of the ellipse, is the minimum possible regolith thickness greater than 3 m. Fig. 3b highlights the depth to the rocky materials and the maximum depth of the rock-free regolith, determined from the network of RECs. This dataset also indicates that the depth to rock is shallower near the center of the ellipse, near the final landing site.

Assuming that the true depth of the regolith is somewhere between the minimum regolith depth (NRECs) and the minimum depth to rock (RECs), the minimum thickness of the regolith at InSight's landing location is ~2.6 m. The minimum depth of the rockier unit is ~3.9 m. Fig. 3c highlights a scenario where the lower contact of the rock-free regolith occurs half-way between the two established depths (50% between values). In this case, the rock-free regolith depth is 3.2 m.

Craters nearby the landing site were also re-evaluated for their ejecta morphology. InSight landed ~320 m northeast of a fresh (Class 2) (Fig, 1b), 45 m diameter REC. The crater exhibits only a handful of m-scale rocks in its ejecta blanket indicating the possibility that the impact reached the coarse breccia unit at a depth of ~3.8 m. However, the terrain surrounding this crater shows a generally higher background rock abundance compared to other locations in the landing site. A revised rock map, constructed for this study using HiRISE color imagery, reveals that the abundance of rocks in the ejecta of the crater does not exceed the background abundance. Therefore, it is possible that the 45 diameter crater is entirely accessing the rock-free unit, which must be at least 3.8 m thick. A ~100 m diameter REC (Class 3), located 370 m to the east of the landing location, indicates the rock-free regolith is less than 9 m thick (Fig. 1a). In this case, the ejecta exhibits several distinct rays of meter-size boulders that surround the entire crater, implying that this impact reached bedrock.

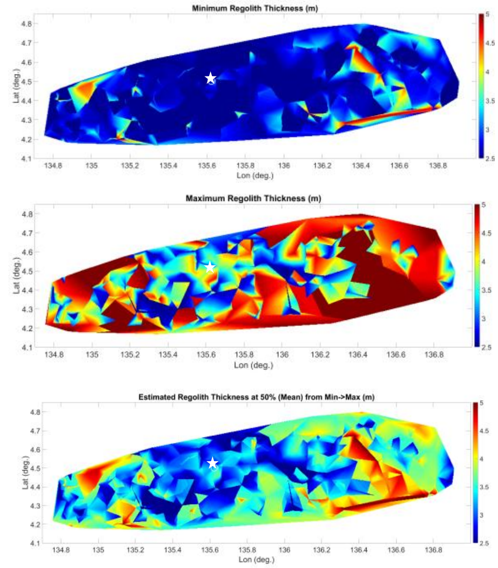

Fig. 3: Results from the 3D Delaunay Triangulation showing (a, top) Minimum regolith thickness, (b, middle) maximum regolith thickness (i.e. minimum depth to rockier unit), and (c, bottom) the estimated regolith thickness halfway between these two values. The final landing site is shown as a star.

Conclusions: RECs in the InSight landing site have been used to constrain the thickness of the regolith and the depth to rockier materials beneath. The rockier unit likely includes a coarser, brecciated layer at the base of the regolith column as well as competent bedrock. Using depth of excavation relationships and the mapped distribution of RECs and NRECs, the rock-free portion of the regolith beneath the InSight lander is ~3 m thick. Below this depth, meter-size rocks are likely to be more abundant and bedrock may be reached at depths approaching 9 m. These constraints meet the minimum depth to penetration requirement of 3 m for HP^3 but indicate the likelihood of rockier materials at depths approaching 5 m.

References: [1] Tanaka, K., et al., (2014), *USGS Sci. Invest. Map*, 3292. [2] Parker, T., et al. (2019), 50th LPSC, this meeting. [3] Golombek, M., et al., (2019), 50th LPSC, this meeting. [4] Golombek, M., et al., (2017), *SSR*, 211, 5-95. [5] Warner, N.H., et al., (2017), *SSR*, 211, 147-190. [6] Golombek, M., et al., (2018), *SSR*, 214, 84. [7] Sweeney, J., et al., (2018), *JGR*, 123, 2732-2759. [8] Spohn, et al. T., (2018), SSR, 214, 96. [9] Melosh, J., (1989), *Impact Cratering, A Geologic Process.* 76-85. [10] Bart, G., & Melosh, J., (2010), *Icarus*, 209, 337-357.