COMPARISON OF DEGRADATION RATES AT THE INSIGHT AND SPIRIT LANDING SITES ON MARS.

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Introduction: The observation that both InSight (Interior Exploration using Seismic Investigations, Geodesy and Heat Transport) and Spirit (Mars Exploration Rover) landed on Hesperian/Early Amazonian lava flow surfaces that were modified by impact and eolian processes offers a unique opportunity to compare the rate of similar degradational processes at two landing sites on Mars. In particular, both sites contain impact craters in a variety of degradational states including highly degraded and abundant impact "hollows" indicating mass wasting and eolian infill. Analysis of the degradation of fresh craters to nearly flat hollows and their size-frequency distributions at these sites yields the rate of change. Here we compare the geology and degradational processes at the two landing sites, assess the rates of degradation, and discuss how the physical properties of old lava flow surfaces compare to other surfaces on Mars.

Geology of the InSight Landing Site: Geologic mapping in Context camera images show volcanic vents and flow fronts that partially fill large craters on the smooth plains where InSight landed [1]. Rocks in the ejecta of fresh craters ~0.5–2 km diameter indicate competent rock ~5–200 m deep with weaker material above and below [2,3]. High Resolution Imaging Science Experiment (HiRISE) images of nearby Hephaestus Fossae show ~10 m of regolith with few rocks over coarse breccia and steep, jointed bedrock below, as expected for an impact generated regolith developed on lava flows. Shallow exposed outcrops in fresh crater walls have mafic mineral spectra consistent with basaltic material [4]. Wrinkle ridges on the plains have been interpreted as fault-propagation folds where slip on a thrust fault at depth results in asymmetric folding in weakly bonded but strong layered material (such as basalt flows ∼200–300 m thick) near the surface [1]. These observations indicate InSight landed on a volcanic surface capped by meters of impact-derived regolith.

The orbital observations are consistent with surface observations from the lander [5,6] and slow shallow seismic velocities [7]. InSight landed in a degraded impact crater with a smooth sand-, granule- and pebble-rich surface. Craters in a variety of degradational states are common on the landscape and sparse eolian bedforms are visible at a distance, sequestered adjacent to large, relatively fresh impact craters. The physical properties of the surface and landforms indicate a surface shaped dominantly by impact and erosional processes [5,8,9].

Degradation of the InSight Landing Site: Observations of 100 m-scale and smaller impact craters in the InSight landing ellipse show that they are in a variety of degradation states from fresh, bowl shaped craters to nearly flat filled in circular hollows [5,8,10]. Analysis of the size-frequency distribution of these craters and the morphometry of the different degradational states from digital elevation models yield timescales and amounts of erosion. Results show that the crater degradation rates are slow (10^{-2} to 10^{-4} m/Myr) [8,10] and consistent with a surface shaped predominantly by impact, mass wasting, and eolian processes, similar to other Hesperian surfaces on Mars [11,12]. Constraints on the age of the volcanic flows from the size-frequency distribution of craters indicates Hesperian ages for craters larger than 5 km, but craters smaller than 2 km diameter [1] indicate volcanic resurfacing in the Early Amazonian (~1.7 Ga) [3,8,13]. In addition, craters smaller than 150 m diameter fall along a −2 power law slope [8,13] indicating that they are in equilibrium with surface processes eroding and filling them in (i.e., new craters form at about the same rate at which they are destroyed) [14]. Finally, analysis of regolith thickness from the source depth of fresh rocky and non-rocky 30-60 m diameter craters shows that most of the ellipse has a regolith 3–5 m thick [6].

Geology of the Spirit Landing Site: Observations of the Gusev cratered plains during the Spirit rover traverse also indicate a similar origin as an impact generated regolith about 10 m thick that overlies Hesperian/Early Amazonian basalt flows that has been degraded by impact, mass wasting and eolian processes [15,16,17]. The Gusev cratered plains have craters in a variety of degradation states. The rocks on the plains are olivine basalts, and field observations identified vesicular clasts and rare scoria similar to original lava flow tops, consistent with an upper inflated surface of lava flows with adjacent collapse depressions [17]. The measured size-frequency distribution of impact craters >20 m diameter in Mars Orbital Camera images shows they also are on a −2 power law distribution, suggesting that they are in equilibrium with surface processes eroding them [14]. Hollows down to ~2 m diameter imaged by the Spirit rover while traversing from the landing site to Bonneville crater are continuous with the distribution for larger craters but have a lower power law slope of −1.5 [17] indicating that smaller craters are being destroyed more rapidly than larger ones.

Degradation of the Spirit Landing Site: Two-toned or patinated rocks and elevated ventifacts indicate eolian deflation of the Gusev cratered plains surface of ~5–25 cm and the transported sand filled the craters to form the hollows [11,17]. Further constraints on the erosion of fines based on rock distributions limits the total deflation from tens of cm to less than 1 m [11,18], which constrains the rate of erosion to $<10^{-3}$ to 10^{-5} m/Myr [11,17]. The size-frequency distribution of craters >1 km in High Resolution Stereo Camera images for the Gusev surface indicate a Hesperian age of ~3.65 Ga [19]. Smaller craters (0.2–1 km) in higher-resolution images follow a production function for a 2.2 Ga, Early Amazonian age [20], consistent with younger resurfacing. The thickness of the regolith on the Gusev plains is estimated at around 10 m from the morphology and morphometry of the largest, freshest crater visited by the Spirit rover. Bonneville crater is a 210 m diameter, 10 m deep, flat floored fresh crater, with a rocky continuous ejecta blanket (Fig. 1). Modification is limited to thin (few meters) drift deposits, and jumbled rocks make up the constant inward sloping walls, with the largest blocks (2.5 m) suggesting Bonneville crater formed in loose rubble ~10 m thick but may have excavated some rocks from deeper bedrock [15,16,17].

Discussion: *Comparison of the Sites***.** There are interesting differences between the two sites. Side-by-side HiRISE images of both surfaces at the same scale show that the InSight surface is smoother and craters are more subdued and degraded and has far fewer fresh craters tens of meters in diameter than the Gusev cratered plains [21] (Fig. 1). The Gusev surface also has more eolian bedforms and more, dark bedforms, suggesting that they are more recently active. Both InSight and Gusev crater ages indicate Hesperian surfaces that were resurfaced in the Early Amazonian. However, the erosion rates at the InSight landing site are 1 to 2 orders of magnitude faster than at the Gusev cratered plains, which could explain the smoother InSight surface. The existence of two landing sites on Mars that formed in a similar manner offers a rare opportunity to better understand the reasons for the differences in degradation rates.

Comparison to other Surfaces on Mars. The similar geologic settings of the InSight and Spirit landing sites suggest that Hesperian/Early Amazonian lava flow surfaces on Mars develop fragmented regolith-dominated surfaces modified by mass wasting and eolian processes with generally low thermal inertia [5,6, 9,16,17]. In these terrains, the mechanically strong blocks of basalt bedrock are fragmented by impact but otherwise resist further significant breakdown by eolian activity [9,22]. On these types of surfaces, the sand produced by the impacts [23,24] is trapped within craters, producing a surface dominated by sand with variable rock abundance and generally low thermal inertia [5,6,17,22]. This is in contrast to other surfaces on Mars with higher thermal inertia that are composed of generally weak, friable clastic rocks that are easily eroded and cleared of comminuted material by eolian activity [22]. Such surfaces generally have higher thermal inertia than those composed of mostly sandy regolith. Examples of weak, friable clastic rocks include the sulfate sandstones of Meridiani Planum that have been easily planed off parallel to the surface by eolian activity [12] and the rocks of the Columbia Hills that lack a regolith cover [18,22]. Future landings on Mars and comparisons to geologic interpretations of remote sensing data from orbit will further test and refine these relationships.

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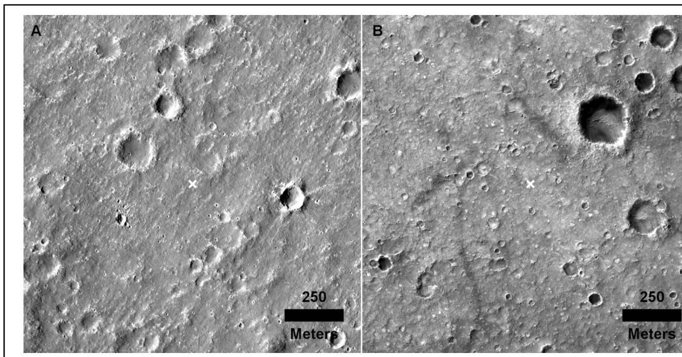

Fig. 1. HiRISE images of the InSight (A) and Spirit (B) landing sites at the same scale. The white crosses (X) show the location of the landers. Note smoother surface and more degraded craters at the InSight landing site compared with the Spirit landing site. Bonneville crater is the largest, freshest crater (210 m diameter) with continuous rocky ejecta blanket investigated by the Spirit rover to the northeast. Compare with the freshest crater near InSight, which is the 100 m diameter rocky ejecta crater around 400 m to east. HiRISE image (a) is ESP_036761_1845; HiRISE image (b) is PSP_001777_1650.