P21A-0132 Missing Holes in the Hills? Studying the Crater Record of the Columbia Hills

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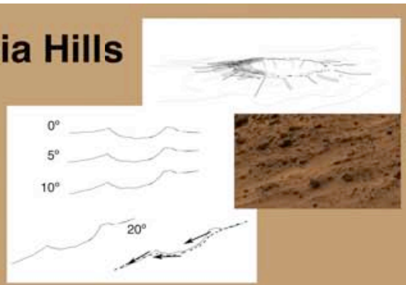


Figure 7. Simple model: viewed in profile a simple small crater in flat terrain (top) is not greatly affected in its geomorphic expression (rim and ejecta), until the slope is sufficient to modify the ejecta deposit, and thereby reduce the imprint of the crater on the landscape. Image is from the Cahokia pan (Fig. 8)

Introduction

Now that Spirit has obtained panoramic views from the Husband Hill summit area in the Columbia Hills (CH), we are afforded the opportunity to reexamine the role of cratering in their geomorphic evolution. The orbital images of the CH taken with the Mars Orbiter Camera (MOC) on Mars Global Surveyor, at first glance, show a lower crater density in the CH as compared to the basaltic volcanic plains that Spirit crossed on the floor of Gusev crater. This apparent paucity of craters is at odds with most of the proposed formation mechanisms for the hills that hypothesize an older age than for the plains basalts. This problem must be reconciled if we are to come to grips with the variety of rocks in the CH and their relationships to one another.

We suggest that three factors likely conspire to varying degrees to mask the CH crater record, likely to varying degrees.

First, slopes will change the distribution of ejecta from craters. While this effect has been assumed for previous planetary studies, it appears not to have been extensively researched. Geomorphic surfaces on the Earth collect debris (produced by various processes) in hollows and on flat surfaces, and we hypothesize that slopes in general, and in the CH on Mars in particular will respond to ejecta emplacement in a similar manner. We discuss a zeroth-order model to illustrate anticipated geomorphic modifications.

Second, the target properties of the CH, potentially quite different than for the plains, i.e. softer rocks, may result in a more poorly expressed cratering record that cannot be clearly detected in orbital imagery. Additionally, illumination and slope effects may also be confounding orbital observation of the crater record in the hills.

Third, the CH are topographically more exposed to eolian effects on average than are the plains, which may serve to soften the topography of craters, or simply mask them, more quickly. Prior to Spirit's arrival in the CH, the MOC images already showed areas of sediment accumulation, and areas where stripping may dominate. Spirit's views from the eolian-bedform-covered crest of Husband Hill into the Inner Basin show drifts, dunes and hollows.

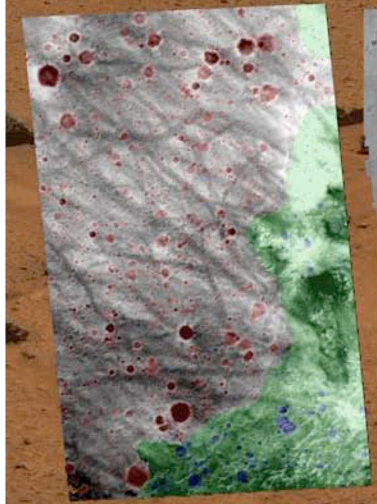


Figure 1. MGS MOC image R13-01467 with 1.47 m/pixel resolution, and north up. The image swath width is 2.94 km. The Columbia Hills are shaded green. Craters were identified interactively and measured using the RSI ENVI software package. The plains/hills contact generally follows maps produced by Crumpler and by Cabrol during the MER mission.

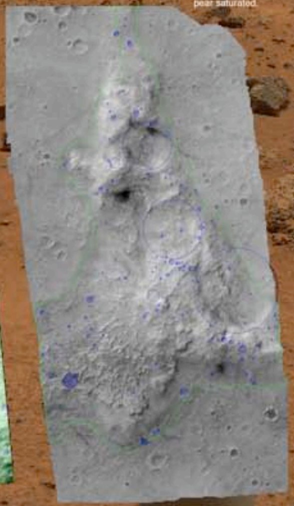


Figure 2. MGS MOC image E03-00012 with 2.86 m/pixel resolution and north up. The swath width in this geographically corrected image from USGS is 2.92 km. The boundary of the CH is shown in green, and only craters within the hills (inside the boundary) were counted. Hachured circles are distinct craters, while the open circles are proposed degraded craters. The crater isochrones were produced for both sets.

Testing the Assertion

Are there really fewer craters in the Columbia Hills? Crater counts in two MOC images, R13-01467 (Figure 1), and E03-00012 (Figure 2) bear this out. One of us (AFCH) counted all the craters in image R13-01467, and then separated the CH craters from the Plains craters to plot the number of craters per km2. The crater counts from Figs. 1 and 2 are plotted over the Hartmann Martian isochrons in Figure 3. The solid boxes for the plains craters in MOC image R13-01467 lie on or very near the saturation line for crater sizes below 100 m. The open triangles and filled circles are the counts in the CH from images R13-01467 and E03-00012 respectively, and show that there is a reduced decameter-to-hectometer crater population in the CH. The difference between the two hills counts is that hills crater identification in R13-01467 (Fig.1) was more aggressive than in the lower resolution image (Fig.2). The addition of more tentative craters ("degradeds") to the E03-00012 count raises the numbers to be more similar to that in R13-01467. The roll-offs in all counts in Fig. 3 at small crater sizes are crater-counter-laziness effects.

This would seem to confirm that there appear to be fewer fresher craters in the hills. In itself this would be startling, as one might construe that the CH are younger than the Hesperian plains that surround them! The major assumption in this discussion that bears stating is the superposition relationship of the Gusev volcanic plains over the Columbia Hills, taking as evidence Spirit's observations at the crossing of that geologic boundary. It is this relationship that creates the puzzle when fewer craters are found in the Columbia Hills.

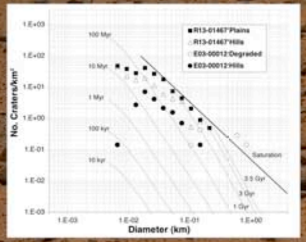


Figure 3. (left) Crater counts from Figs. 1 and 2 (by AFCH) shown over the Hartmann Martian isochrons. Numbers of craters in diameter bins spaced by 20.5 are plotted. The solid boxes for the plains craters in MOC image R13-01467 lie on or very near the saturation line for crater sizes below 100 m, while the counts for the Columbia Hills do not appear saturated.

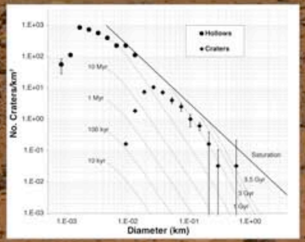
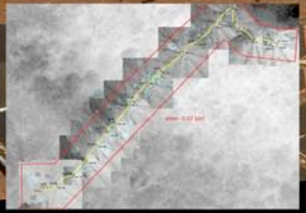


Figure 4. (right) A separate crater count from MOC images R07-01606 and R13-01467 (by LSC, shown in Fig.5) compares favorably with the 3 Gyr Hesperian age for the Gusev plains in Fig.3. A separate count of hollows along the rover track, mapped in Fig.6, is plotted at small diameters.

To bolster our assertion, we compare the counts from Figs. 1 and 2 with independent plains counts made by LSC and reported in Golombek et al. ("Geology of the Gusev cratered plains from the Spirit rover traverse", JGR-Planets, in press) that are shown in Figure 4. The crater count in Fig.4 is also MOC-image based, but was less aggressive than the new counts reported here (Figs. 1 and 2). Notably in Fig. 5, almost no craters are included in the count in the CH portion of the image, although that portion is counted for the km². A further plains comparison that we mention because it relates to qualitative observations in the CH is a crater count of the hollows observed along Spirit's traverse to the rim of Bonneville crater. The smallest craters on the plains also follow the saturation line (and perhaps also follow the atmospherically controlled roll-off at smallest diameters).

Figure 5. A regional image of small impact craters (10 m to 600 m in size) in the vicinity of the Spirit landing site (mosaic of MOC images R02-00357 and R07-01606).

Figure 6. Mapping and counting hollows along Spirit's traverse from her landing site to Bonneville crater.



Significance

Our interest in a thorough mapping of craters in the Columbia Hills stems from our desire to provide a proper structural geologic context for the many rock types being found by Spirit. In the plains, Spirit found no bedrock, but in the hills, she has found several examples.

If the plains basalts are superposed on the hills, and if the plains are at crater saturation in the 10 m diameter range, how should we understand and interpret the occurrence of bedrock in the CH?

It may be as simple as "ejecta slides downhill" to expose target rocks. Also, whether or not the craters in question are primary or secondary is irrelevant to the question of geomorphic differences between crater preservation in the hills versus on the plains.

A Simple Model

We are developing a model of geomorphic slope control for crater morphologic expression. It is expected that crater generation will follow the same physics in sloped terrain as on flat for the contact, compression and likely most of the excavation stage. Simply stated, the impact explosion on a hill slope should begin a spherical zone of effects, as it does on the plains. However, observations of artillery in mountains suggests that gravity can come to control the later excavation stage and subsequent modification stage.

We propose that the geomorphic control over whether a crater in the hills will resemble a flat-terrain crater is the relief of the pre-crater slope relative to the potential crater relief for the crater's size. For example, a 2 km diameter crater would likely obliterate a 300 m diameter hill, but a 30 m diameter crater-forming impact on a 20° slope may well suffer post-impact modification stage erosion, making the crater less circular and therefore less observable. The thought-experiment of the limiting case of an impact on a vertical wall suggests that at some slope gravity must dominate the modification stage of ejecta distribution to produce asymmetric crater morphologies.

Now, there must be more to the process than just slope. For example, aeolian modification of an asymmetric slope, or preferential burial by slope-climbing sands would confound the crater detectability, from the ground as well as from orbit. Furthermore, if the crater is a secondary, or generally is formed by a lower velocity impactor, its inherent depth-to-diameter ratio is lower so it may be more likely to be "overwhelmed" by the CH relief. If the majority of the plains crater population is due to secondaries, this effect may in fact be manifest in what we are observing.

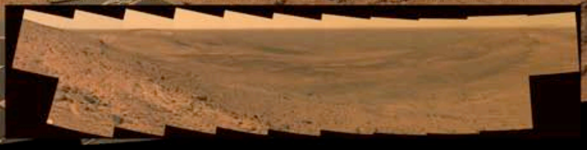
The persistence of ejecta draping many surfaces on Husband Hill argues that there has been relatively little erosional modification of bulk hill form. That is, there has likely been meters of material removed, but not 10's of meters since the ejecta were emplaced. Mini-TES data suggest the ejecta varies in composition (relative to what was observed on plains) and is either from multiple impacts or from a single deep impact somewhere that excavated a range of compositions. The differences in composition of ejecta on hill and on plains suggests that the surfaces on hill predate plains...and are little modified in bulk form. So meters of redistribution gets rid of lots of craters up into the 10's of m diameter range. Coupled with slope effects and possible difficulties in detecting small craters on hill, that might be enough to account for any differences...without requiring wholesale modification of hill form since at least the time the plains were emplaced.

Figure 9. Spirit's Cahokia Pancam panorama, acquired between Sols 213 and 223 from Aug. 9 to 19, 2004. The center of the 360° faces approximately south.

Figure 10. A 360° panorama from the western slopes of Husband Hill between the West Spur and the slope leading up to Larry's Lookout over the "Tennessee Valley". This mosaic was acquired between Sols 318 and 325 (Nov. 24 to Dec. 2, 2004). Some plains-morphology hollows are evident...but not obvious on the slopes...or are they?

Figure 11. Spirit's 360° Everest panorama at the summit of Husband Hill in the Columbia Hills, acquired between Sols 620 and 622 (Oct. 1 to 3, 2005). Are craters visible in the CH from here, in this view centered approximately on north?

Figure 12. A 150° Pancam panorama showing Spirit's view into the East Basin, northeast of Husband Hill on Sol 653 (Nov. 3, 2005). East is along the ridge on the right of image, with Thyra crater on the horizon. Note several craters in the CH in that direction.



Conclusion

Whether or not the reader is convinced that less craters are "countable" in the Columbia Hills, we have established that the craters that are in the hills are "harder to count." This is in fact almost the same issue as whether the craters are "there or not" with which we began. The same factors of geomorphic process and observational bias are at issue, and some resolution is required if effective structural context is to be obtained.

Further tests of the proposed factors need to be pursued with exising MER data:
[1] Beyond our qualitative comparison here, we need to carry out a quantitative "ground-truth" mapping to estimate the size and position of impact craters within the Columbia Hills from Spirit to compare directly with MOC image data of the CH, and with Spirit data from the Gusev plains.
[2] Hectometer diameter crater numbers (viewed with orbital data or from Spirit) need to be compared with quantitative slope information to evaluate, and perhaps refine, our slope cratering model.

More generally, in the new era of bedrock planetary geologic mapping, the planetary geologist will need more refined models of cratering structural geology to properly interpret details of regional lithologic history.

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