PROGRESS ON OLD AND NEW: $D \geq 1$ KM CRATER CATALOGS FOR MARS AND MOON.

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Introduction: During the years 2007–2012, I worked to construct a global Mars impact crater database that had the stated goal of being a complete sample of all impact craters with diameters $D \geq 1$ km, and it numbered ≈375k craters $D \geq 1$ km [1,2]. Since then, the database has been used in nearly 100 peer-reviewed papers, dozens of conference abstracts, and other venues such as grant applications and school projects. However, it has faced some critiques. Meanwhile, I am in the process of finalizing initial work on a similar crater catalog for the Moon that contains nearly two million entries, and this effort was recently awarded a NASA PDART to expand it to include similar information to the Mars database effort. In this abstract and presentation at the 2017 Planetary Crater Consortium, I will detail the lessons learned from Mars, show how I am applying those to the lunar effort and a new effort to revise the martian database, and present comparisons between the lunar work and published lunar crater databases.

Targeted Goal for Mars Database, v1: The initial Mars database was constructed with the goal to study Martian "layered ejecta" (LE) impact craters and have a meaningful control set of impact craters – *i.e.*, all other craters. This large, comprehensive effort – of a scope that had not before been attempted – included crater locations, diameters, ellipse properties, depth information, interior morphology, and ejecta morphology and morphometry. Because past work had focused on larger craters, this effort focused on smaller craters with a goal to identify, measure, and classify craters as small as $D = 1$ km (somewhat arbitrarily chosen, but reasonable given that the basemaps used were 100 m/px such that the smallest crater would span 10 pixels). Due to time constraints, however, only locations, diameters, and ellipse properties were measured for craters $D \geq 1$ km, and the remaining features were only classified and measured for craters $D \geq 3$ km (~75k craters).

Some Criticisms of the Mars Database, v1: The authors of the Mars database (S. Robbins, B. Hynek) have tried to make clear at every opportunity that the database is subject to revision, and if there were issues, to notify either of them so that corrections could be made. In the past five years, only two individuals have done so. Unfortunately, keeping issues to oneself does not benefit anyone. Meanwhile, the authors themselves have recognized several issues, and recent discussions with colleagues have raised more. We briefly summarize several of them here:

1. Inconsistent and Incomplete Image Base: The database was built over five years using two or three iterations of global THEMIS mosaics which each had different control networks, and they are different from the current THEMIS basemap which is also different from the ongoing, multi-year effort to construct a fully controlled THEMIS basemap [3].
2. False Positives, False Negatives: Some craters were missed, and some features which are not impact craters were erroneously included. The "Confidence" column in the database that was meant to help with this issue is not useful because it was under-used during database construction.
3. Some Position/Size/Ellipse Bugs: Two bugs in our rim-fitting code have emerged. The first did not use Great Circle bearings which only affect large, nearly polar craters, such as Prometheus (revised diameter is 20% smaller). As such, it was only discovered when analyzing polar lunar craters due to an absence of large polar martian craters. The second bug is due to the ellipse-fitting code returning a solution matrix that sometimes flipped major and minor axes; when corrected originally, the calculated tilt angle should have also been rotated 90°, but it was not, resulting in nearly useless ellipse tilt angles.
4. Depths of Too Small Craters: The initial database included some crater depths for craters as small as $D = 3$ km using MOLA topography. However, subsequent work [*e.g.*, 4,5] has emphasized MOLA are unreliable for craters smaller than $D \lesssim 10$ km. Also, a just-accepted review article [6] demonstrated that depth can change significantly depending on exactly what data and method is used to measure it.
5. Morphology (Crater, Ejecta): Recent comparisons by N. Barlow [7] have demonstrated that there is inconsistency in the database relative to her efforts in crater morphology; given the incomplete image base, sometimes poor images used in the THEMIS mosaic to construct the initial catalog, and subjective nature of assigning morphology, this is perhaps expected, but it nonetheless is an issue that should be investigated further.

Targeted Goal for Mars Database, v2: I have begun efforts to improve the Mars database as (a) an effort for the community and (b) part of two grants, one to study the LE craters and one to examine small craters on young terrain and large craters on basin rims. For this effort, I am working to improve upon and address all issues that have been raised. They are briefly described here, and the workflow is described in more detail in the next section.

For issue 1, I am using the new THEMIS fully controlled mosaic (100 m/px) where it is available, in concert with global CTX mosaics (20 m/px) and, where neither are available, the current best THEMIS global mosaic. (Craters identified in CTX are tied back to the controlled THEMIS, where available.) While this will still result in an inconsistent map base, they are all significantly improved over what was available a decade ago, and CTX coverage has reached ~95% of the globe (versus 0% to up to ~50–60% during the years of initial database construction). In going through craters on these mosaics, I am working to rectify issue 2, and I am making better use of the "Confidence" column. The CTX mosaics are also being used to revise the crater and ejecta morphology. For issue 3, the bugs in the code have been fixed, so this is no longer an issue (ellipse properties verified by E. Kite).

For issue 4, I plan to improve upon the improved depth code from [4] by including additional definitions of crater "depth" based on the recent review paper [6] (*e.g.*, instead of just a rim average, including maximum-to-minimum, and cords along several compass directions). I also will <u>ex</u>clude MOLA-based depths of craters $D < 10$ km. However, I will include depths of smaller craters based on HRSC DTMs [8] and custom CTX DTMs I have begun to construct using the Ames Stereo Pipeline [9], where each dataset is available, and each can provide cross-checks on the other.

Targeted Goal for Moon Database: To expand upon the statements above about the Mars v2 database, I discuss the Moon database here, which is implementing workflow lessons learned and critiques that have been made of the Mars database.

Phase 1, Initial Construction: The initial database construction is being completed. It has followed the same basic format of the Mars database: Scour the global 100 m/px basemaps (*LRO* WAC [10]) and trace impact crater rims using a polyline and ArcMap's "streaming" tool. The rims are processed with code that calculates the center coordinates, diameter, and ellipse properties. In addition to the WAC basemaps, which are sometimes at sub-optimal lighting (particularly near the sub-Earth point and poles); LOLA DTMs [11]; *Kaguya* DTMs tied to LOLA [12]; *Kaguya* mosaics at dawn, dusk, and noon; and custom WAC mosaics at numerous incidence angles and 70 m/px are being used. Additionally, the lunar control network is significantly better than the Martian. <u>Status:</u> Initial identifications from *LRO* (WAC, LOLA) are done, they are in the process of being added to and subtracted from using the *Kaguya* datasets. As I found on Mars, <u>significant</u> improvement in crater identification and measurement is possible when using elevation data over image data.

Phase 2a, Global Morphology: The next step will be done by myself, selecting regions of secondary craters and again checking crater identifications (correcting false positives and negatives). This is done *en masse* rather than individually because it is faster for many large fields of secondary craters (*e.g.*, near Copernicus).

Phase 2b, Individual Morphology: Next, craters will be examined individually to verify Phase 1 and 2a data, also by myself. Preservation state and ejecta classifications will be made along with the confidence the feature is an impact crater. Example of the latter where a feature may be included but at low confidence would be circular topographic depressions upon large crater walls or within the continuous ejecta deposit of large craters. The former features may be highly irregular craters due to the extreme topography upon which they formed, and the latter may be a buried crater under the continuous ejecta. However, it is not certain that they are impact craters, and as such, will be given a lower confidence. Finally, for complex craters (<5% of the database), additional features (*e.g.*, terraced walls, central peaks) will be noted.

Phase 3, Topography: R. Hoover is a Co-I on the PDART award and will be in charge of crater depth measurement, concurrent with Phase 2. She will use my tools that were developed for Mars to measure crater depths in at least three different datasets (LOLA point data, WAC DTM, and *Kaguya* DTM), provide several different metrics for crater depths.

Phase 4, Validation: Built into the PDART are 24 person-weeks for three Co-Is (C. Chapman, M. Kirchoff, K. Singer) to validate / verify all types of measurements and classifications made by Robbins and Hoover and then correct disagreements or note them in the database. While this is not nearly enough time to check every crater, we are going to work with statistician J. Riggs to design a sampling plan that will allow us to get a meaningful sampling of the craters and allow us to understand the general reliability of the database. <u>This phase is not present in the Mars effort (no funding), but we think that it will be an important part of the lunar effort.</u>

Discussion: I invite further suggestions for improvement in the Mars catalog and workflow suggestions for the Moon catalog as both of these efforts ramp up. At the conference, I plan to outline what has been discussed in this abstract and to show several preliminary comparisons between my lunar database and published catalogs.

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