

## MARTIAN IMPACT CRATER DATABASE : TOWARDS A COMPLETE DATASET OF D>100M AND AUTOMATIC IDENTIFICATION OF SECONDARY CRATERS CLUSTERS.

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**Introduction:** Impact craters on rocky and icy bodies of the solar system are widely used to determine the ages of planetary surfaces. Absolute dating of meteorites or *in situ* geochronology provide a few essential reference points, but these techniques are rare and not yet applicable on a planetary scale. Therefore, impact crater counting techniques remain the major tool of astro-geologists to decipher the history of planetary surfaces. This approach requires mapping and morphological inspection of a large number of circular features to distinguish true and primary impact craters from other surface features and secondary impact craters; in particular on Mars whose surface exhibits a large variety of pseudo-circular features (e.g mounds, collapse pits of lava tubes, circular grabens, glacial cirques, calderas, etc). Once identified, the craters are counted manually. The most complete database of Martian craters [1] contains more than 384,000 impact structures larger than 1 km in diameter. Nevertheless, to determine young and/or small surface ages on Mars impact craters <1km need to be included. [2]. However, crater number scales as a power law, which means the number of impact craters between 10s m and 1 km over the entire surface of Mars reaches into the 10s millions. It would be beneficial to develop a dataset that extended to the limiting resolution of available imagery. Such a dataset would allow ultimate resolution on fine-scale age variation over the surface of Mars. But the task is impossible with manual counting.

**Automated crater detection technique:** To access the crater population of this size range at a planetary scale, the automation of the crater counting process is essential. In previous works, we described our crater detection algorithm (CDA) [3-6]. Subsequent improvements with ongoing advances in machine learning have allowed us to refine it. Our current CDA was trained by selecting 889 tiled THEMIS Day IR images on which 1,762 impact craters from the Robbins database [1] were identified. These images were inspected manually and any ambiguities clarified to produce the largest accurate and validated library of impact craters for use in the automated crater detection. This dataset was further augmented by horizontally and vertically flipping the images to generate a training dataset of 3,556 tiled images.

The total processing time for a single THEMIS quadrangle mosaic (26,674 x 17,783 pixels) taken by our CDA running the detection on a Telsa P100 16GB GPU is ~2 minutes. The output of the algorithm contains the coordinates, in number of pixels, of the image of each corner of the squares framing each detected craters. The diameter and lat/long coordinates of detected craters are derived by applying the known coordinates of the image extent and its resolution (i.e.100m/pixel for THEMIS imagery). We have now applied our CDA [7] to all Mars quadrangles except Mare Boreum and Mare Australe, due to the distortion of crater shapes at latitudes higher than  $\pm 65^\circ$ . The ratio between the total number of craters >1km diameter detected by the CDA and those in the manual database [1] is close to 0.9 [6,7]. Moreover, CSFDs between 1.5 and 10km are similar indicating an acceptable estimation of diameter over this range [6,7].

**One Code to Detect them all:** While the crater population detected by the CDA on imagery at 100m/px could be considered as complete, we tested the efficiency of our THEMIS-trained algorithm on the higher resolution CTX images (5m/px). For this purpose, we used the Murray Lab uncontrolled global CTX mosaic [8] and applied our CDA between  $\pm 45^\circ$  latitude. This resulted in 17 million impact craters, between 40m and 10km, detected over this portion of the Martian surface (Figure 1).

**Initial Results :** The distribution of the 17 million craters detected on the CTX dataset reveals very interesting features, the extent of which have not seen before. We focus here on Tooting Crater in the Amazonis Quadrangle near Olympus Mons. Tooting Crater is a relatively young crater ~30km in diameter. The geology and relative ages of different features within the crater have been thoroughly discussed by [9,10]. We can see in the CTX crater density distribution clear evidence of rays of secondary craters extending from the crater. These secondaries have been noted before. The maximum range of blocks that produced identifiable secondary craters was determined by [9], to be 500km (36 crater radii) from the north-east rim crest. Our database allows us to visualise secondaries ranging from Tooting crater up to 1500km (>100 crater radii). The direction of the longest ray of secondaries is consistent with the main

direction of the ejecta blanket.

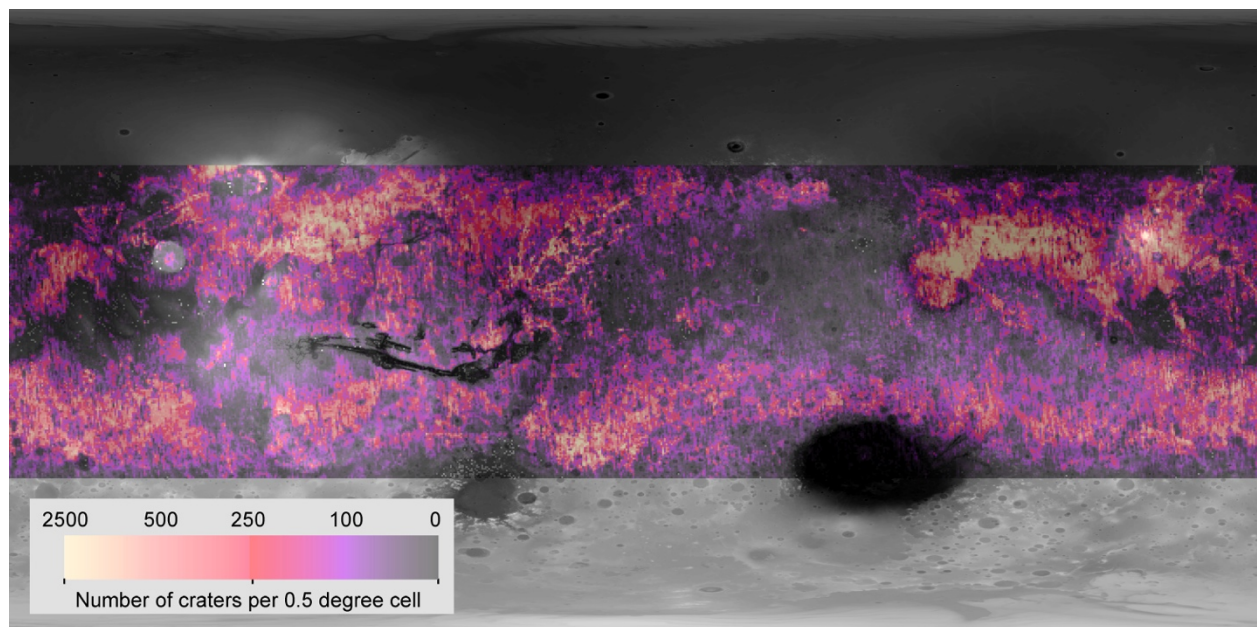
**Secondary crater identification:** Large portions of the Martian surface contain secondary crater clusters which will have an effect of the age derived from the detection. The CDA detects impact craters, but does not distinguish between their primary or secondary origin. However, visual inspection shows that numerous clusters of secondaries have been detected and must be considered and removed before an age can be derived. Taking inspiration from an approach developed by previous workers [11,12,13] we have constructed a Secondary Crater Clusters Algorithm (SCCA). A Voronoi polygon (VP) tessellation is computed over a crater population detected on a counting area where the cratering density should be homogeneous. The SFD of the VP is then calculated and compared to the SFDs of 1000 randomly generated impact crater populations. The mean and the standard deviation of the VP SFD are calculated. The intersection between the VP SFD from the detected crater and those from the simulated population at  $+1\sigma$  correspond to the threshold value polygon size. This size indicates a cutoff which represents the upper size limit of the VPs where associated craters can be considered as secondaries. These detections are then removed from the crater population as well as their associated VP before any ages are derived.

**Conclusion:** Application of our THEMIS-trained

CDA was applied to the highest available resolution global imagery dataset of Mars – the CTX global uncontrolled mosaic. This resulted in 17 million craters detected between 40m and 10km between  $\pm 45^\circ$  latitude. The distribution of craters reveals new and interesting features. Here we discuss secondary cratering. The rays associated with Tooting Crater were investigated and shown to extend about 3 times farther than previous studies.

**References:** [1]Robbins, S. and Hynek, B. (2012) *JGR*, 117, E05004. [2]Quantin, C. et al. (2004) *Icarus Vol.* 172. [3]Norman, C.J. et al. (2018) *Planetary Science Information and Data Analytics Conference*, St. Louis, MO, Abstr #6002. [4]Benedix, G.K., et al. (2018) *49th LPSC*, #2202. [5]Benedix, G.K., et al. (2019) *50th LPSC*, #2140. [6]Lagain, A. et al., (2019) *9th International Conference on Mars*, #6017. [7]Benedix, G.K. et al. submitted to *Earth and Space Science* (19 Nov. 2019). [8]NASA/JPL/MSSS/The Murray Lab. [9]Morris A. et al (2010) *Icarus* 209, 369-389 [10]Mouginis-Mark, P. and Boyce, J (2012) *Chemie der Erde* 72, 1-23. [11]Andronov, L. et al. (2016) *Nature, Sci. Reports*, 6, 2045-2322. [12]Salih, A.L. et al. (2017) *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, XLII-3/W1, 125-132. [13]Michael, G.G. et al. (2012) *Icarus*, 218, 169-177.

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**Figure 1:** Crater density map of detection ( $40\text{m} < D < 10\text{km}$ ; between  $\pm 45^\circ$  latitude) overlain on the CTX mosaic [8]. Due to the sparse crater density on Olympus Mons, it appears highlighted, but is not.