THE POPULATION OF SECONDARY IMPACT CRATERS ON MARS. S.J. Robbins[1] and B.M. Hynek[1,2], [1]LASP, 3665 Discovery Dr., University of Colorado, Boulder, CO 80309, [2]Geological Sciences Department, UCB 399, University of Colorado, Boulder, CO 80309. stuart.robbins@colorado.edu

Introduction: Impact craters are the most ubiquitous exogenic feature on planetary surfaces in the solar system. They have innumerable applications, but one of their primary utilities is to model surface ages: if there are more craters per unit area on one surface, then it is older than another with fewer craters. This very basic method requires the assumption that the craters formed spatially randomly and stochastically with time. Unfortunately, secondary impact craters belie both these assumptions: They form in a geologic instant from cohesive ejecta blocks launched by a primary impact ("primary"), and while they may be spatially correlated with that primary, this is not always the case. Studies have suggested that, overall, the population of secondary impact craters ("secondaries") on Mars is greater than the population of primaries for crater diameters $D \lesssim 1$ km [*e.g.*, 1]. The study presented here is testing that assumption by assessing the diameters at which secondaries start to dominate over primaries on a global scale, and we extend this to show the dominance on a regional level, as well.

Crater Identification: The recent publication of a massive global crater database that is statistically complete for all Martian craters $D \geq 1$ km (approx. 385,000 craters) with an additional ~250,000 craters $D < 1$ km [2] forms the base dataset for this work. It is used in conjunction with THEMIS Day IR global mosaics (≫99% coverage, 100m/px [3]). The entire surface of Mars is being searched for craters that appear to be morphologically distinct secondary craters (*e.g.*, Fig. **1**); for this abstract, we have analyzed the region from 0° to +45° N latitude but will present results for the entire planet in March. Secondaries were craters identified by the following characteristics [4-7]:

- tightly clustered relative to surrounding craters,
- display herringbone ejecta patterns,
- entrained within a much larger crater's ejecta,
- and/or are highly elongated with one major axis end being shallower than the other end.

Fig. **2** shows the non-uniform contamination of secondary craters across the region studied as a scatterplot.

A caveat for this method is that it very likely under-estimates the true population of secondary craters because, by their nature, we cannot distinguish between primaries and "lone" secondaries that some argue form part of a global, background secondary crater population [*e.g.*, 1]. We also cannot recognize if secondary craters start to dominate for crater diameters <1 km because the crater catalog is not complete for those craters.

Another factor that will contaminate our results are crater clusters formed by an impactor breaking up soon before impact because these can display morphologies very similar to secondary crater clusters [8]. However, while this is a contaminant, we argue these kinds of crater clusters are themselves an additional contaminator of the primary crater population because, like secondaries, they form in a geologic instant and are tightly clustered spatially. Ergo, their removal – or an estimate of what crater would have formed from an intact primary – would also be necessary for applications of primary craters such as age-modeling.

Analysis: To determine a "global" value for the dominance of secondaries (within our test region for this abstract), two incremental crater size-frequency distributions (SFDs) were calculated – one for primaries and one for secondaries. If the secondaries' SFD intersected and grew larger than the primaries' at any diameter, that would be considered the transition diameter. To calculate this on a more useful regional basis, the planet was divided into 15°×15° regions and SFDs were constructed in each. A similar analysis was done as described in the preceding paragraph within each bin if the bin contained at least 50 craters.

Results: The results for this broad swath of Mars overall show that there is no intersection, so the population of secondaries did not dominate over primaries. They were approximately 20% of all $D \approx 1$ km craters in this area of the planet, though, indicating significant contamination.

Fig. **3** shows the results of performing this analysis in 15°×15° regions. We performed the analysis for where secondaries match the primary population, where the onset diameter of secondary contamination is only 50% the abundance of primaries, and where it is 25% the abundance of primaries. Other than two anomalous regions near Ascraeus and Pavonis Montes, there are only four small areas where the secondary crater population actually matches the primary crater population, and all are at $D \leqq 2.2$ km. Secondary craters reach 50% the population of primaries (so 33% of all craters) over more of the planet, contaminating Arabia Terra and Isidis.

If the threshold is set to secondaries reaching 25% of the population of primaries (so they account for 20% of all craters), there are regions where the secondaries are significant contaminators at the $D \approx 5$ km level. This occurs throughout Arabia Terra, Syrtis Major, Isidis, Elysium basin, and areas of the Tharsis Montes that had enough craters that can be analyzed.

Distribution-wise, Fig. **2** clearly shows that morphometrically identifiable secondary craters are far from uniform (with the caveat that background "field" secondaries that look like primaries could not be detected). There also appears to be no correlation with unit type nor terrain age (*i.e.*, most young volcanic terrain showing contamination similar to older highlands). We note the high contamination near Ascraeus and Pavonis Montes which could be due to competent lava flows leading to a greater size and abundance of secondaries.

Discussion and Implications: Many researchers go by a broad "rule of thumb" that secondaries become important in Martian crater populations for $D \lesssim 5$ km. Ergo, for many applications where larger craters can be used, a cut-off of 5 km is made. What we have shown here is that this rule of thumb is generally accurate and that while secondaries may reach ~20% of the population of $D \approx 5$ km craters in a few areas, one may typically ignore their contributions for $D > 5$ km.

On the other hand, many researchers today use craters to date smaller features which require smaller craters to have sufficient statistics for an age estimate. Our results show that one <u>must</u> be cognizant of secondary crater contamination because they can reach over 30% of the 1-km-diameter crater population over a broad range of the Martian surface and over many different terrain types.

This work also begins to test the premise in [1] that the transition diameter on Mars for where secondary craters begin to dominate is $D \approx 1$ km, and by March we expect to have extended this analysis to the whole planet. To-date, our results covering 35% of Mars' surface area do not support the notion that secondaries dominate for $D \lesssim 1$ km.

References: [1] McEwen & Bierhaus (2006) doi: 10.1146/annurev.earth.34.031405.125018. [2] Robbins & Hynek (2012) doi: 10.1029/2011JE003966. [3] Edwards *et al.* (2011) doi: 10.1029/2010JE003755. [4] Shoemaker (1962). [5] Shoemaker (1965). [6] Oberbeck & Morrison (1974) doi: 10.1007/BF00562581. [7] Robbins & Hynek (2011) doi: 10.1029/2011JE003820. [8] Popova *et al.* (2007) doi: 10.1016/j.icarus.2007.02.022. [9] Smith *et al.* (2001) doi: 10.1029/2000JE001364.

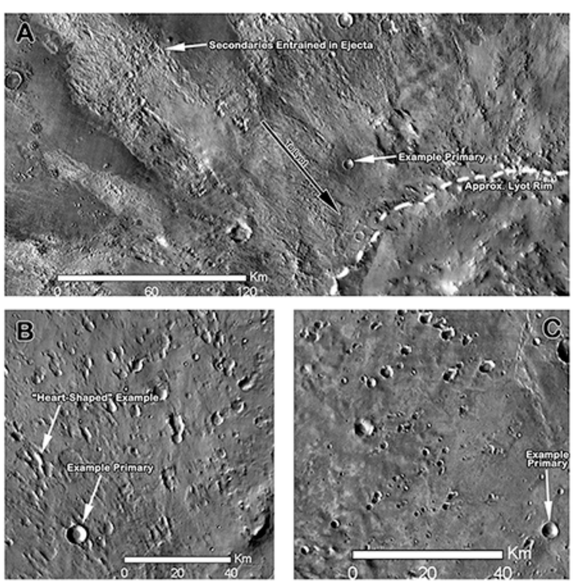

Figure 1: Examples of several different morphologies of secondaries that were identified (adapted from [7]).

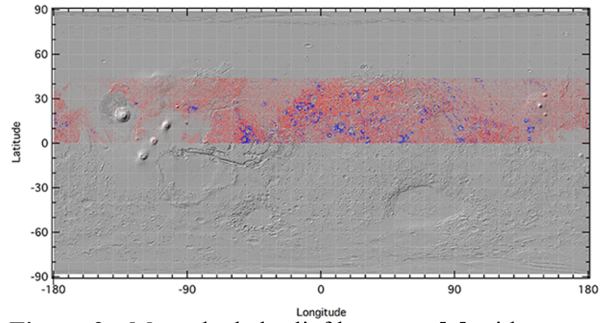

Figure 2: Mars shaded relief basemap [9] with craters with diameters ≥ 1.0 km from [2] between 0° and +45° North latitude overplotted as dots independent of crater size. Craters in red are those classified as primaries, craters in blue are those classified as secondaries.

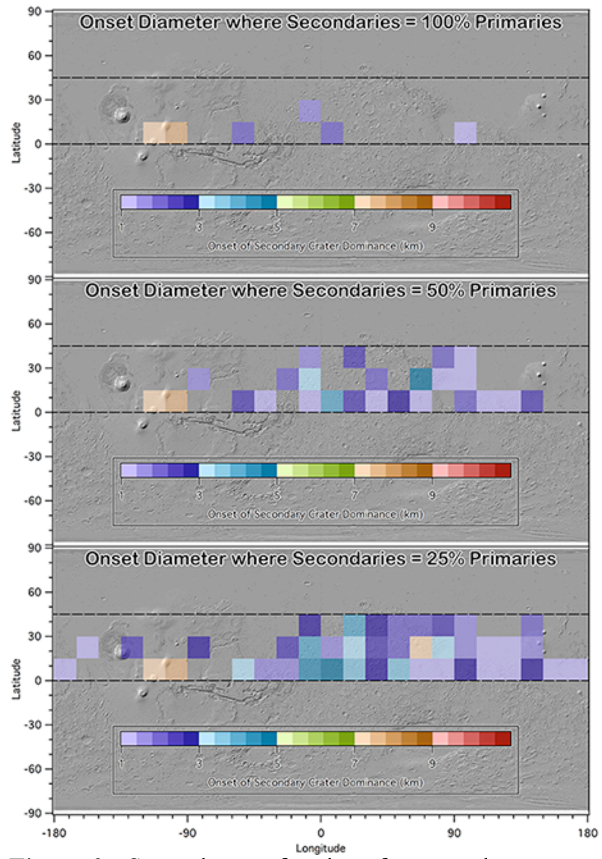

Figure 3: Several onset fractions for secondary craters in 15°×15° area bins. Dashed lines show region analyzed for this abstract, and holes are where classified secondary craters are not significant (to the stated threshold for the panel) for $D \geq 1.0$ km.