Small Craters in the Inner Solar System: Primaries or Secondaries or Both? E. B. Bierhaus[1], C. R. Chapman[2], and W.J. Merline[2], [1]Lockheed Martin (edward.b.bierhaus@lmco.com), [2]Southwest Research Institute ({chapman,merline}@boulder.swri.edu).

Summary: Until the relative abundances of primaries and secondaries are resolved, inferring the small near Earth asteroid (NEA) population from lunar craters will be suspect. Indeed, the important parameters regarding the formation of secondary craters are still not all known, let alone well-quantified. Some research suggests the production of secondaries depends upon the near-surface properties of the target body; i.e. the presence or absence of regolith will affect how many secondaries form from a given primary [1]. For example, a regolith layer may suppress the formation of secondaries until the primary reaches a certain size. The relative abundances of primaries and secondaries could fluctuate over an object as a function of terrain type. Using small craters may set limits on the impactors (i.e. assume *all* craters are primaries, which would set an upper-limit), but one should not use small craters for robust estimation of the small impactor objects.

Introduction: The size-distributions of impact craters on terrestrial planets exhibit a steep-slope (less than -4 power-law index) starting at about 1 km diameter. This characteristic was first identified on the Moon, but spacecraft image data revealed that Mars and Mercury possess similar crater distributions. The impact crater size-distribution mirrors the size-distribution of the objects making the craters, so presumably the impactors (mostly asteroids) also have a steep size distribution at small diameters.

Contamination from non-primary impact craters makes this conceptually simple link between craters and impactors more complex. Endogenic features and secondary craters (craters formed by the material ejected from a primary impact) confuse the correlation between visible craters and the impacting population.

The relative contribution of secondary craters to the crater population was a matter of debate that has waxed and waned over the years. After discussion during the 1960's and early 1970's [2,3,4], the "how many secondaries are there" debate became a background topic – still unresolved, occasionally mentioned [5], but not an area of vigorous research.

Recent Developments: The impact hazard generated enough attention to motivate ground-based telescopic surveys for Near Earth Objects (NEO's), which are primarily asteroids (the NEA's). These surveys have discovered NEA's at an unprecendented rate. The near-term goal of the search programs, as established by NASA's Spaceguard program, is to identify 90% of the greater than 1 km asteroids. However, smaller objects, down to a hundred meters diameter, could cause extensive local damage (e.g. wipe out a large urban area), so there is also motivation to understand the number of NEA's in this diameter range.

The smaller objects are harder to detect observationally, so one method to predict the populations of less than 1 km-scale objects has been to use the lunar crater size distribution [6]. The steep power-law index suggests that there are many of these small objects. That assumes, however, that all (or at least most) of the small craters are primary craters, and not secondaries.

Secondaries on Europa: Recent work [7] demonstrates that secondaries dominate (90+%) the small crater population on Europa. Because there are so few large, primary craters on Europa, extrapolation indicates that a single ~20 km crater produces hundreds of thousands of secondaries down to ten's of meters in size (the smallest size visible in Galileo image data). Equally striking is that these secondaries can appear at a large range of distances from the parent primary, from immediately adjacent to over 1000 km distant.

Secondaries on Mars: Other work [8] shows that a recent, 10 km crater on Mars may have produced up to a million secondaries. Although certain physical properties are different between ice and rock (e.g. equations of state, fracture mechanics), the confirmation on two types of surfaces (icy Europa and rocky Mars) that a single primary crater generates a significant population of secondaries indicates that numerous secondaries are a natural process of primary crater formation on planetary-sized objects.

Cratering on Asteroids: Four asteroids have been imaged by spacecraft well enough to quantify their crater populations: Gaspra, Ida, Mathilde, and Eros. Gaspra, Ida, and Mathilde all reside in the asteroid belt, while Eros is an NEA. The crater distributions on these objects are different, but numerous small craters on Gaspra and Ida indicate that there are indeed small asteroids that make small craters [9]. Eros was the most well-imaged asteroid (in both extent and in resolution); those data reveal a rapid decrease in number density for small crater diameters. The cause for the paucity of small craters is unknown; it could be a lack of small impactors, or the result of an erosional process, or some combination of the two.

Because asteroids have such low escape velocities, any ejecta that re-accumulates directly after an impact must be moving at a relatively low velocity. Indeed, the presence of a large population of boulders on Eros suggests that rather than forming secondary craters, the ejecta returns to the surface in a coherent form. Thus, the small craters on asteroids are likely primaries, rather than secondaries.

Yarkovsky effect: This is a process by which the interaction between an asteroid's rotation and thermal reradiation of sunlight can slowly but inexorably change its orbital properties. An important consequence of the Yarkovsky effect is that it can migrate main belt asteroids into various resonances that subsequently drive those objects into Mars- and Earth-crossing orbits. The Yarkovsky effect is more efficient on small objects (less than 2 km), suggesting that the migration of objects from the asteroid belt to the inner Solar System is weighted towards small asteroids [10].

The Big Picture: On one hand, there is significant evidence to demonstrate that secondaries could overwhelm the small crater population. This is certainly the case on Europa; however, the objects hitting Europa are mostly comets, not asteroids, so Europa's small crater population is not directly analogous to the Moon's. The possibility of numerous secondaries on Mars, however, *is* analogous to the Moon, as both have rocky surfaces and are exposed to roughly the same impacting population.

On the other hand, the fact that asteroids themselves express small craters (with steep size distributions) is an indication that small impactors exist, although the small crater populations are so far not consistent between the measured populations. But the dynamical evolution of asteroids suggests that small objects are more likely to be present in Mars- and Earth-crossing orbits.

Until these observations become incorporated into a consistent model, small crater populations cannot be an unambiguous record of the impacting population.

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