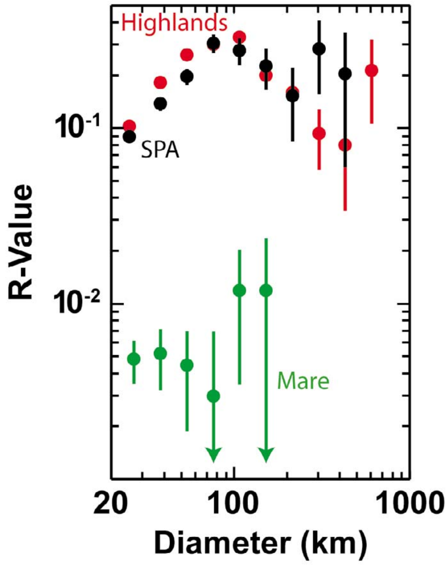

Figure 4. R-Plot showing South Pole-Aitken (SPA) basin, as well as the highlands (excluding SPA, Orientale, and regions covered by mare), and the mare from *Head et al.* [2010]. These data illustrate the difference in population that affected the lunar highlands and SPA compared to the lunar mare. Note that we follow the convention of *Strom et al.* [2005], who term the crater size-frequency distribution of the highlands 'Population 1' and that of younger units like the mare 'Population 2'.

$\sim$1900. Our data indicate $\sim$4000 craters of all types between these two events, the vast majority of which we interpret as primary in origin (see section 3.1).

3. Discussion

3.1. Secondary Cratering

[16] The contribution of basin secondary cratering has the potential to affect the crater size-frequency distribution of individual basins [e.g, *Wilhelms*, 1976; *Wilhelms et al.*, 1978]. However, most secondary craters are smaller than 20 km, even for the largest basins such as Imbrium and Orientale, because of the steep size-frequency distribution of secondary craters [*Wilhelms et al.*, 1978]. Thus, measured crater densities are much less contaminated by secondaries at the scales we consider here (craters ≥20 km in diameter) than would be the case if we included smaller craters.

[17] There are also apparently substantial differences in the number of large secondaries produced from a given large basin. *Wilhelms et al.* [1978] classified 58 craters ≥20 km as secondaries from the Imbrium basin in an area of 4.165×10^6 km^2 (equivalent to N(20) = 14 $\pm$ 2 in their count region), but only one crater ≥20 km as a secondary from the smaller Orientale basin in an area of 1.751×10^6 km^2 (equivalent to N(20) = 0.6 $\pm$ 0.6). The inferred contribution of secondaries from Imbrium is likely a maximum estimate for the density of secondaries that a D $\sim$ 1000 km basin will typically produce, since this measurement was taken where the density of secondaries was highest, and Imbrium produced far more secondaries than Orientale. The contributions of secondaries from later basins to the crater statistics of earlier basins such as Nectaris is likely to be less than 20%, although the precise contribution of secondaries is dependent on the age of the basin and its proximity to later large basins.

[18] Given these factors, we interpret the superposed crater size-frequency distributions of lunar basins as being generally controlled by primary cratering for ≥20 km craters. This view is bolstered by (1) the lack of detection of abundant secondaries ≥20 km surrounding large young basins at appropriate ranges based on LOLA data [*Head et al.*, 2010], (2) the consistency of stratigraphic and crater counting sequence determinations, which suggests that secondary cratering does not significantly contaminate and affect these measurements, and (3) the reasonable agreement of the basin sequence based on craters of larger size (≥64 km) with what is found at N(20); secondary craters ≥64 km in diameter are unlikely to exist.

3.2. Evolution of the Lunar Crater Population and Implications for the Late Heavy Bombardment

[19] A major question in lunar science is whether the crater population or size distribution of impacting bodies that impacted the Moon was stable over time, even though the flux was changing. A long-standing and important hypothesis is that the lunar highlands were impacted by a distinct, early population of impactors that differs from what has affected the Moon since the time of the emplacement of the lunar maria [e.g., *Whitaker and Strom*, 1976; *Wilhelms et al.*, 1978; *Strom*, 1987; *Strom et al.*, 2005; *Head et al.*, 2010]. This idea has been disputed by workers who have argued that the entire visible crater record can be explained by a single impactor population, [e.g., *Neukum and Ivanov*, 1994; *Hartmann*, 1995; *Neukum et al.*, 2001], and that any observed differences in the crater record can be attributed to geological resurfacing and difficulty in finding a terrain that is an unmodified sample of the early impact record.

[20] The basis for the idea that impact populations on the Moon have changed over time is that the observed crater size-frequency distributions of ancient highland terrains are distinct from those that are observed on the maria (e.g., Figure 4) [see also *Strom et al.*, 2005; *Head et al.*, 2010]. This is manifested by a having a lower ratio of $\sim$20–40 km craters to $\sim$80–100 km craters in the highlands than in the mare (in other words, there is an excess of these larger craters in the highlands). That the maria and highland have differently shaped crater size-frequency distributions is statistically significant when applying the two-sample Kolmogorov-Smirnov test to their empirical cumulative densities (Figure 5a). *Ćuk et al.* [2010, 2011] also demonstrated that the size-frequency distribution of Imbrian craters on the Moon are statistically distinguishable from the highlands curve, using data from both *Wilhelms et al.* [1978] and the fresh crater distribution (of class 1 craters) from *Strom et al.* [2005].

[21] As noted above, this observation does not guarantee that the difference in observed crater size-frequency distribution is a direct result of a shift in the impactor population that affected the Moon in its early history relative to more recent times. A viable alternative hypothesis is that early surfaces were bombarded by a crater population similar to the population that impacted the maria, but that geologic processes such as volcanism or repeated cratering preferentially removed small craters and thus resulted in the observed