THE PRODUCTION OF SMALL PRIMARY CRATERS ON MARS. Jean-Pierre Williams[1], Asmin V. Pathare[2], and Oded Aharonson[3], [1]Dept. Earth, Planetary, and Space Sciencs, UCLA, Los Angeles, CA 90095 (jpierre@mars.ucla.edu), [2]Planetary Science Institute, Tucson, AZ 85719 (pathare@psi.edu), [3]Helen Kimmel Center for Planetary Science, Weizmann Institute of Science, Rehovot, 76100 Israel (Oded.Aharonson@weizmann.ac.il).

Introduction: Impact-crater isochrons represent the expected crater size-frequency distribution (SFD) for a given surface age [1]. The discovery of new impact craters forming on Mars by the MOC camera [2], and the CTX and HiRISE cameras [3] provide the first observations of the production of small primary craters on Mars ($D \sim 1 - 40$ m). Impact-crater isochrons predict the crater production rate to have a steeper power law slope than is observed in the fresh craters.

We model crater populations using a Monte Carlo simulation [4] using a size-distribution of impactors scaled from the observed annual flux of near-Earth objects colliding with the Earth [5] to explore the primary crater production function at small diameters and the potential influence of present-day atmospheric filtering due to ablation, deceleration, and fragmentation of projectiles as they traverse the martian atmosphere.

Model Results: Results from our model for 10^6 initial projectiles are shown in Fig 1 (see [4] for model details). The same bulk strength is assumed for all projectiles for simplicity and adjusted until the ratio of crater clusters resulting from fragmentation of the projectiles to total impacts for craters $D > 5$ m is similar to the 73% observed for the $D > 5$ m fresh craters reported by [3]. We find that a bulk of strength of 0.65 MPa best reproduces the observations (i.e. both the observed and modeled craters are dominated by crater clusters at $D > 5$ m of approximately the same fraction).

There is a downturn in the observed SFD at $D \sim 4$-5 m (Fig 1a). However the model craters continue to increase in number down to the $D \sim 20$ cm (Fig 1b). The fraction of clusters for $D < 1$ m becomes negligible as deceleration of the small projectiles limits the dynamic pressure. These results imply that the atmospheric downturn has not been observed in the fresh craters, and that a significant number of craters with $D < 4$-5 m have not been identified. The discovery of fresh craters relies on the detection of dark spots in CTX images in dusty regions. A swarm of fragments will disturb a larger surface area creating, in general, larger dark spots. The predominance of single craters at $D < 5$ m indicates that detection will be more challenging as dark spots become inherently smaller relative to D at these sizes, partly explaining the downturn in the observed SFD at 4-5 m.

Crater populations: We test our model against crater counts conducted on the proximal ejecta of the crater Zunil (7.8°N, 166.1°E) and the impact melt deposit on the floor of Pangboche crater (17.2°N, 226.7°E). Zunil is likely the last $D = 10$ km scale crater to form on Mars [6] with an estimated age of ~1 Ma based on the isochrons [1], so the distribution of small craters on its ejecta are likely to be predominately primary. Pangboche is also a young crater comparable in size to Zunil near the summit of Olympus Mons at an elevation of 20.8 km, over two atmospheric scale heights higher than Zunil with an atmospheric surface density an order-of magnitude lower.

Two model isochrons are generated, one assuming a surface elevation of -2.8 km and one with an elevation of 20.8 km, the respective elevations of Zunil and Pangboche (Fig. 2a). We estimate an age similar to the ~1 Ma age estimated by [7] (Fig. 2b). The influence of the atmosphere on meter-scale craters can be seen by comparing the isochrons for Zunil and Pangboche,

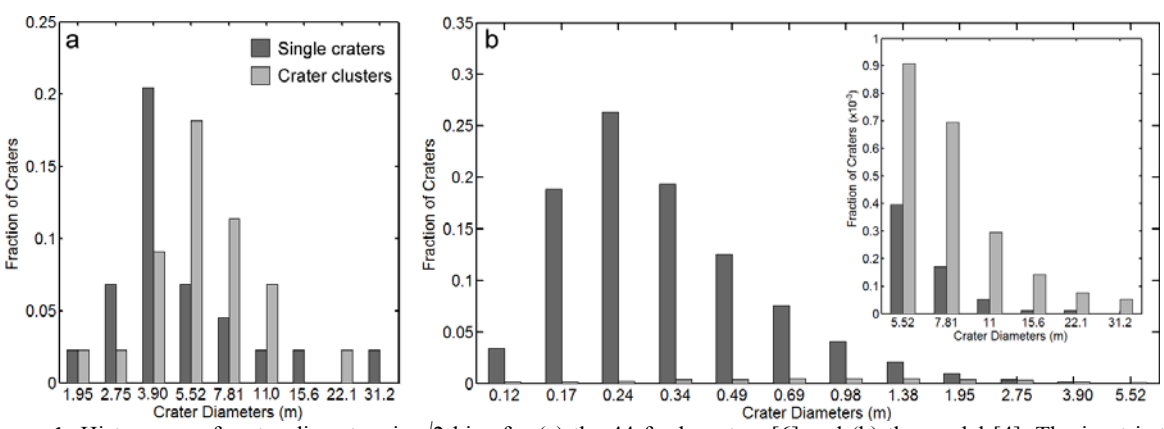

Figure 1: Histograms of crater diameters in √2 bins for (a) the 44 fresh craters [6] and (b) the model [4]. The inset is the model craters for $D > 5$ m.

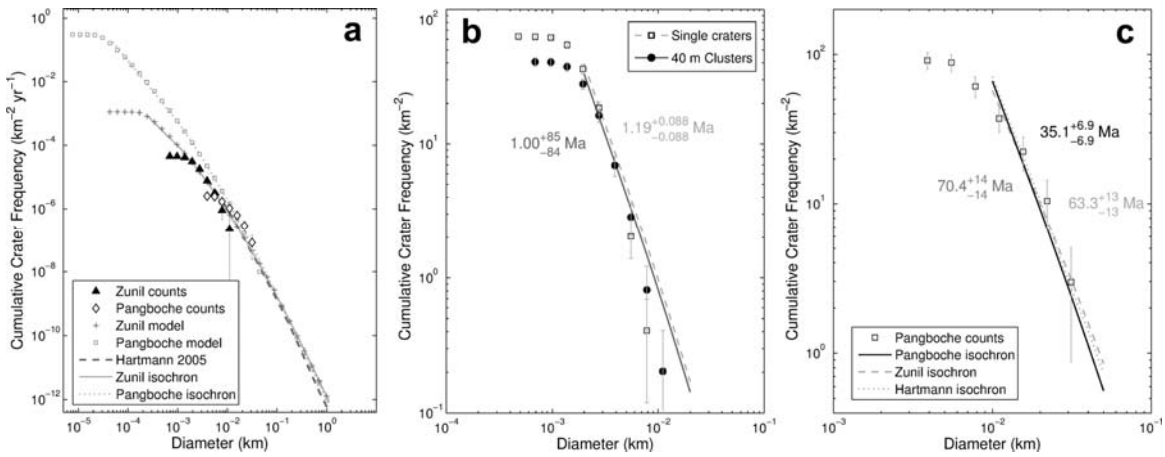

Figure 2: (a) Crater counts and modeled annual SFDs for Zunil and Pangboche craters and isochrons derived from polynomial fits to the model SFDs. The crater counts from the two locations are scaled to the same time/area for comparison with the annual isochrons. (b) Zunil crater counts and ages estimated using the -2.8 km elevation (Zunil) model isochron. The two estimates shown assume each crater counted is an individual impact and that craters within 40 m proximity are part of a cluster. (c) Pangboche crater count with age estimates using the Hartmann isochron [1], the -2.8 km elevation model isochron, and the 20.8 km elevation model isochron.

which diverge at D < 10 m, with the Zunil isochron having more downward curvature due to impactors having to penetrate deeper into the atmosphere to reach the surface. The curvature of the Hartmann isochron (which assumes a 6 mbar pressure atmosphere) closely resembles our Zunil isochron. Both isochrons yield similar age estimates for Pangboche: 63.3±13 Ma using the Hartmann isochron and 70.4 ± 14 Ma using the Zunil isochron (Fig. 2c). However, our Pangboche-specific isochron, which accounts for the crater's higher elevation, yields an age estimate of 35.1 ± 6.9 Ma. Hence, at the summit of Olympus Mons, failure to account for the effects of altitude upon small crater production will result in an over estimation of surface age by a factor of ~2.

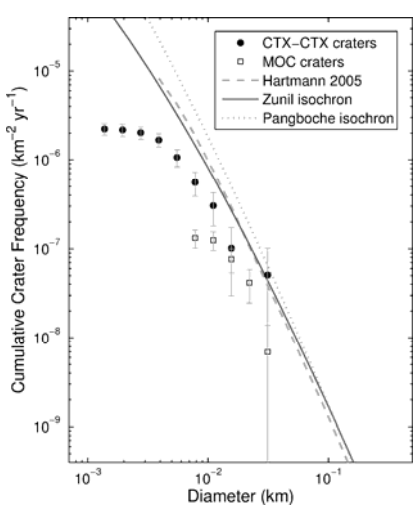

Figure 3: The cumulative SFD for new craters [2],[3] binned in √2 diameter bins, and the isochron of [1] and isochrons derived from our model for surface elevations of -2.8 km (Zunil) and 20.8 km (Pangboche), scaled to the same time/area.

New impact craters: We compare our model isochrons with the 19 fresh MOC [2] and 44 fresh CTX detected craters [3] (Fig. 3). The crater SFDs are scaled to an equivalent time/area for comparison. The fresh craters fall below the isochrons. The largest CTX crater, D = 33.8 m, is consistent with a single D ~ 30 m crater predicted to form annually for the scaled observation area. However, smaller diameter bins are under-populated relative to that predicted by the isochron models. A lack of a contribution from secondaries to the isochrons also cannot explain the discrepancy, as our model generates a primary-only SFD. The fresh craters discovered using MOC also have an apparent deficit of craters at all bin diameters. The MOC camera, with a lower resolution, did not detect any craters below D ~ 10 m and detected fewer craters in all bin sizes that overlap with the CTX craters. The atmospheric downturn is expected to occur at much smaller diameters (sub-meter) than observed, and we find that fragmentation will not substantially deplete the SFD at these smaller sizes.

Conclusion: Atmospheric filtering of projectiles does not explain the discrepancy between the new impact crater SFD [3] and the current martian isochron system [1] and requires further exploration.

References: [1] Hartmann (2005) *Icarus,* 294–320. [2] Malin et al. (2006) [3] Daubar et al. (2013). [4] Williams et al. (2014). [5] Brown et al. (2002). [6] McEwen et al. (2005). [7] Hartmann et al. (2010).