DATING THE MOST RECENT EPISODES OF VOLCANIC ACTIVITY FROM MARS' MAIN VOLCANIC CALDERAE. S. J. Robbins[1,2], G. Di Achille[2], and B. M. Hynek[2,3], [1]APS Department, UCB 391, University of Colorado, Boulder, CO 80309, [2]LASP, UCB 392, University of Colorado, Boulder, CO 80309, [3]Geological Sciences Department, UCB 399, University of Colorado, Boulder, CO 80309.

Introduction: Mars has two dozen major volcanic constructs with visible calderae on its surface today (Fig. 1). Twelve alone are concentrated on the vast Tharsis volcanic rise that contains Mars' most famous volcanoes, including the tallest in the solar system, Olympus Mons. An additional six are concentrated around the Hellas impact basin, the third-largest on the planet. Two form the Syrtis Major complex on the eastern rim of Isidis Basin, and three more form the Elysium complex on the south-western edge of the Utopia Basin. Finally, Apollinaris Patera is located south-west of Elysium and its flows form part of the veneer of material that the *MER Spirit* is currently exploring. An open question has been when the most recent volcanic activity occurred from these volcanoes, and whether it was episodic or continuous. We have attempted to answer these questions by creating high-resolution mosaics of each volcanic caldera and dating them through crater counts within each.

Mosaics and Mapping: Because of the relatively small size of volcanic calderae, we required high-resolution imagery to identify very small craters. We obtained ConTeXt (CTX) Camera images from the *Mars Reconnaissance Orbiter* spacecraft through NASA's PDS. CTX data are available at variable resolution from ~5.5-7.5 m/pixel. We processed the raw images in ISIS 3 (distributed freely through USGS) and rendered the mosaics at a uniform 10 m/pixel resolution. We then mapped each caldera and performed our crater counts within a Geographic Information System (GIS) environment (*e.g.*, Fig. 2).

Identifying and Counting Craters: All craters for our database are identified by visual inspection of the CTX mosaics. We use *ArcGIS* software to outline each crater rim with a ~20 m vertex spacing. *Igor Pro* software is used to calculate best-fit circle and ellipse parameters for each crater after taking into account all map projection effects. The area of each caldera is similarly read into *Igor Pro* and a standard geometric shape analysis is run to determine the area. Craters are binned by $\sqrt[4]{2}\,D$, normalized to number per square kilometer, and bins are affixed with $\pm\sqrt{N}$ uncertainty bars. We compared these with crater isochrons from [1] based on the production function for Mars [2] (*e.g.*, Fig. 3). Note that in all size-frequency plots presented here, bins with 3 or less craters were eliminated.

Limitations of this Method: Our first limitation is resolution. We cannot reliably identify craters smaller than ~5-7 px in diameter, and so our statistical completeness is conservatively estimated to be ~100 m, though at best we are complete to ~60-70 m in many cases. Due to the relatively small size of calderae, this is sometimes insufficient for our needs (*e.g.*, Hecate Tholus, with 6 distinct calderae 10.3-18.3 km^2 in area and 6-58 craters in each).

A second limitation - but also a strength - is that we were *solely* interested in the calderae and hence *only* the most recent volcanism. Through this method, we have no way of knowing when past activity may have occurred that was subsequently erased by a new caldera. Third is the role of secondaries since we ignore accounting for them, despite the likelihood that many craters we identified are not primary impacts [3]. The isochrons we used include secondary craters and did not specifically exclude them, so we also did not make special considerations.

Results - Olympus Mons: Olympus Mons (18.4° N, 133.2° W) shows a complicated collapse history (Fig. 2) with at least 6 distinct calderae. Despite the relatively large and distinct calderae, our results (Fig. 3) indicate that they all formed within ~100 Myr of each other except Caldera VI, which formed ~150 Myr after the others, in general agreement with *Mars Express* HRSC data [4]. It is unlikely that the entire volcano dates to only ~350 Ma, but the Olympus caldera complex presents possible evidence of a clustered, "last gasp" of volcanic activity.

Results - Ascraeus Mons: Ascraeus Mons (11.2° N, 104.4° W) shows a complex structural evolution (Fig. 4) with a large central caldera (I) surrounded by four others (II through V). Caldera V itself is complex with two terraces above it (VI and VII) that we dated separately. Based upon our results (Fig. 5), the only ambiguous caldera age is the lower terrace (Caldera VI). It is possible that this and the large crater in V is why [4] dated this to a split 100 Myr / 3.6 Gyr. However, we show very distinct ages for V and VII, ~250 Myr and ~600 Myr respectively. V is also the youngest, with the central Caldera I showing an age ~300 Myr, and the oldest, III, ~1.2 Gyr. While the present-day calderae from Ascraeus are clearly Amazonian, they span ~1 Gyr in age.

Results - Elysium Mons: Elysium Mons (24.6° N, 146.8° E) displays a relatively simple caldera structure (Fig. 6) with a main caldera (II), ~60% surrounded by a second caldera (III) with a possible third caldera or collapse feature in the center (I). Within the counting statistics of the 100-200 m diameter range, the three calderae are the same age, dating to the Hesperian epoch approximately 3.2 Ga (Fig. 7). II could be a collapse from III, while I could show the covered rim of an older caldera.

Further Work: For the LPSC conference in March 2010, we will present the results of the 19 volcanoes for which we have CTX coverage and report on the timeline of recent martian volcanism.

References: [1] Hartmann, W.K. and G. Neukum. (2001) *Space Sci. Rev.*, *96*, 165-194. [2] Ivanov, B.A. (2001) *Space Sci. Rev.*, *96*, 87-104. [3] McEwen, A.S. and E.B. Bierhaus. (2006) *Ann. Rev. Earth Planet. Sci*, *34*, 535-567. doi:10.1146/annurev.earth.34.031405.125018. [4] Neukum, G. *et al*. (2004) *Nature*, *432*, 971-979.

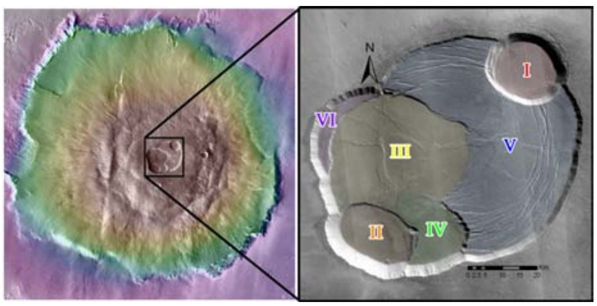

Figure 2: MOLA map of Olympus Mons (left) with inset (right) showing the 6 calderae we identified. Roman numerals correspond to the legend in Figure 3.

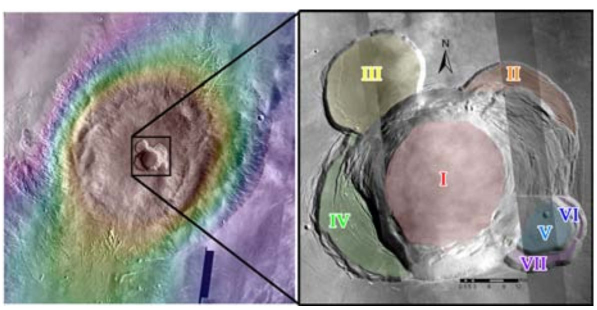

Figure 4: MOLA map of Ascraeus Mons (left) with inset (right) showing the 3 calderae we identified. Roman numerals correspond to the legend in Figure 5.

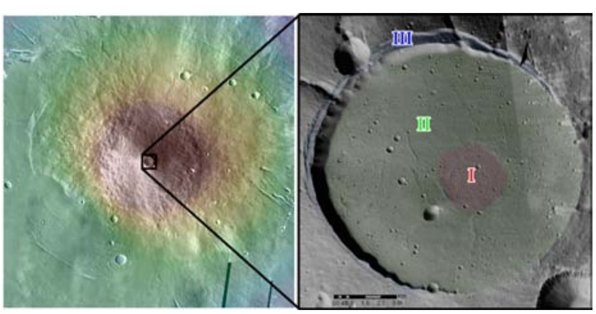

Figure 6: MOLA map of Elysium Mons (left) with inset (right) showing the 3 calderae we identified. Roman numerals correspond to the legend in Figure 7.

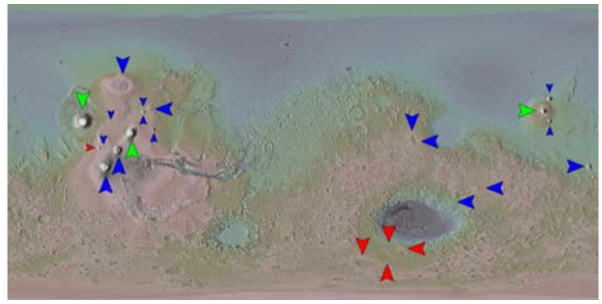
Figure 1: MOLA map of Mars. Arrows point to the 24 major volcanoes on Mars today. Green are those in this abstract, blue are those for which we have CTX coverage, and red are those that we cannot yet analyze.

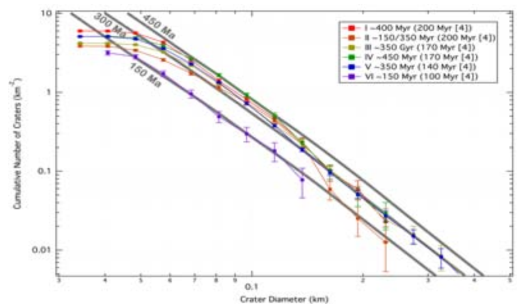

Figure 3: Size-frequency crater counts for the 6 identified Olympus calderae. Within the counting statistics, all calderae are the same age (~350 Myr) except VI, which is ~150 Myr.

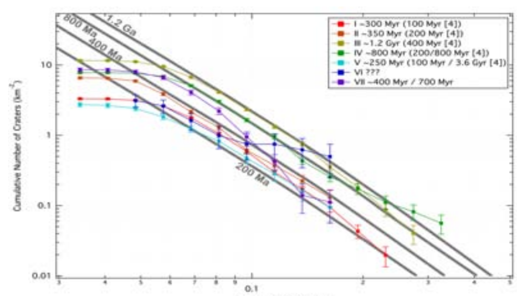

Figure 5: Size-frequency crater counts for the 7 identified Ascraeus calderae. Within the counting statistics, caldera VI has an indeterminate age while the others show distinct ages from ~250 Myr to 1.2 Gyr.

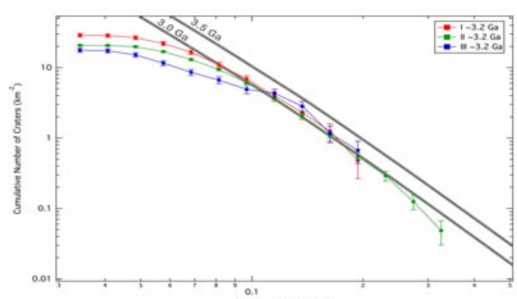

Figure 7: Size-frequency crater counts for the 3 identified Elysium calderae. Within the counting statistics, the calderae are the same age, forming ~3.2 Ga.