DATING THE MOST RECENT EPISODES OF VOLCANIC ACTIVITY FROM MARS' MAIN VOLCANIC CALDERAS. 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 twenty-four major volcanic constructs with visible calderas on its surface today (Fig. 1). Twelve are on the vast Tharsis volcanic rise that contains Mars' most famous volcanoes. An additional six are concentrated around Hellas Basin, the third-largest basin 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 southwestern edge of the Utopia Basin. Finally, Apollinaris Mons is located southwest of Elysium and its flows may 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 addressed 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 areas of volcanic calderas, 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. 2a).

Identifying and Counting Craters: All craters were identified by visual inspection of the CTX mosaics. We used *ArcGIS* software to outline each crater rim with a ~20 m vertex spacing. *Igor Pro* software was used to calculate best-fit circle parameters for each crater after taking into account all map projection effects. The area of each caldera was similarly read into *Igor Pro* and a standard geometric shape analysis was run to determine the area. Craters were binned by $\sqrt[32]{2}D$, normalized to number per square kilometer, and bins were 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). In our size-frequency diagrams (SFDs), cumulative bins with 3 or less craters were eliminated, and cumulative bins where the derivative is 0 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 ~75 m. Due to the relatively small size of calderas, this is sometimes insufficient for our needs (*e.g.*, Hecate Tholus, with 6 distinct calderas 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 calderas 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; one exception is discussed below. 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.

Example Results - Ceraunius Tholus: Ceraunius Tholus (24° N, 262.5° E) illustrates a case where we were able to piece together some of its eruptive and modification history (Fig. 2). The tholus contains four calderas, a main one that completely surrounds a second (differentiated due to topography and texture), and two others topographically elevated from the main. Upon fitting isochrons, we derive ages for the two elevated calderas of $3.41^{+0.13}_{-0.62}$ Ga and $3.59^{+0.05}_{-0.08}$ Ga for caldera 3 and 4, respectively. At diameters smaller than ~150 km, both caldera SFDs show significant evidence of resurfacing before again paralleling nearly the same isochron at roughly 550±50 Ma. The main caldera shows an older age of 630±140 Ma at large diameters and a younger age of 470±40 Ma at smaller diameters; the second caldera is a statistically identical 400±70 Ma. Statistically, these ages are fairly close to the resurfacing age of calderas 3 and 4.

An additional history we illustrate for Ceraunius deals with the valley network that travels from calderas 3 and 4 down the tholus into the floor of Rahe Crater in what appear to be deposits. Crater counting in these regions implies a history of the tholus' last major resurfacing event occurring $3.75^{+0.06}_{-0.09}$ Ga, with the last major tholus-forming eruptions being shown in calderas 3 and 4 roughly 200-300 Ma later. Rahe Crater formed between those events, $3.68^{+0.05}_{-0.07}$ Ga, and the floor deposits formed after, $3.42^{+0.10}_{-0.32}$ Ga. The tholus was quiet after this time, during the Hesperian and much of the Amazonian, until ~400-600 Ma when the final main volcanic activity occurred. This may have caused the resurfacing we observe in calderas 3 and 4.

Discussion: Using our derived ages for volcanic calderas, we are able to illustrate a rich history of martian volcanism that spanned nearly all of Mars' history. We will also be able to relate the activity to the transition between pyroclastic and effusive volcanism and provide a short discussion of the implications of secondary craters on the deca and hectometer scale [5].

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. [5] Robbins, Di Achille, & Hynek. (2010) *Icarus*, submitted.

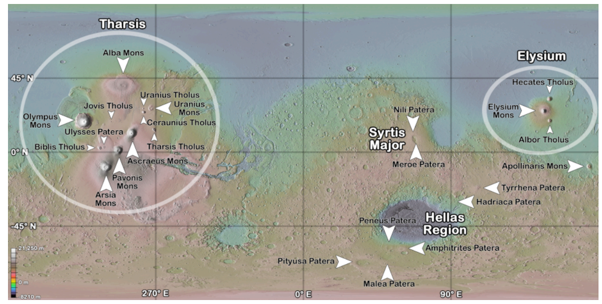

Figure 1: MOLA map of Mars. Arrows and labels point to the 24 major volcanoes on Mars today; size differences are due to space constraints. Regions are also identified.

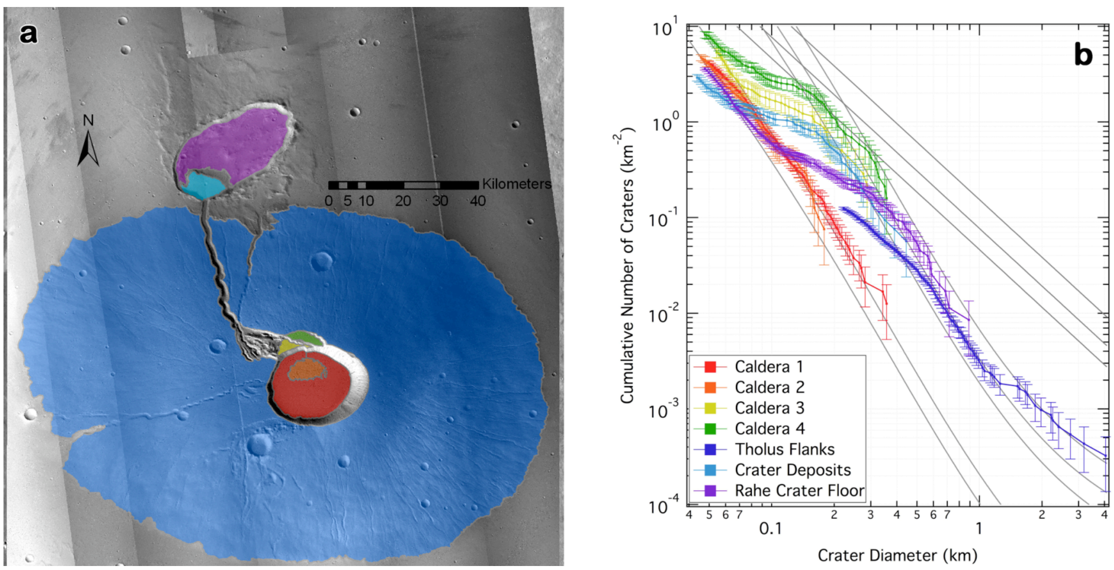

Figure 2: Part (a) shows the geologic mapping and larger context of Ceraunius Tholus, including all mapped regions. Part (b) contains the SFDs of the four calderas, Rahe Crater, the deposits within the Rahe Crater, and the tholus itself. The channel discussed in the text is not shown in the SFD due to its likely anomalous results that we attribute to billions of years of infilling. Isochrons shown are 0.25, 0.50, 3.4, 3.6, and 3.75 Ga. Shallower grey lines are 3%, 5%, and 10% geometric saturation. Derived ages are discussed in the text.

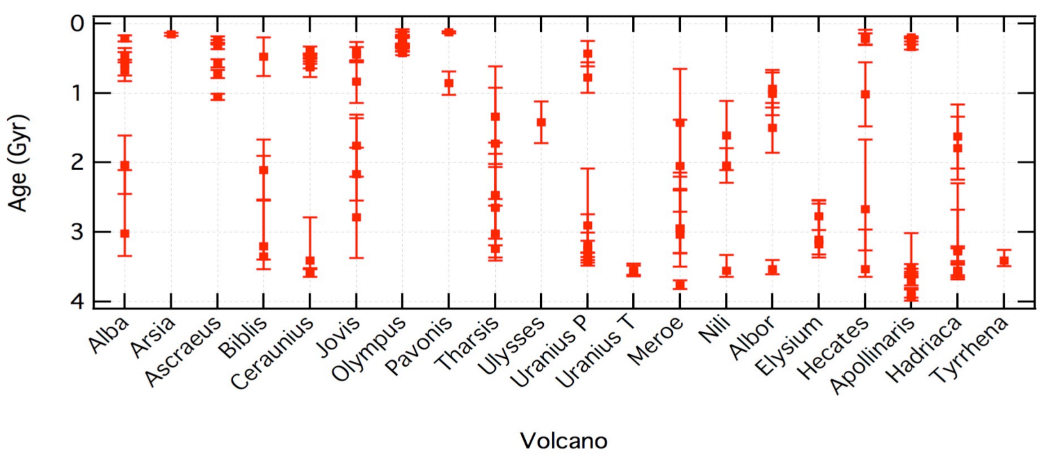

Figure 3: Derived timeline for caldera ages of the major volcanoes (Fig. 1). We show that while some volcanoes have been active over much of Mars' history, others died relatively early in the planet's history while a few had major activity at their summits as recently as ~100-150 Ma.