Building Ascraeus Mons: Summit Calderas and their Big Eruptions.

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Introduction: Ascraeus Mons is the northeastern most of the large shield volcanoes located in the Tharsis province on Mars. The edifice of Ascraeus Mons is 18 km in height and ~350 km in diameter [1] The large caldera complex at the summit of Ascraeus Mons is nearly 60 km in diameter and ~ 3 km deep at its deepest point [1]. Previous mapping campaigns have documented the caldera complex in great detail, however, measurements of the displaced volumes associated with each caldera forming event were not calculated. This new study uses THEMIS, CTX, HiRISE, HRSC, and MOLA imagery and datasets to map the caldera complex of Ascraeus Mons at a 1:100,000 scale as well as perform estimates of displacement volumes from each caldera. Understanding the formation of this caldera complex is critical in the wider understanding of large scale volcanism on Mars.

Methods: In this work, I identify and map in detail the summit calderas of Ascraeus Mons on Mars and provide a sequence of their formation. I analyze each caldera in terms of depth and diameter, and then use these data and the caldera-collapse model of [2] to estimate the amount of erupted magma required to explain the caldera geometries. A 463 m/pix MOLA DEM was also used within ArcGIS 10.5 to estimate volume of each caldera and the volume of the main shield edifice. Volume calculations of each caldera, including the volume of the total caldera complex, were contrasted against the total volume of the Ascraeus Mons edifice. I also derived simple relationships between volume erupted and caldera diameter, volume erupted and caldera volume, and magma chamber volume and caldera diameter. These results are compared to Earth calderas to assess applicability of Earth based caldera formation models to other terrestrial planets.

Results/Discussion:

Caldera Mapping.

Figure 1 is the newly created geologic map of the caldera complex and the summit of Ascraeus Mons at a 1:100,000 scale. Four unique wall units were mapped based on different erosional and tectonic regimes, such as: caldera steep fluted (Acsf), caldera slump (Acsl), caldera stepped (Acs), and caldera mass-wasting (Acmw), and one unit mapped as the caldera floors, caldera floor unit (Acf). The northern and southern walls of the central caldera have crisp, steep scarps with layered lava flows that can be seen on the southern and northern walls where there is no depositional material, displaying the oldest features within the map area and mapped as caldera steep-fluted unit (Acsf). The caldera wall units also represent some of the youngest features as collapsed material from the surrounding wall fall into the crater and deposition of eolian sediment. The caldera floor unit (Acf) is relatively smooth with pond-like lava flow features and may exhibit wrinkle ridges.

The central caldera floor (caldera IX) has large blocks of material that have fallen from the crater walls representing the caldera slump unit (Acsl), **Figure 1**. The eastern and western walls are heavily faulted with the eastern wall displaying many step terraces and concentric graben that have torn apart the caldera floors of III, IV, V and VI, **Figure 2**, representing the caldera stepped unit (Acs).

Caldera IX has been mapped with all wall material units listed above, in addition to a mass-wasting deposit labeled (Acmw). A large wrinkle ridge exists at the floor of the central caldera where it contacts the mass-wasting deposit. The mass-wasting deposit does not appear to embay the large wrinkle ridge and does not flow onto the floor of the central caldera. Floors of each of the calderas are relatively smooth but exhibit many features suggesting the caldera floors may have still been active after each collapse event. Wrinkle ridges are observed on several of the caldera floors and are common at the base where the caldera floor meets the caldera wall. The northwest

Figure 1. 1:100,000 scale map of the caldera complex at the summit of Ascraeus Mons. Pink colors are the caldera floors (Acf), purple represents steep, fluted caldera walls (Acsf), orange is the caldera stepped wall unit (Acs), brown is the caldera slump deposit (Acsl), and the sand color represents the caldera mass-wasting deposit (Acmw). The low shield is denoted by the inferred contacts within the western portion of the central caldera floor.

caldera (II) has two wrinkle ridges in a north-south orientation spanning most of the diameter of the western portion of the crater floor with thinner pond-like flows on the floor of the eastern portion. Calderas III, IV, V, and VI are heavily faulted, inferred to be caused by the collapse of the central crater, producing a step-like pattern down the crater walls to the floor of the central crater, caldera stepped unit (Acs). The unit is also observed on the wall of the southwest caldera (I), but predominantly mapped on the walls of caldera IX. The southeast calderas are relatively smooth, with two larger impact craters within the lower crater floor (caldera VIII, Figure 2). Caldera's VII and VIII are currently being modified by concentric graben, cutting through the caldera floors (interpreted origin for mass-wasting unit (Acmw), and the deposition of eolian features (e.g. sand dunes, mostly found within graben).

Caldera IX has a diameter of ~28 km with the lowest floor elevation at 14,400 m roughly 3.2 km below the caldera complex rim (18,100 m) and ~1.5 km below caldera VIII. A low shield volcano that has been mapped on western portion of the crater floor has a diameter of three kilometers and rises 100 meters above the caldera floor, while the eastern portion of the caldera floor resembles the thinly inflated morphology of a lava lake or ponded lava flow.

The caldera sequencing shown in Figure 2, was mapped by observing the stratigraphic relationships of each collapsed caldera and crater-count ages of [3-4]; and [5]. I have determined the western-most crater to be the oldest (caldera I), consistent with the crater-counts of [3-4]. The northwestern caldera (II) was the next collapse event in the sequence followed by third collapse event of the eastern-most caldera (III) and has been modified by the collapse events of calderas IV, V, and VI. Caldera IV has two smaller collapse craters superposed on top (V and VI) with lower floor elevations. The two southeastern calderas collapsed next with the larger diameter crater predating the smaller crater (VII and VIII). The final collapse was of the large central caldera (IX) with highly disrupted crater walls suggests the possibility of multiple collapse events of the central caldera

Volume Calculations.

Volume calculations of each newly mapped caldera sequence has been calculated using the model of [2]. In this model they have derived a relationship to give the estimated volume erupted to generate collapse of a caldera. These calculations have been compared against the calculations using the Polygon Volume Tool within ArcGIS 10.5, to which it uses the 463 m/pix MOLA DEM elevation and will calculate volumes based on a reference height (used here as 18.1 km). However this reference elevation is uncertain as the northern rim of

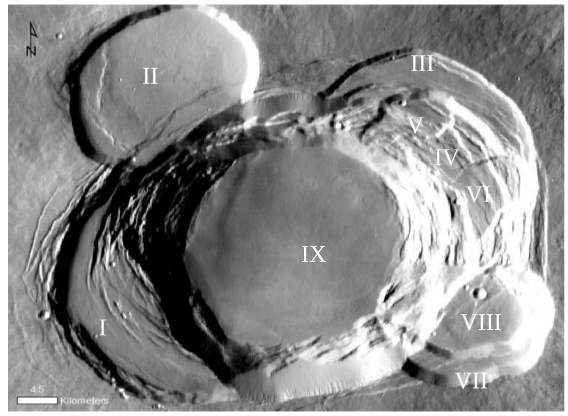

Figure 2. THEMIS Day IR Mosaic of the summit caldera complex of Ascraeus Mons displaying the sequence of collapse based on stratigraphic relations and crater-counts (Neukum, 2004; Werner, 2006; 2009; Robbins et al. 2010), decreasing in age from I-IX.

the caldera complex is at a higher elevation than the southern rim at Ascraeus Mons. Calculations using the model of [2] result in minimum volumes to generate collapse ranging from ~10-300 km^3 compared to the displaced caldera volumes from the Polygon Volume Tool which are typically an order of magnitude higher ranging from ~40-3400 km^3. Errors in these calculations have to do with the uncertainties for varying densities of a basalt for Mars, the estimated bulk modulus of the magma for Mars, the poorly constrained depth to magma chamber for Mars, and probably due to the reference elevations for each caldera's roof (i.e. 18.1-17.4-16.6 km for varying caldera roof elevations). However, the displaced volumes for each caldera (calculated in ESRI ArcGIS™) could be used as an upper-bound for the minimum erupted volume and can potentially be used for better constraining the poorly understood depths to magma chambers for Mars. Further sensitivity analysis will be done on both models used to generate volume estimates as well as applying this model to the calderas at the other large Tharsis Montes (Arsia, Pavonis,) and the largest volcano in the Solar System, Olympus Mons.

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References:

[1] Mohr et al., (*in review) USGS Publication* [2] Geshi et al., (2014) *Earth and Planetary Science Letters* 396 107–115 [3] Neukum et al., (2004) *Nature Vol 432 971-979*. [4] S. Werner (2009) *Icarus 201 44–68.* [5] Robbins et al., (2001) *Icarus 211 (2011) 1179–1203*