MAGMA FLUX AT ARSIA MONS, MARS, OVER THE PAST 300 MILLION YEARS.

J. A. Richardson[1], James A. Wilson[2,3], Charles B. Connor[2], and J. E. Bleacher[1], [1]Planetary Geology, Geophysics, and Geochemistry Lab, NASA Goddard Spaceflight Center, Greenbelt, Maryland, USA; jacob.a.richardson@nasa.gov, [2]School of Geosciences, University of South Florida, Tampa, Florida, USA, [3]DigitalGlobe, Tampa, Florida, USA.

Introduction: The rate of magma delivery to the surface of Mars throughout its history is a primary constraint on the evolution of its climate, lithosphere, and surface, as well as its ability to sustain biotic or prebiotic material through time. We present new estimates of the recurrence rate of volcanic activity and the magma flux for a distributed volcano cluster in the Tharsis Volcanic Province [1]. This large igneous province comprises one-quarter of the surface of Mars, 12 large volcanic constructs [2], and over 1000 small volcanic vents [3]. The volcano cluster in this study includes dozens of these small vents and rests inside of the caldera of the southernmost shield volcano in the Tharsis Montes, Arsia Mons. With the availability of new, high resolution images of the Tharsis region, we are able to map and ultimately model the latest period of volcanic activity at Arsia to characterize how activity at a large igneous complex has waned with time.

Geologic Background. The shield volcano Arsia Mons is a major edifice within the Tharsis Volcanic Province. Arsia is over 300 km in diameter and features a single 110-km-wide collapse caldera at its summit [4]. To construct the main edifice, an average magma supply rate of 1-10 m^3 s^{-1} was likely required [5]. No craters larger than 1 km in diameter are exposed on the surface of the caldera, and several studies have used crater age dating techniques to model an age of ~130 Ma for the entire floor [6,7]. Currently on the floor of the caldera lay a linear trend of small volcanic vents, roughly parallel to rift features that cut the shield flanks to the NE and SW [4], and which are the source of the recent resurfacing events within the caldera [1]. Despite the young caldera floor age, the size of the caldera and the rift features of the shield volcano suggest that it might be more structurally evolved than the other Tharsis Montes [4].

Methods: *Mapping and Volume Estimation.* The 29 volcanic vents in the Arsia Caldera that have been previously cataloged each have lava flows emanating from them. Due to the near 100% coverage of the caldera floor by Context Imager (CTX) data, a 6-m resolution basemap has been constructed in ArcGIS 10.2. Boundaries of each lava flow are mapped to include all lava that can be traced to a mapped volcanic vent. Lavas on the caldera floor that cannot be traced back to a vent (e.g. flows that are separated from cataloged vents by another lava flow front) are not included in this study.

Because it is not currently possible to see the subsurface elevation of each flow, we model the volumes of each lava flow assuming a constant thickness and their exposed areal extents. Two thicknesses 10 m and 80 m are chosen as minimum and maximum flow thicknesses based on other lava flows in Tharsis [8].

Sources of Age Information. The CTX basemap also enables the collection of two types of age dating information. First, stratigraphic relationships between adjacent lava flows have been identified [1] (Fig. 1).

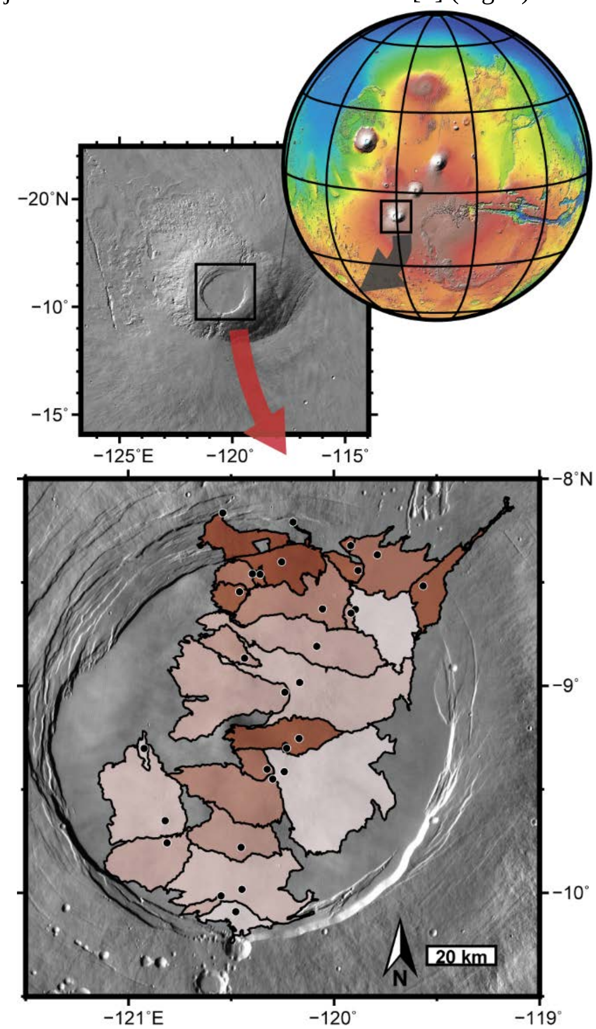

Fig. 1. The Arsia Mons Caldera features 29 cataloged volcanic vents (black circles). Each vent effused lava flows 10s of km downhill. Flows are shaded by stratigraphic height, with uppermost flows lightly shaded and lower flows shaded dark red.

Second, crater counts have been performed for each lava unit in the study area using craters with diameters of >100 m, to avoid background populations of secondary craters and crater burial by dust [7]. The resulting crater distributions are then input into the craterstats2 software to model the timing of lava effusion from each vent, using the Hartmann 2004 Production Function and the Michael 2013 Chronology Function [9]. Mean and uncertainty ages from craterstats2 define a normal distribution age model for each surface.

Modeling Recurrence Rate and Magma Flux. A Volcanic Event Age Model (VEAM) has been developed to incorporate multiple age model data sets in order to identify a potential range of ages for volcanic events in a volcano cluster. In the Arsia Mons scenario, stratigraphic information and crater retention information are combined. First, VEAM estimates an event age based on the Gaussian crater age model. Then VEAM estimates age of each event based on both their corresponding crater age models and their stratigraphic relationships; a stratigraphically lower event cannot be given a younger age than a stratigraphically higher event that has already been dated. This algorithm is run 10,000 times, producing 10,000 sets of potential dates for each volcanic event.

A cumulative function of event count through time is constructed from each set of potential dates. Mean recurrence rate (Fig. 2) is then calculated as the time derivative of the mean cumulative function at a 10 Myr interval. Volume Flux is modeled in the same way, but each event is weighted by its expected flow volume.

Results: The 29 mapped flows cover 6700 km^2, or ~70% of the caldera floor. Lava flow volumes range from 0.04-69 km3, given the potential range of 10-80 m thicknesses for each lava flow. The total volume of the 29 flows is modeled to be 67-540 km^3. Crater age modeling of the entire caldera and one lava flow matches the results from other studies [5,6].

Our main results find that activity in the caldera increased between 300 and 150 Ma, peaked, and declined until quiescence sometime between 10-90 Ma. At peak activity, 1 lava flow was being produced every 1.5-10 Myr with an average of 1 flow every 2.5 Myr. This corresponds to a mean magma flux of 1-8 km^3/Myr.

Geologic Implications: Remnants of tropical mountain glaciers have been identified on the western flanks of Arsia, preserved by up to hundreds of meters of ash. Previous studies have found that the resurfacing age of some glacial deposits in this region are around 200 Ma, around the same time as the volcanic activity in this study [10]. It is possible that the volcanic events within the latest period of Arsia Caldera activity were a source for this ash. This implies that either the mapped effusive eruptions had significant explosive components, or that explosive vents within the caldera were later buried by the currently exposed lavas.

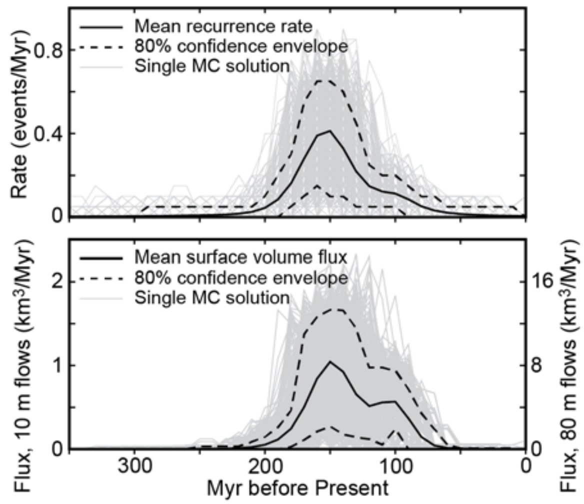

Fig. 2. Above: Modeled event recurrence rate of volcanism over the last 350 Myr. The average recurrence rate peaked at 150 Ma, producing an average of 1 volcanic vent every 2.5 Myr. Below: Modeled magma flux to the surface. Magma flux also peaked at 150 Ma, effusing 1-8 km^3/Myr, assuming flow thicknesses of between 10-80 m. Magma flux declined to essentially nothing between 50-90 Ma.

Assuming an intrusion/extrusion ratio of 10:1, the modeled peak magma flux remains 3-4 orders of magnitude below the amount necessary to supply a lasting magma chamber [5], suggesting that this event might be separate from episodes of main flank construction. Additionally, the magma effusion rate is 2-3 orders of magnitude less than the flux estimated for the last 234 Myr at Central Elysium Planitia [11]. The peak recurrence rate of 1 volcanic event every 2.5 Myr is, however, in line with the production rate at Syria Planum [12], indicating that the caldera volcanism in Arsia might be more related to distributed "plains-style" volcanism than large edifice building periods [3].

References: [1] Richardson J. A. et al. (2017) *EPSL, 458*, 170-178. [2] Hodges C. A. and Moore H. J. (1994) *USGS Prof. Paper 1534*. [3] Bleacher J. E. et al. (2010) *LPSC 41*, Abstract #1615. [4] Crumpler L. and Aubele J. (1978) *Icarus, 34*, 496-511. [5] Wilson L. et al. (2001) *JGR Planets, 106*, 1423-1433. [6] Neukum G. et al. (2004), *Nature, 432*, 971-979. [7] Robbins S. J. et al. (2011) *Icarus, 211*, 1179-1203. [8] Mouginis-Mark P. J. and Rowland, S. K. (2008) *Icarus, 198*, 27-36. [9] Michael G. (2013) *Icarus, 226*, 885-890. [10] Scanlon K. E. et al. (2015) *P&SS, 111*, 144-154. [11] Vaucher J. et al. (2009) *Icarus, 204*, 418-442. [12] Richardson J. A. et al. (2013) *JVGR, 252*, 1-13.