VOLCANIC ASH FROM SUPERERUPTIONS FOUND IN ARABIA TERA, MARS. P. L. Whelley[1,2], and A. Matiella Novak[3], J. A. Richardson[2]. [1]University of Maryland College Park, Department of Astronomy – Center for Research and Exploration in Space Science &Technology II, patrick.l.whelley@nasa.gov, [2]NASA Goddard Space Flight Center, [3]Johns Hopkins University Applied Physics Laboratory.

Introduction: Several large paterae in Arabia Terra are suggested to be calderas that produced colossal explosive eruptions (*i.e.*, supereruptions) [1]. We describe layered deposits containing minerals both consistent with and diagnostic of altered volcanic ash throughout Arabia Terra [2]. These deposits include Al-dominant minerals such as montmorillonite, imogolite, and allophane among others. Altered ash deposits thin (from 1-km to 100-m thickness) away from the suggested calderas – consistent with model predictions. We estimate that the volcanic ash observed in Arabia Terra is the result of between 1,000 and 2,000 individual explosive eruptions over 500-million years. Our observations support the hypothesis that Arabia Terra hosted supereruptions in the late Noachian-early Hesperian that repeatedly blanketed the region with volcanic ßash.

Methods: We use mineralogy and topographic remote sensing data to identify and measure stratigraphy.

Mineralogy: A survey of CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) images of cliff faces and crater walls in Arabia Terra was conducted to identify mineralogical signatures of altered volcanic ash. Images analyzed include full-resolution targeted (FRT) images (~20-m/pixel resolution) and half-resolution long (HRL) targeted image (~40-m/pixel resolution). Each CRISM image described here was analyzed using ENVI-enabled spectral interpretation tools (following methods of [3,4]) to collect spectral signatures of mineralogy assemblages that are indicative of altered volcanic ash. Locations identified in CRISM images to contain volcanic ash (*i.e.,* locations of interest) were followed-up with morphologic and morphometric analysis using topographic data.

Topography: Digital Elevation Models (DEMs) of locations of interest were produced from stereopair Context Imager (CTX) data using Ames Stereo Pipeline (ASP) [5]. Selected CTX images overlap CRISM locations of interest to produce co-located geomorphologic and mineralogic observations. Processed CTX DEMs were aligned to Precision Experiment Data Records (PEDRs) from the Mars Orbiter Laser Altimeter (MOLA) to reference the DEM to the martian aeroid. All DEMs were exported in a Mars sinusoidal coordinate system for GIS ingestion and are archived [6].

CRISM images were digitally draped over the DEMs to produce a 3D visualization of the vertical topography and enable quantitative measurements (*e.g.*, thickness, slope, and dip) of layering within observed mineral bearing units. Topographic profiles were analyzed across mineral contacts and over steep terrain to aid visualization and used to measure layer thickness.

Results: Mineralogically distinct layers were found at seventeen locations of interest (**a** through **q**) [**Fig. 1**]. Analysis is complete on seven (**a** through **g**), where we produced DEMs [6] and scrutinized CRISM spectra.

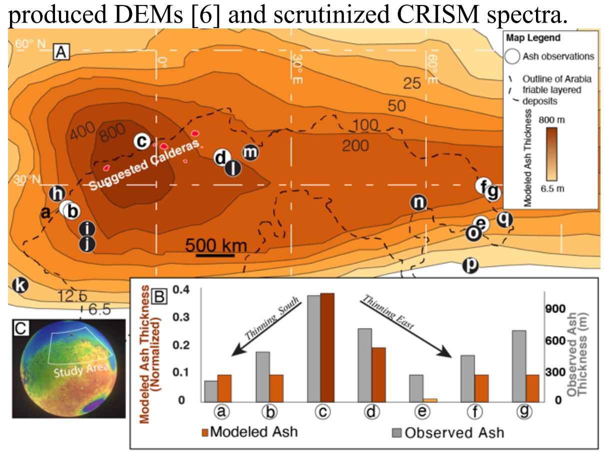

Figure 1: Modeled 35-μm diameter ash deposit thickness (shades of amber, *after* [7]) from supereruptions from the suggested calderas. **B**) compares observed and modeled ash at seven locations of interest. Model results have been normalized to illustrate the regional shape *i.e*., the thinning to the east (right of the peak) and south (left of peak). Both the model and observations show a systematic decrease in ash thickness with distance from the suggested calderas. The matching model and observation trends (except g, which is anomalously thick) suggest the layered altered ash deposits are linked by a regional process across Arabia Terra. Analysis at **h** through **q** is ongoing. **C**) MOLA topography globe of Mars, for context.

At location **a** [**Fig. 2**], the unit in the crater rim is a mix of imogolite, allophane and some jarosite, with weak absorption features at 1.85 and 2.26-µm (indicative of jarosite) and stronger1.92 and 2.2-µm absorptions (indicating Al-phyllosilicates). Stratigraphically below that, in the crater wall, is a layer of montmorillonite and hydrated silica, with 1.41, 1.91 and 2.21-µm absorption features. A middle crater wall unit is spectrally dominated by Fe/Mg smectites with 1.41–1.42-µm, 1.91-µm absorption features, and at a variable wavelength center from 2.28 to 2.32-µm. Within the topographic profile at location **a** the thickness of material diagnostic of altered volcanic ash total ~190-m, and material consistent with volcanic ash include an additional 10 m; summing to 200-m of altered volcanic ash.

Location **b** shows three distinct layers. The upper layer has 2.2-µm absorption features, suggesting the presence of Al-smectite (montmorillonite). The middle layer has strong allophane/imogolite signatures with

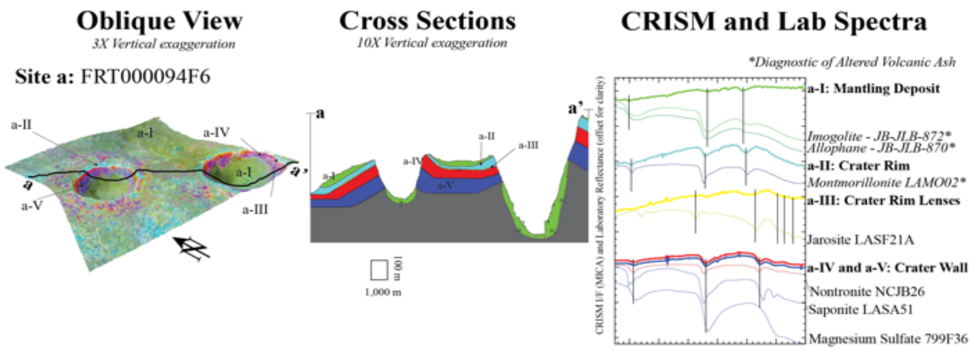

Figure 2: Oblique view (left) of CRISM images at locations of interest **a**, over CTX topography. The cross section (center) is based on the mineralogy observed in CRISM and CTX topography. (right) CRISM spectra (bold lines) compared to lab spectra (thin lines) Mineral names in *italics are* diagnostic of volcanic ash while all others are consistent with ash. The colors are from CRISM parameters (Red = bd2265, Green = bd2250, Blue = sindex2) as defined by [3]. The reddish areas are spectrally dominated by Fe/Mg smectite, the light bluish areas by Al-phyllosilicates, such as montmorillonite, and the greenish areas by aluminosilicates such as allophane and imogolite. Yellow areas are spectrally dominated by jarosite.

absorption features at 1.39-1.40, 1.92, and 2.19-2.20-µm. The lower layer displays absorption features at 1.91, 1.42, and 2.3-µm indicating the presence of Fe/Mg smectite. Together the montmorillonite, allophane/imogolite package, minerals diagnostic of volcanic ash, are about 290-m thick within location **b**.

In Eastern Arabia Terra, a plateau unit (**f**) displays alternating layers of montmorillonite, mixed with imogolite and allophane, and Fe/Mg smectites. On either side of the plateau, weaker absorption features detected by CRISM show a more massive unit that is spectrally dominated by hydrated silica mixed with jarosite and Fe/Mg smectites. At site **f**, layers that are consistent with altered volcanic ash are ~400-m thick and layers diagnostic of altered volcanic ash are ~100-m thick, for a total thickness of ~500-m.

Discussion: The observed deposits of altered volcanic material presented here are broadly consistent with the distribution of ash from sources in western Arabia Terra as modeled by [7], which shows similar trends of thinning deposits with distance from the suggested calderas to the south and east. Our observed deposits of material that are diagnostic of ash are on average 1.5 times thicker than thicknesses produced by the Kerber et al. [7] model using a total eruption volume of $5x10^6$ km^3 as reported by [8]. Additionally, all observed deposits, including material diagnostic of and consistent with volcanic ash, average 3 times thicker than the modeled deposits at each site in this study. Although ongoing identification of more correlated deposits in and surrounding Arabia will better constrain ashfall isopachs in this region, we interpret the thicknesses of observed deposits in this study to represent a total eruptive volume of $7.5x10^6$ to $1.5x10^7$ km^3 from western Arabia Terra.

The amount of magma and number of explosive eruptions required to deposit this volume of material over Arabia Terra and beyond can be estimated using the volumes of the suggested calderas as reported by [1]. The average depression volume for these paterae is >3,300 km^3 [1]. Assuming bulk densities of 1,300 kg/m^3 for tephra and 2,800 kg/m^3 for magma, Michalski and Bleacher [1] estimated "average minimum erupted volumes" of tephra would be 7,200 km^3 per caldera-forming event. To amass the volume of ash represented in the observed deposits in this study ($7.5\text{-}15x10^6$ km^3), western Arabia would need 1,000 to 2,000 caldera forming eruptions between the Mid Noachian and Early Hesperian Periods when Arabia Terra was formed [1,8]. The total erupted volume over this time would have required $3.5x10^6$ km^3 of magma at a minimum to account for the material identified here to be diagnostic of altered volcanic ash and a maximum magma volume of $7x10^6$ km^3 to account for all possible altered volcanic ash deposits. As a comparison, these volumes of magma are 30-60% of the total volume of Olympus Mons [9]. If, during the 500 Ma encompassing the mid-Noachian to early-Hesperian epochs, the number of active source regions remained constant and is now represented by the paterae identified by Michalski and Bleacher, these 1,000 to 2,000 eruptions would have been sourced from seven central volcanoes each with an average repose interval of 1.8-3.5-million years between eruptions.

References: [1] Michalski J. R. and J. E. Bleacher, (2013) Nature, vol. 502, no. 7469, pp. 47–52. [2] Whelley et al. (2021) *GRL,* vol. 48, no. 15. [3] Viviano-Beck, C. E. et al. (2017) *Icarus,* Vol. 284, pp. 43-58. [4] Buczkowski, D. L. et al. (2020) JGR-Planets, Vol. 125. [5] Moratto *et al*, 2010 LPSC XLI, Abstract # 2364. [6] Richardson, J. *et al.* (2021) *UMD Dataset* doi:10.13016/bez2-agt8. [7] Kerber et al, (2013) *LPSC XLIV,* Abstract # 2290. [8] Tanaka (2000) *Icarus*, Vol. 144, Issue (2), pp. 254–266. [9] Isherwood et al. (2013) *EPSL*, Vol. 363, pp. 88–96

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