FORMATION OF MARTIAN PATERAE: INSIGHTS FROM TERRESTRIAL IGNIMBRITE SHIELDS. Jeffrey M. Byrnes and Shanaka L. de Silva, *Department of Space Studies, University of North Dakota, Grand Forks, ND, 58202-9008, byrnes@space.edu*

Introduction: The formation of Martian paterae is poorly understood. "Typical" paterae are considered to be constructed primarily of pyroclastic deposits (e.g. Tyrrhena Patera [1], Hadriaca Patera [2], and Apollinaris Patera [3-4]), whereas others are suggested to be constructed primarily of numerous lava flows (e.g. Biblis and Ulysses Paterae [5] and Uranius Patera [6]). Alba Patera is interpreted to have significant components of both pyroclastic and lava flows [7-8], whereas volcanism may not have been significant in the formation of Orcus Patera [9]. One commonality to all paterae is the feature for which they are named, a shallow summit crater [e.g. 10].

The lack of observed resurgent doming at paterae [e.g. 11] along with the model of basalt-dominated volcanism on Mars [e.g. 12] has lead to comparisons between paterae and calderas formed on terrestrial basaltic shield volcanoes [e.g. 11,13]. However, it remains unclear if this is the most valid terrestrial analog. Calderas in basaltic shields are built upon a large edifice dominated by lavas, whereas this is clearly not the case for pyroclastic-dominated paterae. We suggest that a better paterae analog may be ignimbrite shields, which have received comparatively little attention. These are large-volume pyroclastic shields that show neither significant collapse nor resurgent doming [14-16]. Herein, we consider morphologic similarities between Martian paterae and terrestrial ignimbrite shields in order to further explore the processes responsible for the formation of the paterae.

Martian Paterae: Paterae on Mars are characterized by their shallow summit depression and low slopes. In general, typical paterae such as Tyrrhena and Hadriaca are suggested to have a significant component of pyroclastic deposits based on the observed slopes and the layered, incised flanks, whose nature suggests a friable material, such as ash [e.g. 1-2].

Flank slopes have been measured using MOLA topographic data for Alba, Amphitrites, Apollinaris, Biblis, Hadriaca, Meroe, Nili, Peneus, Tyrrhena, Ulysses, and Uranius Paterae [6,17-18]. Slope values range from 0.25° to 6°, although it should be noted that these values include both pyroclastic and lava flow surfaces.

Terrestrial Ignimbrite Shields: Terrestrial ignimbrite shields are extensive pyroclastic volcanoes that are common in the Central Andes [14-16,19]. They typically form broad shields displaying low-angle flank slopes and have experienced little to no central collapse, although a shallow sag is commonly observed. Lava extruded after the cessation of explosive activity commonly superposes the vent region. The paucity of associated plinian fall deposits indicates that the ignimbrites composing the shields were emplaced in eruptions characterized by low plinian columns or fountains.

We measured average surface slopes for several terrestrial ignimbrite shields using available topographic data: 1:50k scale maps for the Morococala and Cerro Juvina ignimbrites, and 1:250k scale maps for Los Frailes, Laguna Colorado, Cerro Panizos, and Cerro Purico ignimbrites. The slopes that we measured are most representative of the medial portions of the shields because proximal regions were not sampled to avoid topography associated with effusive deposits, and the distal deposits are often not well defined. Over baselines between 2 and 20 km, the measured terrestrial ignimbrite shield topographic profiles display slopes between 1.2° and 4.4°, and typically 2.0° to 2.5°. This compares well with the slopes of 1° to 3° estimated for Cerro Panizos [19].

Discussion: Ignimbrite shields may have been overlooked due to poor representation in the literature in addition to their silicic composition, which is not consistent with the current paradigm for Martian volcanism. Morphologies of pyroclastic deposits, however, are controlled primarily by the nature of fluidization rather than the volume or composition of erupted material [20-21]. This suggests that the eruptive processes involved in the formation of paterae on Mars may be similar to ignimbrite volcanism on Earth, regardless of paterae composition. Furthermore, the enhanced fragmentation expected for Martian volcanism [22] may result in basaltic volcanism on Mars being analogous in some ways to explosive terrestrial rhyolite eruptions. Recent modeling indicates that Martian volcanic plumes cannot reach the great heights previously suggested, but rather are limited to ~10 km (for the current atmosphere) [23]. This is consistent with the model of low columns associated with ignimbrite formation in the Andes. Additionally, the height is not so great as to disperse explosive eruption products over large regional areas [cf. 24].

A characteristic feature of the paterae is the shallow summit depression. For example, Gregg et al. [11] indicate that the average slopes of Hadriaca Patera caldera walls is <10°, which they indicate is consistent with caldera wall slumping during a catastrophic explosive eruption. While slumping may modify a steep-sided cavity, it typically produces a scalloped margin. The lack of a scalloped margin suggests that the morphology may be a primary feature rather than a secondary feature related to mass wasting. Therefore, we suggest that the paterae summit depressions are more similar to broad downsags rather than major collapses [25-27]. Where fractures are present, they may be formed due to centripetal extension that occurs in conjunction with the downsagging. Downsagging is suggested to be favored by relatively deep magma chambers and small volume eruptions [27]. Deep magma chambers associated with Martian paterae are consistent with theoretical considerations that Mars should have a deep neutral buoyancy zone (relative to Earth) because of its lower gravity [22].

While not all paterae were necessarily formed in the same manner, it is possible that volcanic paterae were all built primarily of pyroclastic deposits that were then superposed by lava flows, such as is the case for terrestrial ignimbrite shields. While pyroclastic deposits have not been identified as a volumetrically significant component of all paterae (e.g. Biblis, Ulysses, and Uranius Paterae [5-6]), it should be noted that lava flows as areally extensive as those at Tyrrhena Patera (~1000 km by 250 km [11,28]) would be more than sufficient to completely resurface those constructs. Therefore, it may be that the paterae record a typical local progression of explosive to effusive eruptive styles rather than reflecting global volatile changes.

Conclusions: Martian paterae and terrestrial ignimbrite shields both display significant, layered pyroclastic deposits with low-angle slopes, shallow summit depressions, no resurgence, and post-explosive effusive lava flows. These morphologic similarities are not interpreted to reflect similar feature compositions, but rather that the processes involved in the construction of paterae and ignimbrite shields may be similar. Together with the recognition that terrestrial ignimbrite shields may form from low columns or fountains, this suggests formation of paterae as extensive pyroclastic volcanoes from low (up to ~10 km) eruption columns, followed by downsagging of the central region and extrusion of lava flows.

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