The geomorphology of Martian super-volcanoes and implications for a shift in volcanism at the end of Noachian Mars

D. Susko[1], S. Karunatillake[1], D.R. Hood[1], S. Khorsandi[1][1]Louisiana State University (Davidsusko@gmail.com)

Introduction: Arabia Terra is a region of fundamental geologic interest on Mars, with potential implications for dramatic shifts in geologic processes during the Noachian-Hesperian boundary (3.9-3.6 Ga) of ancient Mars [1]. This region contains several large, spatially concentrated, irregularly shaped depressions, which, according to preliminary geomorphological analysis, may be more appropriately interpreted as paterae, or volcanic collapse features, rather than eroded impact craters [2]. A quantitative and comparative investigation of the morphology of these paterae in NW Arabia, as well as other semi-circular depressions from established volcanic provinces across Mars (Figure 1), could provide confirmation for their geologic origin, as well as insight into the geologic evolution and history of volcanism on Mars.

Also known as plains-style caldera complexes (PSCCs), these paterae features date as the late Noachian Era [2]. The morphologies of these complexes show a strong similarity with features of terrestrial super-volcanoes, such as Yellowstone[2]. Observations from the Gamma-ray Spectrometer (GRS) aboard Mars Odyssey suggest a unique chemistry in Arabia, including an enrichment in volatiles, specifically a high H_2O content, which further motivates the need for additional analysis of these features. The volatile enrichment of Northwest Arabia Terra would also be consistent with the volatile-rich, explosive volcanism style of Yellowstone and other terrestrial super-volcanoes [3].

Effusive, shield-forming volcanism is well documented on Mars throughout the Hesperian and Amazonian Eras[4-6]. Distinctness from the large, structured, super-shields may reflect underlying changes in igneous processes and a transition in volcanism from explosive to effusive during the Noachian-Hesperian boundary[2]. Explosive volcanism in particular may have contributed to the early martian atmosphere, given how, at least on Earth, effusive eruptions tend to be volatile-poor by association with deep mantle plumes, such as the Hawaiian-Emperor Chain [4,7,8]. A new model, describing crater-like features as relict super-volcano paterae in Northwest Arabia provides a reasonable explanation for the formation of regional scale deposits of volcaniclastic rock during Noachian Mars possible. On terrestrial planets, volcanism is not only the primary progenitor of atmospheres and hydrospheres, but also creates habitats suitable for life to thrive[9]. On Earth, whole ecosystems are sustained by the abyssal floor hydrothermal vents[10]. If Northwest Arabia is indeed a martian analog to terrestrial super-volcanoes, it could potentially have been the location of a habitable environment on Mars at the time of the Noachian-Hesperian boundary.

The origin of the PSCCs remains a mystery, although several models have been considered. The first of these models suggests a distinct composition of the martian mantle during the Noachian Era with considerably higher levels of volatile elements or silica, which subsequently became depleted by the Hesperian Era. A less likely model, but still one worthy of consideration, is subduction of early Martian “proto-plates” during the formation of the Martian global dichotomy [11]. On Earth, the most common geologic process driving the formation of volcanism is subduction of tectonic plates and the hydration of the mantle. Given how all PSCCs identified by Michalski and Bleacher [2] lie in close proximity to the boundary of the Martian dichotomy, they could be reflective of a volcanic arc formed by subduction. Should other examples of these PSCCs be identified near the boundary, they would support a genetic relationship between these two phenomena. By exploring for additional examples of these features in strategic locations across Mars we may be able to decipher their origin and the implications for the history of Mars or whether these features are unique to this one locality.

Martian field exploration: We use the data from several orbiting instruments including MOLA, CTX, and HiRISE in conjunction with the most up-to-date mapped geology [12] in order to first identify regions in which exploring for additional semi-circular depressions would be most insightful. We used the Java-based GIS software JMARs to overlap mapped terrain and constructed shape files to outline regions we intend to explore for additional PSCCs. We identify 10 such regions and provide a priority level justification for our choices. The presence or absence of these features within each geographic region will impart clues as to their geologic origin. The highest priority region is Arabia Terra, the location of the five PSCCs identified in previous work. We will start our investigation by looking at other semi-circular depressions in NW Arabia and continue expanding our search out to the rest of Arabia Terra. We first selected regions of comparable Noachian age and terrain type, trying to match the pilot region as closely as possible, making sure to select regions both proximal and distal to the Martian dichotomy boundary for comparison. These included: Terra Sabaea, Tyrenna Terra, Aonia Terra, and Tempe Terra. Next, we targeted regions of similar Noachian age, but varying geology, eventually selecting the two volcanic regions Thaumasia Planum and Malea Planum. Last, we selected regions of geologic age younger than the Noachian. The absence of similar paterae structures within these regions would support the model where these events are a Noachian only process. We selected the Hesperian-aged Syrtis Major Planum and Hesperia Planum, and the Amazonian-aged Elysium Planitia. Sytris Major and Thaumasia Planum are made further interesting by their proximity to friable, potentially volcanoclastic terrains, as well as layered sulfates and stratigraphic clays identified from orbit, similar to features near to Arabia Terra as well. These regions are abbreviated as HiPERs, or High Priority Exploration Regions, and are highlighted in Figure 1. When exploring each HiPER, ideal paterae candidates will lack typical crater morphologies such as ejecta blankets, raised rims, and central peaks [2].

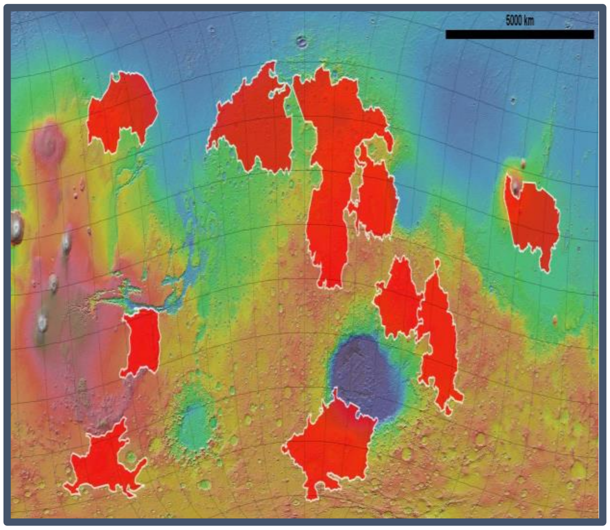

Figure 1: Martian HiPER Map. Represents more scientifically strategic locations to hunt for candidate super-volcano paterae.

Characteristic Morphology: Michalski & Bleacher identified 4 parameters which they used to characterize semi-circular depression and make a distinction between the patera and other features such as craters, terrestrial super volcanoes, and thermokarsts. These parameters included (1) rim-to-floor depth, (2) diameter, (3) minor axis length, and (4) major axis length (2). In this work, we expand their measurements with additional key parameters, including rim slope. We compare the parameters of each of the PSCCs and the other semi-circular depressions with several topographically low-lying shield volcanoes identified in the lava fields of Central Elysium Planitia [4]. The calderas of these volcanoes represent another morphology which must be distinguished from when exploring the HiPERs for candidate paterae, as they most likely associate with different geologic processes then the ones we are trying to investigate in NW Arabia. Candidates from each HiPER are then included in the comparison in order to determine their likeness to the PSCCs and terrestrial super volcanoes, allowing us to determine whether the features in NW Arabia are unique on Mars.

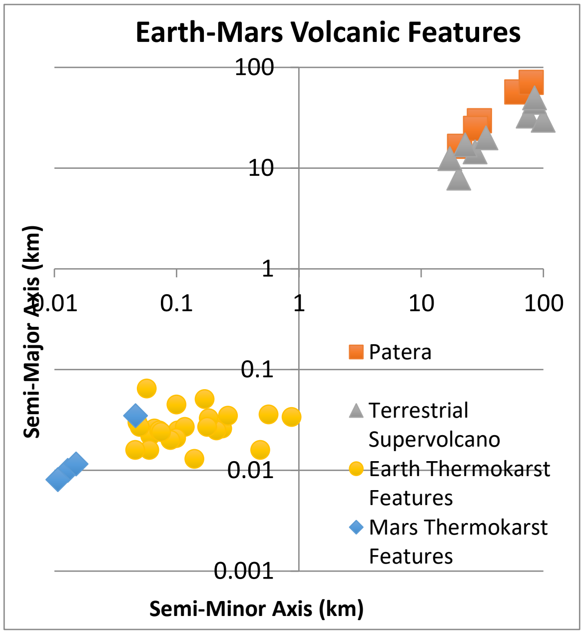

Figure 2: Comparison of two characteristic parameters for study paterae, terrestrial super volcanoes, and both terrestrial and martian thermokart features. Adapted from Michalski & Bleecher (2013).

References: (1) Carr MH, Head JW (2010), (2) Michalski JR, Bleacher JE (2013), (3) Lowenstern JB, Hurwitz S (2008), (4) Vaucher J, et al. (2009), (5) Baratoux D, Toplis MJ, Monnereau M, Gasnault O (2011), (6) Jaeger WL, et al. (2010), (7) Katz MG (2003), (8) Cashman BK V, Mangan MT (2014), (9) Kasting JF (2002), (10) Aharon P (1994), (11) Zuber (2001), (12) Tanaka KL, et al. (2014)