DELINEATING THE ARABIA TERRA REGION ON MARS TO INVESTIGATE PATERAE ORIGINS.

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Introduction: Arabia Terra has been broadly described as a region characterized by Noachian-aged, heavily cratered, highland topography defined by the dichotomy boundary. However, recent geomorphic work by Michalski and Bleacher [1] has evolved the classification of the Arabia Terra region through the identification of spatially concentrated paterae (i.e., volcanic collapse features) in NW Arabia Terra. The presence of paterae constitutes a previously unrecognized volcanic construct on Mars, although analogous to terrestrial super volcanoes (e.g. Yellowstone) and provides evidence for explosive volcanism in early martian history. Furthermore, martian paterae have fundamental implications for early mantle processes, atmospheric evolution, as well as constraints on the geologic timeframe and locations to search for signatures of life on Mars. In pursuance of independently verifying Michalski and Bleacher's [1] proposed paterae model, we completed two objectives: (1) To semi-quantitatively delineate the region of 'Arabia Terra' using a variety of geochemical and geomorphological datasets and (2) To calculate the characteristic bulk composition of the newly defined region. In this work, we discuss the implications of our results for the patera model [1] as well as other hypotheses put forth concerning the evolutionary history of Mars.

Delineating Arabia Terra: Using the computational platform ArcGIS 10.3.1, we semi-quantitatively delineated a 'broad region' and 'focus region' for Arabia Terra by cross referencing the following geochemical and geomorphological mapped data: MOLA map (Mars Orbiter Laser Altimeter), Geologic Map of Mars [2], and Taylor et al.'s [3] Chemical Province map (Fig. 1). Two regions were defined to assess the comparability among the spatially-centered patera region in NW Arabia Terra; a more expansive, geologically-similar region; and the rest of Mars.

Geomorphology. The general Arabia Terra region was previously defined by a northern perimeter coincident with the dichotomy boundary due to contrasting elevation, age, and underlying geologic process characterizing the northern lowlands and southern highlands. The Noachian-aged southern highland geology corresponds to basement material unconformably underlying the northern highlands, suggesting a significant change in geologic process after the Noachian Era [4-8]. For these reasons, we continue to use this boundary for the broad and focus regions of Arabia paterae. Additionally, the broad region was confined by high elevations along the southern perimeter.

Geology. Both regions were mapped to contain similar characteristic geology [2], namely Early, Middle, and Late Noachian highland units, with unavoidable Amazonian-Hesperian impact units from more recent impact craters. The Noachian-aged highland units can be generally described as having a high abundance of basaltic compositions, including iron- and low-calcium-bearing pyroxenes and olivines, and characteristic mounds of friable material [2]. Early Noachian units consist of igneous rocks and impact breccias and melts while Middle Noachian units have a comparably higher proportion of sedimentary and volcanic materials. The broad region also has an insignificant amount (<1.0%) of an Amazonian and Noachian apron unit that is unable to be spatially discerned on a regional scale. Furthermore, the focus region is geographically concentrated around the identified paterae [1] (i.e., Eden, Siloe, and Ismenia Patera).

Geochemistry. The Martian surface can be described by six distinct geochemical provinces [3]. The broad region encompasses Chemical Provinces 2 (compositionally similar to average Mars, except for distinctively low Ca), 4 (compositionally similar to average Mars) and 6 (compositionally distinct, with enrichments in K, Th, Fe, Si) [3]. In contrast, the focus region, localized around the identified paterae cluster [1], is located entirely within Chemical Province 6.

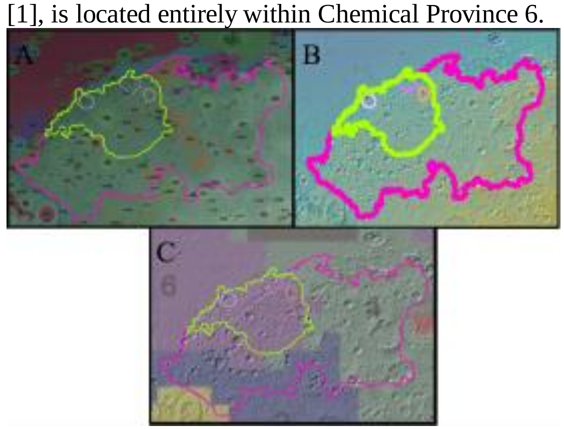

Figure 1. Arabia Terra Focus Region (green) and Broad Region (pink) delineated using (A) the geologic map [2], (B) MOLA map, and (C) Geochemical Province map [3].

Bulk Composition: The chemical maps from the Mars Odyssey Gamma Ray Spectrometer (GRS) contain averaged geochemical data, specifically, Al, Ca, Cl, Fe, H, K, S, Si, and Th, in 5°×5° bins for latitudes ± 45°. The decimeter scale depth sensitivity of GRS measures geochemical signatures previously unobtainable due to the thick layers of globally-mixed aeolian dust covering the Arabia region [9] as shown by insightful chemical province constructions from previous GRS investigations [2,10,11]. We use GRS-derived chemical data as an effective tool to describe and statistically compare the bulk compositions of the Arabia Terra focus and broad regions to the rest of Mars. This study used the most recently released gamma ray data (2014) and applied Baratoux's method for calculating an estimated value of Mg [12]. Figure 2 shows the comparisons of the bulk compositions of Arabia Terra focus region and broad region, and average mars on modified box-and-whisker plots [10]. This method of statistical analysis shows relative enrichments and depletions of elements between two regions.

Figure 2A compares the delineated Arabia Terra focus region to broad region (without the focus region) to measure for a distinct patera geochemical signature. The focus region is depleted in Mg relative to the broad region while the remaining elements are at unity or slightly enriched. Figure 2B compares the focus region to the entirety of Mars to test for a unique geochemical signature of the region. The focus region reveals a depletion in Mg and enrichments in H_2O, K, S, and Th. Figure 2C compares the combined focus and broad regions to the entirety of Mars to measure the geochemical distinctness of the larger region. Similar to Figure 2c, the combined region shows depletions in Mg as well as Cl/H_2O and S/H_2O ratios, and an enrichment in H_2O.

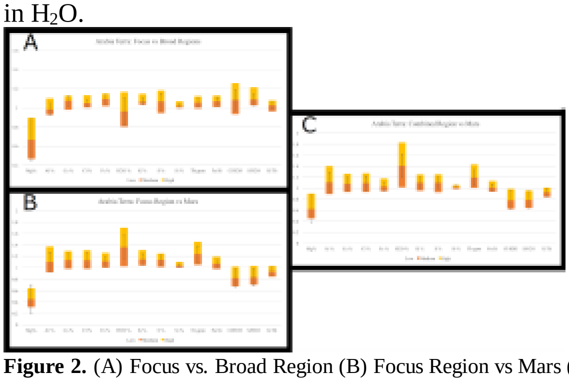

Figure 2. (A) Focus vs. Broad Region (B) Focus Region vs Mars (C) Combined Region vs Mars. For an element, the high value (yellow) is a ratio of 75% in Region I to 25% in Region II, the medium value (orange) is a ratio of 50% in Region I to 50% in Region II, and the low value (clear), is a ratio of 25% in Region I to 75% in Region II. If median and high values lie above unity, the element is considered enriched in Region I and depleted in Region II. Error was calculuated using the median absolute deviation (MAD) for each element.

Discussion: The delineated regions of Arabia Terra contain bulk compositions that are geochemically distinct compared to the rest of Mars. Furthermore, the broad region is geochemically representative of the focus region, which is indicative of a similar evolutionary history and suggests that the impact of the proposed paterae was geographically expansive. In fact, this identifies a potential source for the fine debris fields that are commonly found in equatorial regions [11]. Additionally, our observations provide the first geochemical underpinnings for a new type of volcanism on Mars, which may relate to an ancient crust (Noachian-aged) dominated by explosive volcanism [1].

In general, the broad and focus regions show depletions in Mg and enrichments in volatiles, such as H_2O, compared to the rest of Mars. A high H_2O value is consistent with a volatile-rich explosive volcanic geochemical signature, thus supporting the proposed patera model [1] for Noachian Mars. This signature may also provide an explanation for the fine-grained, friable crustal constructs overlying Arabia Terra, which may have been derived from a more hydrated mantle (e.g., more comparable to Earth's mantle- this further supports the analogy between the patera [1] and terrestrial supervolcanoes) [13]. Additionally, high H_2O values are consistent with Dohm's work [12] suggesting some sedimentary input from a proposed impact basin nearby in Arabia Terra, with the subsequent uplift and exhumation yielding anomalously high H_2O values. This is also consistent with the deviation of the K/Th ratio from the typical martian crustal value.

Conclusions: The distinct geochemical signature of the Arabia Terra focus and broad regions has many implications on proposed evolutionary models of Mars. If explosive volcanism was in fact the dominant process during Noachian Mars, the mantle and atmosphere would have been significantly different than the current effusive-volcanism dominated processes. Additionally, the confirmation of paterae will provide context for the possibility of similar spatially clustered volcanic signatures elsewhere on Mars. Finally, this type of volcanism may provide added insight (geologic time and location) to the habitability of ancient Mars.

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