THE PUTATIVE MARTIAN PATERAE WITHIN NORTHWEST ARABIA TERRA COMPARED WITH CONTEMPERANEOUS VOLCANIC PROVINCES.

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Introduction: The Arabia Terra region is one of the oldest martian landscapes, and has been geomorphologically interpreted to bear evidence of paterae eruptions similar to terrestrial supervolcanoes [1]. As structures unique to Arabia, these represent a possibly new class of volcanism on Mars [1]. This possibly represents the earliest explosive-style volcanism on Mars, in contrast to the effusive volcanism that dominated the landscape later in the planet's history [9]. As such, it signifies a possible source for much of the mid-latitudinal and equatorial friable and possibly volcanogenic sedimentary strata whose origins are currently ambiguous [1]. Furthermore, the potential to link Noachian-aged explosive volcanism within Arabia Terra to friable sedimentary units and indirectly to the sulfur cycle has global implications in terms of habitability and atmospheric chemistry [1]. However, it is unknown if the paterae-bearing region is geochemically consistent with volcanism. Therefore, analyzing the Arabia Terra region further, both in terms of geochemistry and geomorphology, in comparison to other Noachian-aged volcanic provinces, will lead to a greater understanding of the planet's geologic evolution, and provide insight into the early surface conditions on Mars.

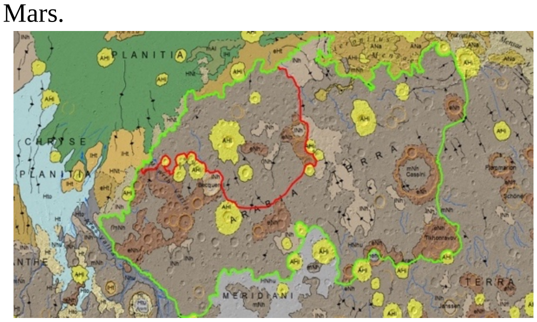

Figure 1: *The delineated broad (green) and focus (red) regions according to Carnes et. al (2017) overlain on the geologic map from Tanaka et. al (2014).*

In this study, we compare crater and mapped geology based ages of two delineated areas within Arabia Terra, the broad and focus regions, as shown in figure 1. As defined by Carnes et. al 2017, these are of sufficient spatial extent to characterize chemically and are geologically consistent with the paterae interpretation [2]. Additionally, using the geochronological datum, several volcanic provinces with comparable age were chosen to compare with the broad and focus regions' geochemistry.

Methodology: In order to quantitatively determine an age for the broad and focus regions, we used the technique outlined by Platz et. al [3]. This method involves outlining crater rims within a target area using ArcGIS. These data are then exported to craterstatsII, a program which calculates an age based on the frequency of crater sizes. We compared the resulting estimate with that based on the ages of mapped geologic units. Using the map by Tanaka et. al (2014) [4], and ArcGIS, the area of geologic units within the delineated regions was used to create an age-based areal fraction pie chart for the regions. Comparing the age of this area from two techniques serves several purposes, one of which is to establish the degree of consistency between the region versus mapped geologic units. This comparison also helps to reveal the effects of error and sampling size in delineating craters manually to enable cumulative crater-size distributions. Furthermore, using mapped geology to estimate an age also shows the areal distribution of other-aged units within the regions, whereas the crater-calculated age simply returns a number. Combined, these two techniques offer a robust characterization of the age of the delinated areas and age variability within the areas.

The geochemical datum was derived from Mars Odyssey Gamma Ray Spectroscoper (GRS) observations archived at the NASA-PDS, as well as from published chemical maps [5]. This datum is compiled from Si, Cl, Fe, H, Ca, S, Al, Th, and K chemical maps and is binned into 5° × 5° squares, according to the methods detailed by Karunatillake et. al (2014). The map from Tanaka et. al (2014) [4] was used to identify Noachian-aged volcanic provinces elsewhere on Mars, whose locations were best-fit using the Tanaka et. al (2014) geologic map and Java Mission-planning and Analysis for Remote Sensing (JMARS) as the program to place rectangular boundaries around Thaumasia Planum (Site A), Malea Planum (Site B), Hisperia Planum (Site C), and Appolinaris Mons (Site D). Using the coordinates of these outlined areas, GRS datum was compiled for the provinces and analyzed accordingly. The datum, as seen in figure 2, was reported by taking the ratio of $75^{th}/25^{th}$, $50^{th}/50^{th}$, and $25^{th}/75^{th}$ percentiles for a each element at two areas being compared, according to the technique detailed by Karunatillake et. al (2011) [6].

Results: The two geochronological methods used returned age ranges that agreed with each other, dating the focus region to 3.9 ± .011 Ga (95% confidence) and the broad region to 3.77 ± .00064 Ga (95% confidence). The geochemical datum for the broad region shows an enrichment in sulfur, thorium, potassium and H_2O (computed stoichiometrically from H abundance) relative to the other four comparably-aged volcanic provinces.

This trend continues when the broad region is compared to the Martian crust; enrichments in H_2O, sulfur, thorium and potassium are less pronounced, but enrichments in chlorine, iron, calcium and aluminum are present. The focus region also shows enrichment in water, sulfur, thorium and potassium in relation to the other volcanic provinces, while also showing enrichments in chlorine, iron, calcium and silicon, but showing a depletion in aluminum. When compared to the crust, the focus region has variable degrees of enrichment, with pronounced enrichments in H, Th, K, Fe, and S.

Discussion: Voclanic provinces on Mars tend to be slightly depleted in H and Cl relative to the average crust, with the exception of site D. This contrasts with the geologic evolution proposed for the similarly aged paterae region by Michalski and Bleacher (2013): that the ancient thin crust of Mars facilitated facilitated the rapid ascent of magma, enabling it to retain volatiles needed for explosive volcanism. The notable depletion of Cl and H in these provinces, except for Site D, suggest the possibility that the ancient crust in the other regions was thicker and there weren't any paterae-analog processes taking place in these areas that stretched or thinned the lower crust.

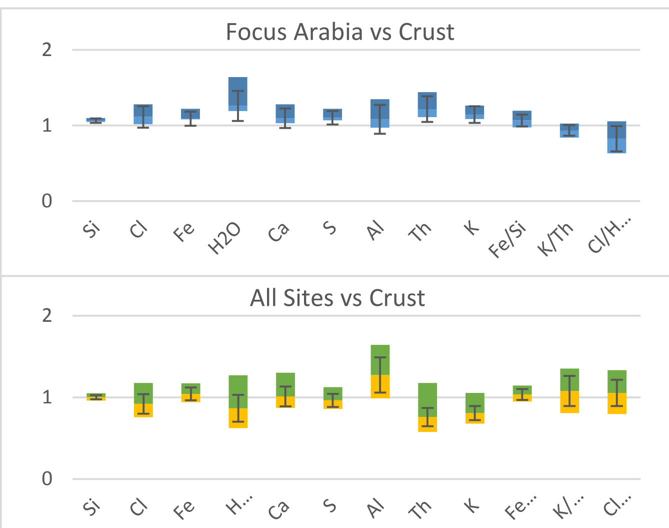

Figure 2: *The geochemical data for the Focus region vs All other Volcanic Provinces (top) the rest of Mars (middle) and All Sites vs Rest of Mars (bottom)*

Variations in Thorium and Potassium abundances are primarily affected by fractionation from aqueous processes or coupling during fractional crystallization or melting in igneous settings [10]. Since the K is preferentially higher relative to Th among all the volcanic sites, it is unlikely that the cause of this enrichment is due to chemical weathering under neutral conditions, since as rocks experience more chemical weathering, K tends to decrease and Th remains the same or increase [10]. It is also difficult to determine whether or not the enrichment is due to igneous processes or aqueous ones since both processes can produce similar K/Th ratios. However, igneous processes tend to couple K and Th [10], so one would expect the ratios of K and Th, relative to the average crust, to follow similar trends. For the volcanic sites, K and Th are consistently depleted, as shown in Figure 2, and Focus Arabia is enriched. In addition, there is a shared enrichment of Fe, Si, Ca, and Al among All Sites and Focus Arabia, which are elements that are major components of igneous rocks. This reinforces the possibility of a K/Th ratio influenced primarily through igneous means. Therefore, it is highly probable that the K/Th ratio is influenced primarily by igneous processes. This suggests there must be a unique difference in these processes between Focus Arabia and the other volcanic sites, since the sites' K and Th ratios diverge from Focus Arabia's. This difference could arise from a thinner lower crust, or from some other combination of factors that were at play during the Late Noachian.

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