**THE COMPOSITION OF AMAZONIAN MATERIALS IN THARSIS AND ELYSIUM, MARS.**

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**Introduction:** The Tharsis and Elysium plateaus are the two youngest large regions of Amazonian-aged volcanic materials on Mars. Both are dominated by volcanic landforms with an almost omnipresent cover of very fine-grained dust. The dust mantle in these regions is continuous with no evidence for exposure of rocky materials at hundreds-of-meters spatial scale (Christensen et al. 2003) and is thick enough to obscure underlying bedrock composition to visible/short-wave infrared (VSWIR) reflectance spectroscopy and thermal infrared emission spectroscopy.

The primary minerals that dominate VSWIR spectra of non-dusty regions of Mars are pyroxene, olivine, glass, and more rarely plagioclase [e.g., 1]. Global low-resolution spectral mapping indicates that pyroxene comprises a dominant component of the igneous Martian crust [2-6]. At VSWIR wavelengths, pyroxene displays broad diagnostic absorptions near 1 and 2 µm that result from crystal field transitions of iron in octahedral coordination. In low-calcium pyroxene (LCP), these bands are centered at 0.9 and 1.8 µm, whereas in high-calcium pyroxene (HCP) they are centered at 1.0 and 2.3 µm. In Fe-bearing glass (GLS), the absorptions' wavelengths (1.1 and sometimes 1.8 $\mu$m) are distinct from pyroxene. Olivine (OL) has three overlapping absorptions forming a composite feature centered near 1.05 µm. This composite absorption strengthens and broadens toward longer wavelength with increasing Fe content [7], or increasing grain size, such that coarse-grained low-iron olivine is spectrally similar to fine-grained high-iron olivine [8]. In the coarsest grain materials, the absorption approaches saturation, becoming flat-bottomed with a center shifted to longer wavelengths.

Spectral modeling of mineral mixtures to simulate VSWIR spectra has been performed both for globally distributed data from the OMEGA instrument (350-10,000 m/pix) and local, higher resolution data from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM). The results show that that most regions of Mars consist of pyroxene and plagioclase with a variable olivine component [6, 9], consistent with the basaltic to olivine basaltic composition indicated by in situ measurements [10-12]. A subset of Noachian materials such as in Nili Fossae are ≥40% olivine and picritic in composition [6]. In addition, the ratio of low-Ca pyroxene to high-Ca pyroxene in volcanic materials decreased from the early Noachian to the Hesperian period, indicating a change in magma composition over time [5, 6]. Similar assessments of temporal changes of mineralogic composition of volcanic materials into the Amazonian period have, thus far, not been possible due to the heavy dust cover in Amazonian volcanic units at the scale of OMEGA, TES, and THEMIS pixel footprints.

**Methods:** To assess the compositional diversity of Tharsis and Elysium, relatively dust-free volcanic materials in >300 CRISM observations within Amazonian terrain (as mapped by [13]) from ~110-302° E longitude (roughly corresponding to the Elysium and Tharsis regions. Spectra were analyzed for the presence of mafic phases (pyroxene, olivine, mafic glasses). Locations of mafic mineral exposure were initially identified using a combination of summary parameters and browse products [14] to identify the presence of mineralogic variability within the scene. Spectra were extracted from each observation (from fresh crater ejecta, "blast zones" where some dust has been removed [15], relatively dust-free scarps, or sand dunes) and ratioed to an in-column denominator over globally spectrally-uniform dust to isolate the mafic minerals signatures [16]. Most fresh crater locations revealed only underlying, relatively darker spectrally-neutral material. Extracted spectra with non-dust/neutral features were fit using a linear continuum removal for the 1-$\mu$m band position and shape using methods comparable to those of Horgan et al. [17], which allow for classification of ferrous mineral mixtures, using a combination of 1-$\mu$m band center and asymmetry, into six subgroups: LCP, intermediate/mixed pyroxene (LCP-HCP), HCP, LCP+OL/GLS, OL, and a group that includes many phases/mixtures (GLS, OL, PYX/GLS+OL) [17]. Classifications were corroborated and refined using the presence of the 2-$\mu$m band. For comparison, we also analyzed Hesperian and Noachian igneous materials for which quantitative compositional analysis of OMEGA data has been performed [6] (Fig. 1, B-D).

**Results:** The results of the 1-$\mu$m band classification as applied to laboratory mixtures of mafic phases from Horgan et al. [17] are shown in Figure 2 (top), to indicate how each compositional zone is determined. The 1-$\mu$m band analysis of spectra from Noachian, Hesperian, and Amazonian terrain are shown in Figure 2 (bottom) with the same compositional zones indicated. Olivine from some Noachian and Hesperian regions fall outside the compositional bounds, likely due to absorption band saturation shifting the continuum removed 1-$\mu$m band center to longer wavelengths. Spectra from Amazonian terrains are consistent overall with spectra from Hesperian terrains but distinct from Noachian terrains, where LCP and endmember OL dominate. A breakdown of the 'count' of each classification type comparing Elysium vs. Tharsis region (Fig. 3) shows that the two provinces are comparable in bedrock composition.

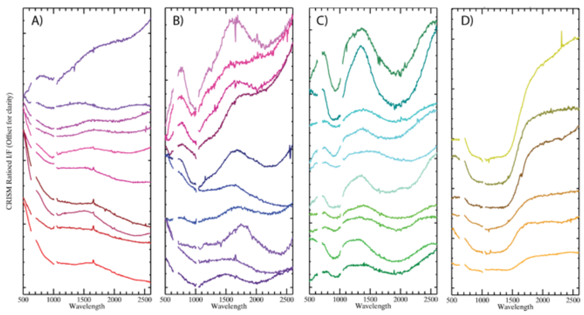


**Figure 1.** Representative CRISM ratioed I/F spectra from **a)** Amazonian (PYX+/-OL), **b)** Hesperian (PYX+/-OL), **c)** Noachian (LCP-rich), and d) Noachian (OL-rich) terrains.

**Discussion and conclusions:** These results suggest that Amazonian volcanic materials are comparable in their range of mafic mineral composition to Hesperian volcanics, but distinct from Noachian igneous material. Broadly, the Elysium region and the Tharsis regions have relatively similar ranges of mafic phases present (Fig. 3, pie charts). However, within each of these volcanic provinces, significant spectral variability exists. In addition the spatial distribution of the mafic signatures is telling: they occur mostly along the margins of the high dust-cover-index (DCI; [18]) regions of Tharsis and Elysium. In the "cores" of the two volcanic plateaus having the highest DCI values, few fresh craters exhibit mafic spectral signatures. This result is consistent with a thicker cover of dust that may not be entirely penetrated by small fresh impacts.

**References:** [1] *Ehlmann & Edwards* (2014) *Ann. Rev. Earth Planet. Sci.* 42:291-315. [2] *Bibring et al.* (1989), Nature, 341, 591-593. [3] *Bandfield et al.*, (2000) *Science*, 287(5458), 1626-1630. [4] Bandfield *et al.*, (2002) *JGR*, 107(E6), 5042. [5] *Mustard et al.* (2005) *Science*, 307, 1594-1597. [6] *Poulet et al.* (2009) *Icarus*, 201, 69-83. [7] *King & Ridley* (1987) *JGR*, 92(B11), 11457. [8] *Clénet et al.* (2011) *Icarus*, *213*(1), 404-422. [9] *Lapotre et al.* (2017) *JGR*. [10] *McSween et al.* (2008), *JGR*, 113, E06S04. [11] *Morris et al.* (2006), *JGR*, 111, E02S13. [12] *Achilles et al.* (2017), *JGR*, 122, 2344-2361. [13] *Tanaka et al.* (2013) *USGS*, 3292. [14] *Viviano-Beck et al.*, (2014) *JGR*, 119, 1403-1431. [15] *Daubar et al.* (2016) *Icarus*, 267, 86-105. [16] *Murchie et al.* (2009) *JGR*, 114, E00D07. [17] *Horgan et al.* (2014) *Icarus*, 24, 132-154. [18] *Ruff & Christensen*, (2002) *JGR*, 107(E12), 5127.

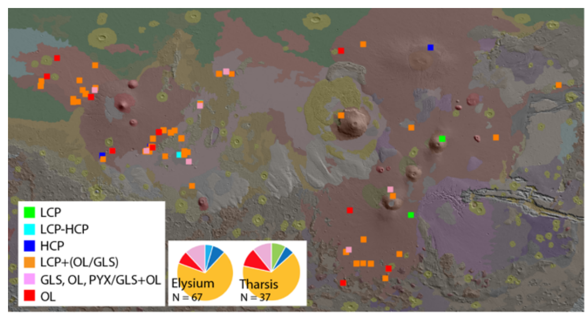


**Figure 3.** Distribution of mafic materials exposed in Amazonian terrains (in shades of red), as classified through the 1-$\mu$m classification scheme (see Fig. 1). Pie charts indicate distribution of phases associated with Elysium- vs. Tharsis-related materials.

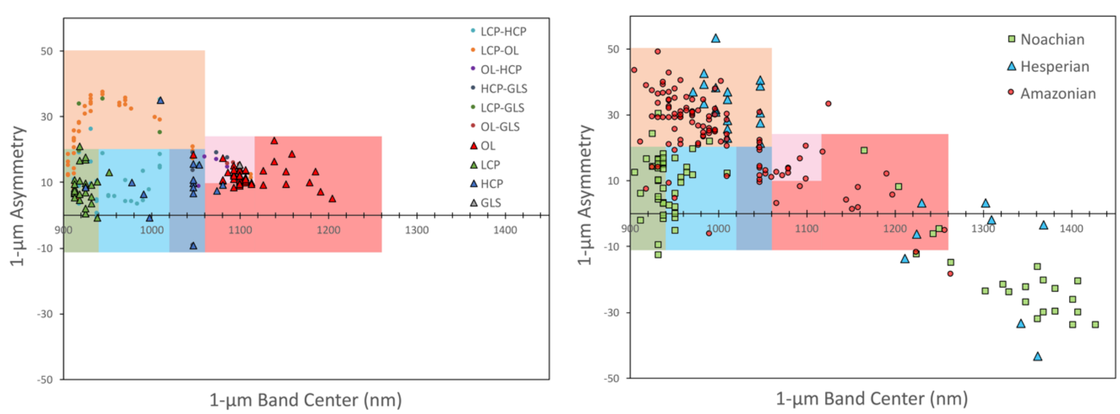


**Figure 2.** 1-$\mu$m classification scheme for library spectra (**left**) from [17]. Colored boxes are consistent with the following compositions: *Green*: LCP, Cyan: LCP-HCP, *Blue*: HCP, *Orange*: LCP+(OL/GLS), *Pink*: GLS, OL, PYX/GLS+OL, *Red*: OL. (**right**) The same 1-$\mu$m band classification as applied to spectra from Noachian, Hesperian, and Amazonian-aged surfaces.