Crystalline Igneous Crust of Mars: New Insights from the Southern Highlands. J. R. Skok[1], J. F. Mustard[1], L. L. Tornabene[2], P. Isaacson[1], S.L. Murchie[3] [1]Department of Geological Sciences, Brown University, Providence, RI, 02912, John_Skok@brown.edu [2]LPL, University of Arizona, Tucson, Arizona, [3]JHU/APL, Laural, Maryland.

Introduction: The composition of the primary crust of Mars is important for understanding the igneous evolution of the planet. The formation of a primary crust from a magma ocean has been suggested based on heat production calculations [1] but has been questioned as observations differ form known magma ocean produced primary crusts [2]. This may be tested by determining deep crustal mafic mineralogy and comparing to the 60% olivine, 40% pyroxene, high Fo# lithologies predicted thermodynamically [1]. Remote observations of the crust are complicated by surfical volcanism, alteration and impact gardening. The single, non-representative view of the composition of the primary crust of Mars is from the 4.56 Ga orthropyroxenite Martian meteorite ALH84001 [3]. Additional observations of pristine, unaltered sections of the crust are key to the understanding of the true mafic character of the primary crust. We focus on exposures in crater central peaks that excavate material from depth. Initial analysis focuses on exposures throughout the Southern Highlands.

Data: Data for this study was acquired by instruments on the Mars Reconnaissance Orbiter (MRO) spacecraft. Spectral data was acquired by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) [4] and imaging was provided by the High Resolution Imaging Science Experiment (HiRISE) [5] and Context Camera (CTX) [6] instruments. CRISM observations provide visible and near-infrared (VNIR) spectral coverage (0.32–3.92) with maximum resolution of ~18 m/pixel. High resolution imaging of the deposits are provided at ~6 m/pixel from the CTX instrument and ~30 cm/pixel from the HiRISE camera.

Methods: Compositional analysis focuses on mafic mineral absorptions. Pyroxene's 1 and 2 µm absorption band centers are modulated by Ca content and to a lesser degree, Fe content [7]. The complex of absorptions near 1 µm for olivine are a function of Fo# [8]. We look to constrain these spectral features in terms of the specific observed units to best constrain the mineralogy on a fine scale. The Modified Gaussian Method (MGM) [7,8,9] is used to fit the olivine and pyroxene spectral features in order to determine precise band depths and positions leading to compositional determinations. MGM spectra fits are determined here by setting absorptions at known absorption positions and allowing adjustment of band center, band width and band strength to achieve smallest modeled error.

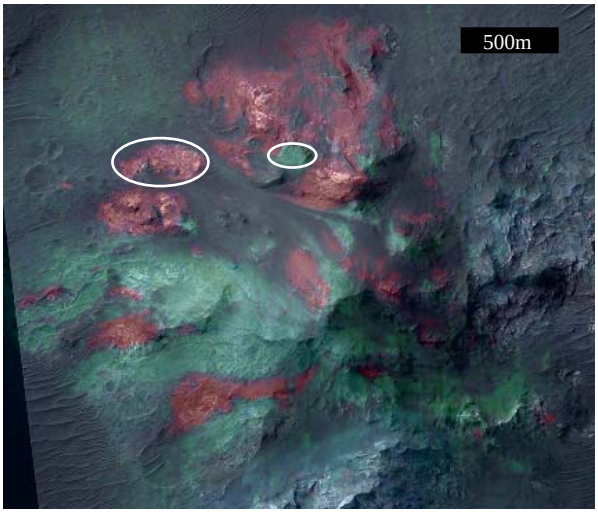


Figure 2: HiRISE of Alga Crater central peak with CRISM mafic parameter overlay. Light-toned olivine-bearing units indicated in red. Low-calcium pyroxene (LCP) bedrock unit is in green. Smooth, spectrally bland unit is grey. Outlines show region of spectra in Figure 2, overlay color matches line color. (R: Olivine; G: Low-calcium pyroxene; B: High-calcium pyroxene (HCP))[10]

Observations: Dozens of potential deep crustal exposures have been detected throughout the Southern Highlands [11], however, the initial attempt to characterize spectral properties of mafic minerals will focus on a few selected sites that feature strong mafic signatures and limited alteration. Of these we focus here on the unit morphology and mineralogy of Alga crater (24.3S, 26.8W), a particularly well exposed example as a template for crustal analysis.

Alga is a relatively fresh 18 km diameter crater and located near the center of 85 km Chekalin Crater just to the southeast of Ladon Valles. Alga should provide central peak excavation depth of ~2 km [12] superimposed on top of ~8 km excavation from Chekalin. The relatively young exposure of Alga's central peak displays strong mafic spectral signatures with little alteration.

Unit Morphology: The central peak is divided into three general units (Figure 1). The first contains angular light-tone blocks, along the periphery of the central peak. This unit has a very strong olivine spectral signature (Figure 2) and displays negative relief. The second unit forms much of the central peak bedrock and is characterized by a strong low-calcium pyroxene (LCP) spectral signature (Figure 2). The third is spectrally bland and is dark toned and shows abundant small angular clasts, several to tens of meters across, and is widely distribution throughout the crater floor and on the central peak structure.

Unit Mineralogy: The light-toned olivine-bearing unit does show a weak alteration absorption with a 1.9 µm H_20 related feature, but the highly defined olivine absorption indicates no more than a few percent hydrous alteration minerals [13]. The ratioed 1 µm olivine absorption is among the most pristine seen on Mars with clearly distinguishable M1 and M2 features (Figure 2) [8]. MGM fits of these features can constrain the cation composition of the olivine mineralogy (Figure 3). Applying these modeled fits to the relationship developed from laboratory spectra [8] we determine an initial value of Fo# 52, while understanding that our modeled band widths are atypical for this procedure [14]. Similarly, the cation composition of the pyroxene-bearing unit can be constrained with the MGM. Laboratory analysis has shown that the relative pyroxene abundance is related linearly to the ratio of the endmember absorptions strengths to within ±10% [15]. From the spectral fit in Figure 4 we see a LCP/(LCP+HCP) value of 0.56 for the 1 µm region and 0.53 for the 2 µm region. This indicates sub equal LCP-HCP composition with a slight LCP enrichment.

Conclusions: Examination of sites of deep crustal exposure in the southern highlands often displays three distinct units. A light-toned, olivine-bearing unit that is often exposed in discrete deposits. Lack of any 2 µm absorption band indicates no pyroxene but cannot rule out the presence of common minerals with weak VNIR features like plagioclase. The strong olivine feature points to a dunite composition with a few percent hydrated alteration minerals to account for the weak 1.9 µm feature. The widespread pyroxene-bearing bedrock unit with absorptions on the short side of 1 and 2 µm indicating slight LCP enrichment. Again, ratio spectra show classic pyroxene features indicating very low if any amounts of other minerals with a VNIR response. This unit would be classified as an unaltered websterite with intermediate composition. Finally, a spectrally bland smooth unit that typical surrounds the olivine-bearing unit and fills in much of the crater floor and contains varying amounts of light-toned angular clasts and may be a clast-rich impact melt. We plan to extend these analyses with TES mineral estimates.

Références: [1] Elkins-Taunton et al. (2005) *J. Geophys. Res.* 110, E12S01. [2] Taylor et al. (2007) *J. Geophys. Res.* 111, E03S10. [3] Christensen, P.R. et al. (1992) *Space Science Reviews*, 110, 85-130. [3] Mittlefehldt, D.W. (1994) *Meteoritics* 29, 214-221 [4] Murchie et al. (2007) *J. Geophys. Res.* 112. [5] McEwen et al (2007) *J. Geophys. Res.* 112. [6] Malin et al. (2007) *J. Geophys. Res*. 112. [7] Sunshine and Pieters (1993) *J. Geophys. Res.* 98, E5, 9075-9087 [8] Sunshine and Pieters (1998) *J. Geophys. Res.* 103, E6, 13675-13688. [9] Sunshine at al. (1990) *J. Geophys. Res.* 95, B5, 6955-6966. [10] Pelkey et al . (2007) *J. Geophys. Res*. 112, E08S14. [11] Tornabene et al (2010) *LPSC LVI* [12]Melosh, H.J. (1989) *Oxford Univ. Press*. [13]Ehlmann et al. (2009) *LPSC LX* Abstract #1771 [14] Isaacson et al. (2010) *LPSC VLI* Abstract #1809 [15] Kanner et al. (2007) *Icarus* 187, 442-456

Representative Spectra of Alga Crater Units

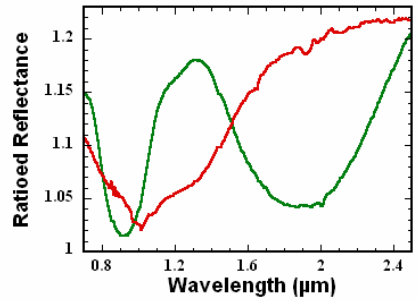
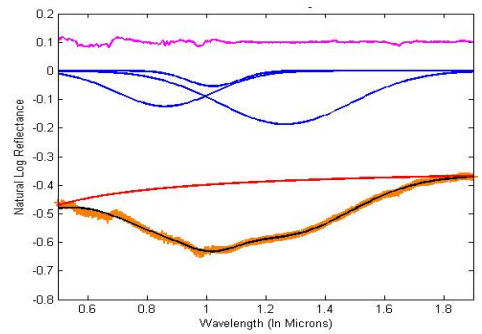


Figure 2: Ratioed spectral representations of the olivine-bearing unit (red) and pyroxene-bearing unit (green).

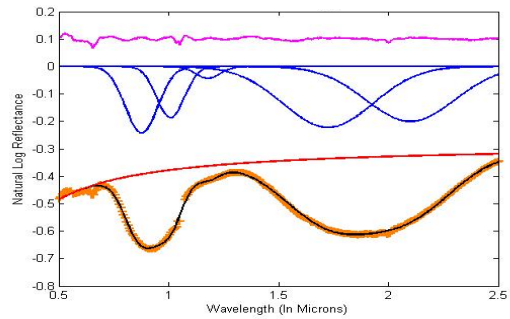
MGM Model of Olivine Absorption



Band	Band center (µm)	Band Width (µm)	Band Strength
1	0.86	0.39	-12.5
2	1.02	0.21	-5.4
3	1.27	0.52	-18.7

Figure 3: Left: MGM fit of ratioed CRISM olivine spectra from Alga crater. Red: continuum, Orange: ratioed CRISM data, Black: spectral fit, Blue: modeled absorptions, pink: model error. Table contains parameters of fitted bands. In this iteration all parameter were allowed to vary.

MGM Model of Pyroxene Absorption



Band	Band center (µm)	Band Width (µm)	Band Strength
1	0.88	0.17	-24.2
2	1.01	0.15	-18.7
3	1.18	0.13	-4.3
4	1.72	0.49	-22.2
5	2.10	0.48	-20.0

Figure 4: MGM fits of ratioed CRISM pyroxene spectra from Alga crater. Red: continuum, Orange: ratioed CRISM data, Black: spectral fit. Table contains parameters of fitted bands. Blue: modeled absorptions, pink: model error. In this iteration all parameter were allowed to vary.