Spectroscopic and Morphological Analysis of Alga Crater's Central Peak: Implications for Mars Primary Crust Formation.

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Introduction: The igneous crust of Mars has undergone a dramatic shift in composition throughout the differentiation and history of the planet. The majority of the unaltered igneous surface is dominated by Hesperian-aged basaltic volcanic plains [1] that are partially characterized by a significant proportion of high-calcium pyroxene (HCP) [2] and typically an olivine component. This is in contrast to observations of Noachian igneous terrains that are relatively enriched in low-calcium pyroxene (LCP) [3].

Well exposed Noachian mafic terrains are rare on Mars. Among the most pristine outcrops are in the central peaks of relatively well-preserved craters uplifted from depth later in Martian history, avoiding the intense near-surface weathering and aqueous alteration during the Noachian [4, 5]. The central peak of the ~18 km diameter Alga crater is one of the best spectrally exposed mafic units on Mars and is well suited for the application of several spectral methods for compositional determination. Here we combine an in-depth lab supported spectral analysis to determine the unaltered mafic composition or the upper crust.

Data: The morphology and topography of the Alga Crater central peak were determined by stereo imagery obtained by the High Resolution Imaging Science Experiment (HiRISE) [6]. Visible and near-infrared (VNIR) spectral data was acquired by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) instrument on the MRO spacecraft [7].

Methods: This study focuses on the spectral determination of the mafic composition of the lithologies exposed within the central peak of Alga crater as likely outcrops of unaltered Noachian crust. Composition was determined with spectral observations in the VNIR wavelengths. The Modified Gaussian Method (MGM) [8, 9, 10] was used to model crystal field absorption features to estimate the mafic mineral compositions measured spectra from the CRISM instrument.

Olivine is characterized by a 1 µm feature that is comprised of three overlapping absorptions, each of which was modeled with the MGM. The exact position of these absorptions are a function of cation composition ranging from shorter wavelengths for Mg-rich olivine to longer wavelengths for Fe-rich olivine [10]. Bandcenters of individual absorptions will be compared to an experimentally determined trend to calculate the Fo# (Mg/(Mg+Fe)) [10]. Of the three absorptions centered at 0.87, 1.08 and 1.25 µm, the last has

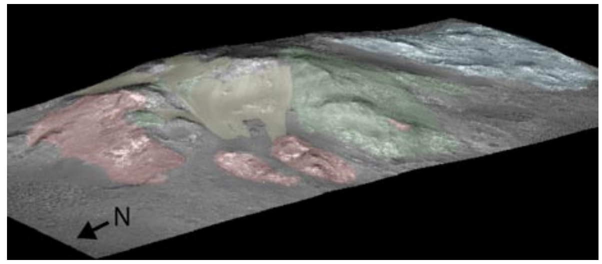

Figure 1. Oblique view of Alga Crater central peak with HiRISE topography. The olivine-bearing unit is highlighted in red, the pyroxene bedrock unit in green, the light-toned pyroxene unit in blue and the impact melt unit is the smooth texture region highlighted in yellow. Image is 2km wide east to west.

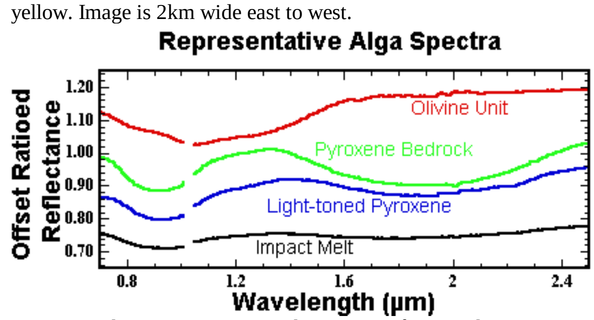

Figure 2. Characteristic VNIR observations from each main unit in the Alga Crater central peak. Spectra is ratioed against dust to highlight unique feature and are offset for readability.

the least composition sensitivity per wavelength change and is best constrained by CRISM spectra thereby determining the mineral composition.

Pyroxene units are characterized by absorptions at 1 and 2 µm [8]. The band position of each absorption is largely dependent on calcium content [8, 9]. The pyroxenes were modeled with high and low-calcium endmembers for each absorption to determine the relative calcium content. Calcium content is determined by a ratio of low-calcium endmember band strength to combined modeled absorption band strengths; (LCP/(LCP+HCP)) [12].

Observations: The central peak of Alga crater can be divided into several distinct spectral-morphological units (Figure 1). The first is a fractured and massive light-toned olivine bearing unit (Figure 2). This unit is exposed in clearly defined outcrops on the central peak and one place on crater rim near the western floor of Alga. The MGM of this unit constrains the Fo# to 30±15, indicating an enrichment in Fe over Mg (Figure 3).

The second unit is a pyroxene-bearing bedrock unit located near and occasionally in contact the olivine-bearing unit. This unit forms the main bedrock of the central peak. The well defined pyroxene absorptions features have minimums near 0.9 and 1.9 μm indicating a composition dominated by low-calcium pyroxene [Figure 2]. MGM analysis of this unit gives a LCP/(LCP+HCP) value of 0.76 ± 0.15 (Figure 4). This unit has the strongest pyroxene absorptions of any of the pyroxene exposures (Figure 2).

The third unit is a distinct pyroxene-bearing unit located at the base of the central peak in to main deposits, one to the south and one to the east of the central peak. This unit is distinctly brighter than the previous pyroxene unit but has significantly weaker absorption features and a broader 2 μm absorption potentially indicating a slightly enriched high-calcium pyroxene contribution despite a LCP/(LCP+HCP) value within error of the previous unit (Figure 2). This unit is characterized by the negative relief into the crater floor and by thin dark-toned fractures that permeate the rock.

The fourth unit occurs spatially between the first and second units. It is characterized by a weak pyroxene spectral signature and smooth texture and contains a small proportion of sub meter sized angular clasts. This unit is most likely a breccia or impact melt-bearing unit that crystallized quickly, preserving some flow textures and includes clasts of other units. The spectral signature may be due to the entrained clasts of excavated pyroxene bearing rocks. The modeled LCP/(LCP+HCP) value is also similar to the pyroxene-bearing unit but is distinct in that it has weaker absorptions (Figure 2).

Conclusions: The uplift of the Alga central peak and the well-defined spectral signatures make it an ideal location to examine the composition of the deep crust of Mars. The single plate nature of the Martian crust makes it likely that the deep exposure is sampling ancient crust that crystallized in the Early Noachian. Two key observations from this site are the lack of significant mixing between the olivine and pyroxene and the dominate low-calcium nature of the detected pyroxene. Typical Hesperian-aged Martian surface basalts contain some mixed olivine and pyroxene [1,2]. However the Alga deposits show no observable olivine-pyroxene mixing. This implies a Noachian crust that has been strongly segregated by cumulate crystallization and settling. The adjacent placement of these units argues against a mantle scale stratification and supports more local segregation process. This could represent a small scale plutonic body that experienced fractional crystallization, impact mixing of widely spaced mafic units or a complex igneous crustal stratification with well differentiated but nearby units.

The second observation is the enrichment in low-calcium pyroxene. This is consistent with crystallization from a hotter magma source capable of higher degrees of partial melt that would be dominated by orthopyroxene formation. LCP dominated units are common to Noachian terrains while Hesperian volcanics show enrichments in HCP [13], providing temporal context for these units.

While Alga crater's central peak is among the best morphologically and spectrally exposed unaltered mafic deposits on Mars, many other sites show high quality observations. In addition to the vital data point provided by this work, we are developing a clear procedure for analysis of other sites to improve the understanding of the unaltered Noachian crust of Mars.

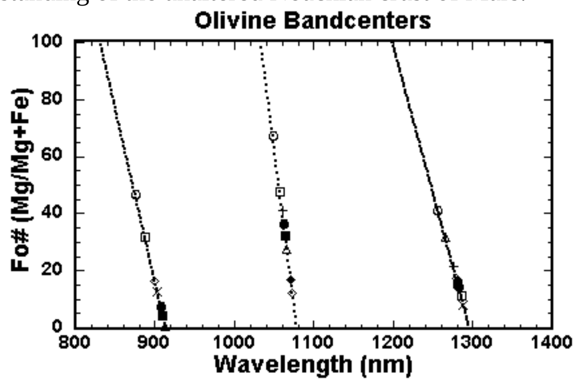

Figure 3: Bandcenters of component olivine absorptions indicated high Fe enrichment. Same symbols indicate a single olivine region. Compositional relationships based on laboratory measurements [10].

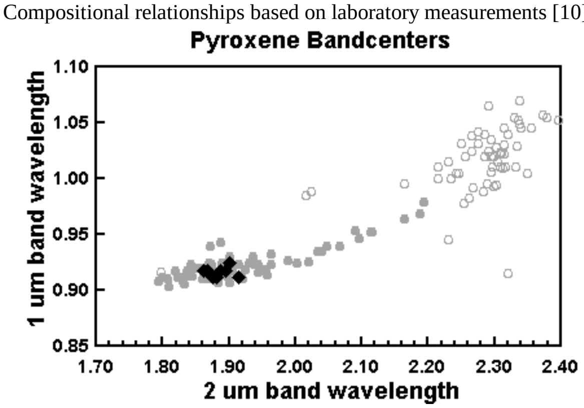

Figure 4: One micron bandcenter plotted against two micron bandcenter. Grey points are laboratory measured pyroxenes with low-calcium pyroxenes marked with filled circles and high-calcium pyroxenes marked in empty circles. Alga pyroxenes are plotted with black diamonds and are well within the low-calcium pyroxene range [14,15].

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