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VARIABILITY IN MT. SHARP GROUP BEDROCK AS SEEN BY CHEMCAM PASSIVE AND ACTIVE SPECTRA. H. T. Manelski¹, R. Y. Sheppard², A. A. Fraeman³, R. C. Wiens¹, J. R. Johnson⁴, E. B. Rampe⁵, J. Frydenvang⁶, N. L. Lanza⁷, O. Gasnault⁸, ¹Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN, USA, ²Planetary Science Institute, Tucson, AZ, USA, ³Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA, ⁴Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, USA, ⁵NASA Johnson Space Center, Houston, TX, USA, ⁶University of Copenhagen, Copenhagen, Denmark, ⁷Los Alamos National Laboratory, Los Alamos, NM, USA, ⁸Institut de Recherche en Astrophysique et Planétologie, Université de Toulouse 3, CNRS, CNES, Toulouse, France

Introduction: The Curiosity rover landed in Gale crater in August 2012 and has since been travelling up the central sedimentary mound known as Mt. Sharp. The ChemCam instrument on Curiosity was designed primarily for the use of Laser Induced Breakdown Spectroscopy (LIBS), where a laser ablates a small amount of material from the target and the spectrum of the resulting plasma yields elemental abundance data [1]. ChemCam's three spectrometers range from 240-905 nm and can also take passive spectra (without the use of the laser) [2]. The spectral range ChemCam passive spectra observe is sensitive to charge-transfer and crystal field absorptions related to iron-bearing minerals [3].

In the first 2934 sols of Curiosity's mission, 9,400 passive spectra were taken of bedrock targets in Mt. Sharp's Murray and Carolyn Shoemaker formations. We examine these spectra using spectral slope/ratio and band depth calculations as well as Principal Component Analysis (PCA). For the first time, paired passive spectra and LIBS elemental abundances are compared on a large scale. Finally, ChemMin data are compared to ChemCam passive observations to understand sources of spectral variability.

Methods: Passive spectra were trimmed to 440-840 nm because the UV spectrometer responsivity, VIO spectrometer responsivity <440 nm, and VNIR spectrometer responsivity >840 nm are relatively low. Spectra were smoothed using a Savitzky-Golay filter. Only spectra classified as "bedrock" within the Murray and Carolyn Shoemaker formations prior to sol 2934 were included. Various spectral parameters were calculated including band depth at 535 nm (BD535) and slope between 840 nm and 750 nm (S7584). BD535 is caused by the presence of ferric phases and S7584 is a proxy for a broad absorption at ~860 nm, related to some ferric phases such as hematite [3].

To determine the primary sources of variance in passive spectra, PCA was used. PCA reduces dimensionality and represents each spectrum with a few principal components that can explain a large percentage of the overall variance in the dataset. The PCA results and spectral parameters were compared to elemental abundance data derived from LIBS.

Results: The first principal component explained 92.62% of the variance in the dataset and was strongly correlated with average relative reflectance (Spearman's $\rho = 0.99$). PC2 accounted for 6.61% of

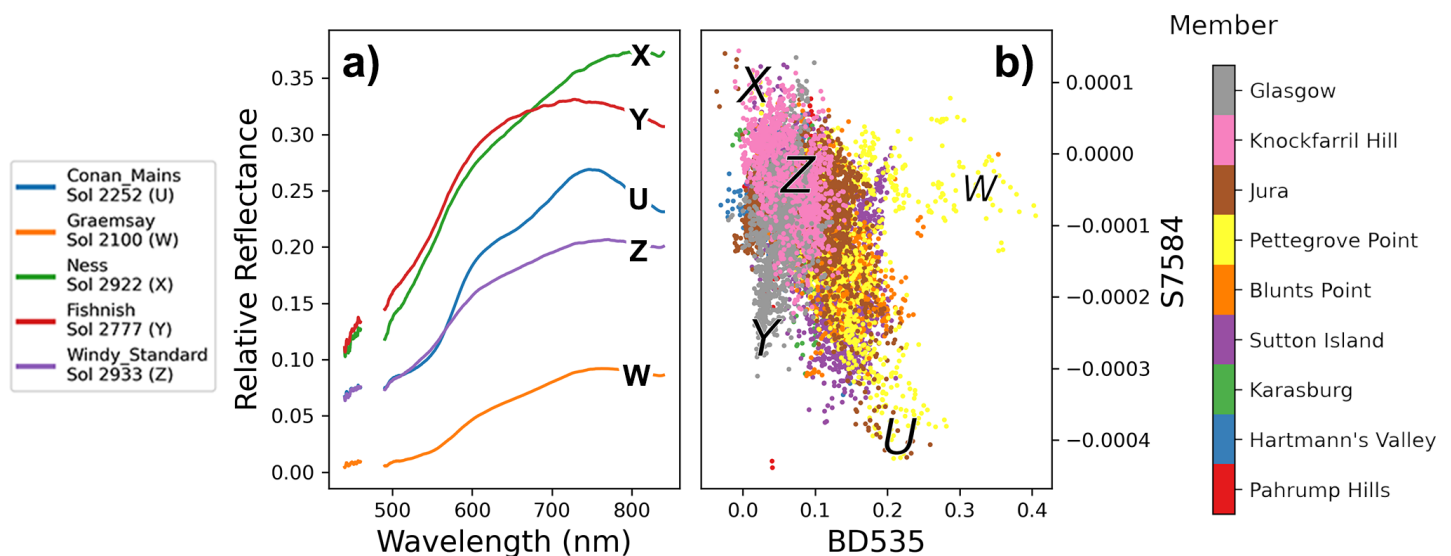


Figure 1. (a) Relative reflectance plotted against wavelength for five endmember spectra. (b) S7584 plotted against BD535, colored by geologic member, for all passive ChemCam observations in the dataset. Letters U-Z in (b) correspond to the spectra shown in (a), which are averages for a given target.

the variance and was negatively correlated with BD535 ($\rho = -0.73$). PC3 and PC4 explained 0.42% and 0.23% of the variance respectively. PC3 was weakly correlated with BD600 ($\rho = 0.6$) and PC4 was negatively correlated with S7584 ($\rho = -0.85$). Cumulatively accounting for less than 0.12% of the variance in the dataset, PCs beyond PC4 were not found to correlate with any spectral parameters.

There are significant variations in the passive spectral parameters across the Mt. Sharp group. BD535 increases until the Sutton Island-Blunts Point boundary where it decreases. Another decrease in BD535 is seen in Jura, followed by a more gradual decrease during the rest of the traverse. There is a peak in BD535 near the area in the Vera Rubin ridge (VRR) with the deepest BD860 absorptions seen by CRISM from orbit [4]. Plotting S7584 against BD535, two parameters demonstrated by PCA to explain significant variance in the dataset, reveals four endmember spectra (Fig. 1). Class U exhibits large BD535 values and steep NIR slopes, indicative of ferric oxides such as hematite. Class Y is a group of observations in the Glasgow member with steep NIR slopes but near-zero BD535. Class W are spectra taken during the 2018 global dust storm [5] and have features consistent with atmospheric dust contamination (low average relative reflectance, anomalously high R6744, very strong BD535).

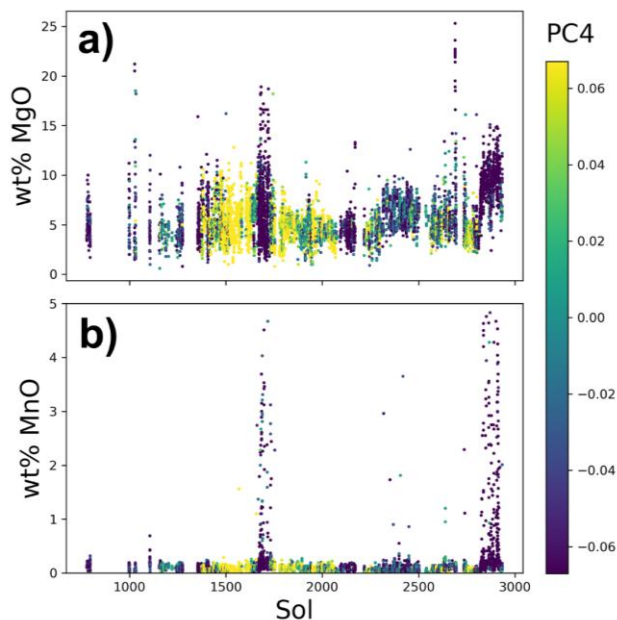


Figure 2. Weight percent MgO and MnO plotted against sol. Colored by PC4.

When considering all Mt. Sharp group bedrock targets, there were no correlations between any major or trace oxides measured by LIBS and passive spectral

parameters. There is, however, a relationship between PC4 and high magnesium and high manganese targets (Fig. 2). High MgO/MnO targets, such as those around the Sutton Island-Blunts Point transition as well as in Knockfarril Hill tend to have lower PC4 than the surrounding bedrock.

Comparison between passive spectra and Chemistry and Mineralogy (CheMin) data showed that total ferric phases (hematite + akageneite + jarosite) was correlated with BD535 ($\rho = 0.75$) in the 14 drilled targets in the dataset modified by Curiosity's Dust Removal Tool (DRT). Amorphous FeO_T was also moderately correlated with S7584 ($\rho = 0.66$).

Discussion: PCA showed that after average relative reflectance, the biggest driver of variability in ChemCam passive spectra in Mt. Sharp group bedrock was changes in ferric-related absorptions (BD535 and S7584). This work highlights the spectral uniqueness of the Sutton Island-Blunts Point transition as well as the Glasgow member. Most Knockfarril Hill targets have spectral features similar to typical Mt. Sharp bedrock, whereas in Glasgow there are many targets with low BD535 and strongly negative NIR slopes (Class Y in Fig. 1). This could be the result of average Mt. Sharp group bedrock mixing with a spectral endmember with coarser grained ferric phases; interestingly, this interval is believed to be a transition from a predominantly lacustrine to fluvial setting.

Comparison of LIBS and passive data highlights the Sutton Island-Blunts Point transition as a region of interest. Magnesium rich targets in this region, previously identified as hydrated magnesium sulfates [6], were found to have significantly lower S7584 (lower PC4) than the surrounding bedrock. This area has been proposed as a region of low lake level [6] and this work is consistent Mastcam observations which indicate a significant decrease in crystalline hematite in this interval compared to the rest of the Murray formation [7].

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