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**CLASSIFICATION OF CHEMCAM PASSIVE SPECTRAL TARGETS IN GALE CRATER.** H. T. Manelski<sup>1</sup>, R. Y. Sheppard<sup>2</sup>, A. A. Fraeman<sup>2</sup>, J. R. Johnson<sup>3</sup>, R. Wiens<sup>4</sup>, N. Lanza<sup>4</sup>, J. Frydenvang<sup>5</sup>, O. Gasnault<sup>6</sup>, <sup>1</sup>Columbia University, New York, NY, <sup>2</sup>Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, <sup>3</sup>Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, <sup>4</sup>Los Alamos National Laboratory, Los Alamos, NM, <sup>5</sup>University of Copenhagen, Copenhagen, Denmark, <sup>6</sup>L'Institut de Recherche en Astrophysique et Planétologie, Toulouse, France

**Introduction:** The Curiosity rover is exploring and characterizing the sedimentary mound Mt. Sharp in Gale Crater. The ChemCam instrument onboard the rover contains three spectrometers designed to measure the plasma formed during Laser Induced Breakdown Spectroscopy (LIBS) where the laser vaporizes a rock target. LIBS is useful when analyzing dusty targets and provides detailed chemical information in a small area (~250-550  $\mu\text{m}$  spot diameter) [1]. Early in Curiosity's mission, a new method was developed wherein ChemCam can be used to collect passive spectral observations (without the laser), obtaining meaningful spectral data on target composition [2]. These high-spatial and spectral resolution spectra span 440-840 nm and are especially useful in documenting changes in iron-bearing phases which cause charge transfer and crystal field absorptions in this spectral range.

In the first 2934 sols of Curiosity's mission ChemCam collected 33,468 passive spectra of a variety of different target types from rocks to veins to calibration targets [6]. We performed statistical analyses

on the complete dataset of ChemCam passive spectra from the Bradbury and Mt. Sharp groups to classify the spectra into meaningful groups, compare spectral classes to LIBS elemental abundances, and examine these results in their stratigraphic context.

**Methods:** We trimmed ChemCam passive data to 440-840 nm to remove spectral regions with low signal-to-noise. We then passed the spectra through a Savitzky-Golay filter for smoothing, making it less likely that observed spectral features were the result of localized noise. Only bedrock targets were included.

To explore the spectral diversity and help classify spectra into groups, we used Principal Components Analysis (PCA) to reduce dimensionality and represent the dataset with orthogonal principal components (PCs), explaining a high percentage of the variance in the dataset with only a few axes needed (Fig. 1).

We also calculated spectral parameters relevant to this spectral range (440-840 nm). Two prominent parameters we used were band depth at 535 nm (BD535) and the slope between the reflectance at 750

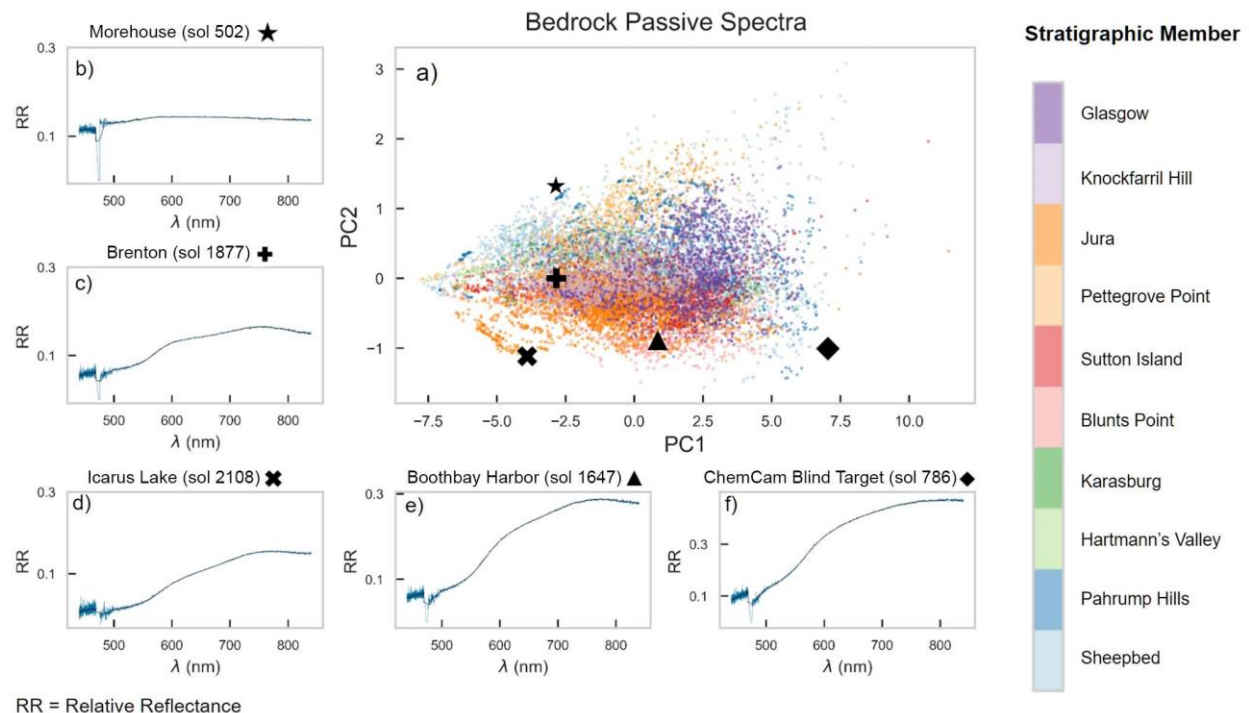


Fig. 1. (a) ChemCam passive spectral statistical analyses highlighting variance. Principal component 2 (PC2) of all spectra plotted against principal component 1 (PC1), colored by geologic member. Example end member spectra (b-f) are taken along each axis with the symbol in their title corresponding to a point on the main plot, informal target names are listed.

and 840 nm (S8475). An absorption at 535 nm is caused by the presence of crystalline ferric oxides in the target [2] and S8475 is indicative of the strength of another ferric iron absorption centered ~850-920 nm [3].

Most passive spectra targets also had corresponding LIBS elemental measurements, allowing for the pairing of LIBS chemical data to passive spectral mineralogical data. We created plots showing how the passive spectral data compare with the elemental abundances provided by LIBS.

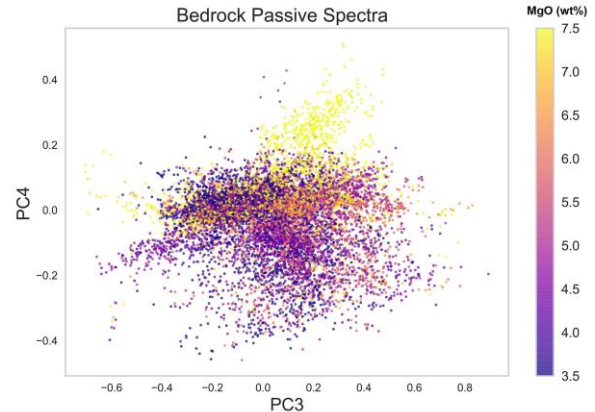
**Results:** PC1 explains 92.11% of the variance and corresponds to target albedo (Fig. 1, d vs. f). PC2 explains 7.24% of the variance and has a negative correlation with BD535 (Spearman's  $\rho = -0.668$ ). PCs 3 and 4 cumulatively represent less than 0.6% of the variance in the dataset but still have meaningful relationships to chemical abundances from LIBS.

We divided spectra into eleven distinct spectral classes based on BD535, S8475, and analysis of the individual spectra. This was accomplished by combining smaller groupings until shared traits (both quantitative and qualitative) became evident. The spectral class with very strong BD535 and the most negative S8475 values mapped to the Vera Rubin ridge (VRR), an area known from CRISM orbital observations to be rich in hematite ( $\alpha\text{-Fe}_2\text{O}_3$ ) [4]. The class with the highest BD535 values and low S8475 mapped to Pettegrove point during sols where the rover measured targets with exceptionally low albedo; these observations were taken during the 2018 global dust storm and were removed from further analysis.

Targets with high albedo (PC1) tended to be rich in  $\text{SiO}_2$ . The observations with the highest concentration of  $\text{SiO}_2$  (>70%  $\text{SiO}_2$ ) have very low BD535 and S8475, indicating there is little to no  $\text{Fe}^{3+}$  present. The highest FeOT targets (>25% FeOT) also have low BD535; this is consistent with the highest FeOT targets along Curiosity's traverse being composed of ferrous iron minerals that lack this  $\text{Fe}^{3+}$  absorption feature.

Plots of areas with high  $\text{K}_2\text{O}$  and high MgO concentrations form two distinct clusters. High MgO targets (>9%) tend to exhibit S8475 near zero whereas high  $\text{K}_2\text{O}$  targets have more negative S8475 values. MgO and  $\text{K}_2\text{O}$  rich regions are better distinguished based on their 3<sup>rd</sup> and 4<sup>th</sup> PCs (Fig. 2). Examination shows that PC3 is positively correlated with the slope between the reflectance at 750 and 600 nm (S7560), with PC4 separating the MgO and  $\text{K}_2\text{O}$  rich regions. A positive correlation between PC3 and sol is observed in spectra with high MgO (Spearman's  $\rho = 0.677$ ).

There is a MgO rich spur with exceptionally high PC3 and PC4 between sols 2815 and 2925 (Fig. 2). These observations were taken in Knockfarril Hill and have very high S7560 and minimal BD535.



**Fig. 2.** PC4 plotted against PC3, colored by MgO concentration from LIBS observations.

**Discussion:** PCA of Murray bedrock passive spectra (440-840 nm) from Curiosity's ChemCam instrument showed that the main driver of spectral variance is albedo with the second largest being the presence of a spectral absorption at 535 nm caused by the presence of  $\text{Fe}^{3+}$ . The third and fourth PCs, collectively less than 0.6% of the variance in the dataset, proved useful in identifying areas rich in MgO and  $\text{K}_2\text{O}$  (Fig. 2). Targets with the largest BD535 and S8475 mapped to an area (the VRR) with deep spectral absorptions attributed to red hematite in orbital observations. While some of the targets on VRR had higher than average FeOT concentrations, many of the observations with the highest FeOT had low BD535 values, highlighting regions of Curiosity's traverse that contain iron-rich but non-oxidized phases.

Future research will focus on expanding these findings by performing these analyses on non-bedrock target types, especially the abundant  $\text{CaSO}_4$  veins found throughout Mt. Sharp [5], and further investigating the dichotomy between MgO and  $\text{K}_2\text{O}$  rich observations.

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