SCIENCE RESULTS FROM A COMPREHENSIVE MASTCAM SPECTRAL DATABASE FOR CURIOSITY'S TRAVERSE.

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Introduction: The Mars Science Laboratory Curiosity rover has traversed nearly 20 km and gained over 375 m in elevation since landing in 2012. Across this traverse, Curiosity has encountered a wide variety of stratigraphic units, the chemical and mineralogical compositions of which have been studied in detail using remote sensing (ChemCam), *in-situ* (APXS), and laboratory (SAM and CheMin) investigations. In addition to these quantitative techniques, Curiosity's Mastcam multispectral instrument can help to constrain mineralogy qualitatively and extend the mapping of compositional units beyond where *in-situ* measurements have been acquired.

To date, nearly 500 Mastcam multispectral images have been acquired, but no traverse-scale analysis of the full multispectral dataset has yet been performed. In this work, we present initial science results from the first comprehensive analysis of all multispectral observations. Our objectives are to: (1) quantify systematic variations in Mastcam multispectral parameters along the full traverse; (2) compare to ChemCam passive spectra and to chemo-stratigraphic variations seen by ChemCam and APXS; and (3) define broad Mastcam multispectral classifications to help constrain variations in mineralogy and iron oxidation.

Methods: Mastcam is a multispectral, stereoscopic imaging instrument that can acquire visible to near-infrared (VNIR) spectra in 12 unique wavelengths from ~400-1000 nm [1], which are calibrated as described by [2] and [3]. Unlike the CheMin, SAM, APXS and ChemCam instruments, which acquire data from a single spot or raster in each observation, Mastcam acquires on the order of a million spectra in a single observation (one in each pixel). To analyze this immense dataset, we have developed a systematized process for extracting a limited number of representative "end member" spectra from each multispectral observation. All spectra and accompanying metadata (including feature type, viewing geometry, sol, local true solar time (LTST), tau, elevation, L_S, etc.) have been compiled into a searchable database. Full details of this methodology, the database and analysis software are provided in [4].

Results: The Mastcam wavelength range is particularly sensitive to variations in iron mineralogy and oxidation state. Mastcam spectral parameters that broadly distinguish iron oxides from other iron-bearing minerals include the 527 nm band depth, the 867 nm band depth, and the 495 to 676 nm slope (a "redness" parameter). Across Curiosity's traverse, we observe broad variations in these three parameters that correlate with known variations in outcrop composition. Figure 1 shows a comparison of Mastcam 867 nm band depth to a related parameter calculated from ChemCam passive spectra (750 - 840 nm slope) [5], with notable similarities in the broad spectral trends observed by both instruments. This agreement is impressive, considering the differences in spectral and spatial sampling between the two instruments: in its "passive" mode, ChemCam acts as a point spectrometer that collects spectra from ~1-2 mm sized spots at thousands of wavelengths between 400 and 840 nm [6], whereas Mastcam spectra are averaged from regions covering several to tens of cm [4].

In interpreting Mastcam spectra, it is important to understand which variations are due to outcrop oxidation state, and which might reflect differences in dust cover and/or viewing geometry. To minimize these complicating factors, we can restrict our analyses to observations acquired within 90 minutes of local noon (LTST 10:30-13:30) and to outcrop targets that are nearly dust-free (dust removal tool (DRT) targets, drill sites, freshly-broken or strongly-windswept rocks). Figure 1 shows the relatively dust-free targets emphasized as larger symbols, and it is these spectra that most closely follow the trends in ChemCam passive spectra. (The ChemCam passive spectra are of dust-free surfaces as well, as they are acquired after LIBS shots that clear dust from the spectrometer's field of view [7]).

To further rule out variations in viewing geometry and/or atmospheric dust opacity as causes of observed spectral variations, we can also compare outcrop spectra to adjacent soil spectra, which are expected to be more homogenous across the traverse [*e.g.,* 8]. Any spectral variations due to illumination effects should impact the entire Mastcam observation, and therefore if trends in spectral parameters are seen in outcrop that do not track with soil variations, those are most likely due to real outcrop properties. Figure 1 shows that the 867 nm band depth for soils across the traverse is restricted to a narrow range of negative values, whereas the clean outcrop spectra exhibit a much wider range (with band depths approaching 0.10 on the Vera Rubin Ridge).

The creation a comprehensive Mastcam spectral database also allows for comparisons of specific stratigraphic units to the full suite of traverse lithologies. For example, Figure 2 shows the red slope and 867 nm band depth values for members of the Murray Formation on the Vera Rubin Ridge compared to relatively dust-free outcrop targets observed across the entire traverse. Rocks in the Pettegrove Point member plot in a distinct region of this parameter space, as they have consistently "redder" and have stronger 867 nm bands than other units. In contrast, the Jura member outcrop spectra span the full range of the parameter space, including the highest 867 nm band depths observed to date at "red" Jura rocks, but also some of the lowest values at "gray" Jura targets. This observation is consistent with a range of oxidation states and spectral subclasses within this member [*e.g.,* 5]. Further spectral trends corresponding to variations in bedrock lithology are presented in [9].

Conclusions: Trends in Mastcam spectra across Curiosity's full traverse show a wide range in parameter values associated with ferric iron, and these are largely consistent with results from ChemCam passive spectra. This cross-instrument comparison demonstrates that multispectral data correlate with known compositional trends, and thus going forward, Mastcam multispectral images can be used to extend chemical/mineralogic mapping to regions where *in-situ* and/or ChemCam measurements are not available.

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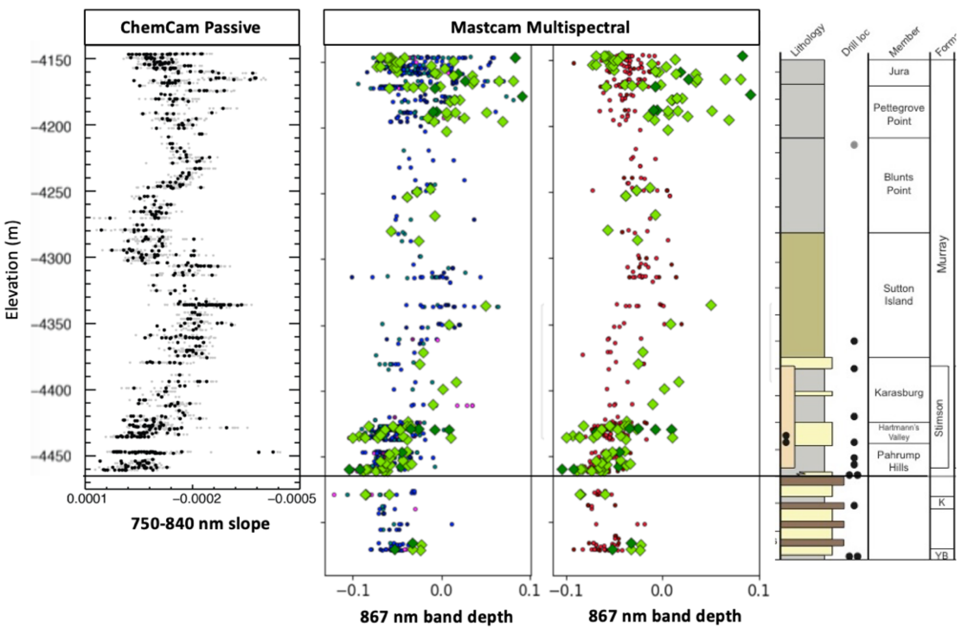

Figure 1. Comparison of variations in the Mastcam 867 nm band depth to ChemCam passive spectral variations with elevation across Curiosity's traverse. Green diamonds in Mastcam data represent dust-cleared outcrop targets, small blue dots in the middle left plot represent other (dusty) outcrops, and small red dots in the middle right plot represent soil spectra. Soil spectra are largely consistent across the full elevation range, whereas outcrop spectra show significant variation in iron oxidation parameters. Stratigraphic column on right from [10].

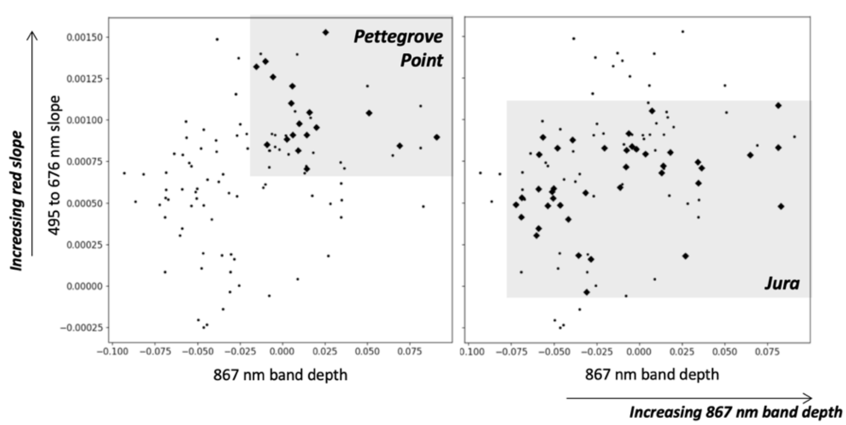

Figure 2. Parameter space plots from Mastcam spectra of all dust-cleared outcrops imaged across Curiosity's traverse (shown in small dots). The "red slope" from 495 to 676 nm and the 867 nm band depth parameters are indicative of increased iron oxidation. Left: large diamonds indicate values from dust-cleared rocks within the Pettegrove Point member on the Vera Rubin Ridge; Right: large diamonds indicate values from dust-cleared rocks of the Jura member.