THE CHEMOSTRATIGRAPHY OF LOWER MT. SHARP: USING ROVER-SCALE OBSERVATIONS TO TEST ORBITAL-SCALE HYPOTHESES.

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Background: In September, Curiosity crossed a geologic boundary that put its wheels on strata that orbital-based mapping demonstrate are part of lower Mt. Sharp [1]. These rocks exhibit variable dust/soil cover, but it is clear from both rover and orbital imagery that there is a greater exposure of bedrock in this region than on the hummocky plains that dominated Curiosity's traverse path to the north. This is consistent with orbitally-acquired CRISM reflectance spectra that show these units to represent the stratigraphically lowest detections of hematite and hydrated minerals in Mt. Sharp [2]. Curiosity now begins a journey in which orbital mineral detections and associated hypotheses can be assessed at the rover scale.

This portion of lower Mt. Sharp (Pahrump Hills) consists of sedimentary lithologies that include mudrocks and sandstones. The apparent susceptibility of these units to eolian erosion is variable, with the stratigraphically lower beds being consistent with finer-grained lithologies that erode to form shallow slopes and overlying units containing coarser-grained beds that form steeper slopes. At the ~18 m/pixel scale of CRISM data it is likely that the finer-grained, low-slope forming beds dominate the orbital spectral signatures due to greater areal exposure, and it is these units that have thus far dominated Curiosity's exploration of the Pahrump Hills (Fig. 1).

CRISM signatures of strata equivalent to Pahrump Hills indicate the presence of hematite and one or more hydrated phases [2]. The former was confirmed (~8 wt.%) *in situ* by CheMin XRD analysis of the Confidence Hills drill target in the lower exposures of Pahrump [3]. Orbital signatures of the hydrous component(s) are ambiguous enough that possible phases may include hydrated salts (e.g., jarosite, gypsum), clay minerals, and/or hydrated silica. Alternatively, the observed metal-OH and H_2O absorptions may be associated with XRD-amorphous components.

Curiosity's initial traverse of the Pahrump Hills (Pass 1) focused on remote sensing (e.g., Mastcam imagery and ChemCam LIBS/RMI data). The subsequent Pass 2 traverse re-examined these strata with a focus on contact science (APXS chemistry and MAHLI imaging). Curiosity's systematic documentation of chemical and textural trends as a function of stratigraphic position can be combined with orbital CRISM data to significantly enhance our understanding of how to interpret orbital-scale observations in their proper context.

Specifically, detailed chemostratigraphic analysis using Curiosity's payload, coupled with textural information from imaging, can help us determine which chemical/mineralogical signatures reflect variations in primary sediment composition versus diagenetic processes. Such observations can be placed in stratigraphic context and understood in terms of process, which will in turn help us understand how best to interpret orbital data in Gale beyond the traverse path of Curiosity.

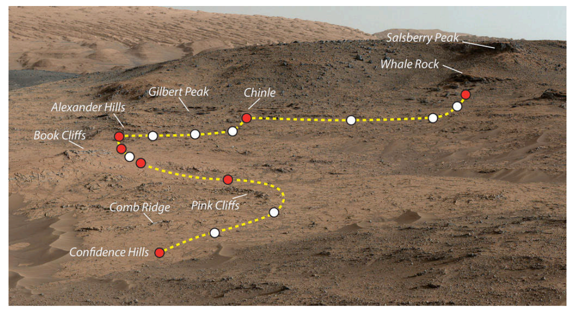

Figure 1. Pahrump Hills as seen by Mastcam, with labels for major outcrops explored during Pass 1 & 2. Red points indicate Pass 1 locations. Courtesy NASA/JPL/MSSS.

Methods: In increasing stratigraphic position, primary outcrops of the Pahrump Hills include Shoemaker, Confidence Hills, Pink Cliffs, Book Cliffs, Alexander Hills, Chinle, and Whale Rock [4]. During Pass 1, ChemCam examined a variety of bedrock and diagenetic targets within these outcrops, many of which were acquired as 10 or 5 point vertical rasters that ran perpendicular to bedding and/or laminations. Data for individual points were arranged in increasing stratigraphic order. Points within an observation are evenly spaced, but the vertical and/or horizontal distance *between* different observations is variable.

Corresponding RMI images showed that some points within individual observations were associated with diagenetic features (e.g., veins, nodules); these points were removed from our analysis such that the results reported here are considered to be the best representation of bulk bedrock chemistry (including possible cementing agents) as observed by ChemCam. Oxide averages for each point were calculated by the ChemCam team using the PLS1 routine [5] for Si, Al, Fe, Mg, Ca, Na, K and Ti. These oxide values were normalized to sum to 100%. The resulting stratigraphically ordered ChemCam point measurments were examined individually and also passed through a 3-point moving average to reduce point-to-point variability and to highlight dominant chemostratigraphic trends (e.g., Fig. 2). Individual elemental abundances and elemental ratios (e.g., to Si) were examined for comparison against APXS data acquired in similar stratigraphic units.

In this study we focus on APXS bedrock targets that were brushed prior to analysis and diagenetic targets (e.g., nodules) that were either brushed or unbrushed. APXS oxide abundances were provided by the APXS team and the same oxides reported by ChemCam were normalized to sum to 100%. APXS was also used to assess variations in S, Cl, and Br abundance.

Results: Our chemostratigraphic analysis of ChemCam and APXS data indicate that major elements (Si, Mg, Fe, Ca, Na, K) vary to different degrees throughout the Pahrump section, with at least three chemically distinct rock types [6]. Notably, there is an apparent increase in Al, decrease in Si, and decrease in Fe in strata between Confidence Hills and Whale Rock that is observed by both instruments (e.g., Al/Si trend in Fig 2). The uppermost outcrop (Whale Rock) exhibits increased Ca, Na, Mg, Fe and decreased Si, Al, and K compared to underlying outcrops, consistent with an increased salt (sulfate or chloride?) abundance as suggested by numerous light-toned veins and masses observed in Mastcam and RMI images of these sandstones. As a whole, these data indicate that the Confidence Hills drill sample is enriched in Fe and depleted in Si compared to most of the strata in this location. One possibility is that this is a reflection of the drill location containing a higher proportion of Fe-oxides.

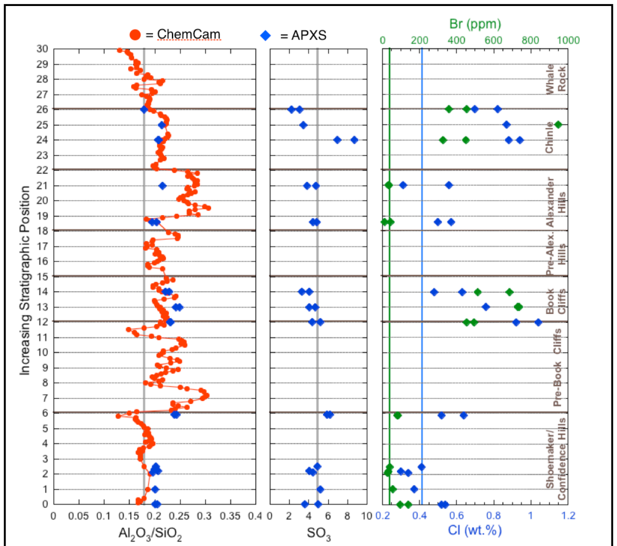

Figure 2. ChemCam and APXS chemostratigraphy of the Pahrump Hills. Al/Si is elevated in all middle units compared to the Confidence Hills bedrock and drill sample. APXS Br and Cl data are also elevated in some of these strata, indicating salts may be important diagenetic phases, possibly contributing to orbital spectral signatures in lower Mt. Sharp. Vertical lines indicate drill sample values.

APXS data show that diagenetic features are increased in Mg, Ca, S, and Cl relative to bedrock, suggesting they contain a higher proportion of salts. Trends in these elements within bedrock targets are more variable. Book Cliffs bedrock targets exhibit a pronounced increase in Cl and Br (Fig. 2) and yield high CIA values, but there is no corresponding increase in S. Indeed, bedrock targets exhibit poor correlations between Mg or Ca and S, whereas Mg and Cl are positively correlated. In general, abundance of redox sensitive elements such as Fe and Mn exhibit minimal variation between Confidence Hills and WhaleRock.

Figure 3. MAHLI image of Topanga target in Book Cliffs outcrop. Dark and light 'clasts' are indicataed by black and white arrows, respectively. These rocks also exhibit increased levels of Br and, to a lesser extent, Ca.

Conclusions: Major chemical trends observed by ChemCam are typically also observed in APXS data for stratigraphically equivalent targets (we note that ChemCam and APXS data are often not acquired on identical locations), though the former exhibit greater variability within the measured section. Strata with increased Al/Si may indicate increasing proportions of non-silicate components (i.e., salts), which would also be consistent with the observation that certain outcrops exhibit increases in Cl, Br, and S.

The chemostratigraphy of Pahrump indicates proportions of siliciclastic and cements/early diagenetic components likely vary, where the latter may result from near-surface evaporative processes or deeper basinal brines. Such processes are suggested by the presence of and relationship between light and dark-toned 'clasts' seen in MAHLI images of some targets (Fig. 3). These features are not observed in all outcrops and may be crystal growths associated with the increased Br and Cl values seen by APXS.

Absolute wt.% Fe is not highly variable, but orbital detections of hematite and the presence of significant amounts of Fe-oxides in the drill target suggest understanding the mineralogical host(s) of Fe will be important in assessing the habitability of this portion of lower Mt. Sharp. Hydrated salts may be responsible for the orbital CRISM signatures, and if confirmed by additional *in situ* measurements this could imply that volumentrically minor diagenetic components may dominate spectral signatures in lower Mt. Sharp.

References: [1] http://mars.jpl.nasa.gov/msl/news/-whatsnew/ press release 11-Sep-2014; [2] Milliken, R.E. et al. (2010), *GRL*, 37, L04201; [3] http://mars.jpl.nasa.gov/msl/news/whatsnew/ press release 4-Nov-2014; [4] Stack, K. et al. (2015) *this conference*; [5] Wiens et al. (2013) *Spectrochim. Acta B*, 82, 1-27; [6] Forni, O. et al. (2015) *this conference*.