CHEMISTRY OF MILLIMETER-SCALE PETROGRAPHIC ENDMEMBERS DETERMINED BY THE MARS SCIENCE LABORATORY ALPHA PARTICLE X-RAY SPECTROMETER AND MARS HAND LENS IMAGER. S.J. VanBommel[1], R. Gellert[1], L.M. Thompson[2], J.A. Berger[3], J.L. Campbell[1], K.S. Edgett[4], M.J. McBride[4,5], M.E. Minitti[6], E.D. Desouza[1], N.I. Boyd[1], and the MSL Team, [1]University of Guelph, Guelph ON, Canada, [2]University of New Brunswick, Fredericton NB, Canada, [3]University of Western Ontario, London ON, Canada, [4]Malin Space Science Systems, San Diego CA, USA, [5]Purdue University, West Lafayette IN, USA, [6]Planetary Science Institute, Tucson AZ, USA.

Introduction: The Alpha Particle X-ray Spectrometer (APXS) is an arm-deployed bulk chemistry instrument that conducts high-precision in-situ measurements of Martian rocks and soils onboard both active NASA rovers [1]. The APXS on the Mars rover *Curiosity* is capable of conducting multi-spot (raster) investigations in a single evening. By combining APXS raster spectra and Mars Hand Lens Imager (MAHLI) images, we can localize the APXS field of view (FOV) positions, thereby mitigating arm placement uncertainty, and enabling in turn an investigation of the chemistry of millimeter-scale chemically and visually distinct components in heterogeneous targets.

We improve on [2, 3] by utilizing MAHLI focus merge (MFM) products to provide a 3D surface model of the target compensating for the effects of sample relief in APXS spectra. Through mathematical minimization, we are able to arrive at millimeter-scale chemistry yielding the chemical compositions of veins and other diagenetic features as well as dust-free rock.

Sample Relief Mitigation: An APXS spectrum represents the weighted sum of the signals from within the spectral FOV. The off-nadir contribution of a small surface area, *dA*, to a spectrum is well understood [2, 3]. In addition to this radial component, the contribution of *dA* to the spectrum is also dependent on the vertical separation (standoff) with respect to the APXS detector.

MFM products are the result of a stack of images acquired at different focus positions at a single camera position. Onboard software identifies portions of each image that are in focus and merges these portions into a single best-focus image. Accompanying the in-focus color image is an 8-bit/pixel monochromatic image in which the pixel shading corresponds to the relative relief of the target [4]. The pairing of a MFM relief product and its color counterpart produces a color 3D surface of the target (Fig. 1).

Employing a MFM relief map, APXS placement is modeled in a 3D environment, permitting variable APXS docking (standoff, deployment angle). This improves the accuracy of the FOV modeling and thus improves raster analyses. Varying APXS docking, however, is computationally intensive. When computing many iterations, as described in [2, 3], it is beneficial to utilize a small angle approximation. The approximation is accurate to within 2% so long as MAHLI and APXS are within the arm angle deployment uncertainty (10 degrees [5]) of co-alignment.

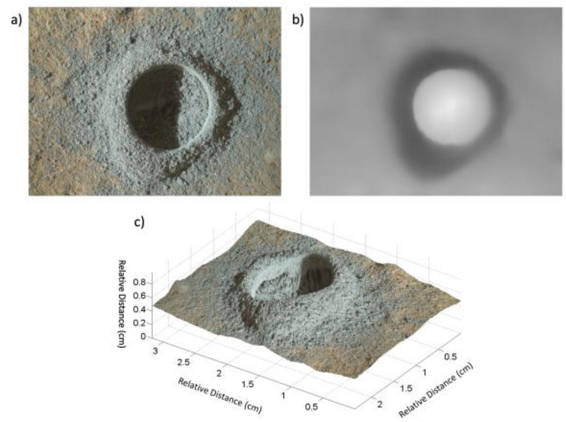

Figure 1: *Sol 1117 Big Sky mini start hole. Hole diameter is ~16 mm. a) MAHLI best focus image product. b) MAHLI range map and product. c) Relative surface relief of the Big Sky mini start hole as a composite of the images in a) and b).*

Raster Localization in Three Dimensions: Merging sample relief data from MFM data products with MAHLI color images increases the number of parameters to compare with APXS spectral data, improving raster localization. In addition to the chemistry trends described in [2, 3], there is now the possibility to include the spectrum geometric norm (norm) as a parameter fit during raster localization analyses. The norm is a spectrum-specific value related to peak areas (count rate) and serves as a proxy for deducing instrument standoff and thus FOV size.

When positioning an APXS FOV during localization, the norm is estimated from the surface relief. The modeled standoff (FOV size) is then varied until the observed norm matches that determined spectrally. This serves as a means to properly address FOV size on targets of varying sample relief and in turn more closely model what the APXS actually interrogates on the surface of Mars.

With an appropriately sized FOV, localization then proceeds with chemistry correlations. For samples with many visually distinct components, *N*, and an APXS raster consisting of *M* spots, one has a *MxN* matrix, *P*, of the abundance of each visually distinct component for each APXS FOV. Following the assumptions of [3], the chemistry of each visually distinct component is then given in a *Nx16* matrix, *C*. *C* is calculated and inferred by the values which minimize

$$((P \cdot C - S)/E)^2 \tag{1}$$

where *S* is a *Mx16* matrix corresponding to the sixteen-element bulk chemistry reported by the APXS and *E* is a matrix of the corresponding errors of *S*. The minimum χ^2 of the locations tested suggests a raster location within instrument deployment uncertainty in best agreement with the observed APXS spectral data while providing chemistry on all *N* visually distinct components of the sample. Methods used to orthogonally classify pixels in MAHLI images are described in more detail in [2, 3].

In lieu of images, endmember chemistry can be deduced through fitting *P* and *C*, provided *N<M*. However, an image-based analysis provides smaller errors and has physically observable constraints.

Results: Chemistry of the *Sayunei* target vein and surrounding rock (sol 165), *Stephen* dusty and dust-free rock (sols 627-629) and *Morrison* bare host rock, dusty host rock, diagenetic feature and added component (sols 767-779) are all reported in [3]. For *Sayunei*, the χ^2-minimized results are consistent with a calcium sulfate vein as previously reported in [2]. By compensating for dust, the MnO concentration of the bare *Stephen* target is 4.8±0.1 wt% [3]. The *Morrison* diagenetic feature arose from a Mg-, Ni-sulfate-rich fluid mixing with the local *Maturango*-like (sol 755) bedrock at a ratio of roughly 1:9 [3].

More recently, APXS was used in a study of the Garden City outcrop [6]. The area is highlighted by contrasting light and dark veins (Fig. 2) with cm-scale variability in surface relief (Fig. 3). Through 3D localization and χ^2 minimization, a light vein composition dominated by calcium sulfate and a dark vein composition that is enriched in CaO, MnO, Ni and Zn, with respect to average Mars (Fig. 4), fits the measured APXS spectral data well when paired with the physical observations by MAHLI at each APXS raster location.

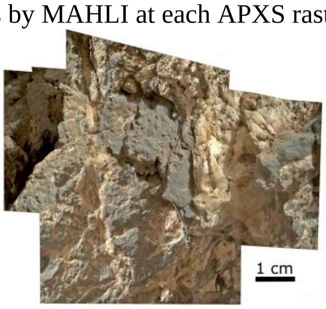

Figure 2: *MAHLI mosaic of the Alvord Mountain raster location.*

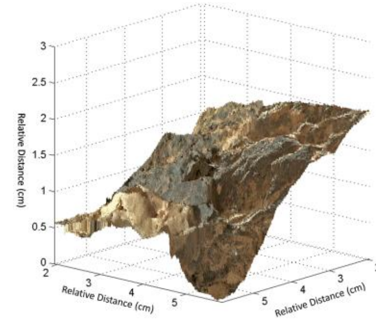

Figure 3: *Section of Alvord Mountain using a mosaic of MAHLI focus merge data products illustrating the variable surface relief.*

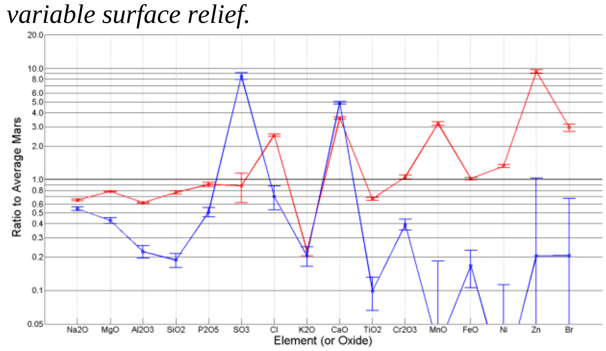

Figure 4: *Alvord Mountain dark vein (red) and light vein (blue) endmember chemistry determined via 3D raster localization and endmember χ^2 minimization.*

Conclusions: Obtaining mm-scale petrography with the APXS greatly improves the scientific return of data acquired on the surface of Mars with important implications for decoding the formation mechanisms of the bedrock and soil targets. The ability to deconvolve the chemistry of visual heterogeneities facilitates measurements of heterogeneous samples on Mars and also brecciated samples like the recently discovered "Black Beauty" Martian meteorite with the lab-based APXS on Earth. Lab measurements of "Black Beauty" and its paired samples will directly tie Earth measurements of Martian meteorites with the ever-growing APXS dataset acquired on Mars.

References:

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