RETRIEVAL OF COMPOSITIONAL ENDMEMBERS FROM OPPORTUNITY ROVER OBSERVATIONS OF A SCUFFED FRACTURE ZONE IN MARATHON VALLEY, ENDEAVOUR CRATER RIM. R. E. Arvidson[1], N. T. Stein[2], J. A. O'Sullivan[3], J. G. Catalano[2], E. A. Guinness[2], D. V. Politte[3], R. Gellert[4], S. J. VanBommel[4]. [1]Washington University in St. Louis Department of Earth and Planetary Sciences, [2]California Institute of Technology Division of Geological and Planetary Sciences, [3]Washington University in St. Louis Department of Electrical Engineering, [4]University of Guelph Department of Physics.

Introduction: Marathon valley was the site of an extensive Opportunity rover science campaign (Fig. 1) [1]. Fine-grained impact breccias dominate the valley and are cut by fractures. We utilize measurements of the bedrock target Pierre Pinaut and a nearby soil-filled fracture zone to retrieve selected endmember compositions.

Measurements: The Pierre Pinaut rock target was the site of Pancam, Microscopic Imager, and Alpha Particle X-ray Spectrometer (APXS, [2]) observations. Opportunity was also commanded to drag its left front wheel across a fracture zone adjacent to the Pierre Pinaut outcrop, exposing a mixture of relatively bright and dark soils (Fig. 2). Ten APXS observations were collected in the scuff zone: three overlapping measurements of the red-toned pebbles (George_Drouillard) adjacent to the scuff zone, three overlapping measurements covering relatively bright soil within the wheel scuff (E_Cann), and four overlapping measurements centered on bright soil (Private Joseph Field). Pancam 13F data were also collected for these targets.

Retrieval of Compositional Endmembers: The field of view (FOV) of each APXS measurement describes the relative signal strength of X-rays as a function of lateral distance from the center of the observation [2]. The FOVs of the George_Drouillard, E_Cann, and Private Joseph Field APXS measurements each contain multiple minerals, and hence the measured signal represents the aggregate composition of the targets. Examination of Pancam color composites in the scuff zone and surrounding region, coupled with visual inspections of the spectra, show the dominance of three spectral endmembers: red pebbles, dark soil, and sulfate-rich soil. The location and relative abundance of these endmembers were computed using the sequential maximum angle convex cone (SMACC) method on Pancam 13F data [3] (Fig. 3). The resulting endmember abundance map was convolved with the signal strength of the APXS observations to produce a transfer matrix C describing the relative abundance of the spectral endmembers in each APXS measurement. Given a matrix D that contains the oxide weight abundances of each APXS measurement, a matrix A containing the composition of each endmember can be calculated by solving the non-invertible matrix equation:

$$CA = D$$

A was computed using an iterative algorithm to maximize a likelihood function with the assumption of Poisson distributed data. The algorithm alternately minimizes a cost function over the pair *(A, C)* subject to the constraint that the endmember abundances sum to unity. *A* is initialized with a guess of the endmember compositions and updated with each iteration. *C* is updated during each iteration to correct for inaccuracies in the initial transfer function matrix.

Endmember Compositional Abundances: The retrieved red pebble endmember composition exhibits elevated Al_2O_3 (10.4 ± 0.4 wt%) and SiO_2 (55.0 ± 2.2 wt%) and depleted FeO (10.1 ± 1.2 wt%) and MgO (5.8 ± 0.3 wt%) relative to the relatively unaltered basaltic sand of the nearby Joseph Collin target. The sulfate-rich endmember is highly enriched in SO_3 (33.6 ± 2.3 wt%) and depleted in SiO_2 (26.7 ± 2 wt%) relative to the Joseph Collin target. The dark soil endmember is similar in composition to Joseph Collin, but with enhanced FeO (19.2 ± 1.1 wt%) and SO_3 (10.0 ± 2.3 wt%) that may result from intermixing with sulfate-rich soil.

A correspondence analysis was performed for all APXS measurements in Marathon Valley, including the three endmember compositions, to understand how the endmember retrievals match regional compositional trends (Fig. 4). The dark soil endmember has a close affinity to nearby bedrock targets such as Pierre Pinaut, whereas the sulfate-rich and red pebble endmembers extend the differences in composition between targets in fracture zones such as George_Drouillard and targets that partially cover a mixture of sulfates and basaltic soil such as E_Cann and Private Joseph Field. The trend for Pierre Pinaut displayed in the CA shows more Mg and S for abraded as opposed to undisturbed surfaces.

Inferred Mineral Assemblage of Sulfate-Rich Endmember: The compositional trends of the sulfate-rich soil endmember could be explained as forming by the evaporation of a sulfate-rich fluid. This hypothesis was tested using a thermodynamic model in which the elemental components of the endmember were added to pure water and mineral formation was predicted by equilibrium solubility conditions as in [4]. The calculations produced an assemblage consisting of >40 wt% Mg sulfate, with other major components including amorphous silica, schwertmannite, gypsum,

and aluminum sulfate phases. These calculations suggest that the sulfate-rich endmember is the product of alteration and leaching by an acidic, sulfate-rich fluid followed by evaporation within the fracture zone.

Conclusions: Our analyses show that the dark soil endmember is compositionally similar to relatively unaltered basaltic soil. The red pebbles are enriched in Al, Si, and K and depleted in Fe and Mg relative to the nearby Pierre Pinaut target, consistent with their formation via the alteration of breccia within fracture zones. The sulfate-rich endmember is interpreted to have resulted from alteration and leaching by an acidic, sulfate-rich fluid flowing along fractures. Results are consistent with pervasive aqueous alteration along fractures that provided a conduit for fluid flow.

References: [1] Mittlefehldt, D. W. et al. (2016). *LPSC 47.* 2086. [2] Gellert, R. et al. (2006) *JGR* 111, E02S05. [3] Gruninger, J. H. et al. (2004). *Proceedings SPIE.* [4] Liu, Y. and Catalano, J. G. (2016). *Icarus.*

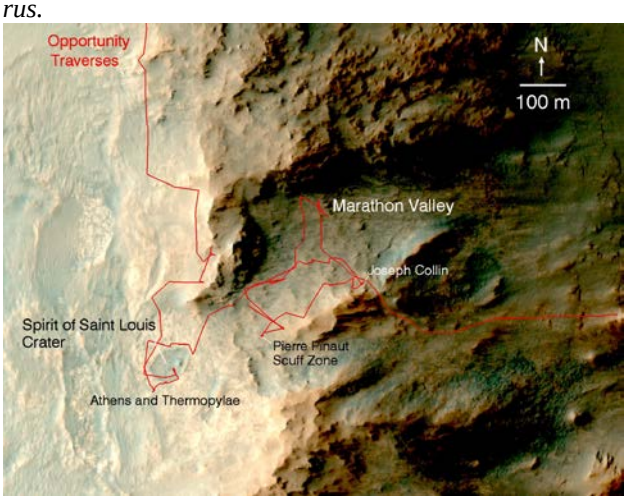

Figure 1: *HiRISE view of Marathon Valley, located on the western rim of Endeavour Crater overlain with Opportunity's traverses.*

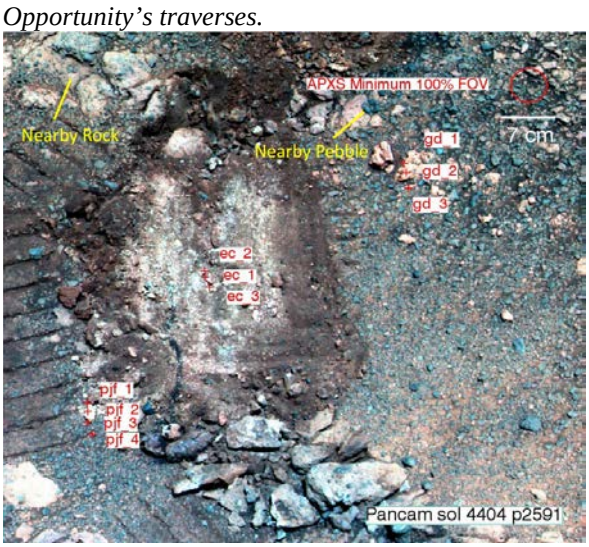

Figure 2: *Pancam false color image (sol 4404) of the scuff zone and each of the 10 APXS targets that were used to calculate endmember compositions. The red circle denotes the approximate extent of each APXS FOV.*

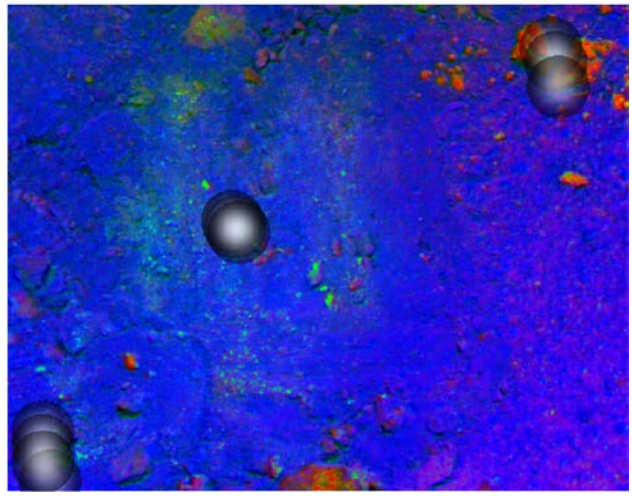

Figure 3: *Map of spectral endmembers concentrations: R: Red pebble,. G: Dark soil. B: Sulfate-rich endmember. The gray circles denote the APXS relative intensities.*

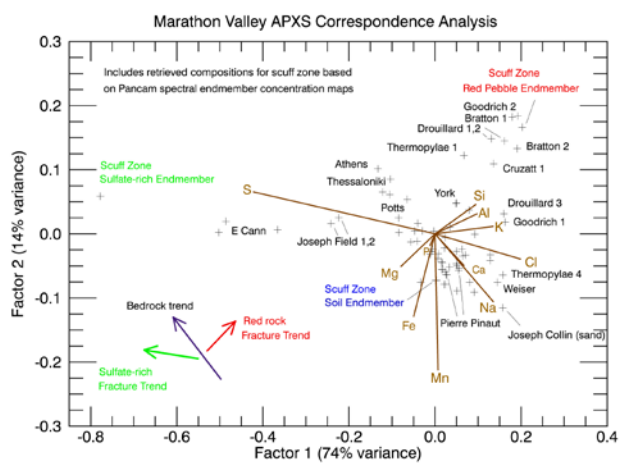

Figure 4: *Correspondence analysis for the first two factor loadings for Marathon Valley observations. The dark soil endmember has a close affinity to relatively unaltered basaltic soil. The sulfate-rich endmember is characterized by an affinity for S and smaller quantities of Mg. The red pebble endmember is characterized by an affinity for Si, Al, and K, and modest enrichment of Cl, Ca, and Na.*