

INVESTIGATION OF MARTIAN AQUEOUS PROCESSES USING MULTIPLE ALPHA PARTICLE X-RAY SPECTROMETER (APXS) DATASETS. A. S. Yen¹, D. W. Ming², R. Gellert³, D. Vaniman⁴, B. Clark⁵, R. V. Morris², D. W. Mittlefehldt², R. E. Arvidson⁶, and the Athena and MSL Science teams, ¹Jet Propulsion Laboratory, California Institute of Technology (Albert.Yen@jpl.nasa.gov), ²NASA Johnson Space Center, ³University of Guelph, ⁴Planetary Science Institute, ⁵Space Science Institute, ⁶Washington University in St. Louis.

Introduction: The APXS instruments flown on the Mars Exploration Rovers (MER) Spirit and Opportunity and the Mars Science Laboratory (MSL) Curiosity were based on the same fundamental design. The calibration effort of the MSL APXS used the same reference standards analyzed in the MER calibration which ensures that data produced by all three instruments provide the same compositional results for the same sample. This cross-calibration effort is unprecedented and allows direct comparisons and contrasts of samples analyzed at Gusev Crater by Spirit, Meridiani Planum by Opportunity, and Gale Crater by Curiosity.

Comparing Similar Soils: Over 700 distinct APXS measurements have been collected at the three landing sites. While the S:Cl ratio is highly variable over the datasets, it remains relatively constant for the basaltic fines ubiquitous on the martian surface (Fig. 1). In order to maintain such a constant ratio over global scales, the sulfur and chlorine are likely condensates of volcanic vapors. Furthermore, to preserve the ratio of these mobile elements, the fines have experienced negligible amounts of chemical weathering after the addition of the volcanic volatiles. The use of cross-calibrated APXS data from the three landing sites shows not only the consistency of S:Cl, but also the relatively small variation in all measured elements in martian soils (Fig. 2).

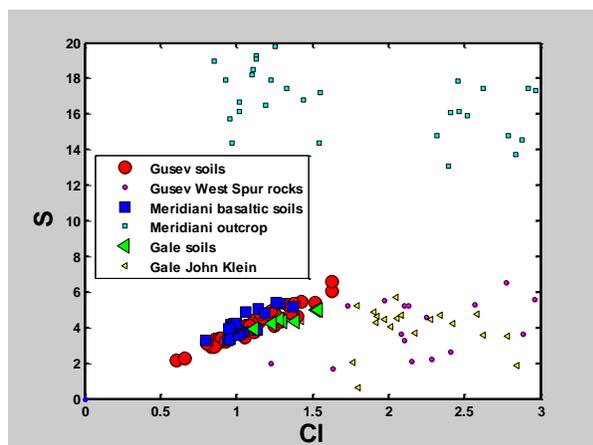


Fig. 1: Molar sulfur versus chlorine for MER and MSL APXS measurements. Basaltic soil data points with a ~3.5:1 S:Cl ratio are highlighted.

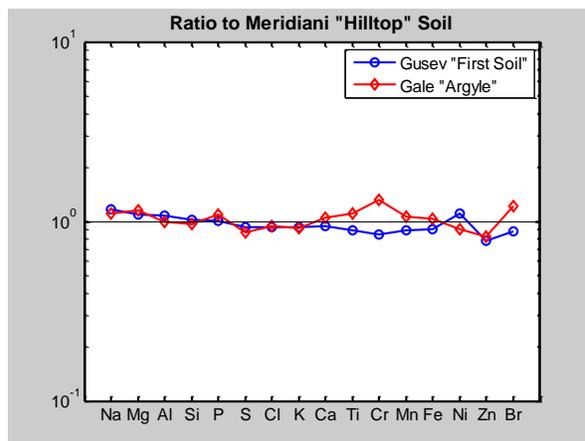


Fig. 2: Ratio of representative soil samples at the three landing sites showing only minor differences and minimal contributions from local rocks.

Contrasting Calcium Sulfates: The presence of Ca-sulfates has been clearly established by the APXS instruments at the three landing sites. The target Halley at Gusev Crater (Fig. 3a) is found on the eastern margin of the Home Plate, a hydrothermal region characterized by fumarolic deposits [1] and enhanced concentrations of elements mobilized in volcanic fluids [2]. The Opportunity APXS discovered Ca-sulfate-rich veins in rocks at the rim of Endeavour Crater (e.g., Figs. 3b/c), and similar deposits were found along Curiosity's traverse in Gale Crater (e.g., Fig. 3d).

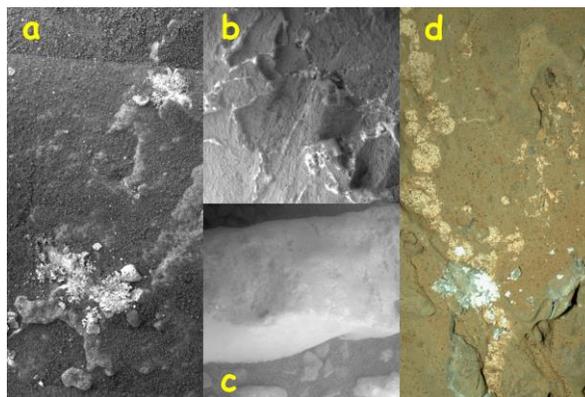


Fig. 3: Calcium sulfate exposures at (a) Gusev Crater (target=Halley), (b) Meridiani (Ortiz), (c) Meridiani (Homestake), and (d) Gale Crater (Sayunei). Each image is approximately 2 cm in width.

Fluid Temperatures. The molar ratio of Ca:S is approximately 1:1 in all of these samples (Fig. 4), consistent with mineral phases of the form: $\text{CaSO}_4 \cdot n\text{H}_2\text{O}$ (where at least one component has $n \neq 0$ [3,4]). Additional Ca-bearing phases are likely and minor S-bearing phases cannot be excluded from these samples. Interestingly, a replot of the same data points to show the Cl:Zn relationship results in distinct trends for the samples at each landing site (Fig. 5). Cl:Zn can be useful as an indicator of fluid temperature for a given redox state [5]. The Gusev data for Halley suggests precipitation at elevated temperatures, consistent with other evidence for hydrothermal alteration in the vicinity of Home Plate [1,2]. Assuming no significant remobilization of the chemical signatures after deposition, these data indicate that the Ca-sulfates at the Meridiani and Gale landing sites likely formed at lower fluid temperatures than the Gusev deposits.

Redox Conditions. Furthermore, an examination of the Fe:Mn relationship of these samples provides additional insight into the formation of these sulfates, assuming minimal post-deposition weathering. Fe^{2+} and Mn^{2+} have similar ionic radii and maintain a constant relationship in igneous systems. Chemical weathering of these elements results in higher oxidation states which have differing mobility depending on the redox conditions and pH of the environment. Fig. 6 suggests that the Ca-sulfate deposits at Meridiani have two distinct chemical regimes (and physical appearances, Figs. 3b/c) corresponding to two distinct redox environments, while the Gusev and Gale precipitates may have developed under similar redox conditions.

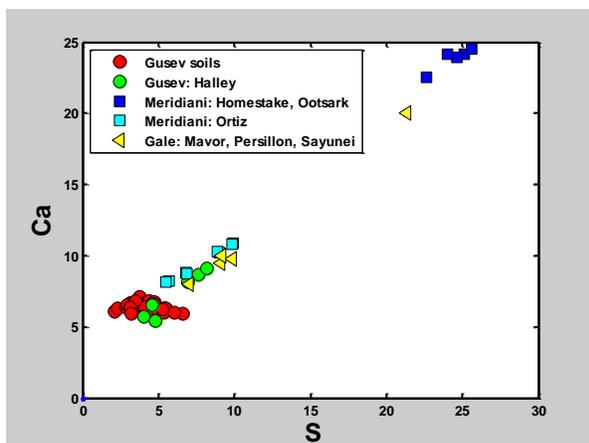


Fig. 4: Molar values for Ca-S-rich targets. Basaltic soils at Gusev Crater are plotted for reference.

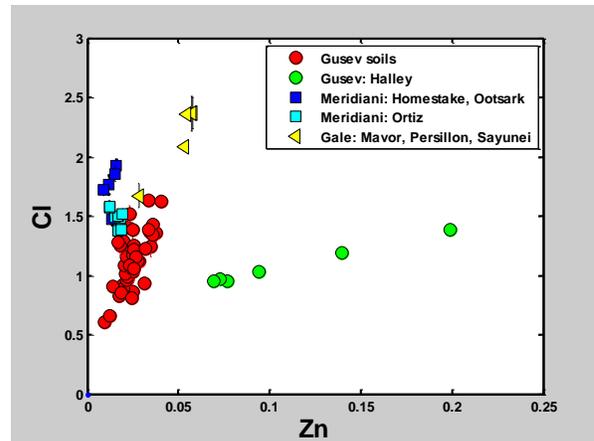


Fig. 5: Molar Cl versus Zn for the same samples in Fig. 4 showing distinct clusters/trends for samples at each landing site.

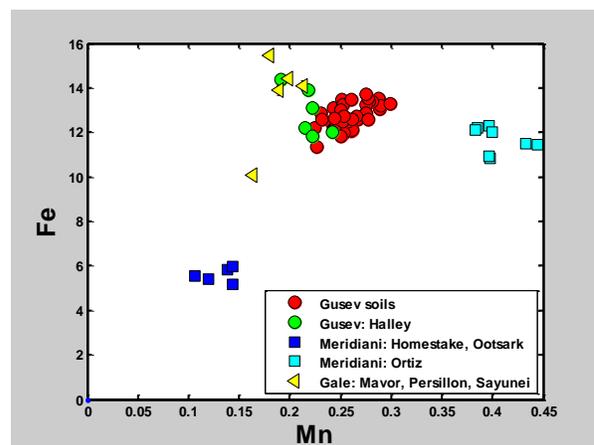


Fig. 6: Molar Fe versus Mn for the same samples in Fig. 4 showing partitioning of Fe:Mn in the formation of these Ca-sulfate deposits.

Conclusions: Comparing and contrasting the cross-calibrated APXS datasets provides insight into aqueous weathering process at three martian landing sites. Here, minimal aqueous weathering is demonstrated by the consistency of mobile element compositions of surficial soils. In addition, Ca-sulfate deposits found at the three landing sites are likely to have formed under different thermal and redox regimes.

References: [1] Yen A. S. et al. (2008) *JGR*, 113, E06S10. [2] Schmidt M. E. et al. (2008) *JGR*, 113, E06S12. [3] Squyres S. W. et al (2012) *Science*, 336, 570-576. [4] Nachon M. et al (2014) *8th Mars*. [5] Seewald J. S. and Seyfried W. E. (1990) *EPSL*, 101, 388-402.