

Sr in Ca-Sulfate Veins and Cements at Gale Crater, Mars. R. S. Jackson¹, A. M. Ollila², M. A. Nellesen¹, A. M. Baker¹, R. C. Wiens², O. Forni³, N. Mangold⁴, A. Cousin³, J. Frydenvang⁵, S. Clegg², and H. E. Newsom¹
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Introduction: The ChemCam instrument on the Curiosity rover uses Laser Induced Breakdown Spectroscopy which allows for ~400 μm spot analyses on Mars [1, 2]. The ChemCam instrument is designed for rapid remote analyses with this micro-probe device. These abilities allow the ChemCam instrument to differentiate between the bulk composition of the host rock and composition of chemically distinct diagenetic materials, like veins [3].



Figure 1: Veins in Yellowknife Bay. NASA/JPL/Caltech/MSSS

The rover has sampled Ca-sulfate veins since entering Yellowknife Bay (Fig. 1), during the earliest part of the mission, up until the current drive through the Murray formation, which makes up the lower portion of Mount Sharp [4, 5]. In addition, Ca-sulfate cements were previously identified in the Murray and reported by Nellesen et al. [6].

Sr^{2+} can substitute for Ca^{2+} in the structure of several minerals – including Ca-sulfates. Sr as well as Mg, Na, and K will precipitate in gypsum at differing rates depending on temperature, concentration in the solution, and growth rate of the crystal. For example at higher brine concentrations, Sr will coprecipitate at higher concentrations relative to Ca [6]. During the deposition of evaporites like Ca-sulfates, fluids and other salts will be incorporated into the evaporite. These inclusions will have different chemistries from the evaporite in question, and importantly to this study, different partition coefficients for trace elements. When these inclusions are sampled along with the primary evaporite, they have the effect of obscuring information on the aforementioned paleo-environmental factors. Previous work has shown that the Sr abundance in Ca-sulfates is the least influenced by the presence of fluid

and solid inclusions. [7]. This suggests that the in-situ Sr/Ca ratio as sampled by ChemCam should be robust. Previous work in the Nijar Basin of Spain was able to differentiate between diagenetic veins and gypsum bearing units, one deposited in a marine environment and one deposited from mixed marine and non-marine fluids. Much of that work was done based on the variations in the Sr/Ca ratio and confirmed by other stratigraphic and geochemical methods [8].

Methods: This study currently uses the Sr and Ca abundances reported by the ChemCam team, including previously developed univariate calibration curves for quantitative analysis of Sr (and other trace alkalis) using >400 quantitative standards [9, 10, 11]. The data consists of cemented bedrock – from the list generated by Nellesen et al. [6] – and veins – determined by selecting points with >25% CaO. The data in this abstract were collected through sol 1865. The data were separated into the appropriate stratigraphic members and the ratio between Sr ppm and CaO wt. % was computed. The standard deviation divided by mean (σ/μ) was calculated for targets with at least four Ca-sulfate cement bearing points to investigate spatial variability in Sr.

Results: Throughout the Murray stratigraphy, the Sr/Ca ratios are varied (Fig. 2), with values from all stratigraphic members stretching from ~0 to >10 and a few members with values above 20. The lower members tend to contain the highest Sr/Ca. In Pettigrove Point, which is the lowest member of Vera Rubin Ridge, the minimum values rise gently with elevation, but the maximum values are not much greater than at Blunts Point, the member immediately below (Fig. 2).

Veins mostly have low ratios (<5) but show higher ratios at the base of Sutton Island and in Pahrump Hills. The four vein points with high ratios are in the targets Hoskinnini in Pahrump Hills and Palapye in Sutton Island (Fig. 2).

ChemCam's small spot size allows it to sample the spatial variations of Sr that occurs due to the low abundance of trace elements in the fluids that formed the cements. Cements across stratigraphic units have standard deviations in Sr abundances above 0.5 of the mean with some targets having standard deviations >0.7 of the mean (Fig. 3).

Discussion: Due to the limitations between Martian data and terrestrial data, and the potential that much of the Ca sulfates were deposited during diagenesis, it is not possible to quantitatively determine the paleo-

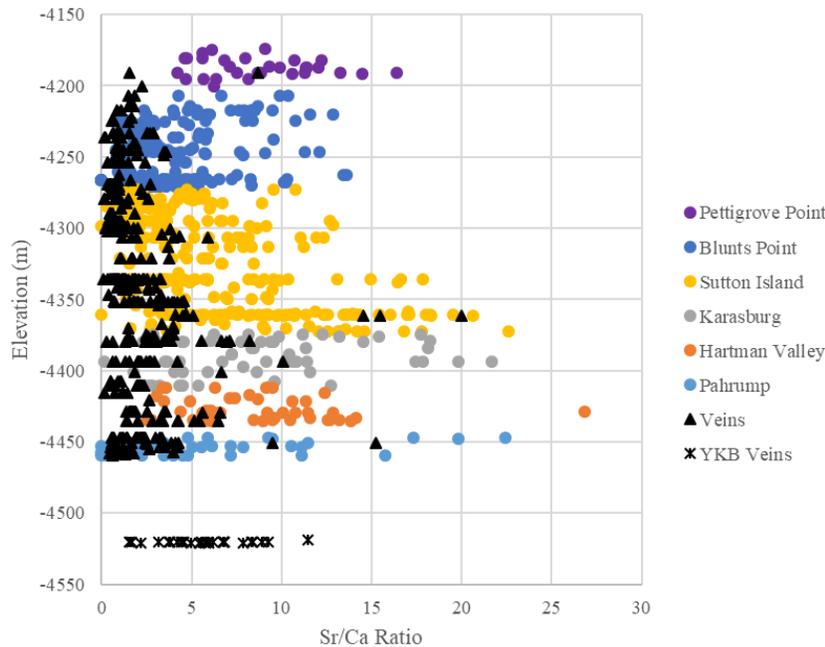


Figure 2: Variation in the Sr (ppm) to Ca (wt. %) ratio with elevation across the Murray Formation for Ca-sulfate veins and cements (triangles and colored circles respectively) and at the Yellowknife Bay (YKB) location (asterisks). Stratigraphy in the Murray formation is divided into geologic members which are color coded for the cement data. Veins are placed according to elevation, so their geologic members can be determined by the color of the surrounding cement data. Higher ratios suggest deposition from a more saline fluid.

salinity of the lake during the deposition of each stratigraphic member [6, 8]. It is possible to determine the relative salinity of the fluids that deposited these sulfates within the Murray Formation. The lower members were deposited in more saline groundwater than the upper members; this transition occurred in the lower portion of the Sutton Island member. The higher minimum ratios on Vera Rubin Ridge suggest a change in

groundwater to increased salinity (Fig. 2). The lower ratios of the veins could have resulted from several scenarios. For example, the veins could have been emplaced by a groundwater that had flowed through a sulfur-rich unit rather than more typical surficial runoff. The data are also consistent with a diagenetic event remobilizing Ca-sulfates and ‘purifying’ them of trace elements.

The variation observed in ratios may have many causes, including increasing salinity as water is lost from the system or multiple pulses of fluids. Fig. 3 shows a large amount of variation on the scale of individual ChemCam points within the same target. Indicating that some of the variability in the Sr/Ca ratio is due to spatial variation.

Future Work: Laser Induced Breakdown Spectroscopy can be sensitive to materials with different physical and optical properties [12]. To test our calibrations for Li, Ba, Rb, and Sr we plan to check peak

areas from emission lines of these elements in >20 terrestrial Ca-sulfate samples of known trace-element compositions. For this, 14 gypsum samples have been provided from a study in the Society Cliffs Formation (Bylot Supergroup, northern Baffin Island) [13]. The rest are Ca-sulfate standards that were used as part of the ChemCam calibration [1, 10, 11].

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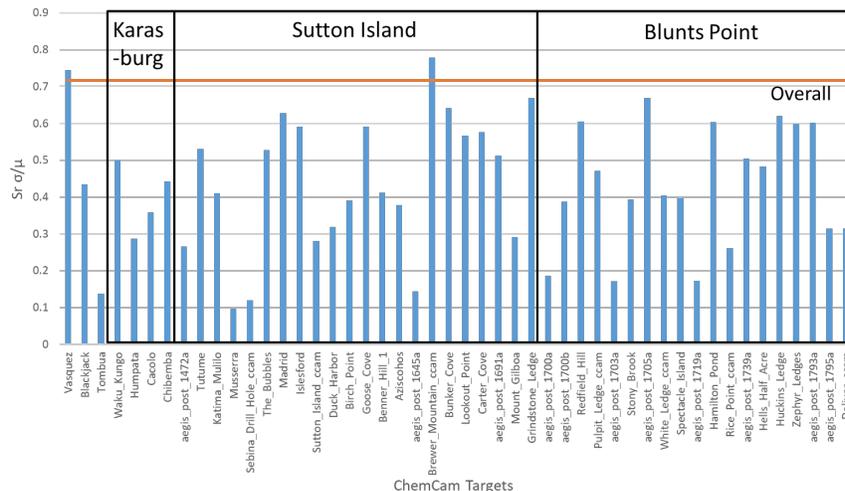


Figure 3: Blue bars: the σ/μ of Sr (ppm) for every ChemCam target with ≥ 4 points containing Ca-sulfate cements. Red line: the overall σ/μ for all points containing Ca-sulfate cement.