

The Role of Diagenesis at Vera Rubin ridge in Gale crater, Mars, and the Chemostratigraphy of the Murray formation as Observed by the ChemCam Instrument. J. Frydenvang¹, N. Mangold², R.C. Wiens³, A.A. Fraeman⁴, L.A. Edgar⁵, C. Fedo⁶, J. L'Haridon², C. C. Bedford^{7,8}, S. Gupta⁹, J.P. Grotzinger¹⁰, J.C. Bridges¹¹, B.C. Clark¹², E.B. Rampe⁸, O. Gasnault¹³, S. Maurice¹³, P.J. Gasda³, N.L. Lanza³, A.M. Ollila³, P.-Y. Meslin¹³, V. Payré¹⁴, F. Calef⁴, M. Salvatore¹⁵, C.H. House¹⁶, T.S.J. Gabriel¹⁷. ¹Univ. Copenhagen, Denmark; ²LPG, Univ. Nantes, France; ³LANL, NM, USA; ⁴JPL, Caltech, CA, USA; ⁵USGS Astrogeology Science Center, Flagstaff, AZ, USA. ⁶U. Tennessee, TN, USA; ⁷LPI, USRA, TX, USA; ⁸NASA JSC, TX, USA; ⁹Imperial College, UK; ¹⁰Caltech, CA, USA; ¹¹U. Leicester, UK; ¹²Space Science Inst., CO, USA; ¹³IRAP, U. Toulouse, CNRS, CNES, UPS, France; ¹⁴Rice U., TX, USA; ¹⁵Northern Arizona U., AZ, USA; ¹⁶The Pennsylvania State U., PA, USA; ¹⁷Arizona State U., Az, USA.

Introduction: The Mars Science Laboratory (MSL) Curiosity rover explored Vera Rubin ridge (VRR) in Gale crater, Mars, for almost 500 sols (Mars days) between arriving at the ridge on sol 1809 of the mission in September 2017 and leaving it on sol 2302 upon entering the Glen Torridon area south of the ridge (fig. 1a). VRR is a topographic ridge on the central mound, Aeolis Mons (Mt. Sharp), in Gale crater that displays a strong hematite spectral signature from orbit [1]. In-situ observations on the ridge led to the recognition that the ridge-forming rocks belong to the Murray formation, the lowermost exposed stratigraphic unit of the Mt. Sharp group, that was first encountered at the Pahrump Hills location (fig. 1b). Including VRR rocks, the Murray formation, interpreted to be primarily deposited in an ancient lacustrine environment in Gale crater, is more

than 300 m thick [2-4]. VRR itself is composed of two stratigraphic members within the Murray formation, the Pettegrove Point member overlain by the Jura member [3]. The Pettegrove Point member overlies the Blunts Point member of the Murray formation (fig. 1b) [5]. Areas of gray coloration are observed in the Jura member predominantly, but also in the Pettegrove Point member. Generally, gray areas are found in local topographic depressions, but contacts between red and gray rocks crosscut stratigraphy [3,6]. Additionally, cm-scale dark concretions with very high iron-content are commonly observed in gray rocks, typically surrounded by a light-toned zone that is conversely depleted in iron [7]. A key goal for the VRR campaign was to characterize geochemical variations in the ridge-forming rocks to investigate the role of primary and diagenetic controls on the

geochemistry and morphology of VRR. Here, we present observations by the ChemCam instrument on VRR and compare these to the full Murray formation chemostratigraphy. This work was recently submitted [8] to a special issue of JGR-Planets that detail the full VRR campaign.

Methods: ChemCam observations [10,11] enable quantification of major [12] and select minor elements [13]. Reflecting the speed and relative low cost, in terms of power consumption and time, of performing ChemCam measurements, more than 710,000 spectra have been downlinked from Mars (Nov 2019).

Our investigations of VRR include two (N-S) traverses of the ridge (fig. 1c). This enabled investigation of both stratigraphic and lateral geochemical variability on VRR.

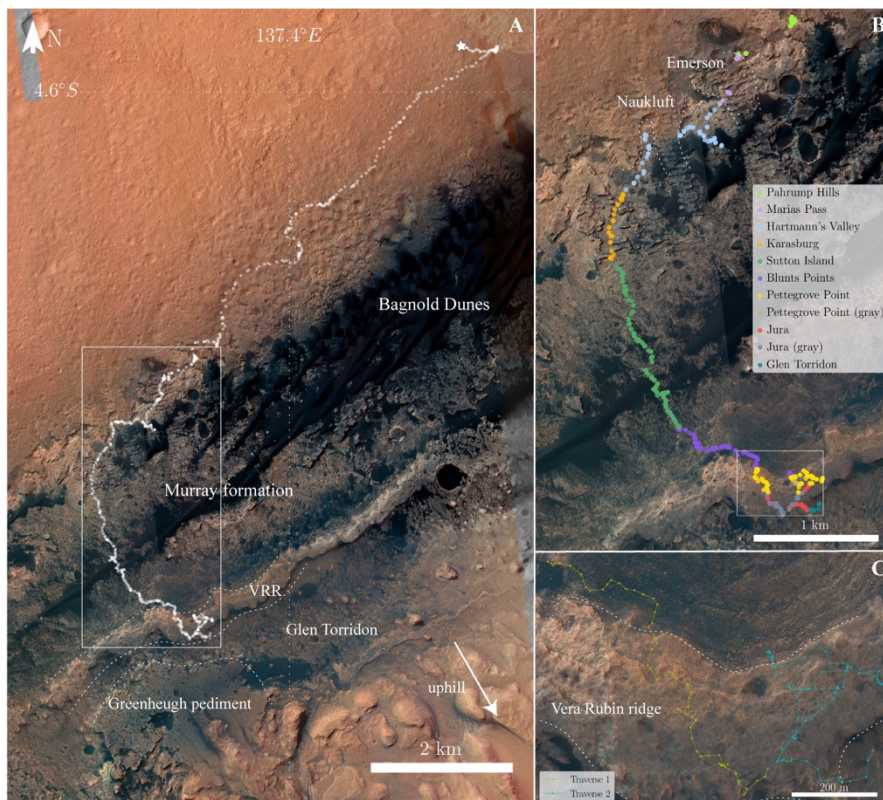


Figure 1: A) Traverse of the Curiosity rover from landing in Gale crater, Mars up to sol 2315. B) Murray bedrock observations along the rover traverse. C) Two separate transects of the VRR stratigraphy. Figure from [8], using HiRISE mosaic as detailed in [9].

Results: VRR is geochemically similar to the Murray formation overall. This includes the baseline bedrock iron content, which is not higher on VRR despite the strong hematite spectral signature observed from orbit. While overall within the geochemical range observed in lower-lying Murray formation members, notable decreases in Li and the Chemical Index of Alteration (CIA) were observed across the VRR stratigraphy. Both Li and CIA decreased across the Pettegrove Point member rocks when ascending the northern slope of VRR (fig. 2), and reached a constant low level in the Jura member rocks at the top of the ridge. Upon entering the Glen Torridon area south of VRR, both CIA and the Li abundance increased to levels similar to those observed below VRR. Additionally, a prominent enrichment in Mn was observed near the contact between the Pettegrove Point and Jura member rocks. The enrichment in Mn is located right above the zone where both Li and CIA decreased to the low level observed at the top of the ridge.

The transects of VRR highlight that the geochemical variations follow the geomorphology of the modern-day ridge rather than elevation (a proxy for stratigraphic position). Importantly, the Glen Torridon area south of VRR is at an elevation similar to the Jura member rocks on VRR, implying a shared stratigraphic position.

Discussion: Both CIA and Li abundance can be related to clay mineral abundance. The correlation between CIA and clay mineral content has been reported at local to global scales on Earth [14]. For Li, terrestrial studies have shown that Li is typically found in the clay fraction, and typically associated with clay minerals [15,16]. Hence, the observed decrease in Li and CIA on VRR is inferred to imply a decrease in clay mineral content in the ridge rocks, yet not in the Glen Torridon area south of VRR, and hence not stratigraphically controlled. This interpretation is supported by mineralogical results from the CheMin instrument [17], which reveal a relatively low abundance of clay minerals on VRR and a high abundance in Glen Torridon [18, 19]

From the available observations, it is not possible to ascertain whether the enrichment in Mn is detrital or diagenetic in origin. If detrital, the location of the enrichment right above the decrease in clay-mineral content is coincidental. Alternatively, Mn is mobilized in low pH fluids as well as by reducing fluids, but the observed preferential Mn enrichment on VRR favors mobilization in a reducing fluid [20]. In such a diagenetic

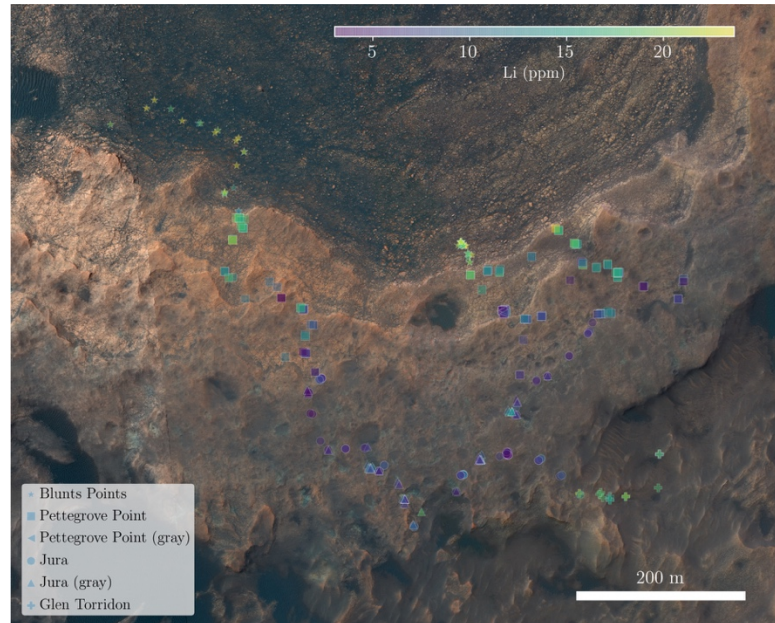


Figure 2: ChemCam observation points plotted on HiRISE mosaic showing the Vera Rubin ridge in Gale crater [9]. Color code shows median Li content of bedrock point in each ChemCam target acquired on the ridge. Figure from [8]

scenario, the location of the enrichment in Mn could be caused by the Pettegrove Point member being more impermeable due to higher clay mineral content, causing Mn mobilized from the Jura member by a reducing fluid to be retained and reprecipitate there. This reducing fluid could also explain the apparent small-scale iron mobilization observed in gray rocks.

Overall, no single process has been identified that explain all observations on VRR, suggesting that VRR rocks likely underwent a complex series of diagenetic events that caused pervasive dissolution of clays in VRR rocks and their overall induration relative to surrounding Murray formation rocks. This provides additional evidence that groundwater activity persisted in Gale crater even after the lake environment ceased.

References: [1] Fraeman A.A. et al. (2016) *JGR-P*, 121. [2] Fraeman A.A. et al., *JGR-P* in review. [3] Edgar L.A. et al., *JGR-P* in review. [4] Stein N.T. et al, *JGR-P* in review. [5] Fedo C.M. et al. (2019) *9th Int. Conf. on Mars*. [6] Horgan B. et al., *JGR-P* in review. [7] L'Haridon J. et al., *JGR-P* in review. [8] Frydenvang J. et al, *JGR-P* in review. [9] Calef F. & Parker T. (2016) *PDS Annex, USGS*. [10] Wiens R.C. et al. (2012), *Space Sci Rev* 170. [11] Maurice S. et al. (2012) *Space Sci Rev* 170. [12] Clegg S.M. et al., (2017) *Spectrochim. Acta B*, 129. [13] Payré V. et al. (2017) *JGR-P*, 122. [14] McLennan S. et al., (2000) *GRL* 27(9). [15] Benson R.T. et al. (2017) *Nature Comm.*, 8. [16] Villumsen A. & Nielsen O.B. (1976) *Sedimentology*, 23. [17] Blake D.F. et al., (2012) *Space Sci Rev* 170. [18] Rampe E. et al., *JGR-P* in review. [19] Thorpe M.T. et al., this meeting. [20] Bonatti E. et al. (1971) *Geochim. et Cosmochim Acta*, 35.