COMPOSITIONAL CHARACTERISTICS AND TRENDS WITHIN THE VERA RUBIN RIDGE, GALE CRATER, MARS AS DETERMINED BY APXS: SEDIMENTARY, DIAGENETIC AND ALTERATION HISTORY

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Introduction: The Mars Science Laboratory (MSL) Curiosity rover has spent the last two years investigating a prominent resistant ridge, informally named the Vera Rubin Ridge (VRR), at the base of Mount Sharp (Aeolis Mons). The ridge has been a high priority science target for the MSL mission since landing in Gale crater more than 6 years ago because of the detection of a strong hematite spectral signature [1,2], and its distinct topography. Examining the chemistry of the ridge can aid in determining the relationship to other rocks analyzed during the rover traverse, specifically the Murray formation (fm) encountered below the ridge. We can also determine compositional trends with elevation and/or laterally within the ridge, and whether spectral properties observed on the ridge, both from orbit and in situ, correspond with changes in chemistry. The composition of the ridge, combined with mineralogy of drilled samples, can help to elucidate bigger picture questions regarding depositional environment, possible changing lake water chemistry and diagenetic/alteration history.

Alpha Particle X-ray Spectrometer (APXS): The Canadian built APXS combines Particle Induced X-ray Emission and X-ray Fluorescence techniques to determine the composition of rocks and unconsolidated materials within Gale crater. It is situated on the end of a robotic arm such that it can be placed in contact with a sample, resulting in a 1.5 cm field of view. APXS has acquired >700 analyses since landing, and >140 as Curiosity traversed the VRR (Fig. 1).

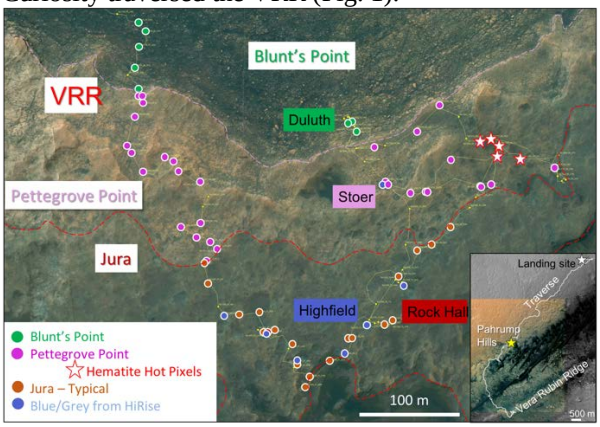

Figure 1: Map showing the location of APXS targets on the VRR. Coloured boxes refer to drill targets. Inset shows Curiosity's traverse since landing.

APXS-Derived Chemistry and Implications: APXS analyses reveal that the VRR falls within the compositional range exhibited by the Murray fm encountered up to the ridge (Fig. 2), supporting the sedimentological interpretation that the ridge strata are a continuation of the Murray fm and its associated depositional environment [3]. However, for the majority of elements it shows as much chemical variability as for the whole of the rest of the Murray fm. A few VRR samples trend to lower Ti, Mn and Fe and higher Ni than the underlying Murray fm (Fig. 2).

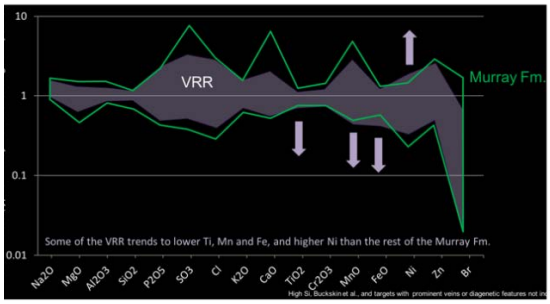

Figure 2: Murray fm targets below the ridge (green outline) and VRR targets (grey) ratioed (log) to a typical Murray fm target, Ganda.

Chemostratigraphic plots (Fig. 3) also highlight the compositional variability of the VRR over a relatively narrow elevation range (~50 m), and laterally, compared to the underlying Murray fm, indicating mobility of elements and extensive fluid flow through the ridge. In general, the VRR strata trend to higher Si and Al, broadly elevated Na, and lower Fe, Ti, P and Zn than the immediately underlying Blunt's Point (Pt) member of the Murray fm. In particular, the upper VRR Jura member and specifically the targets analyzed within grey patches, accentuate these trends and have concentrations of Si, Al, and Fe not observed since the base of the Murray fm. This could be consistent with higher plagioclase content detected in the crystalline component of the Highfield (grey Jura) and Rock Hall (red Jura) drill samples compared to the underlying Murray fm [4]. However, accounting for the XRD-amorphous and phyllosilicate components present, Blunt's Pt and Pettegrove Pt drill samples have similar bulk plagioclase contents to the Jura samples, indicating elevated Si and Al in the amorphous component of the Jura samples, particularly the Highfield sample.

Elemental trends within the ridge (increasing Si, Al, Na and decreasing Fe with elevation) are the reverse of those identified in the Murray fm up to the contact with the VRR. The Si and Al exhibit a strong positive correlation within the VRR, and are negatively correlated with FeO_T.

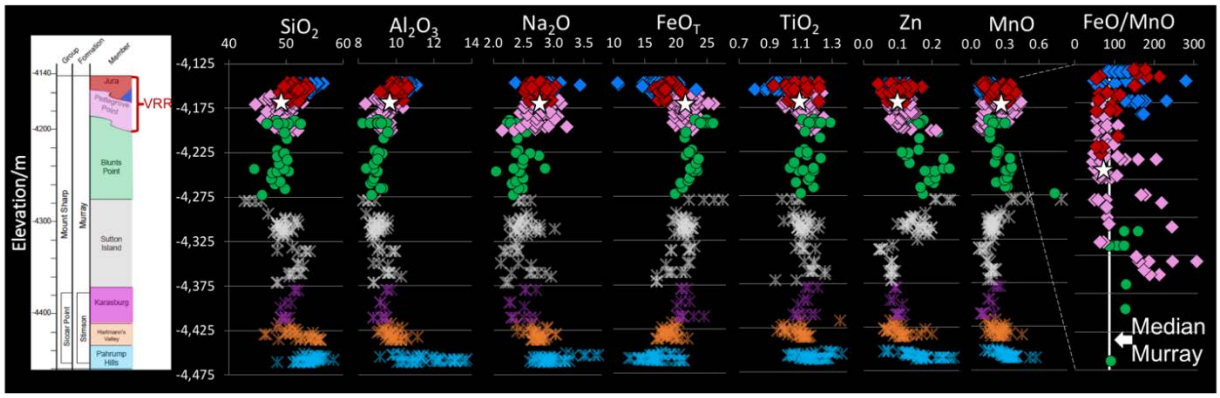

Figure 3: Chemostratigraphic plots showing compositional variation of the Murray fm with elevation. VRR trends are at the top of each of the plots. Stars indicate APXS targets sampled from the pixels with the strongest hematite spectral signatures encountered on the VRR. The FeO/MnO plot is over a narrower elevation range.

There is no increase in Fe concentration within the Pettegrove Pt and red Jura associated with hematite spectral signatures compared to the underlying Murray fm (Fig. 3). Specifically, targets analyzed from areas exhibiting the strongest hematite signatures along the traverse have typical Murray fm Fe concentrations. This indicates that Fe has not been added to the bulk Murray bedrock, i.e., as a cementing oxide and is consistent with similar hematite abundances detected in VRR drilled samples compared to the rest of the Murray [4].

Curiosity's traverse allowed us to sample across the contact between the ridge and the underlying Blunt's Pt member, as well as across the contact between the Pettegrove Pt and Jura members of the VRR, at two laterally separated locations (Fig. 1). No consistent, distinct changes in composition were observed, except for a decrease in Mn at the Blunts Pt/Pettegrove Pt contact (Fig. 3). However, the same chemical trends are observed across both transects, but at different elevations. This strongly implies that the trends and morphology of the ridge are not the result of primary sedimentary or depositional processes, but are instead the manifestation of later diagenetic/alteration episodes .

Variable Fe, and particularly Mn concentrations, result in a range of FeO/MnO on the ridge. The FeO/MnO was high (>150) as Curiosity climbed onto the ridge, and low (mostly <100, 100 being the average FeO/MnO for the Murray fm) through the middle of the ridge, until we reached the Jura member, for which the FeO/MnO is extremely varied (from <100 to >200) (Fig. 3). Mn was obviously mobile within the ridge sediments, indicating extensive alteration of primary mafic igneous minerals, to allow for the fractionation of Mn from Fe. The high FeO/MnO (very low MnO) measured as the rover traversed onto the ridge and the highly variable ratio within the Jura might indicate that these horizons were a focus for secondary fluid flow.

Significant crystalline hematite content is detected in the Highfield, grey Jura drill sample [4], consistent with high FeO/MnO measured by APXS for the majority of grey Jura targets, contradicting the lack of ferric spectral signatures observed and the grey colour. This, along with other work on the spectral characteristics of the VRR and lab observations indicate that the source of the ferric spectral signatures is more complex than just the Fe^{3+}/Fe^{2+} [5,6,7,8]. In particular, the XRD-amorphous component likely plays an important role.

Conclusions: APXS compositional measurements of the VRR highlight:

- continuation of the Murray fm depositional sequence
- elemental trends associated with each VRR unit, which whilst helping to distinguish the units also indicate geochemical transition and overlap
- compositional variability over a relatively narrow elevation range (~50 m), and laterally, indicating mobility of elements and extensive fluid flow
- the discordant nature of elemental trends associated with the ridge-forming strata, which implies secondary diagenetic/alteration processes cutting across stratigraphy being responsible for the formation of the VRR

References: [1] Fraeman, et al. (2015), *Geology, 41(10)*, 1103–1106. [2] Fraeman, et al. (2016) *JGR Planets*, *121*, 1713-1736. [3] Edgar, et al. (2018) *AGU P41A-01*. [4] Morris, et al., *this conference* [5] Fraeman, et al. *this conference* [6] Jacob, et al. *this conference* [7] Horgan, et al. *this conference* [8] Johnson, et al. *this conference*

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