DIAGENETIC IRON ENRICHMENTS OBSERVED BY CHEMCAM ON VERA RUBIN RIDGE, GALE CRATER, MARS

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Introduction: The Curiosity rover reached a local topographic high known as Vera Rubin Ridge (VRR) on sol 1800 after more than 17 km of traverse since landing in the Gale crater on Mars. The ridge is characterized by a hematite signature in CRISM spectra [1], which was confirmed during the approach by both Mastcam multispectral and ChemCam passive spectra [2-3] observations. Hematite was also observed previously in the Murray lacustrine mudstones stratigraphically below VRR.

Recent observations since sol 1800 on the ridge from the ChemCam instrument did not show any strong increasing Fe trend in the host rock [4-5], but highlighted sporadic, anomalously high Fe detections. These observations are often associated with light-toned Ca-sulfate (bassanite) veins, which were observed consistently across the rover traverse [6-7].

Data processing: All data used in this study were collected by Chemcam [8], the Mars Science Laboratory (MSL) Laser Induced Breakdown Spectroscopy instrument, and the associated Remote Micro-Imager (RMI). Chemical quantifications for major elements are obtained using an updated multivariate analysis technique [9].

Observations: ChemCam observed high Fe abundances (>24 wt. % FeO_T) at several locations in the VRR along with lower abundances in other major elements (Si, Al, Ti, Mg, K and Na). These high Fe observations are associated with varying Ca content and form two distinct chemical trends: (1) high Fe – high Ca and (2) high Fe – low Ca (Figure 1).

High Fe and Ca abundances are observed on host rock targets crossed by Ca-sulfate filled fractures, along which high Fe observations are located but also on grey patches within large Ca-sulfate veins (e.g. Fair_Isle target; figure 2). High Fe – low Ca observations are located on dark-toned features along similar Ca-sulfate filled fractures, which often display elongated and polygonal morphologies (e.g. Arran target; figure 2).

As for minor elements, these features show depleted Ba, Cr, Li, and Sr but variable Mn, Rb and Zn, correlated with Si content and thus probably associated with the surrounding host rock chemistry. ChemCam sensitivity is limited to S, but the only cases where S has been detected is with high Ca, and there appears to be no obvious correlation between S and Fe. Likewise, there is no clear evidence of P, F, Cl or Ni in these high-Fe features.

Passive reflectance spectra normally show weak to non-existent ferric absorptions (535 nm band, down-turn after 750 nm) associated with the dark-toned fea-tures, contrasting with typical spectra associated with VRR host rocks. These dark, spectrally neutral features could represent coarse-grained (gray) hematite or an-other iron oxide phase, such as magnetite.

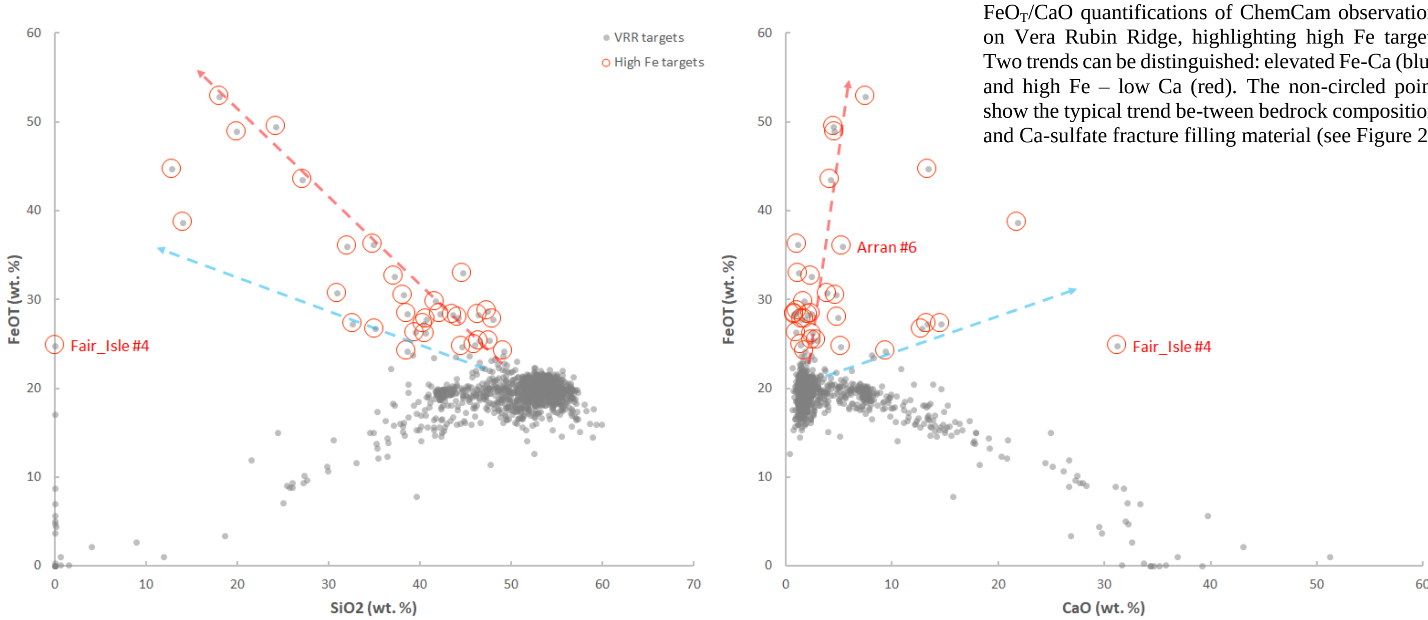

Figure 1: Bivariate plot showing FeO_T/SiO_2 and FeO_T/CaO quantifications of ChemCam observations on Vera Rubin Ridge, highlighting high Fe targets. Two trends can be distinguished: elevated Fe-Ca (blue) and high Fe – low Ca (red). The non-circled points show the typical trend be-tween bedrock compositions and Ca-sulfate fracture filling material (see Figure 2).

Interpretation: Fe enrichments in VRR appear to be mainly associated with dark-toned clasts often encountered along Ca-sulfate filled fractures, which likely explain the weak correlation observed with CaO, as well as the scatter along the 2 trends due to sampling of two neighboring minerals. These observations thus point toward a diagenetic origin for the formation of these Fe-rich phases.

The negative correlation observed with other major and minor elements, the elevated sum of quantified major elements, and the absence of high abundances of S, P and Cl suggest that this Fe-enrichment is associated with a pure FeO mineral phase, i.e. Fe-oxide.

The lack of strong Fe^{3+} related absorptions and the absence of other diagnostic spectral features in some of the passive spectra suggest relatively less oxidizing conditions of formation, even though crystallinity, grain size and their small dimension with respect to the probed area can influence the spectral properties [10].

Discussion: Associations of Fe and Ca-sulfate were previously observed by ChemCam at several locations along the rover traverse. Fe^{3+} enrichments were observed in Ca-sulfate bearing light-toned veins near the Naukluft Plateau (sol ~1200-1400), which formed by diagenetic fluid circulation in an oxidizing and potentially acidic environment [11] Dark-toned inclusions within Ca-sulfate veins showed Fe^{2+} enrichments associated with elevated P [12] and slightly elevated Mn [13] near the Old Soaker outcrop (sol ~1500-1600) which hints at a change in redox conditions, from the formation of these inclusions or precursor material in an oxidizing environment (P adsorption onto Fe^{3+}-oxide [12]) to more reducing conditions associated with the emplacement of the veins [11].

As we show here, Fe enrichments in the VRR are also encountered alongside Ca-sulfate light-toned veins and thus appear to be of diagenetic origin. However, no clear constraints can be put here on the conditions of formation of these features in terms of oxidation or pH. In addition, the relationship between these features with orbital and in-situ hematite detections in neighboring host rocks remains unclear, but appear to be unrelated to a change in depositional environment [3]. In light of these observations, a postdepositional oxidation of the sediments scenario is favored, potentially associated with late diagenesis fluid circulation and emplacement of Ca-sulfate veins or early diagenetic cementation, rather than primary deposition along a redox boundary in a lacustrine setting [14].

These new observations highlight the significant role played by ground water circulation and diagenesis in the mobility and distribution of Fe (and other redox sensitive elements) at Gale crater as well as in contributing to the redox conditions that prevailed within the sediments.

Further observations from the rover Curiosity on the VRR and as it continues its ascension of Mount Sharp to the Clay and Sulfate units will be invaluable in order to better understand the depositional and diagenetic history of the Gale crater sediments.

References: [1] Fraeman, A. et al. (2013), Geology, 41(10), 1103–1106. [2] Johnson, J.R. et al., this meeting. [3] Fraeman, A. et al., this meeting. [4] Frydenvang, Y. et al., this meeting. [5] David, G. et al., this meeting. [6] Nachon, M. et al. (2016), *Icarus, 281*, 121. [7] Rapin, W. et al. (2016), EPSL, 452, 197–205. [8] Wiens, R.C., et al. & Maurice, S. et al. (2012), *Space Sci. Rev.*, 170. [9] Clegg, S. et al. (2017) *SCAB.* [10] Johnson, J.R. et al. (2016), *Am. Mineralogist*, 101, 1501–1514. [11] L'Haridon, J. et al. (2017), *Icarus*, in revision. [12] Meslin, P.-Y. et al., this meeting. [13] Gasda, P. et al., this meeting. [14] Hurowitz, J. A. et al. (2017), *Science* (80-.)., 356(6341).

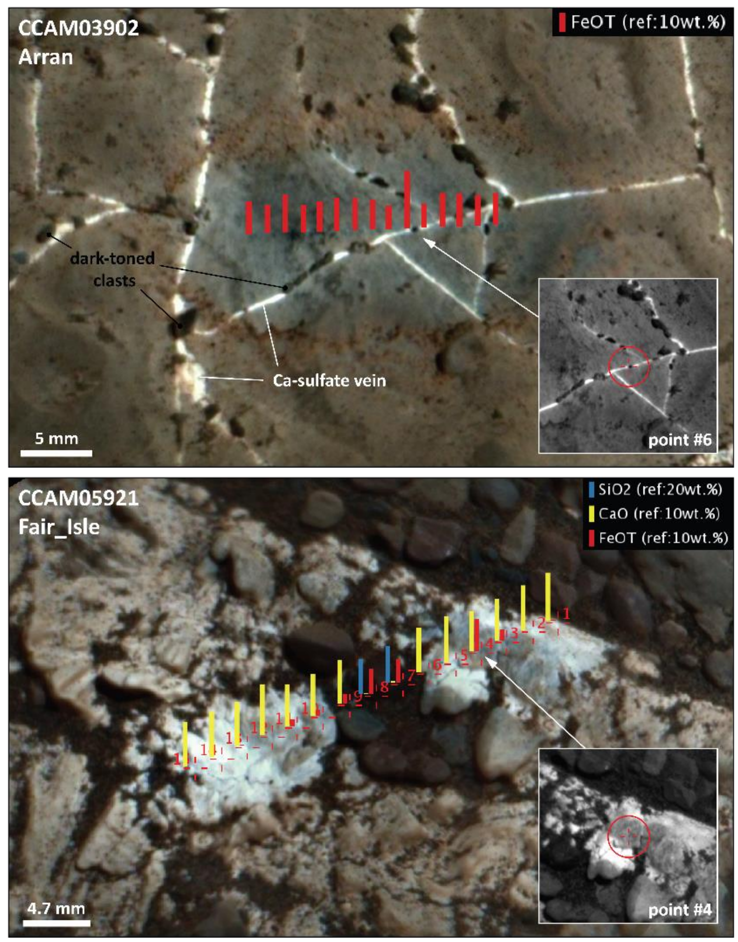

Figure 2: RMI images (colorized with Mastcam) of the Arran (top) and Fair_Isle (bottom) targets. The Arran target shows evated FeO_T content on the point #6 associated with a dark-toned clast. Similar clasts are observed in the vicinity, prefencially along Ca-sulfate filled fractures, showing on occasion elongated and polygonal shapes. The Fair_Isle target shows grey patches within a large Ca-sulfate vein that present elevated FeO_T content (e.g. point #4).