CHEMICAL CHARACTERIZATION OF FE-RICH DIAGENETIC NODULES WITH CHEMCAM IN THE GLEN TORRIDON REGION, GALE CRATER, MARS.

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Introduction: Since 2012, the Curiosity rover has been investigating Gale crater on Mars. Today, after ~3000 Sols (martian days), it is now located in the clay-rich region of Glen Torridon (GT). GT sedimentary strata are conformable with the previous terrains of the Murray formation, and the lower part of the GT region is stratigraphically equivalent to Jura, the upper member of Vera Rubin ridge (VRR) [1]. In some sedimentary rocks of Glen Torridon, particularly in the "fractured Intermediate Unit" (fIU), diagenetic concretions have been observed (e.g., Figure 1). Such features are relatively common in the Murray formation and many kinds of concretions were encountered along the rover traverse with distinct morphologies and chemical compositions (e.g., [2]) that suggest a complex hydrological history with multiple episodes of fluid circulation in the sedimentary rocks of the crater.

Objectives of the study: Among the scientific payload of the rover, the submillimeter scale of the ChemCam [3, 4] laser beam is well suited to assess the chemical composition of small features such as diagenetic nodules. Chemical analysis of these structures could help to constrain post-depositional fluid conditions that affected the sedimentary rocks of Gale. The first ChemCam results reveal that some of the nodules from the fIU are iron-rich (i.e., >25 wt.% FeO_T). Interestingly, measurements in between the nodules show low iron contents (i.e., ~10-15 wt.% FeO_T). Such assemblages are reminiscent of diagenetic features investigated by Curiosity in the Jura member of VRR (Sols ~1800 to 2300), where sporadic, mm-scale, Fe-rich dark-toned nodular concretions within or in close association with Ca-sulfate veins were observed [5]. A dedicated iron calibration was performed by [6] to refine the characterization of the VRR dark-toned features with ChemCam. This calibration method revealed that the diagenetic features of VRR have a composition consistent with pure iron oxides. In turn, this result supports the formation process proposed by [5] in which the iron of the dark-toned features was leached from the host rock by redox-driven chemical reactions during diagenesis.

Here, we want to study the potential link between the Fe-rich diagenetic features observed in VRR and the diagenetic nodules found recently in 5 ChemCam targets at Glen Torridon between Sols 2954 and 2962 ("Achnaha", "Achnacarry", "Bruggs", "Ben_Hee", "Ben_Hee_2") by refining the iron quantification.

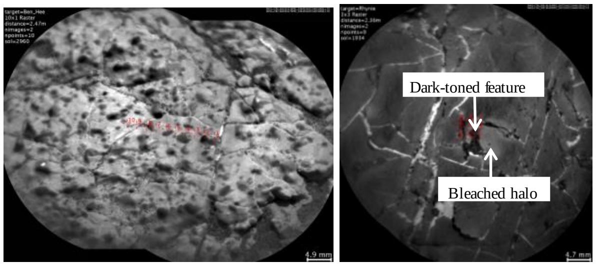

Figure 1: Left) Illustration of nodular bedrock observed in the Glen Torridon region (Ben_Hee ChemCam target, Sol 2960). Right) Dark-toned features and bleached halos observed in the Jura member of VRR (Rhynie ChemCam target, Sol 1934).

Method of iron quantification: The refined method of iron quantification is based first on the extension of the current geological standards used in the ChemCam calibration database [6, 7]. Powders of hematite, goethite, and magnetite were mixed at different concentrations with basaltic materials (from 0 up to 100 wt%). Four different matrices were used: 1) pristine JSC martian simulant [8]; 2) a mixture of JSC martian simulant with ilmenite ($FeTiO_3$) to match the iron content of martian basalts (~20 wt% FeO_T); 3) magnesium sulfate (kieserite) and 4) calcium sulfate (a mixture of bassanite, anhydrite, and gypsum). Mixtures were then pressed into pellets and analyzed with the ChemCam testbed in Toulouse, in a chamber that mimics martian conditions for atmospheric pressure (~7 mbar) and compositions (mainly CO_2). Then, to avoid issues between laboratory and flight instrumental response functions, a new method was developed based on the Pearson correlation factor (PCF). PCF was calculated between the spectrum of each laboratory sample and the spectrum of a pure iron reference: the Mont Dieu iron meteorite [9]. Then, using all the samples of the calibration database (437 samples), a calibration curve was built. For martian data, the PCF was computed between flight data and spectra acquired on the Aeolis Mons 001 iron meteorite, obtained with ChemCam on Mars (target Egg Rock from Sol 1505 [10]). This allowed PCF for laboratory and ChemCam Mars data to be directly compared and enabled us to estimate the iron abundance of martian targets. Finally, the uncertainties of the model are obtained from the Root Mean Square Error (RMSE) [6].

Results: Iron abundances obtained with the refined model in GT targets containing nodules are shown in Figure 2 (orange squares). The highest iron content observed in the nodules reaches 47.4±18 wt.% FeO_T, consistent with the iron MOC prediction. For comparison, dark-toned materials investigated in VRR (black squares in Figure 2) have much higher iron abundances, some of which consistent with nearly pure iron oxides. The lower iron contents observed in the GT nodules could be due to the contamination from the host rocks (i.e., the laser beam sampling both the nodule and the surrounding rocks) although the laser pits do not seem to be located particularly on the edge of the nodules. Alternatively, the lower iron abundances in these nodules could be the result of different mineral assemblages (e.g., iron oxides intimately mixed with basaltic materials) compared to the diagenetic features observed in VRR.

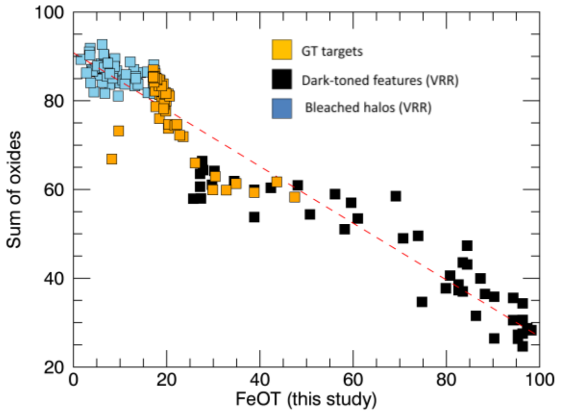

Figure 2: Iron abundances from the refined model as a function of the sum of other major oxides (i.e., MOC total minus FeOT) for targets with dark-toned nodules found in GT, and dark-toned diagenetic features and bleached halos found in VRR.

Interestingly, Fe-rich points on these nodules are not associated with variations of relative abundances among the other major elements (Figure 3). Dark-toned diagenetic features and associated bleached halos observed at VRR are also shown to illustrate the trend expected in the case of pure FeO_T enrichment (black and blue squares). Host rock (including low iron abundances) and Fe-rich nodules of GT follow the same overall trend. This result could suggest a similar formation mechanism between GT nodules and VRR diagenetic features, i.e., leaching of Fe from the host rock, followed by re-precipitation in the form of nodules. However, the process that formed the nodules must be less advanced in GT as shown by its host rock and nodules having less extreme compositions compared to VRR features (Figure 3).

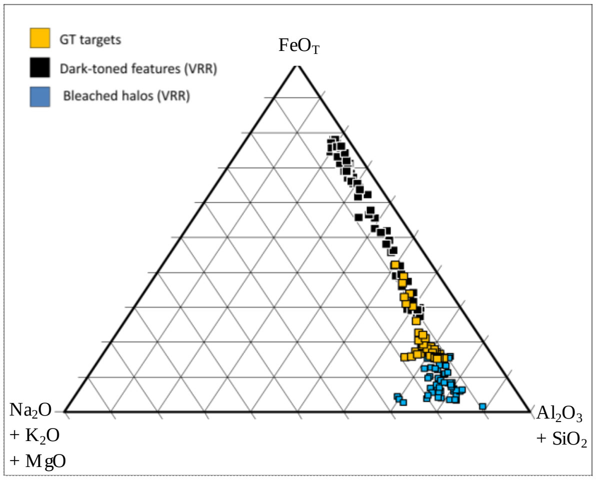

Figure 3: Ternary diagram (in molar proportion) showing GT nodular targets as well as dark-toned diagenetic features, and bleached halos found in VRR.

Summary and conclusion: Our preliminary results support the existence of chemical diversity in the diagenetic features of Glen Torridon [11] and confirm that some of them are enriched in iron. However, the iron abundances are not at the same level of enrichment as those observed in the dark-toned materials encountered in VRR. It is not clear if such differences are real or linked to analytical bias (e.g., we have not yet hit the pure material). Additional ChemCam observation points on these features could be useful to address this issue and decipher if the nodules are mainly composed of iron oxides (and consequently probably related to VRR diagenetic features) or if they consist of a mixture between iron oxides and basaltic materials. In the latter case, nodules could be more related to the diagenetic spherules found in Meridiani by the Opportunity rover [12] that are thought to be composed of hematite with basaltic debris.

References: [1] Fedo, C.M. et al. (2020). *LPSC LI* Abstract #2345. [2] Sun V., et al., (2015). *Icarus 321*. [3] Maurice S. et al., (2012). *Space Science Reviews*, 170,95. [4] Wiens R.C. et al., (2012). *Space Science Reviews*, 170, 167. [5] L'Haridon J. et al. (2020). *JGR: Planets*, 125(11) [6] David G. et al., (2020). *JGR: Planets*, 125(10). [7] Clegg S. M. et al., (2017). *Spectrochimica Acta B*, 129. [8] Allen C. C. et al., (1998) *LPSC XXIX*. [9] Grossman J. N. et al., (1997), *The Meteoritical Bulletin*, 81. [10] Meslin. P. Y. et al., (2017) *LPSC XLVIII*. [11] Gasda P. J. et al., (2020) *This conference* [12] McLennan S. M. et al., (2005) *Earth and Planetary Science Letters*, 240.