

IDENTIFICATION AND IMPLICATIONS OF IRON DETECTION WITHIN CALCIUM SULFATE MINERALIZED VEINS BY CHEMCAM AT GALE CRATER, MARS

J. L'Haridon¹, N. Mangold¹, W. Rapin², O. Forni², P.-Y. Meslin², A. Cousin², V. Payré³, E. Dehouck², M. Nachon⁴, L. Le Deit¹, O. Gasnault², S. Maurice², R. Wiens⁵

¹ Laboratoire de Planétologie et Géophysique de Nantes, Nantes, France, ² IRAP, UPS-OMP, Toulouse, France, ³ GeoRessources, Nancy, France, ⁴ UC Davis Earth and Planetary Science, Davis, California, USA, ⁵ Los Alamos National Laboratory, Los Alamos, New Mexico, USA

✉ jonas.lharidon@univ-nantes.fr

OBSERVATIONS OF DIAGENETIC FEATURES BY CHEMCAM

The Mars Science Laboratory instrument ChemCam [1] (LIBS and the associated RMI camera) has observed **diagenetic mineralized veins** [2,3,4] at Gale Crater Mars, along the **Curiosity rover traverse**, starting at **Yellowknife Bay** shortly after landing (Figure 1). Among these features, light-toned veins – primarily composed of Ca-sulfate (anhydrite [5] and bassanite [6]) – are pervasive to all units and cross-cut other diagenetic features [7], thus hinting at a **regional late-stage episode of fluid circulation**.

Recent observations show the presence of **iron and magnesium** within the **bulk of the veins**, seemingly **unrelated to the host rock silicate components** as revealed by shot-to-shot analysis of the LIBS spectra. This chemistry appears to differ from mixed composition observed at the interface between distinct lithologies, which are not uncommon with ChemCam because the LIBS laser spot is up to 500 μm in size.

The chemical composition deviating from the *Host rock – Ca-sulfate* mixing line seen so far may thus hint at **chemical heterogeneity within the light-toned vein facies**.

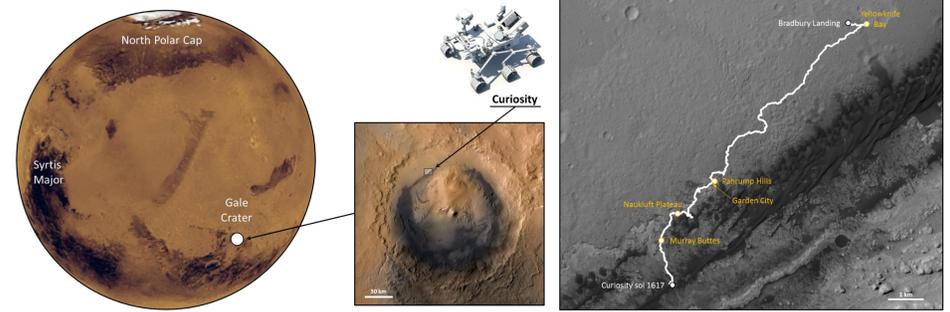


Figure 1: Localization of Gale Crater (5.4°S 137.7°E) and the Curiosity rover traverse on Mars (left) and the Yellowknife Bay, Pahrump Hills, Naukluft Plateau and Murray Buttes localities along the Curiosity rover traverse (right).

IRON DETECTION IN LIGHT-TONED VEINS

A thorough investigation of the LIBS spectra of every light-toned vein observed so far by ChemCam has been conducted in order to distinguish Fe-enhanced vein chemistry from host rock contributions. This selection was made based on the ratio of maximum intensity between Fe (260.017 and 404.695 nm) and Si (288.242 nm) peaks deviating significantly from typical host rock ratios. A **Fe-rich subset of light-toned veins** has thus been identified (Figure 2), mainly in the last ~ 500 sols of the mission.

In addition, ChemCam recently observed **darker-toned material**, often associated with light-toned veins as inclusions, which display **very high FeO₇ and MgO abundances** associated with high MnO and P detection [8]. A potential genetic link between these features and the iron enrichment in light-toned veins is considered, especially in the more recent iron detections.

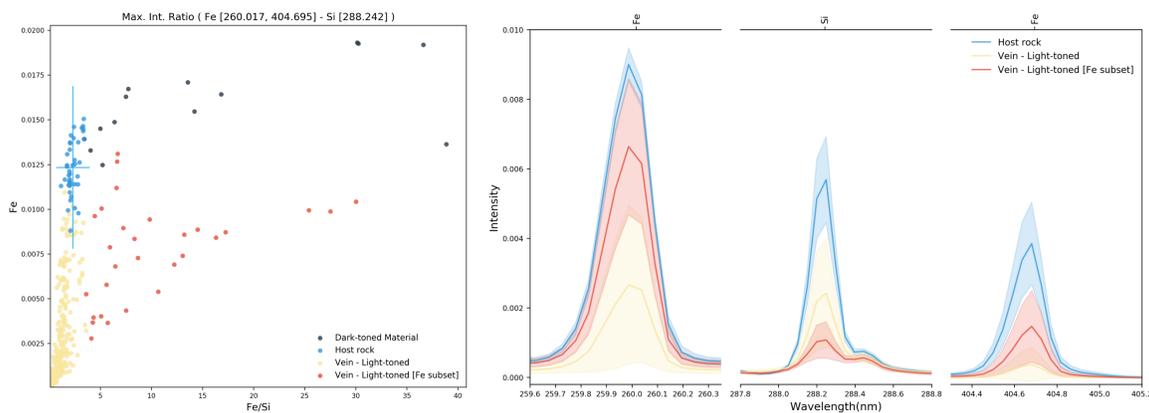


Figure 2: Bivariate plot (left) in maximum intensity showing Fe/Si against Fe illustrating the light-toned veins subset points selection for light-toned vein targets with a Fe/Si ratio greater than host rock typical ratios (the blue cross represents the host rock mean value and 3- σ standard deviations). Mean spectra and 1- σ standard deviation (right) for host rock, light-toned veins and subset points showing an anti-correlation between Fe and Si in the latter.

INTERPRETATION FOR MINERAL PHASE

Ternary diagrams (Figure 4) of ChemCam major elements quantified contents (MOC quantification [9]) illustrating a **similar FeO₇ enrichment** in light-toned veins and in dark-toned features in the vicinity. A genetic link between these features is considered and may provide constraints on the chemistry of the iron phase detected, potentially indicating a **Fe sulfate and/or phosphate component**.

In addition, Fe appears to be weakly correlated with **higher Al₂O₃ and MgO** (separately) potentially indicating two distinct chemical trends toward **Fe-Al and Fe-Mg mineral phases**.

Ti is for the most part not correlated with Fe in these features, likely indicating a **non detrital origin for the Fe-rich phases**.

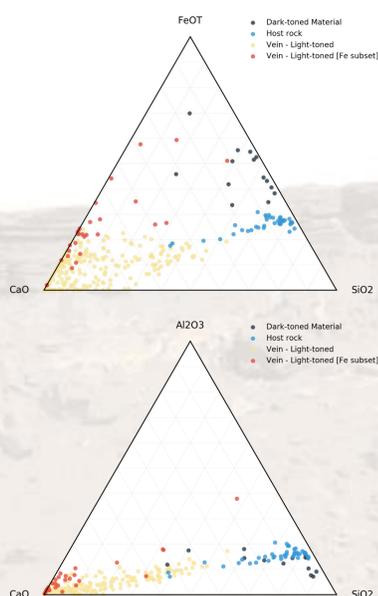


Figure 4: Ternary diagram in major element contents (wt.%, normalized) showing similar FeO₇ enrichments in light-toned subset and dark-toned material compared to the silicate-rich host rock and calcium sulfate light-toned veins chemistry (top) as well as a slight Al₂O₃ enrichment in light-toned veins subset points potentially indicating an Fe-Al mineral phase (bottom).

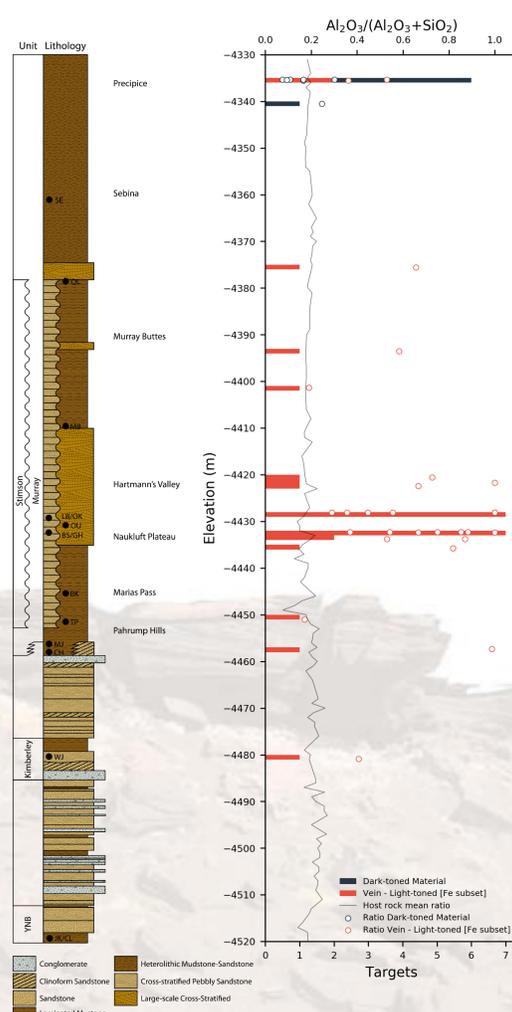


Figure 5: Distribution of light-toned Fe-subset veins in the stratigraphy (adapted from [10]), highlighting the concentration of these targets in the Murray formation, and especially at Naukluft Plateau and Precipice localities. The distribution of the dark-toned Fe/Mg-rich material and Al₂O₃/(Al₂O₃+SiO₂) ratios are also indicated.

TEXTURE AND STRATIGRAPHIC DISTRIBUTION

Fe-rich light-toned veins are often associated with a **branched texture and spotted aspect** (i.e. displaying darker areas within the vein, Figure 3), as opposed to the massive texture and pristine aspect of the pure Ca-sulfate veins [1,2].

These detections are also **heterogeneous within the light-toned veins**, with several LIBS points displaying a Fe-rich chemistry amidst an otherwise *pure* calcium sulfate phase (e.g. in Khoabendus target).

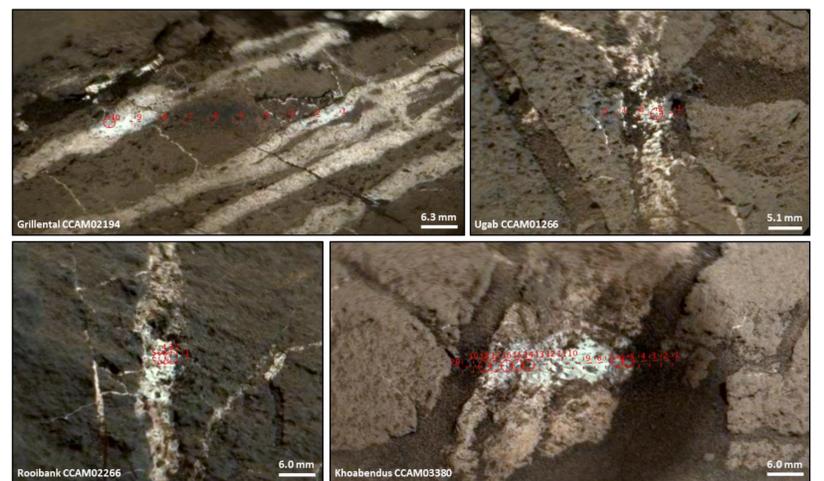


Figure 3: RMI images (colors from Mastcam) of selected subset targets showing Fe-rich and Si-poor signature within light-toned veins (the LIBS points of the subset are circled in red). These veins display a branched texture for the most part, and present a grey spotted aspect especially on the locations with elevated Fe/Si ratio. These detections in some case appear only on part of the veins e.g. in the Khoabendus target, with a clean patch on the vein showing a pure calcium sulfate signature (points 8 to 13).

STRATIGRAPHIC CONTEXT

The distribution of the Fe-bearing calcium sulfate vein targets in the Gale stratigraphy (Figure 5) show that they are mostly encountered within the **Murray formation** (lake mudstones), especially near the **Naukluft Plateau** and **Precipice** localities.

The dark-toned features were also found near **Precipice**, supporting the case for a **co-genetic deposition** alongside calcium sulfate, potentially as **Fe-Mg phosphate**.

Naukluft Plateau on the other hand is located near the stratigraphic unconformity with the overlying **Stimson formation** (eolian sandstones), where a **Si-rich composition** was identified in fracture related halos [11] (Lubango (LB) and Greenhorn (GH) drill holes). This chemistry may result from the **acid leaching of the host rock** [12] concentrating **iron and aluminum** in the fluids, that would have later re-precipitated in the vicinity either as **Fe-Al sulfates** (coquimbite) or as **Fe & Al oxides**.

CONCLUSION

Observations of **Iron-rich chemistry** within calcium sulfate veins attest for evolving fluid chemistry. Two deposition mechanisms are proposed to account for these observations:

- 1 Related to Fe-Mg (+P/Mn) rich **dark-toned features** near **Precipice**, and a potential co-genetic precipitation as a **phosphate phase**.
- 2 **Acid leaching** in the overlying Stimson unit near **Naukluft Plateau** with subsequent concentration of **Fe & Al** in fluids, and later re-precipitation as either **sulfates or oxides**.

As for mineral phases implications, an **Fe-sulfate** phase would indicate a more **acidic** diagenetic fluid composition while **Fe-oxides** and **phosphates** could point toward both **oxidizing and acidic** conditions.

In addition, light-toned vein chemistry may be influenced by the proximity to the **hematite ridge** [13] and the **sulfate layers** observed from orbit [14] farther up the slopes of Mount Sharp, as the rover continues its ascent.

REFERENCES

- [1] Wiens, R.C., et al. & Maurice, S. et al. (2012), Space Sci. Rev., 170 [2] Nachon, M. et al. (2014), JGR Planets, 119, 1991–2016. [3] Nachon, M. et al. (2016), Icarus, 281, 121. [4] Léveillé, R. J., et al. (2014), JGR Planets, 119, 2398–2415. [5] Vaniman D. T. et al. (2014) Science 343. [6] Rapin W., et al. (2016) EPSC 452, 197-205. [7] Kronyak, R. et al. (2015), AGU abstract. [8] Forni, O. et al. (2017), LPSC #48 (this meeting). [9] Clegg S. et al. (2017) Spectrochim. Acta B, 129, 64-85. [10] Grotzinger, J. et al. (2015), Mars. Science 350. [11] J. Frydenvang et al. (2017), submitted. [12] A. Yen et al. (2016), LPSC #47. [13] Fraeman, A. et al. (2016), Fall AGU, San Francisco. [14] Anderson, R. et al. (2010), Mars J., 5, 76–128.