Carbonate Dissolution in Lafayette

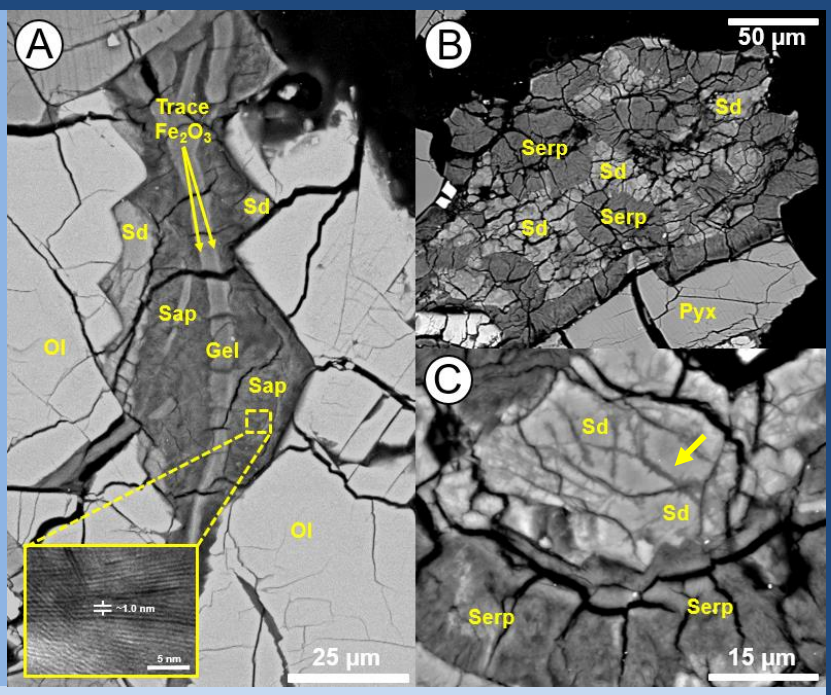
J. D. Piercy[1]*, J. C. Bridges[1], L. J. Hicks[1]

[1]Space Research Centre, School of Physics and Astronomy, University of Leicester, UK, LE1 7RH. (*jdp32@leicester.ac.uk).

1. Introduction

Lafayette is a member of the **nakhlites**, the group of martian meteorites which show the most evidence of hydrous alteration **[1]**. Lafayette hosts the most evolved alteration assemblage of the nakhlites consisting of siderite, ferric-phyllosilicates, smectitic gel and trace iron oxides **(Fig. 1)**. Previous work **[2, 3, 4]** developed a model which proposes a hydrothermal fluid, created from the melting of CO_2-rich ice during an impact-induced event, percolates upwards through the nakhlite igneous mass. The Ca-siderite contained within Lafayette's olivine and mesostasis hosted assemblages display textures indicative of **corrosion, dissolution and replacement** by saponite and serpentine respectively. This dissolution of siderite contributes to the evolving nature of the fluid just as the dissolution of olivine and mesostasis plagioclase does in the first stages of alteration.

Interpretation of these carbonates informs us about the fluid history of the parent fluid, including its **composition, pH, temperature** and thus potential for **habitability.** Mars2020 will target a carbonate-bearing region on Mars, therefore meteorites such as Lafayette provide a unique analog.



▲ **Figure 1** – **A)** BSE image of olivine assemblage showing siderite, ferric-saponite, trace iron oxide and amorphous gel. Inset shows HRTEM image of saponite lattice spacing's. **B)** Irregular mesostasis assemblage consisting of siderite and a crystalline radial serpentine. **C)** Mesostasis carbonate showing its dissolution and incipient alteration (arrow) from adjacent serpentine.

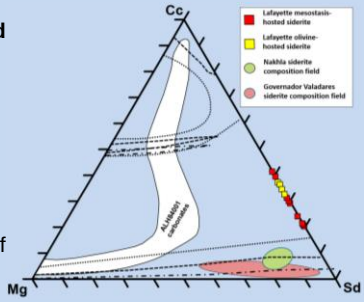
2. Olivine Alteration

Olivine hosted siderite:

- **0.8 vol.%** of the thin section.
- Found in notches of **saw-tooth fractures** within an **ordered assemblage** clearly showing precipitation sequence **(Fig. 1a).**
- Av. composition: **$Mg_0Cc_{28}Sd_{49.5}Rh_{22.5}$** and **metastable (Fig. 2).**
- **Partially dissolved** by adjacent saponite **(Fig. 1a and 3).**

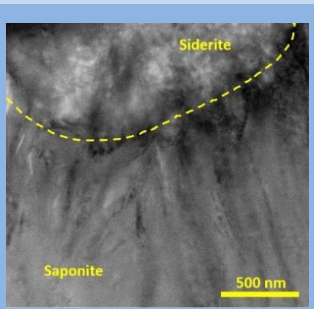
Mesostasis hosted siderite:

- **3.2 vol.%** of the thin section.
- Found in **interstitial areas** within an **irregular assemblage** of siderite and a radial phyllosilicate precipitate **(Fig 1b).**
- Av. composition: **$Mg_0Cc_{29.2}Sd_{70.3}Rh_{0.5}$** and **metastable (Fig. 2).**
- **Partially dissolved** by adjacent serpentine **(Fig. 1c).**



◄ **Figure 2** – *Carbonate ternary showing the compositions of both types of carbonate within Lafayette. Also shows compositional fields of carbonates within ALH84001, Nakhla and Governador Valadares [5]. Calculated stability fields for carbonates formed at 400 °C (dash-dot), 550 °C (dashed) and 700 °C (dotted) are also shown [6].*

► **Figure 3** – *STEM Dark Field image of siderite-saponite boundary within the olivine alteration assemblage. Darker areas and veins can be seen crossing the boundary (dotted line), indicating the dissolution and replacement of the carbonate.*



3. TEM and XAS

Lattice *d*-spacing's of **1.0 nm (Fig. 1a)** and **0.7 nm**, identified in HRTEM, indicate saponite is present in the olivine assemblage whereas serpentine is seen within the mesostasis, supporting **[2, 3].** STEM dark field imagery **(Fig. 3)** shows the lack of a discrete boundary between olivine siderite and saponite, highlighting the dissolution and replacement of siderite.

X-ray Absorption Spectroscopy (XAS), performed at ***Diamond Light Source***, reveals the ferric nature of saponite **(Fe3+/ΣFe = 0.86)** and serpentine **(= 0.99)** compared to ferrous igneous olivine. Measurements of the carbonate also showed some ferric iron, consistent with partial dissolution and replacement.

4. Discussion

Mineralogical, textural and X-ray analyses of Lafayette alteration assemblages reveal two distinct carbonate components. Both sets of carbonate contain no Mg component, suggesting they are much more likely to have **formed via precipitation from a fluid as opposed to direct carbonation of silicates**. Visible textures and XANES analyses show evidence for partial dissolution by a ferric fluid. **Their metastable compositions suggest that they cooled quickly**, likewise the central gel feature seen in the olivine assemblage also cooled quickly, as shown by its amorphous nature.

The **large carbonate content of 4 %** observed within this Lafayette section, initially higher prior to the partial replacement by saponite and serpentine, if taken as an upper estimate on the possible average throughout the martian crust, equates to **2200 mbar pCO_2**. Considering the thick ancient atmosphere model predicts **~400 mbar pCO_2** trapped as carbonate on current day Mars **[7]**, this new upper limit is **consistent with thick pCO_2 models for ancient Mars**.

Mars2020 will touchdown in **Jezero crater**, a Noachian paleolake with similar mineralogy to the nakhlites. Olivine-rich rocks were possibly excavated by the Isidis impact **[8]** and subsequently hydrothermally altered to produce **Fe-rich smectite (nontronite or saponite) and Fe/Mg carbonates [9]**. Studying the nakhlite alteration assemblage is hugely important as an analog for studying aqueous processes and habitability at Jezero crater.

References: [1] Gooding et al. (1991) *Meteoritics* **326**, *135-143*. **[2]** Changela and Bridges. (2011) *Meteoritics* **45**, *1847-1867*. **[3]** Hicks et al. (2014) *Geochimica et Cosmochimica Acta* **136**, 194-210. **[4]** Bridges and Schwenzer. (2012) *Earth and Planetary Science Letters* **359-360**, 117-123. **[5]** Bridges et al. (2019) *Volatiles in the Martian Crust*, *89-118*. **[6]** Anovitz and Essene. (1987) *Journal of Petrology* **28**, 389-415, **[7]** Bridges et al. (2001) *Space Science Reviews* **96**, 365-392. **[8]** Mustard et al. (2009) *Journal of Geophysical Research* **114**, E00D12. **[9]** Ehlmann et al. (2008b) *Science* **322**, 1828-1832.