Carbon Sequestration on Mars: Possible Insights from the Mg-Carbonate/Olivine Lithologies at NE Syrtis or Jezero Crater

L. Hallis, A. Macartney, L. Daly, A. O'Brien, N. Mari, B. Cohen, and M. R. Lee
Mineral Carbonation

- Were the Mg-carbonates at NE Syrtis and/or Jezero crater formed via carbonation?

- How do these carbonates compare to the Comanche Spur carbonates?

- Was carbonation a globally significant process on Mars?
Mineral Carbonation

- Carbonation is the water-mediated replacement of silicate minerals by carbonate.
- Occurs at low temperature and pressure, where CO$_2$ and H$_2$O are available.
- Exothermic reaction = self-propagating.
- Common on Earth (e.g., Samail Ophiolite, Oman).

Image Credit: Evelyn Mervine
Serpentinization

$$2\text{Mg}_2\text{SiO}_4 + \text{SiO}_2 + 4\text{H}_2\text{O} \rightarrow 2\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4$$

Mg-olivine + aqueous silica + water $\rightarrow$ serpentine

Carbonation

$$\text{Mg}_2\text{SiO}_4 + \text{CaMgSi}_2\text{O}_6 + 2\text{CO}_2 + 2\text{H}_2\text{O} \rightarrow \text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4 + \text{CaCO}_3 + \text{MgCO}_3$$

Mg-olivine + CaMg-pyroxene + carbon dioxide + water $\rightarrow$ serpentine + calcite + magnesite

$$2\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4 + 3\text{CO}_2 \rightarrow \text{Mg}_3\text{Si}_4\text{O}_{10}(\text{OH})_2 + 3\text{H}_2\text{O} + 3\text{MgCO}_3$$

serpentine + carbon dioxide $\rightarrow$ talc + water + magnesite
Jezero and NE Syrtis carbonates

Jezero crater lithologies. Goudge et al. 2017 *EPSL*

NE Syrtis cross section. Ehlmann and Mustard, 2012 *GRL*
Possible alteration sequence for E. Nilli Fossae Mg-carbonate/olivine rich region

Initial heat source = lava/ejecta emplacement

2.3 µm absorption feature represents talc and/or saponite

Rover mineralogical and textural analyses could test this model

Viviano et al., 2013 *JGR*
Typical lithological textures

Quartz and Carbonate veins

dolomite veins

Images adapted from Kelemen and Matter, 2008 *PNAS*

Images adapted from Falk and Kelemen, 2015 *GCA*
Returned sample microscopic textures

Small scale features include:

- rounded/embayad olivine relics
- Increased porosity

Images of altered dunite, adapted from Lacinska et al., 2017 *Frontiers in Earth Sci.*
Evidence in Nakhlites?

A-C are cartoons showing a sequence of replacement reactions within Lafayette olivine, resulting in (D) a carbonate-rich alteration vein. Images adapted from Tomkinson et al., 2013 Nature. Comms.

A: Propagation of a ferrous saponite vein

B: 

C: Siderite replacement of olivine

D: 

10 µm
What information could be gained from returned carbonates?

- Temperature of formation: carbonate clumped isotope paleothermometer is based on the temperature-dependent abundance of $^{13}$C–$^{18}$O bonds in carbonate minerals.
- Age of formation IF formed from single fluid event.
- Fluid composition(s) – possible presence of fluid inclusions?
- Quartz veins – ideal environments for the preservation of microfossils.
Jezero and NE Syrtis carbonates

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NE Syrtis cross section. Ehlmann and Mustard, 2012 *GRL*
Carbonation reactions

\[ 2\text{Mg}_2\text{SiO}_4 + \text{Mg}_2\text{Si}_2\text{O}_6 + 4\text{H}_2\text{O} = 2\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4 \]

Mg-olivine + Mg-pyroxene + water = serpentine

\[ \text{Mg}_2\text{SiO}_4 + 2\text{CO}_2 = 2\text{MgCO}_3 + \text{SiO}_2 \]

Mg-olivine + carbon dioxide = magnesite + quartz

\[ \text{Mg}_2\text{SiO}_4 + \text{CaMgSi}_2\text{O}_6 + 2\text{CO}_2 + 2\text{H}_2\text{O} = \text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4 + \text{CaCO}_3 + \text{MgCO}_3 \]

Mg-olivine + CaMg-pyroxene + carbon dioxide + water = serpentine + calcite + magnesite
Carbonation reactions

\[ 2\text{Mg}_2\text{SiO}_4 \text{(Mg-olivine)} + \text{Mg}_2\text{Si}_2\text{O}_6 \text{(Mg-pyroxene)} + 4\text{H}_2\text{O} = 2\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4 \text{(serpentine)} \]

\[ \text{Mg}_2\text{SiO}_4 \text{(Mg-olivine)} + 2\text{CO}_2 = 2\text{MgCO}_3 \text{(magnesite)} + \text{SiO}_2 \text{(quartz)} \]

\[ \text{Mg}_2\text{SiO}_4 \text{(Mg-olivine)} + \text{CaMgSi}_2\text{O}_6 \text{(CaMg-pyroxene)} + 2\text{CO}_2 + 2\text{H}_2\text{O} = \text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4 \text{(serpentine)} + \text{CaCO}_3 \text{(calcite)} + \text{MgCO}_3 \text{(magnesite)} \]