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

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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_2O are available
- Exothermic reaction = self-propagating
- Common on Earth (e.g., Samail Ophiolite, Oman)

Samail Ophiolite, Oman.
Image Credit: Evelyn Mervine

Serpentinization

$$2Mg_2SiO_4 + SiO_2 + 4H_2O \rightarrow 2Mg_3Si_2O_5(OH)_4$$

Mg-olivine + aqueous silica + water → serpentine

Carbonation

$$Mg_2SiO_4 + CaMgSi_2O_6 + 2CO_2 + 2H_2O \rightarrow Mg_3Si_2O_5(OH)_4 + CaCO_3 + MgCO_3$$

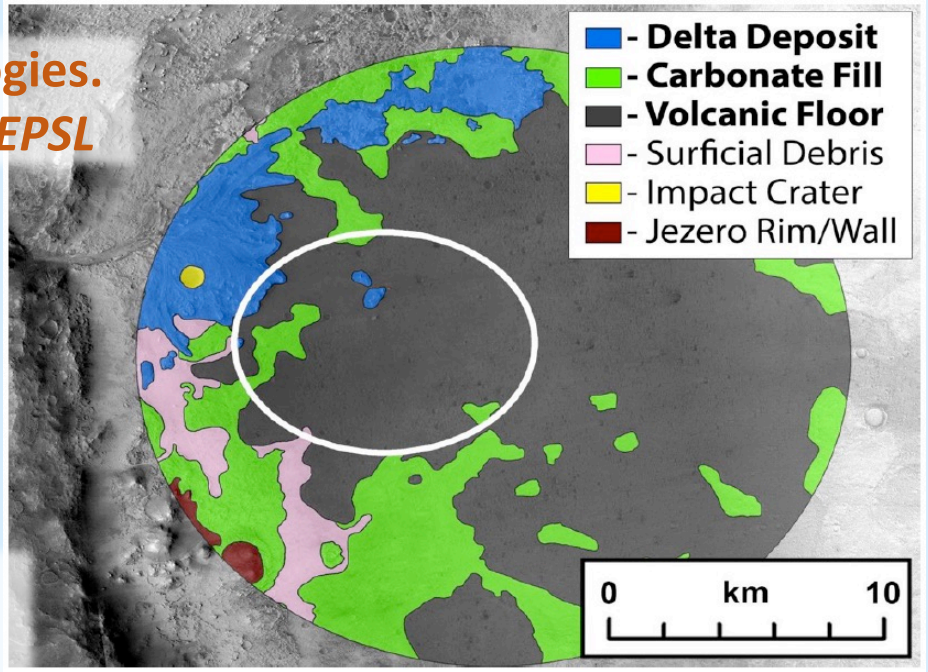
Mg-olivine + CaMg-pyroxene + carbon dioxide + water → serpentine + calcite + magnesite

$$2Mg_3Si_2O_5(OH)_4 + 3CO_2 \rightarrow Mg_3Si_4O_{10}(OH)_2 + 3H_2O + 3MgCO_3$$

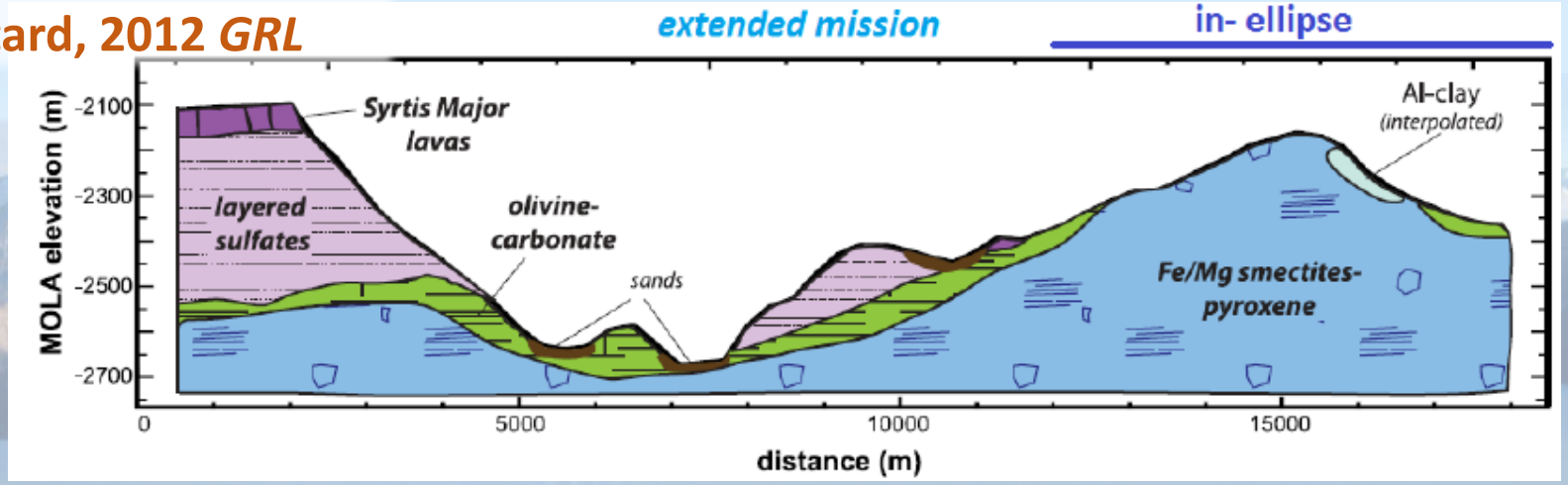
serpentine + carbon dioxide → talc + water + magnesite

Jezero and NE Syrtis carbonates

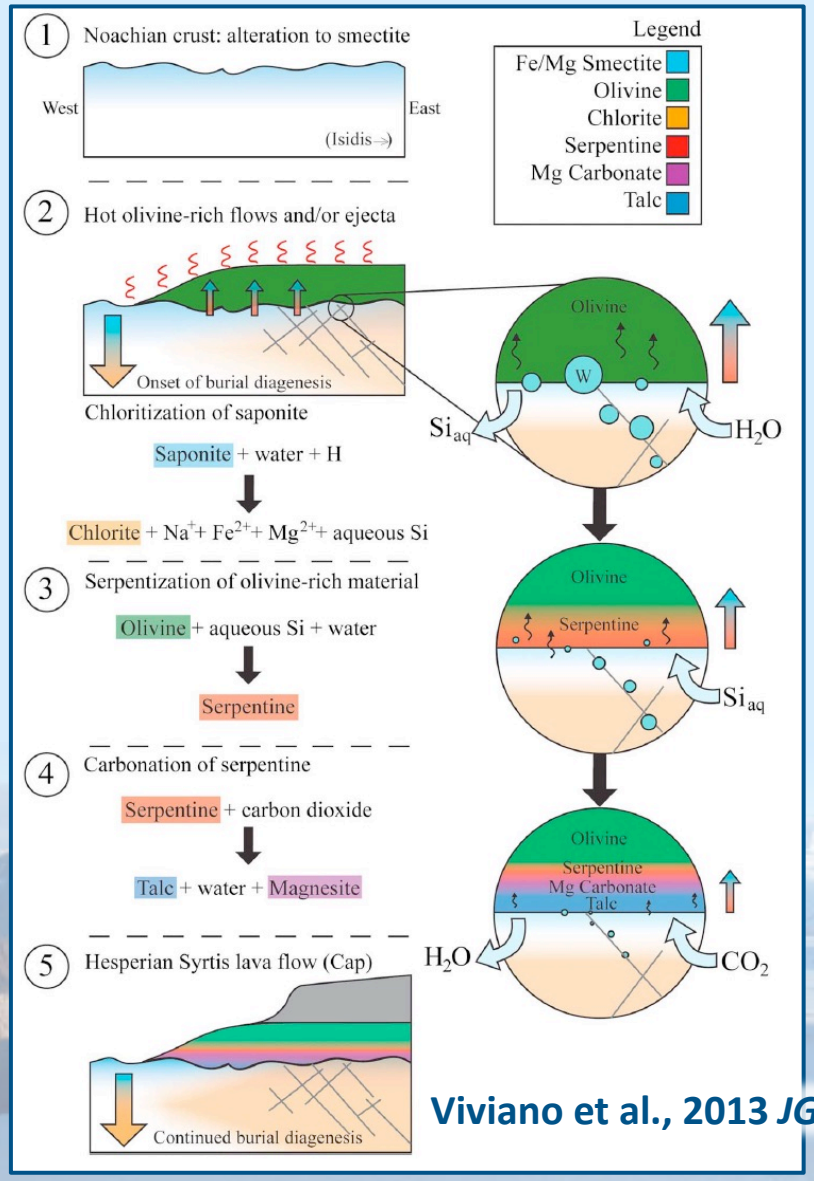
Jezero crater lithologies. Goudge et al. 2017 *EPSL*



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



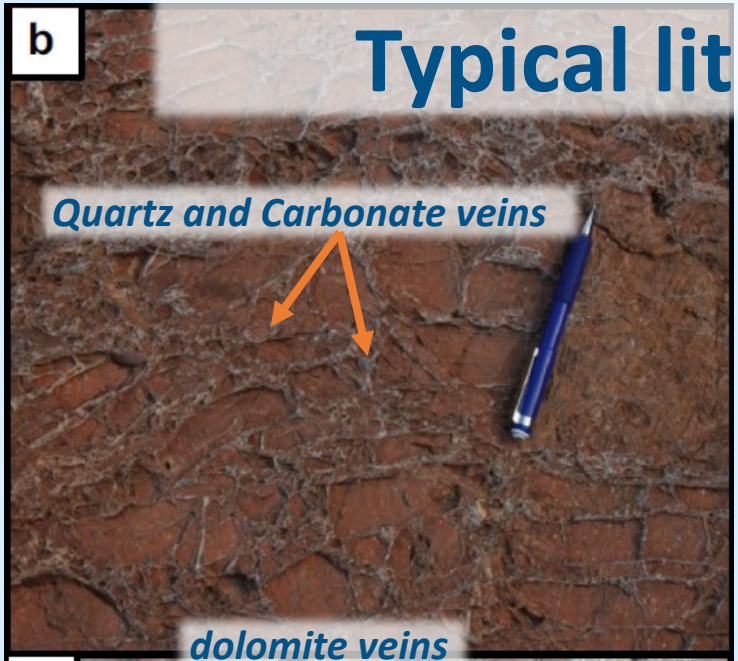
Formation Model



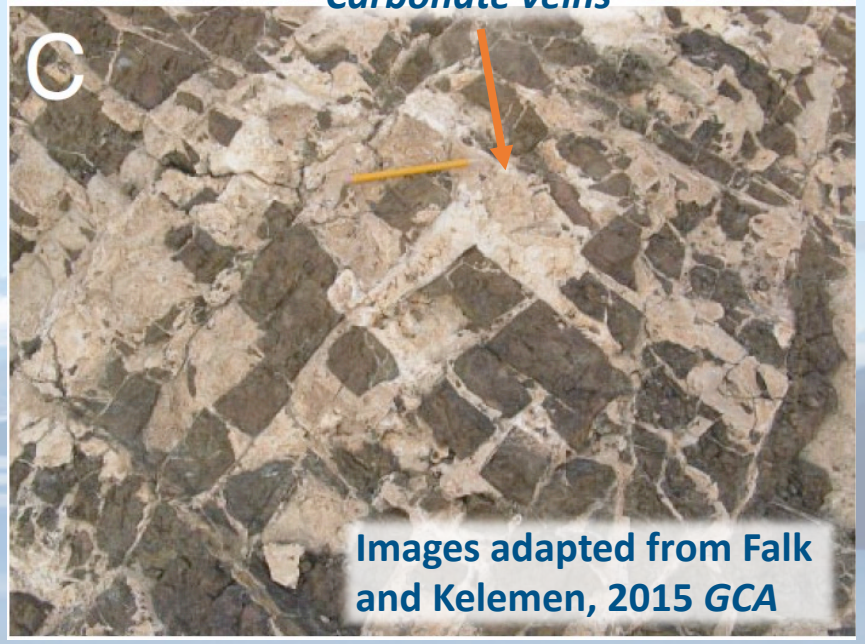
Viviano et al., 2013 *JGR*

- **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**

Typical lithological textures



Images adapted from Kelemen and Matter, 2008 *PNAS*

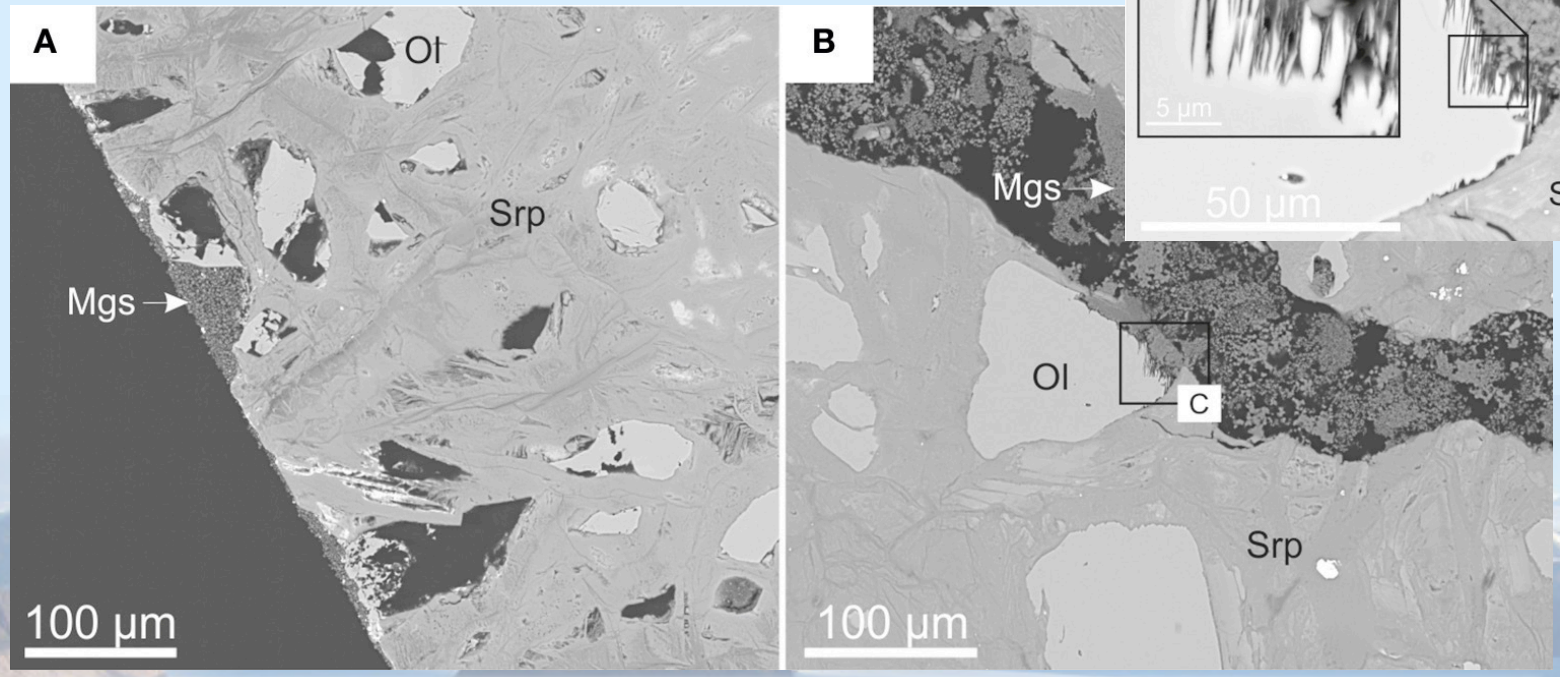


Images adapted from Falk and Kelemen, 2015 *GCA*

Returned sample microscopic textures

Small scale features include:

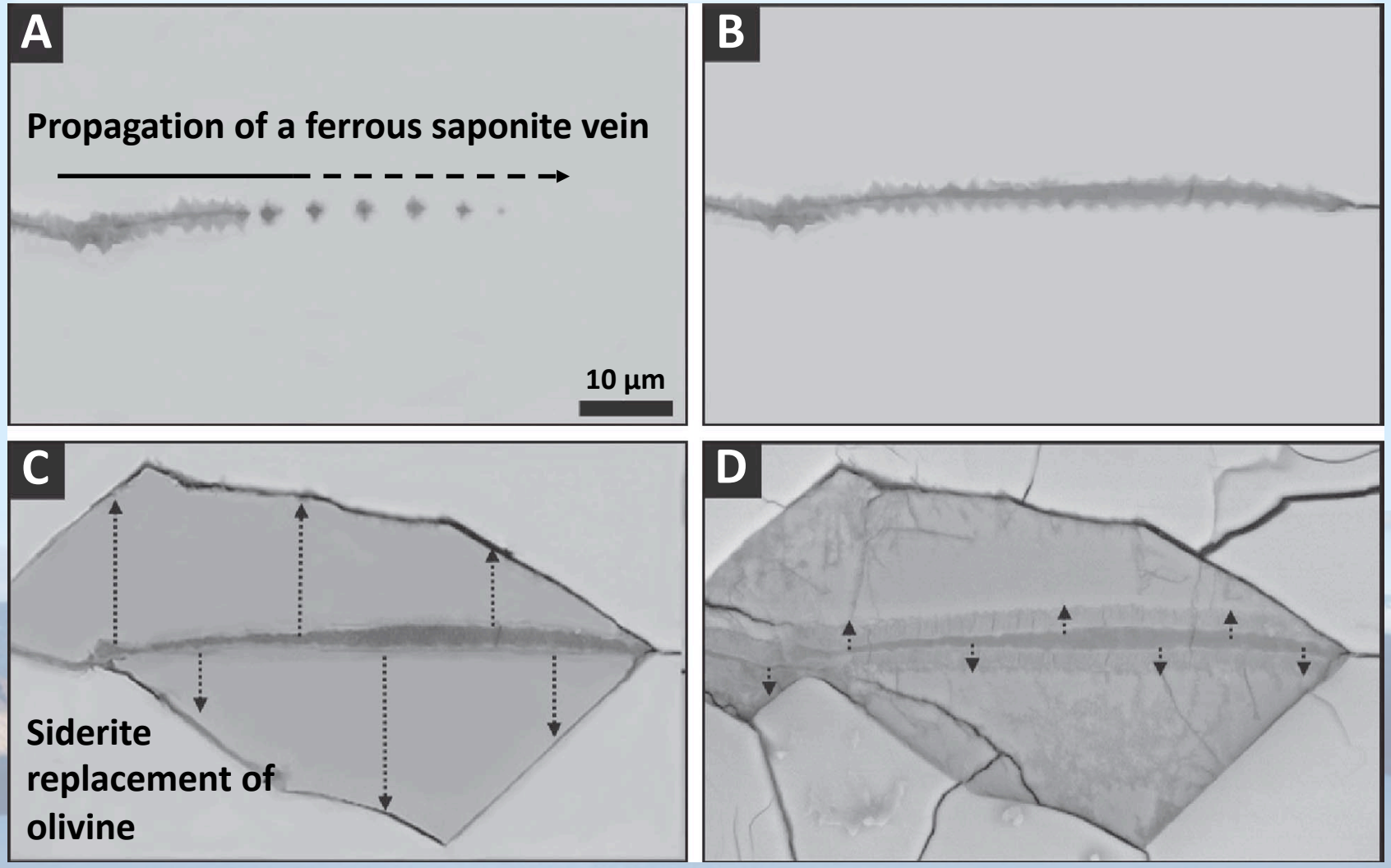
- **rounded/embayed olivine relics**
- **Increased porosity**



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.*



What information could be gained from returned carbonates?

A B

- 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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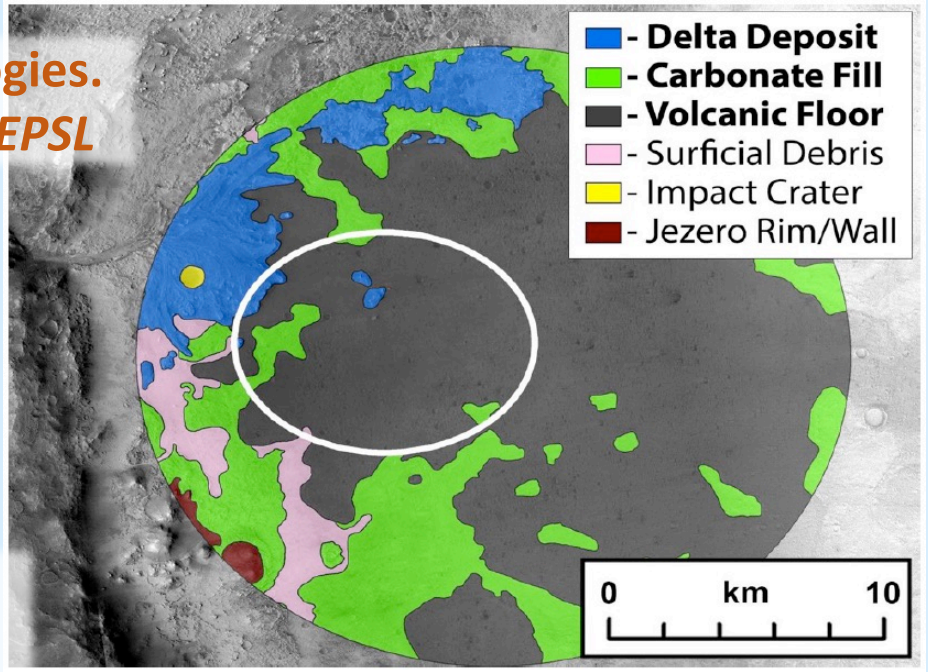

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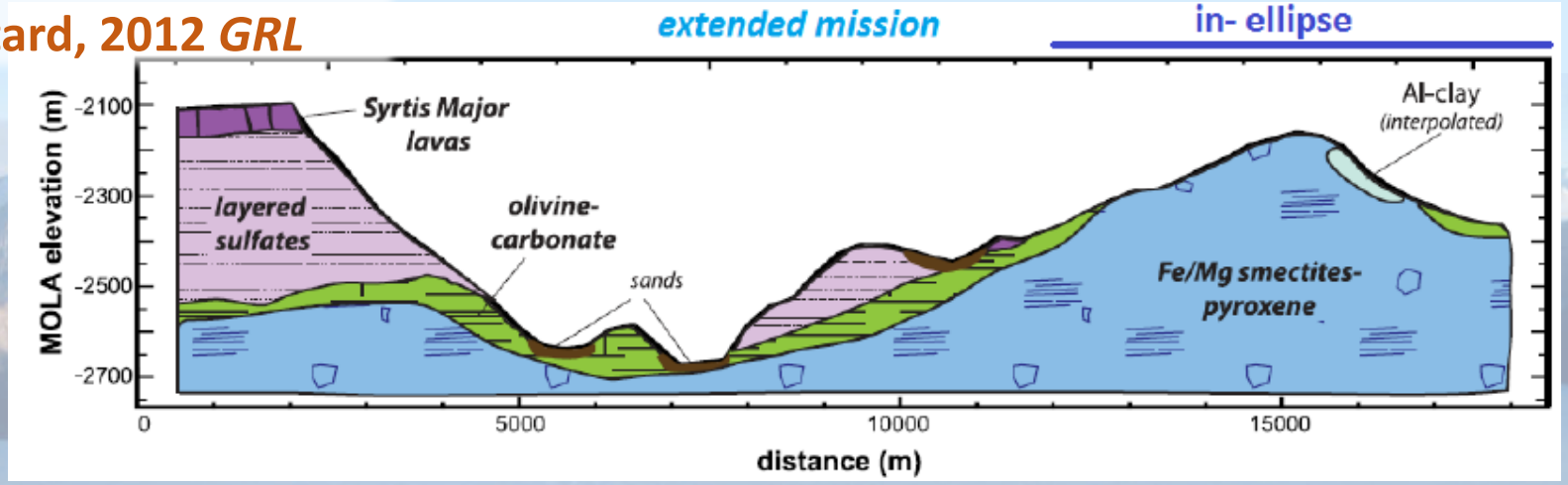

Carbonation reactions

$$2Mg_2SiO_4 + Mg_2Si_2O_6 + 4H_2O = 2Mg_3Si_2O_5(OH)_4$$

Mg-olivine + Mg-pyroxene + water = serpentine

$$Mg_2SiO_4 + 2CO_2 = 2MgCO_3 + SiO_2$$

Mg-olivine + carbon dioxide = magnesite + quartz

$$Mg_2SiO_4 + CaMgSi_2O_6 + 2CO_2 + 2H_2O = Mg_3Si_2O_5(OH)_4 + CaCO_3 + MgCO_3$$

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

Carbonation reactions

$2Mg_2SiO_4$ (Mg-olivine) + $Mg_2Si_2O_6$ (Mg-pyroxene) + 4H2O = $2Mg_3Si_2O_5(OH)_4$ (serpentine)

Mg_2SiO_4 (Mg-olivine) + $2CO_2$ = $2MgCO_3$ (magnesite) + SiO_2 (quartz)

Mg_2SiO_4 (Mg-olivine) + $CaMgSi_2O_6$ (CaMg-pyroxene) + $2CO_2$ + $2H_2O$ = $Mg_3Si_2O_5(OH)_4$ (serpentine) + $CaCO_3$ (calcite) + $MgCO_3$ (magnesite)