# Analogues to Martian crustal and aqueous processes: Lessons learnt from mineralogy and geochemistry of rocks in the PTAL collection

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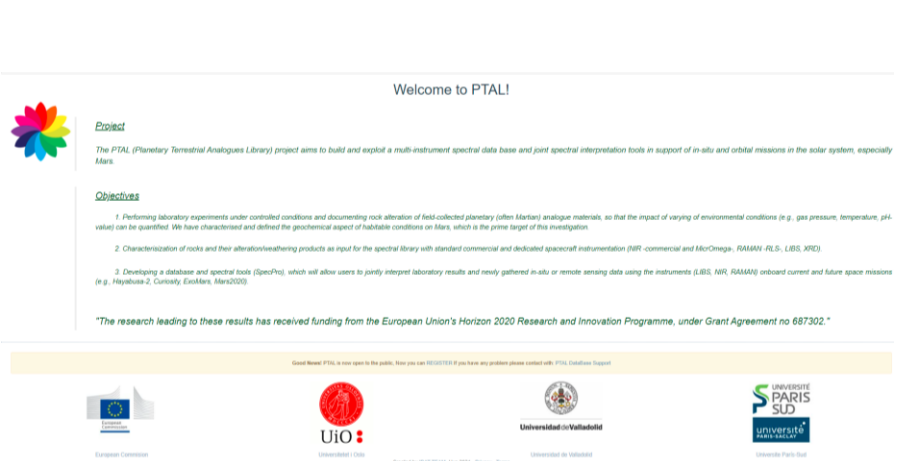
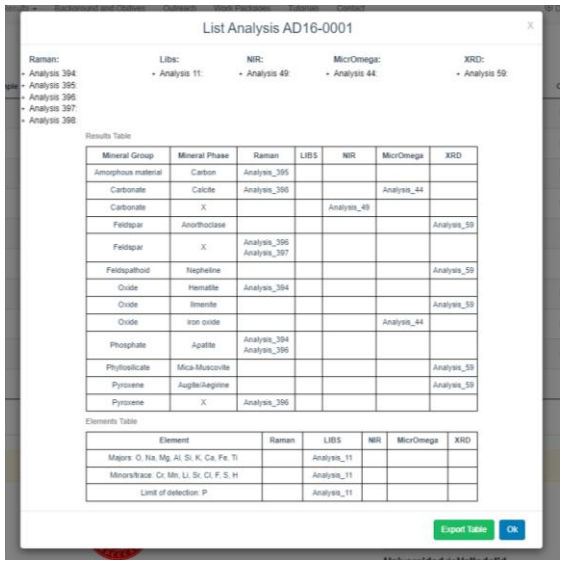
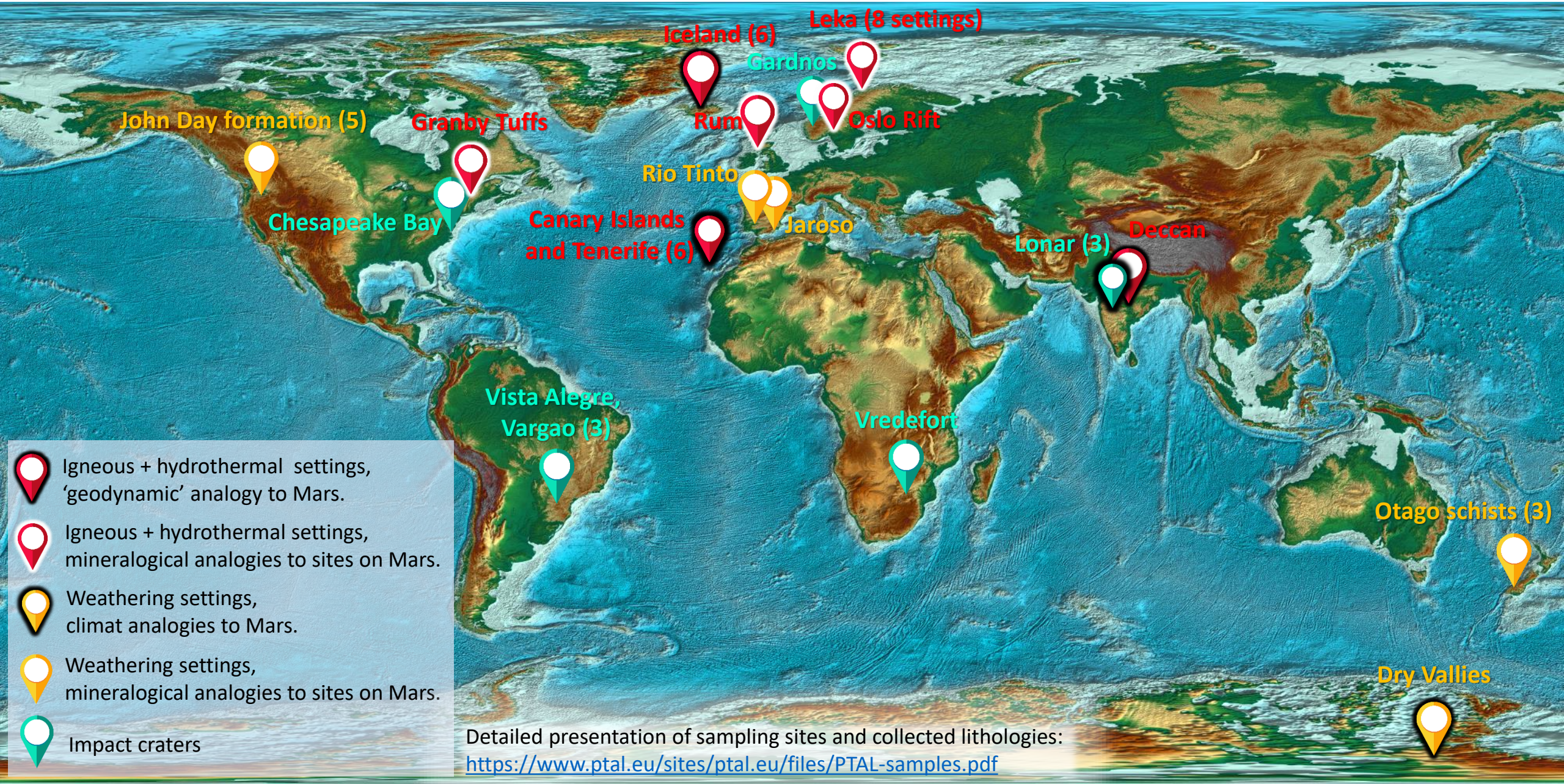
- ***Planetary Terrestrial Analogues Library*** – collection of rocks and spectral data relevant for exploration of Mars.
- Collection of witness samples – 106 rocks from 19 localities on Earth (www.ptal.eu).
- Each rock characterized petrographically and mineralogically + spectroscopically with NIR, Raman and LIBS.
- PTAL multispectral database released in September 2021 and freely accessible (http://erica.uva.es/PTAL/).



# Overview of the PTAL analogue sites



# Analogues – mineralogy vs process

- Igneous + hydrothermal settings, 'geodynamic' analogy to Mars.
  - Iceland, Canary Islands, Deccan Traps – mantle plume volcanism, metasomatism and crustal contamination

- Igneous + hydrothermal settings, mineralogical analogies to sites on Mars.
  - Oslo Rift (Fe-rich basalts), Rum ferropicrites, Granby Tuff (with Fe-rich phyllosilicates) – Fe-rich igneous minerals and rocks
  - Leka serpentinites (serpentinization and carbonation)

- Weathering settings, climat analogies to Mars.
  - Dry Vallies in Antarctica – dry weathering in glacial condtions

- Weathering settings, mineralogical analogies to sites on Mars.
  - Rio Tinto and Jaroso – jarosite
  - Otago schists – Fe-rich vermiculite
  - John Day formation – weathering profiles of diverse igneous rocks

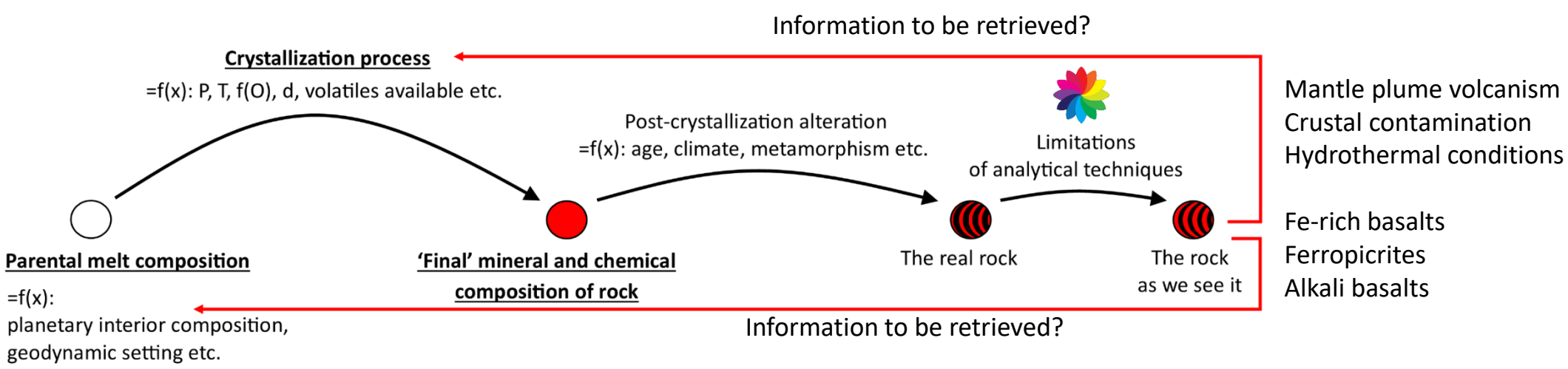
- Impact craters

Detailed presentation of sampling sites and collected lithologies:
https://www.ptal.eu/sites/ptal.eu/files/PTAL-samples.pdf

# Analogue – what do we want to learn from them?

**Terrestrial analogue = a rock that approximates, <u>in some respect</u>, the geological and environmental conditions on another planetary body.**

**Crustal**




**Aqueous**

**Q1: To what extent, are we able to retrieve information using techniques as on board Martian missions?**

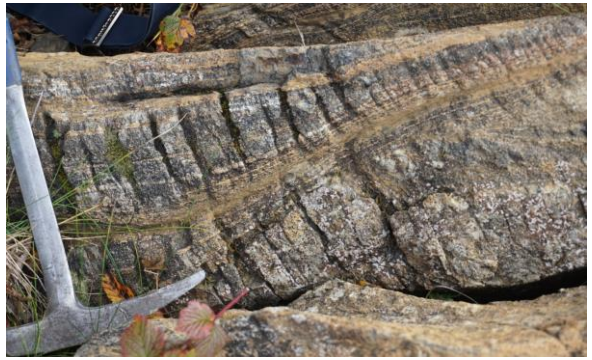
**Q2: How far mineralogy/geochemistry of a terrestrial rock can be used to understand process(es) on Mars?**

Q2a: How to approach the potential process parallelism from mineralogical match?

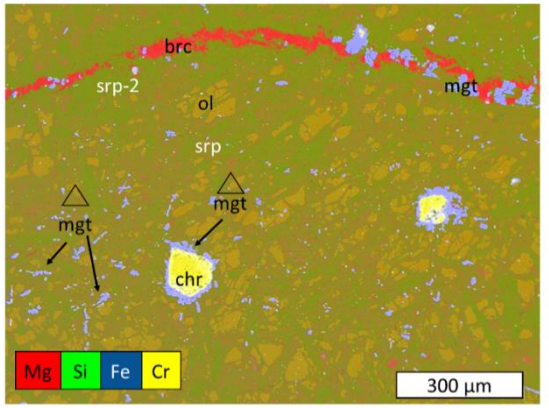
Q2b: Purportedly same formation and/or alteration conditions → how close will final rock be in composition, mineralogy etc?

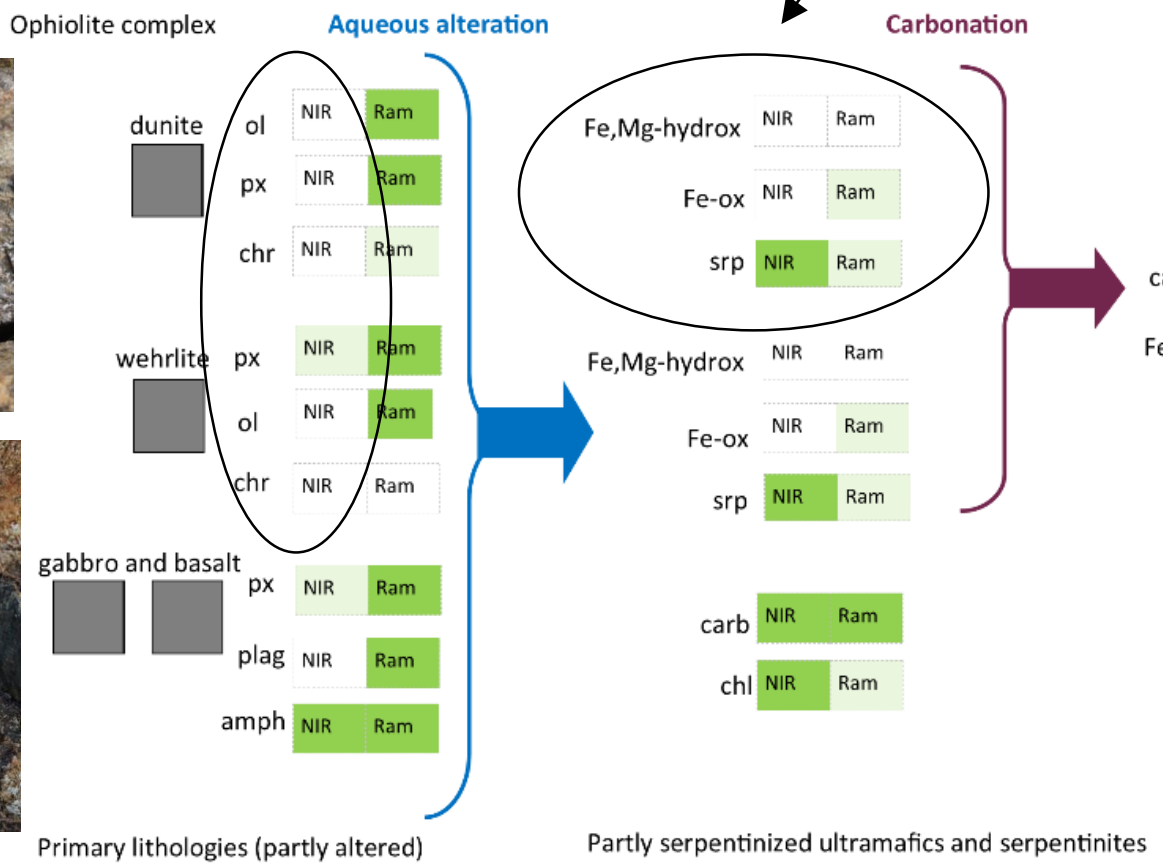
# Q1:Detection limitations – primary scope of PTAL.

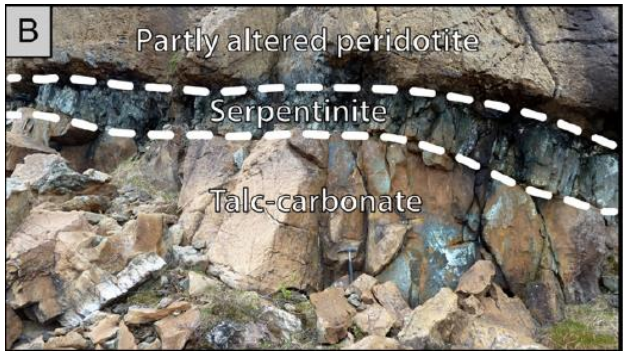
## Example of serpentinites from Leka



Brucite and magnetite – recorders of serpentinization conditions



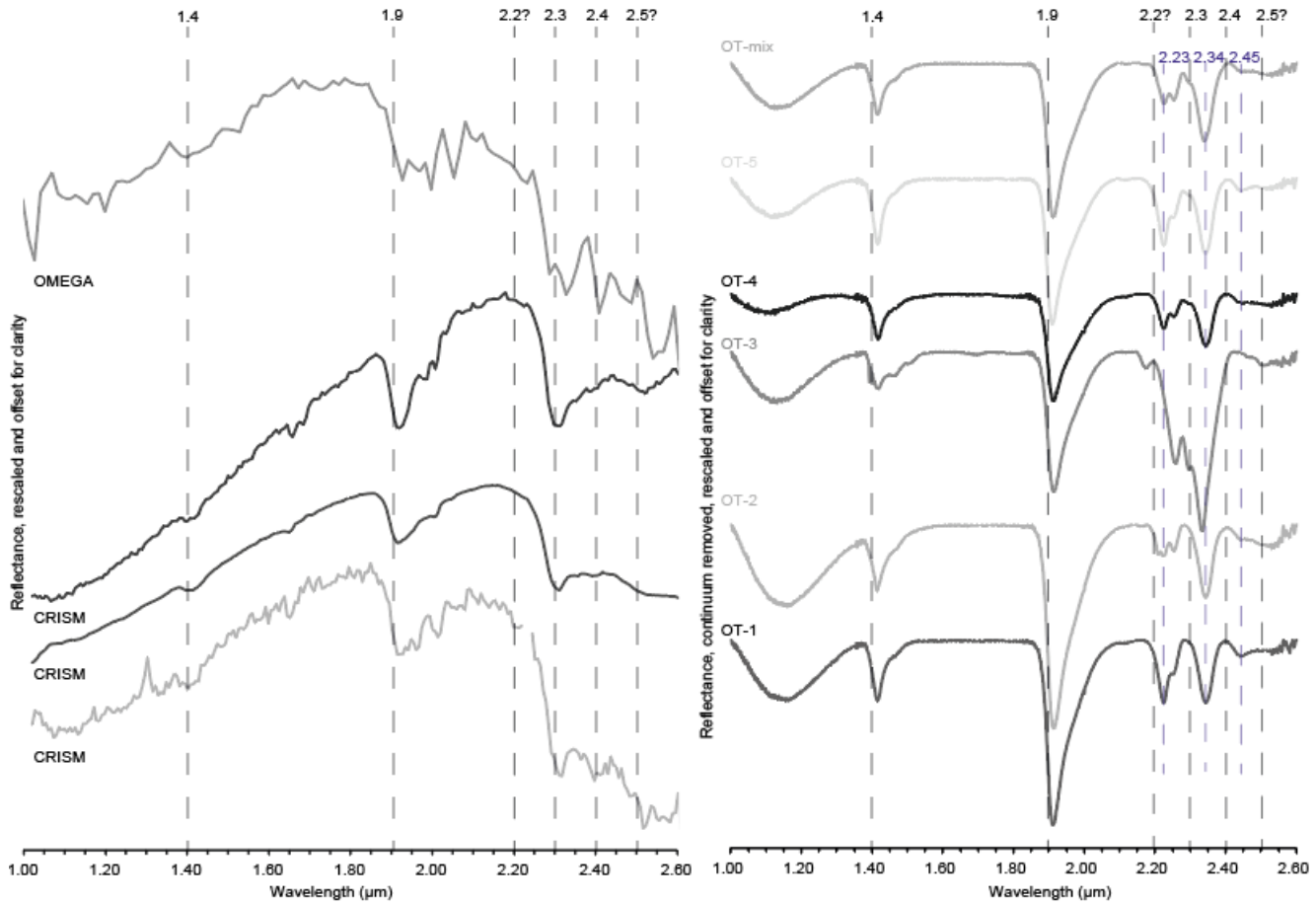



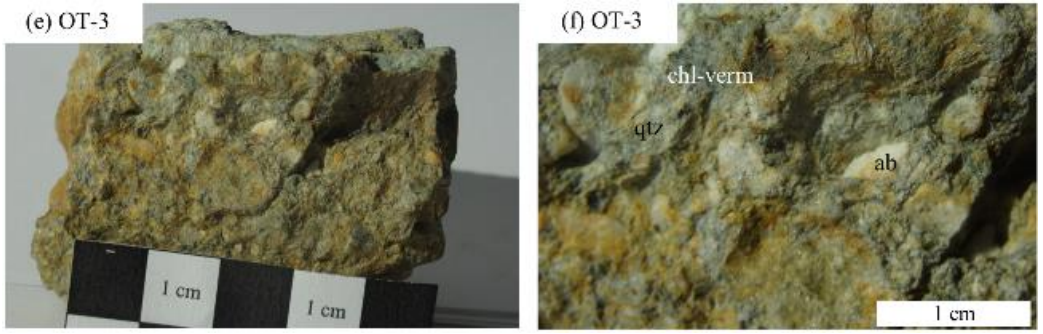

- **Information on protolith minerals is unretriveable when alteration starts**
- **Conditions of alteration – on Earth often known from accessory minerals – commonly are lost; techniques are not sensitive to them**

NIR and Raman data credit: Cateline Lantz, Damien Loizeau and Marco Veneranda @ the PTAL team

# Q2a: Does mineralogy imply a process?

## Example of Otago vermiculite



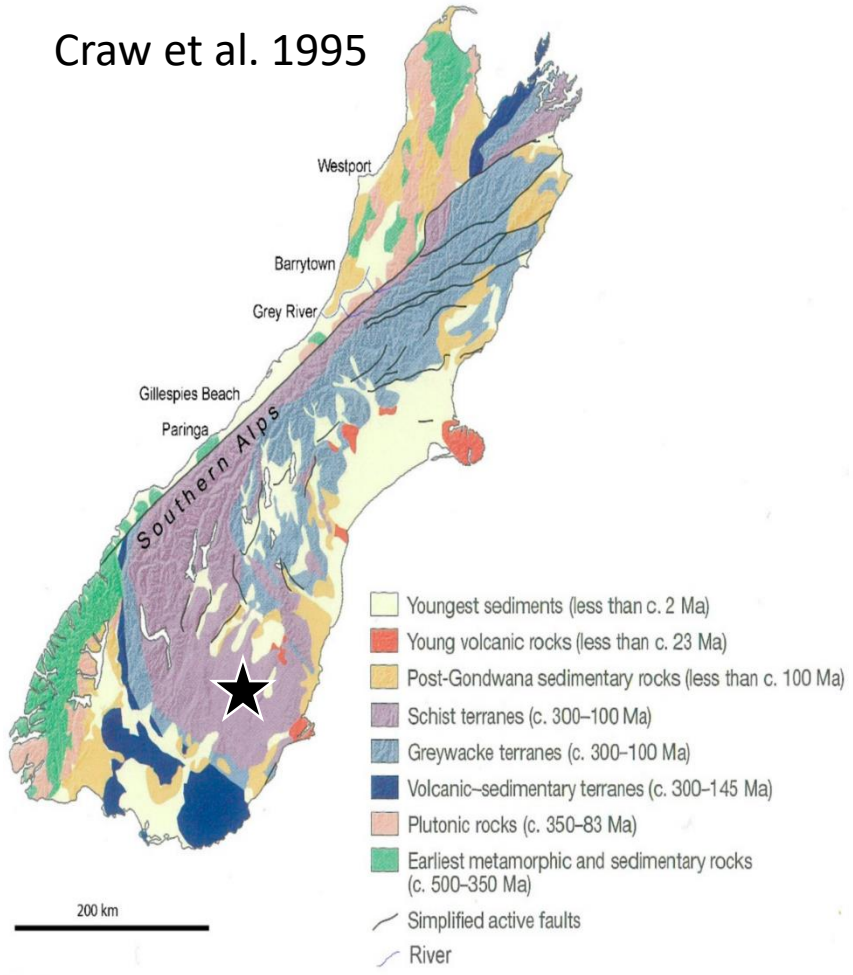

- Fe-rich vermiculite matches spectrally clays on Mars (at Oxia Planum).
- Difference in position of absorption at 2.3 um – the oxidation state or Fe/Mg ratio differs.
- Vermiculite = 1vol% of schists.
- Schists formed in tectonic setting → unlikely implication for process.
- But: unique mineralogy of Otago vermiculite schists is thanks to rapid transport and burial of chlorite + anoxic alteration.

- **Mineralogy ≠ Process**
- **Specific physicochemical conditions during the alteration (if retrieved) bear implications for the alteration setting.**

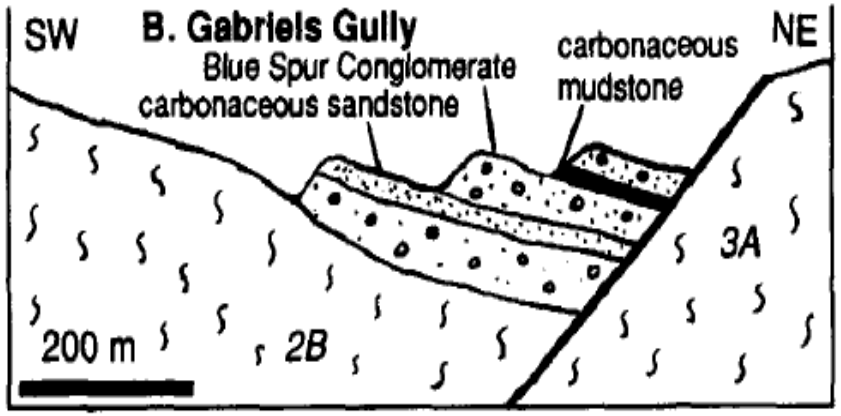
Detailed study of Otago schist analogues available @ Krzesinska et al., 2021, Astrobiology.

# Otago schists geological context

Craw et al. 1995




- Basement metamorphosed Fe-chlorite-bearing schists.
- Late Cretaceous-Paleogene extension, fault formation.
- Deposition along scarps. Short transport and limited oxidation of chlorite → **vermiculite.**
- Alteration during diagenesis → groundwaters and not transport → **illitization of vermiculite (Al).**



# Otago schists and vermiculite samples collected

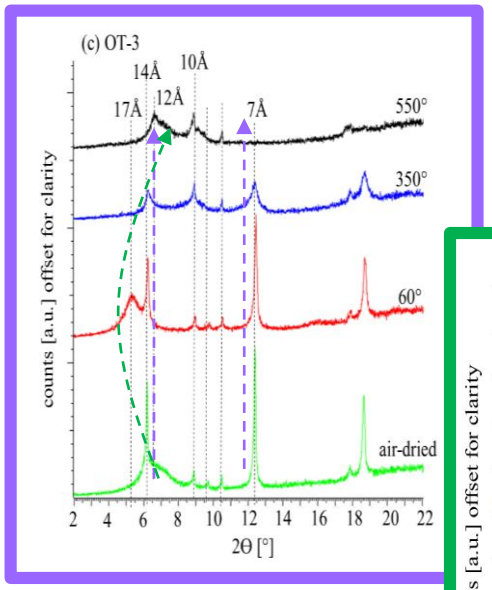

- Basement metamorphosed Fe-chlorite-bearing schists.
- Late Cretaceous-Paleogene extension, fault formation.
- Deposition along scarps. Short transport and limited oxidation of chlorite → **vermiculite.**
- Alteration during diagenesis → groundwaters and not transport → **illitization of vermiculite (Al).**



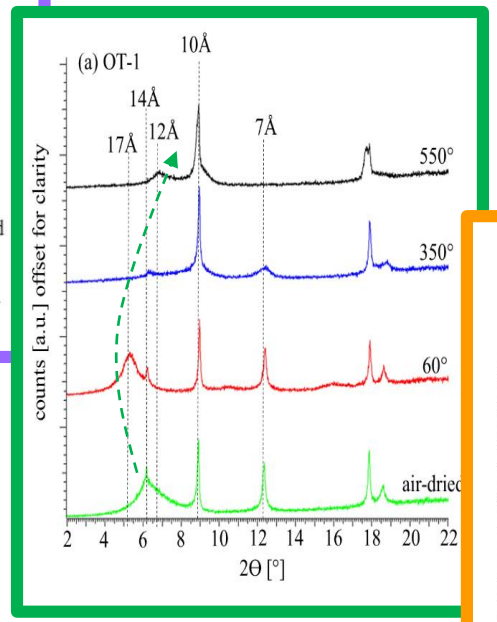
# Identification of clay minerals

- Clay fraction separation and XRD identification with treatment: glycolation, heating to 350°C and 550°C



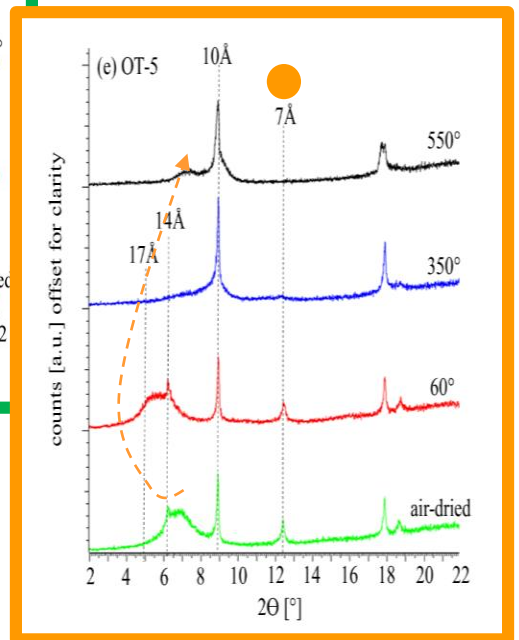




Chlorite and minor vermiculite + interstratified illite-verm



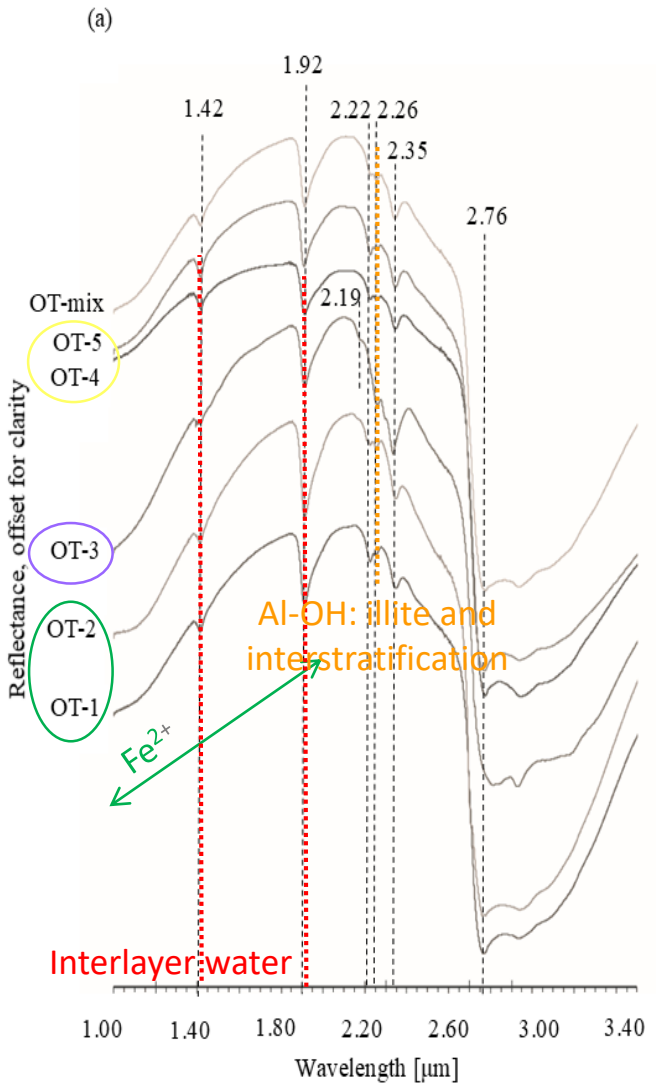

Vermiculite ($Fe^{2+}$) interstratified, minor chlorite

Illite (+kaolinite) and interstratified vermiculite-illite ($Fe^{3+}$)

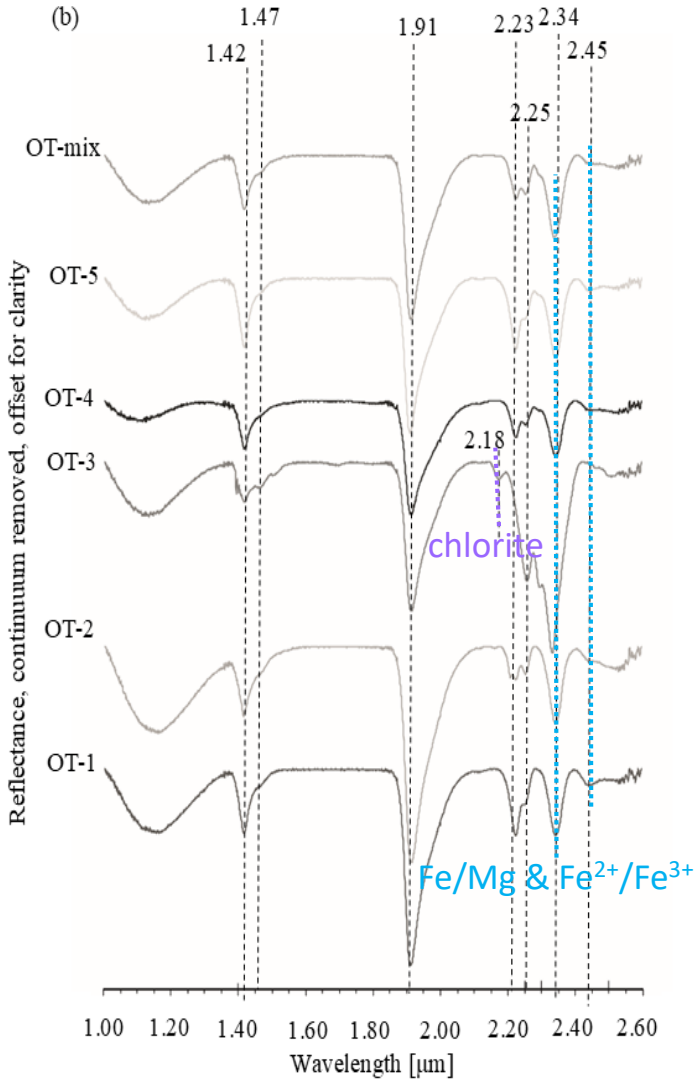


# NIR spectra - band identification

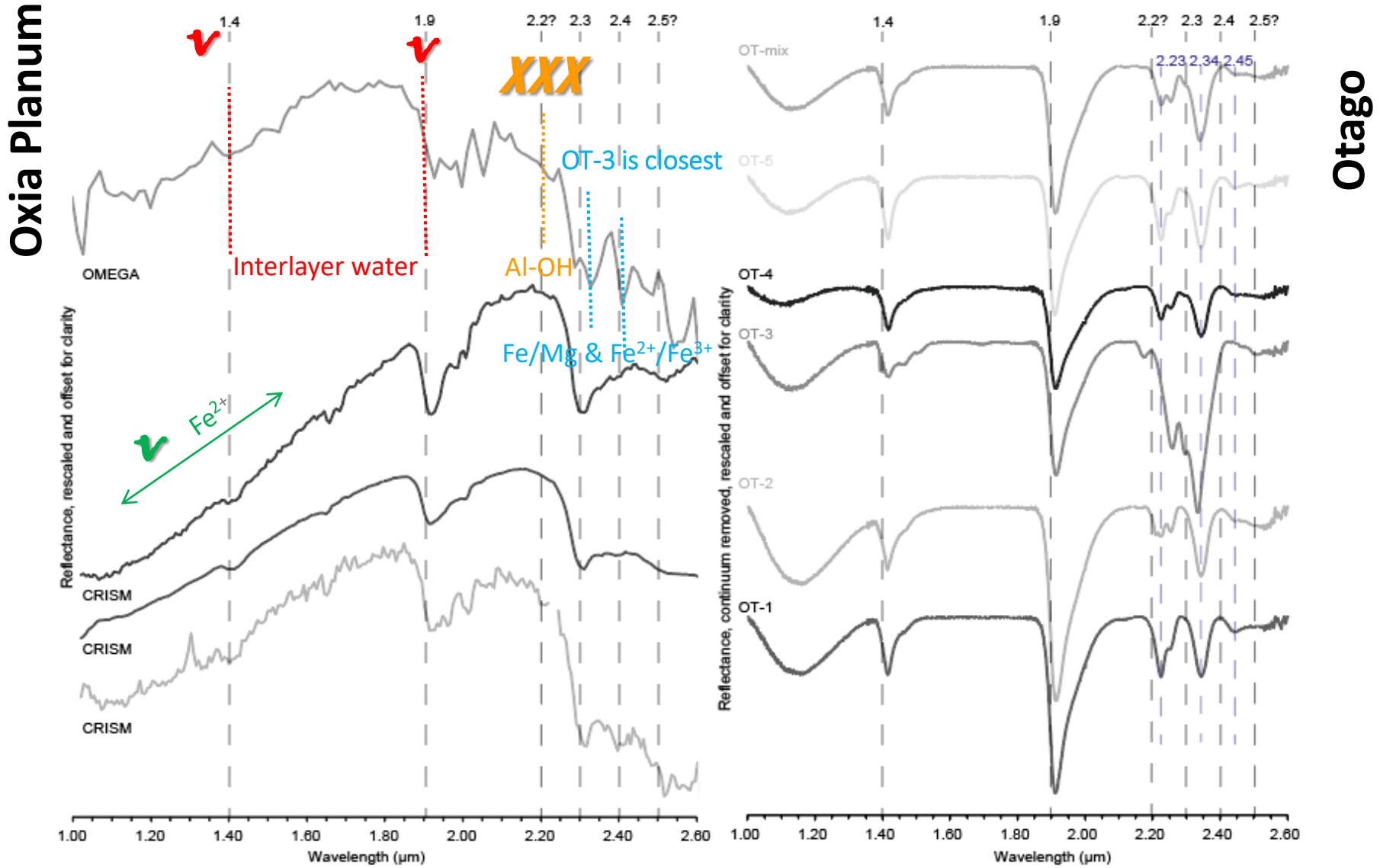



NIR, continuum-removed

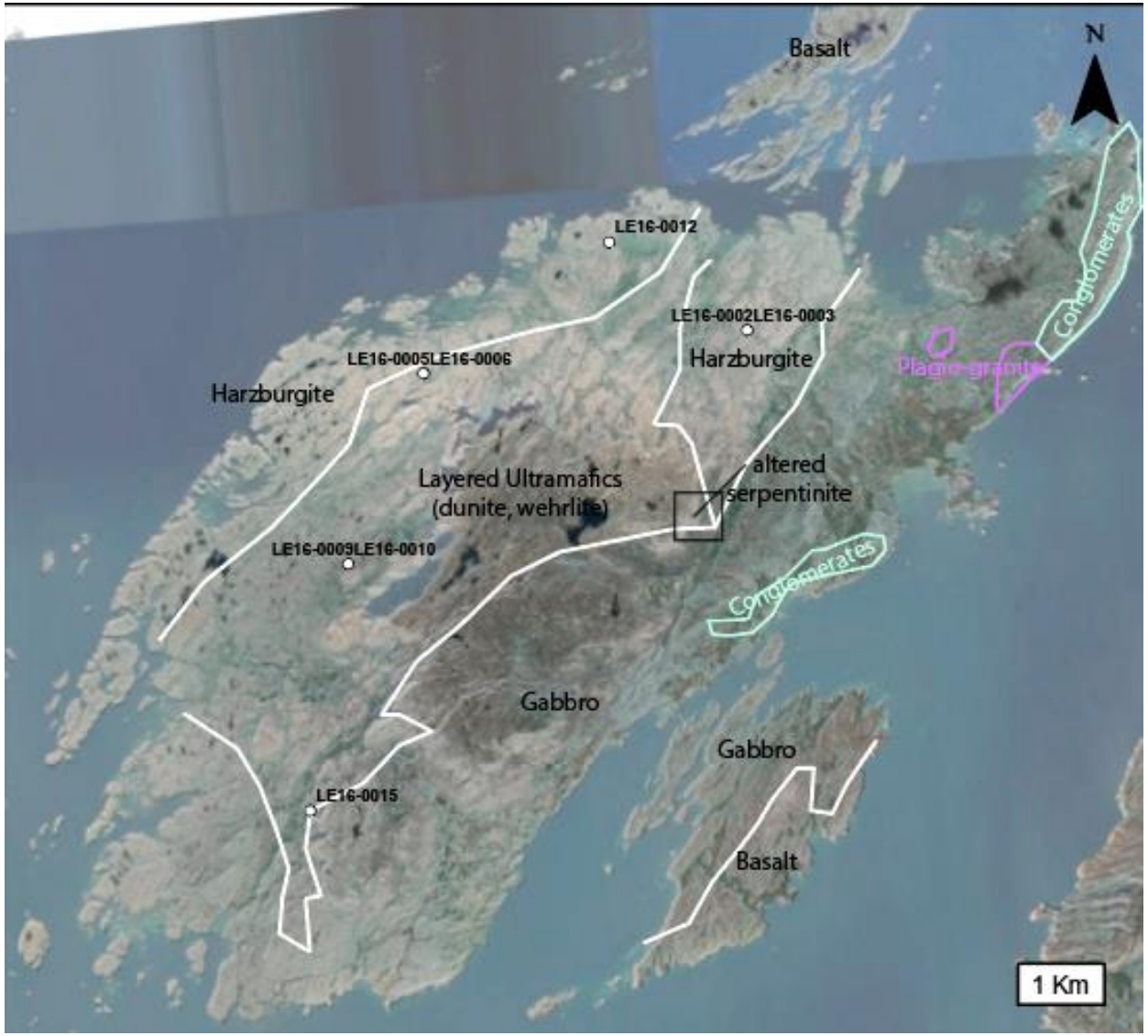


# Spectral comparison with Oxia Planum

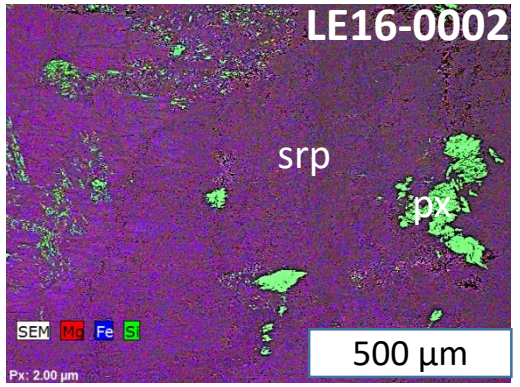


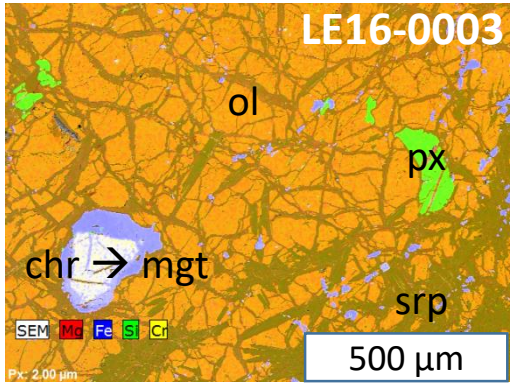
# Q2b: Does ‘the same’ aqueous path leave a fingerprint?

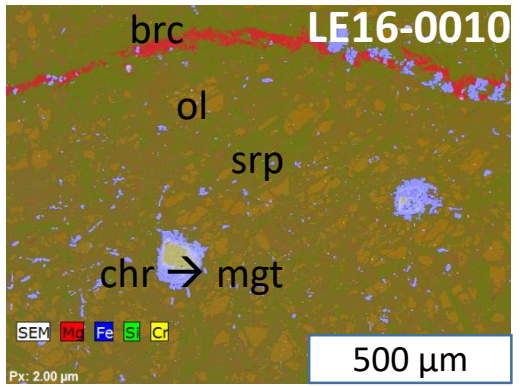
## Example of Leka serpentinites

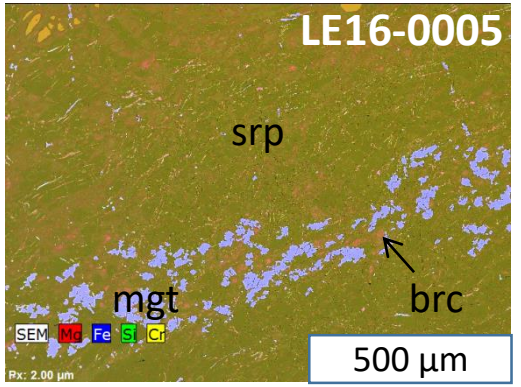


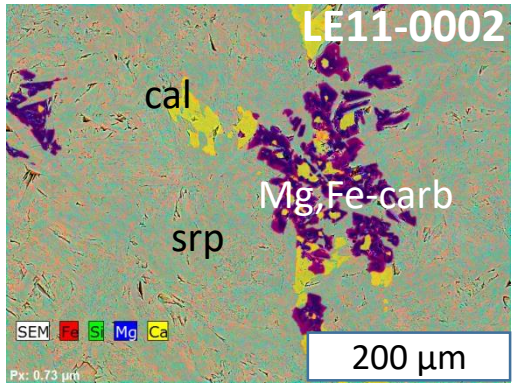

**Detailed mineralogical assemblages by SEM -EDX**

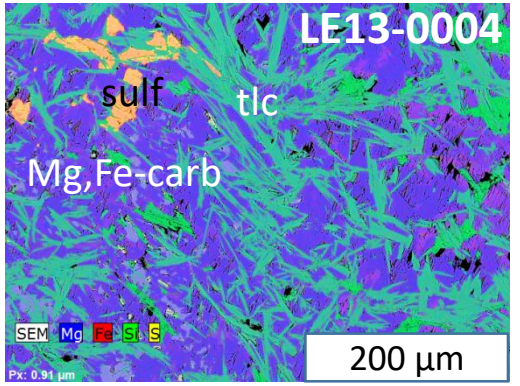


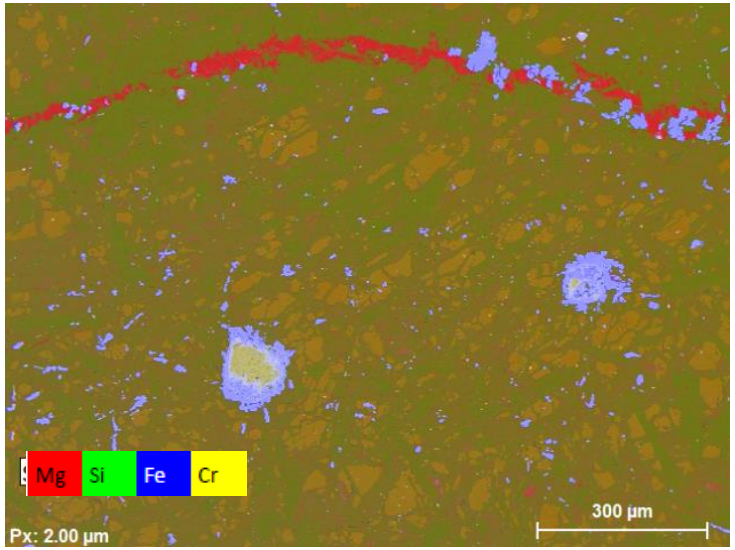



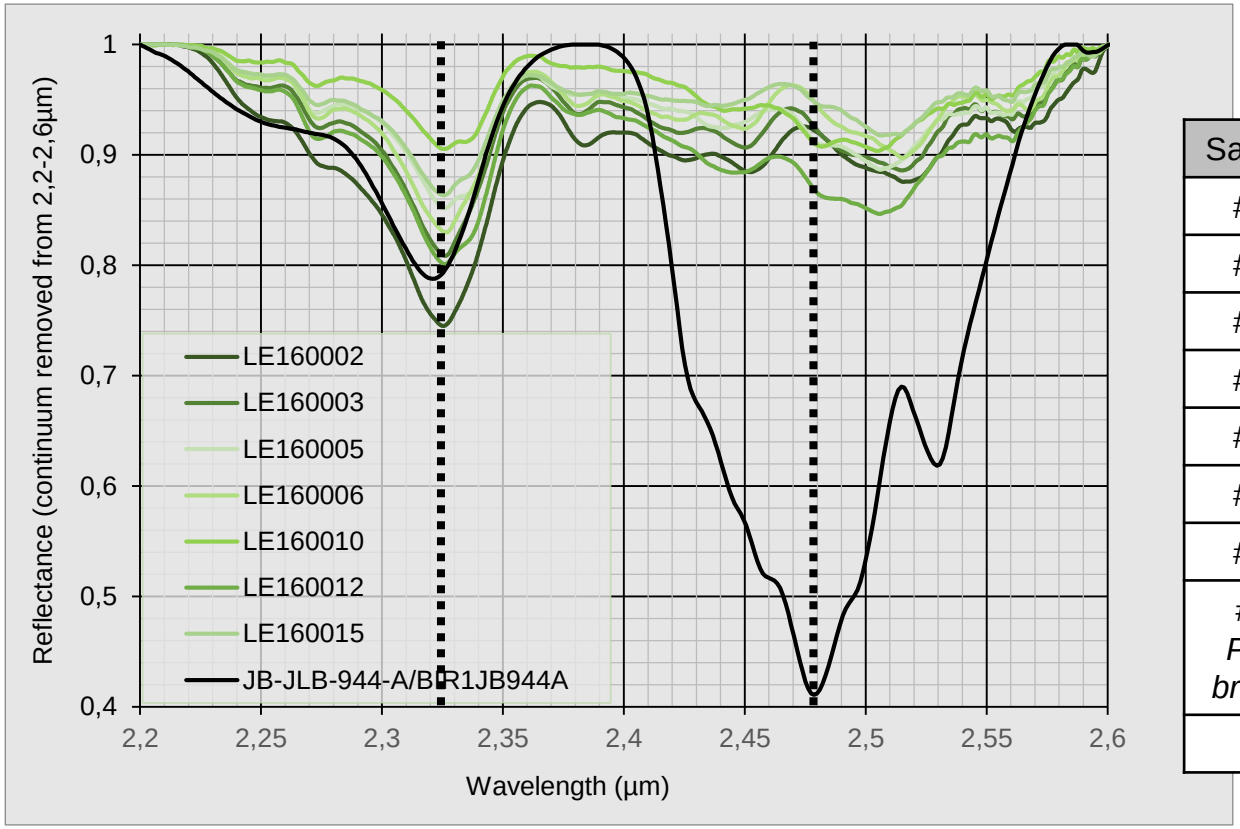



# Brucite

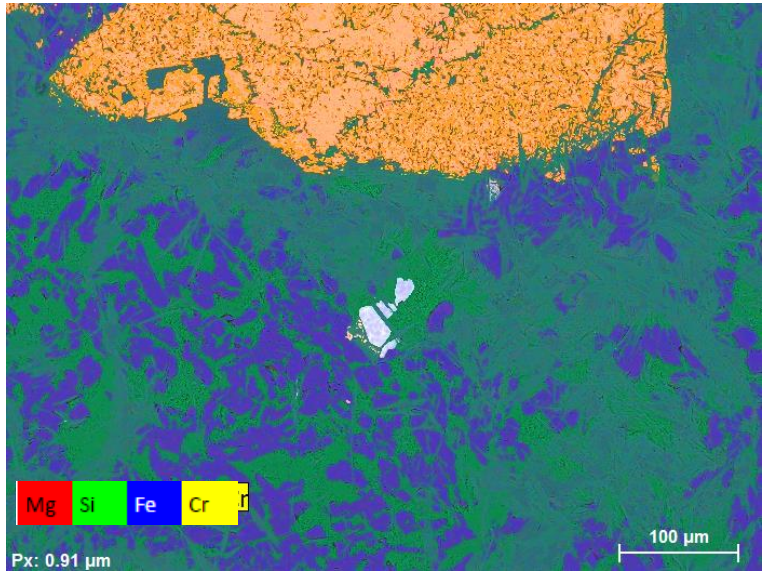


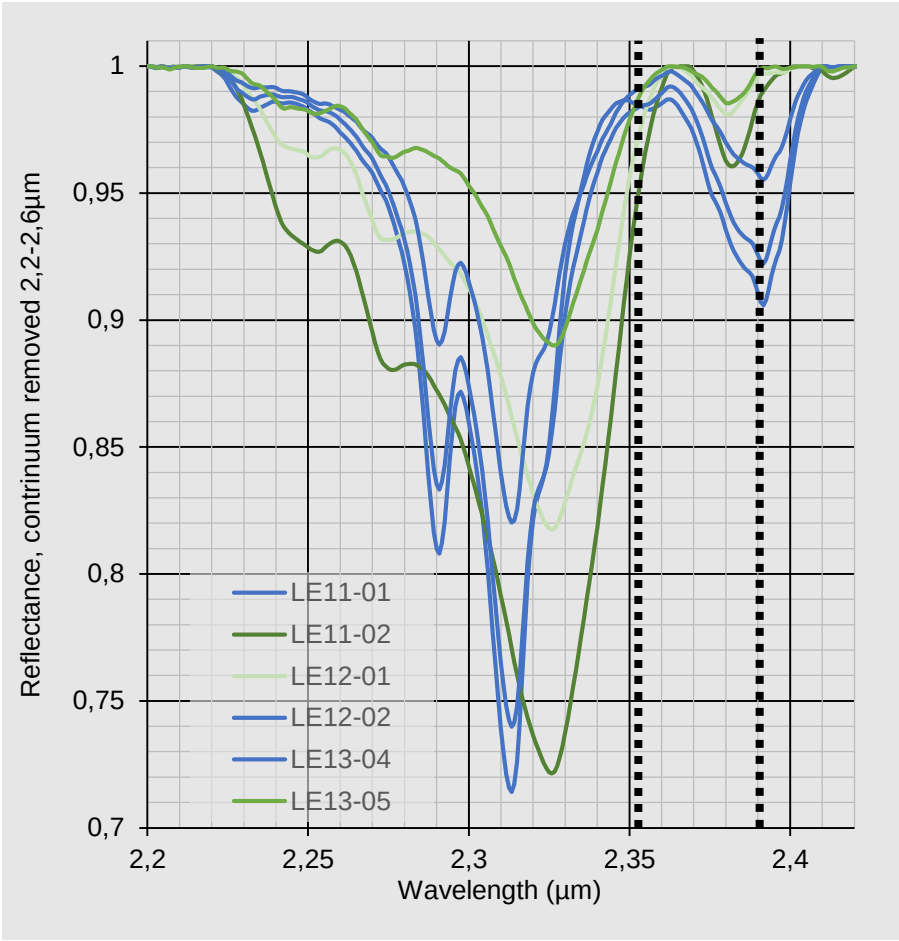




| Sample | **Ratio2325Br** | EDX |
|---|---|---|
| #02 | **0,06** | No brucite |
| #03 | **0,19** | No brucite |
| #05 | **0,33** | Minor brucite |
| #06 | **0,12** | No brucite |
| #10 | **0,49** | Brucite |
| #12 | **0,36** | Brucite |
| #15 | **0,17** | No brucite |
| *#lib Pure brucite* | ***0,72*** | - |
| Empirical threshold of 0,25 | | |

*Brucite is a common mineral associated to serpentine on Earth, never confirmed on Mars where serpentine is detected*
*Focus on absorptions near 2,3µm and 2,5µm (**band depth 2,5/band depth 2,3** is higher for brucite than serpentine)*
*Result from most to less brucite: #10> #12> #05> #03>#15> #06> #02*
***Need for a good threshold. Even low proportion of brucite can be detected***
***Problem: if carbonates are present, possible false positive to be checked.***

# Carbonates

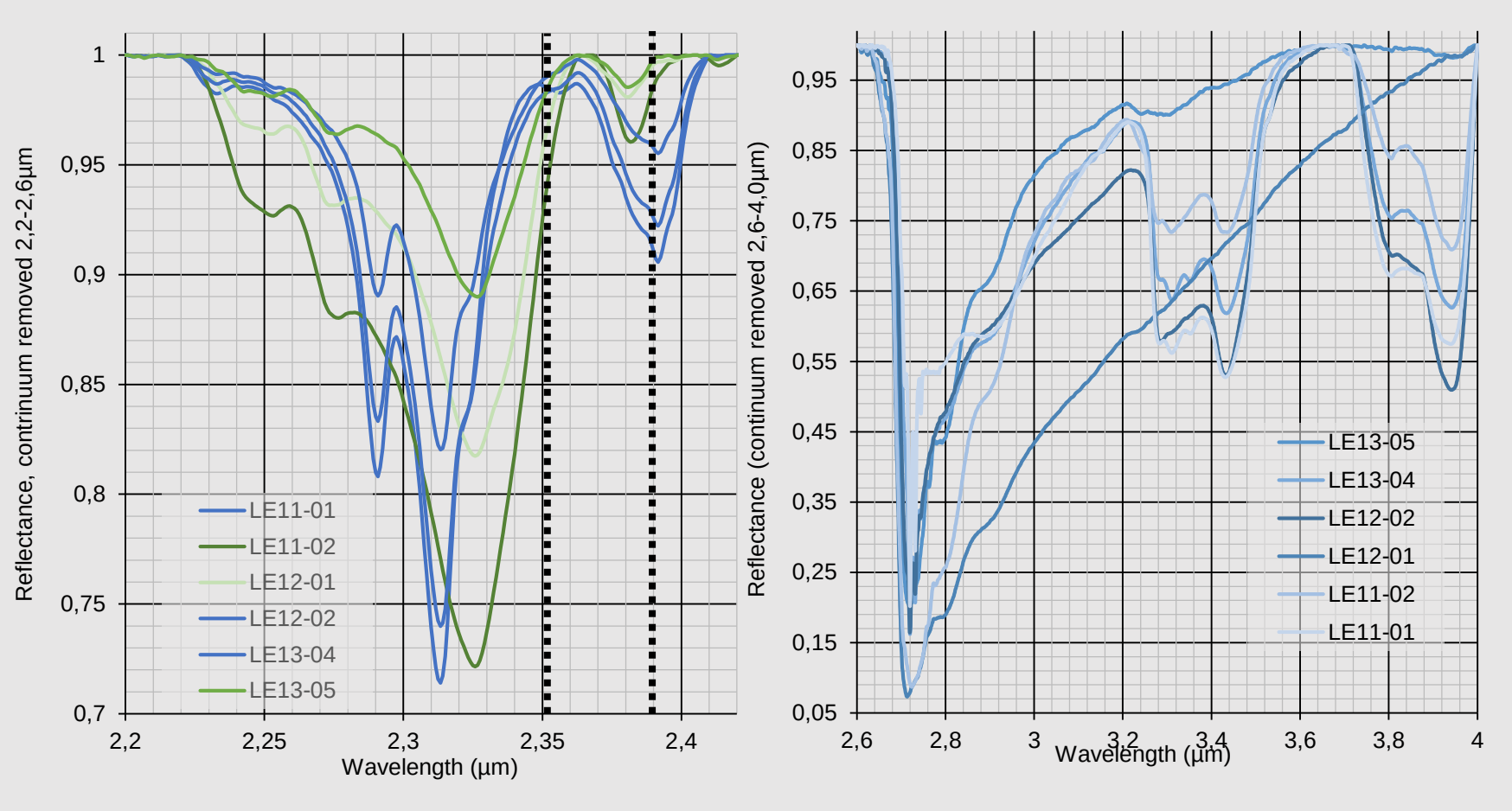



| Sample | Viviano-Beck et al, 2014 criterion | **BD2390** | Bjerga et al, 2015 |
|---|---|---|---|
| #11-01 | 0,014 | **0,089** | Talc |
| #11-02 | 0,075 | **0,014** | No talc |
| #12-01 | 0,044 | **0,004** | No talc |
| #12-02 | 0,011 | **0,042** | Talc |
| #13-04 | 0,018 | **0,074** | Talc |
| #13-05 | 0,021 | **0,002** | No talc |

*Spectral **criterion from Vivivano-Beck 2014** is tested and compared to **BD2390. Results from BD2390 match better the results of analogues***

# Carbonates

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| #11-01 | 0,014 | **0,089** | Talc |
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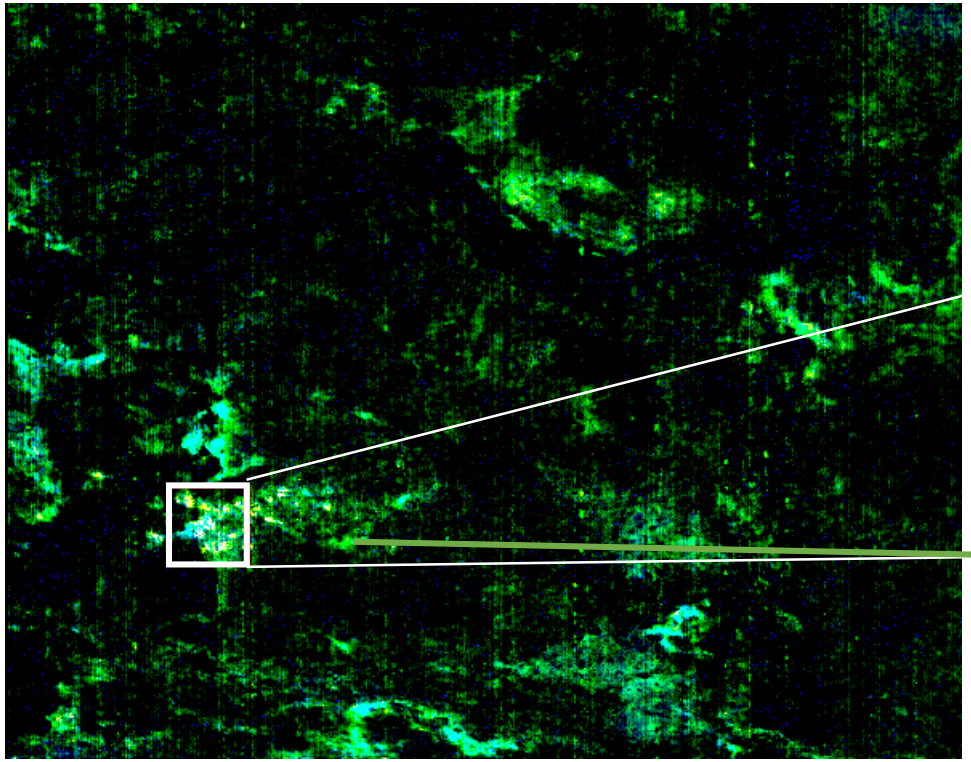
| #12-01 | 0,044 | **0,004** | No talc |
| #12-02 | 0,011 | **0,042** | Talc |
| #13-04 | 0,018 | **0,074** | Talc |
| #13-05 | 0,021 | **0,002** | No talc |

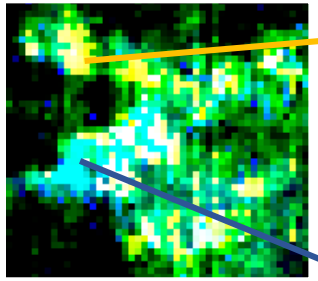
| Sample | MIN2295_2480 | MIN2345_2537 | **Carb 3900** | Bjerga et al, 2015 | EDX |
|---|---|---|---|---|---|
| #11-01 | 0,042 | -0,003 | **0,313** | Yes | 35% |
| #11-02 | 0,017 | 0,035 | **0,142** | Minor | 13% |
| #12-01 | 0,052 | 0,036 | ***NaN*** | No | 0,5% |
| #12-02 | 0,028 | 0,008 | **0,294** | Yes | 50% |
| #13-04 | 0,022 | 0,011 | **0,232** | Yes | 35% |
| #13-05 | 0,003 | 0,009 | ***NaN*** | No | 0% |

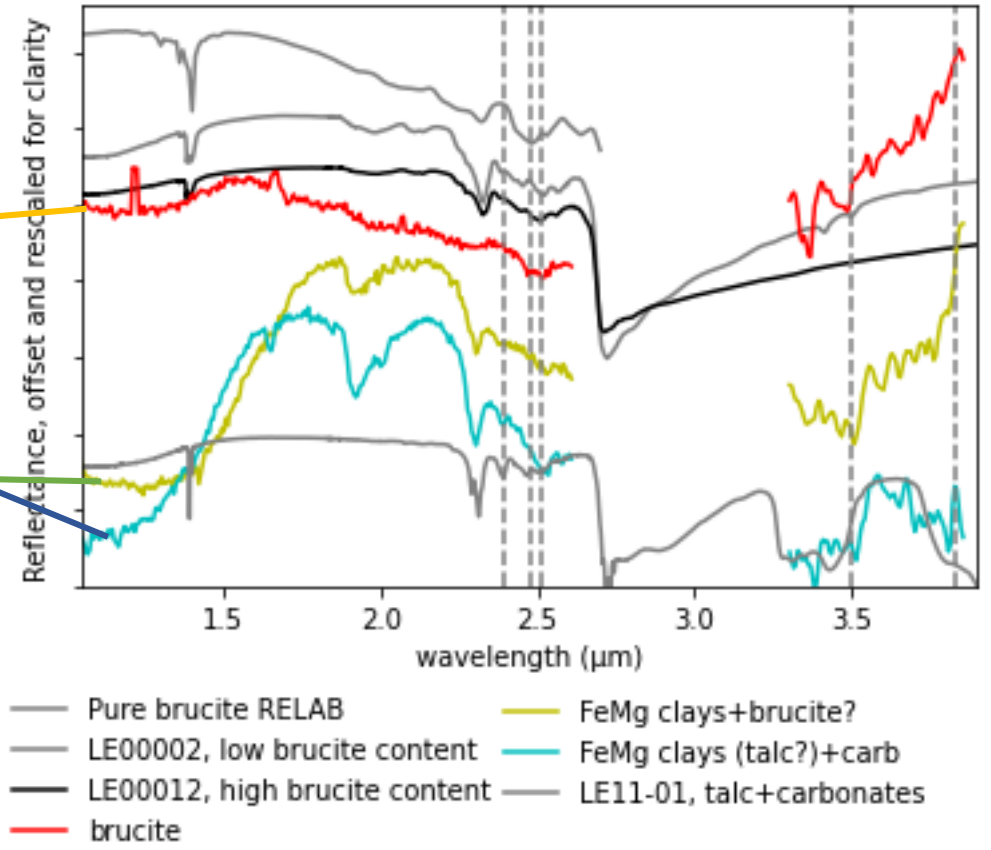
*Spectral **criterion from Vivivano-Beck 2014** is tested and compared to **BD2390. Results from BD2390 match better description from Bjerga et al, 2015.***

*Carbonates are detected here based on the **spectral feature near 3,5-3,9µm**. Paramater used for Mars data are tested as well and both are compared. **Our criterion is most efficient. "Martian criteria" return false positive and false negative result***

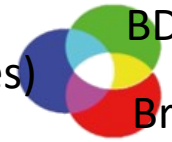
# Application on Mars data








BDcarb (carbonates)

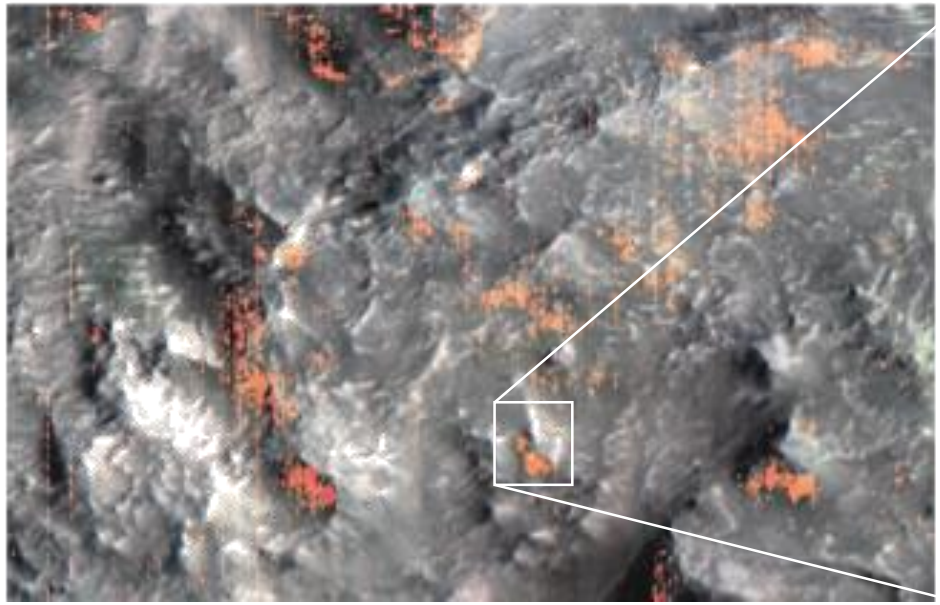


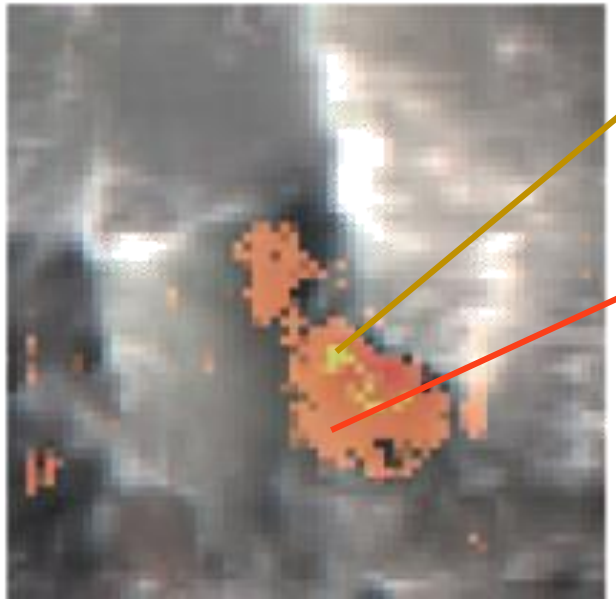
BDa230 (FeMg-clay minerals)

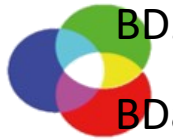
BrIndex (brucite)

***Detection of brucite together with serpentine at Nili Fossae***

# Application on Mars data

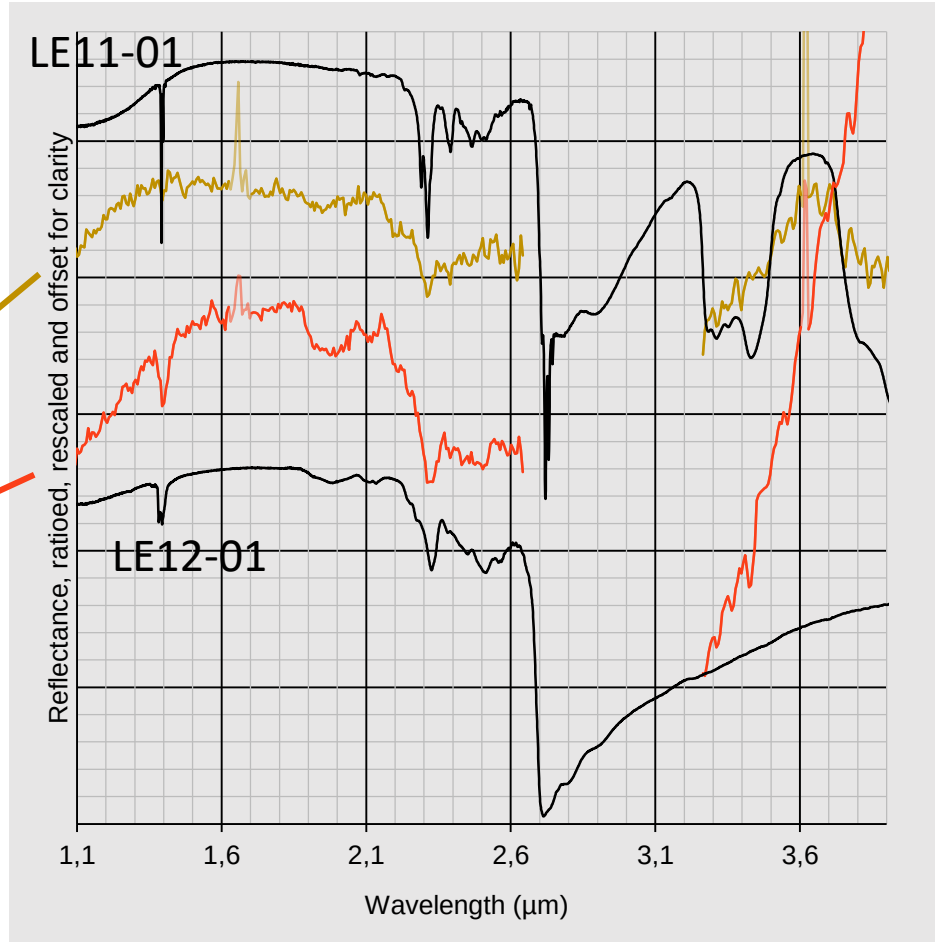






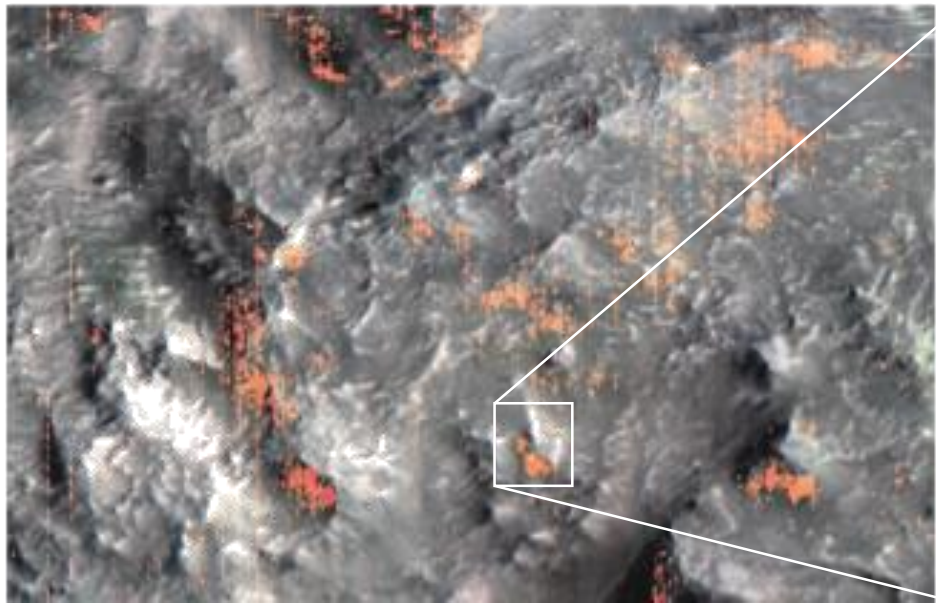
BD239 (Talc)

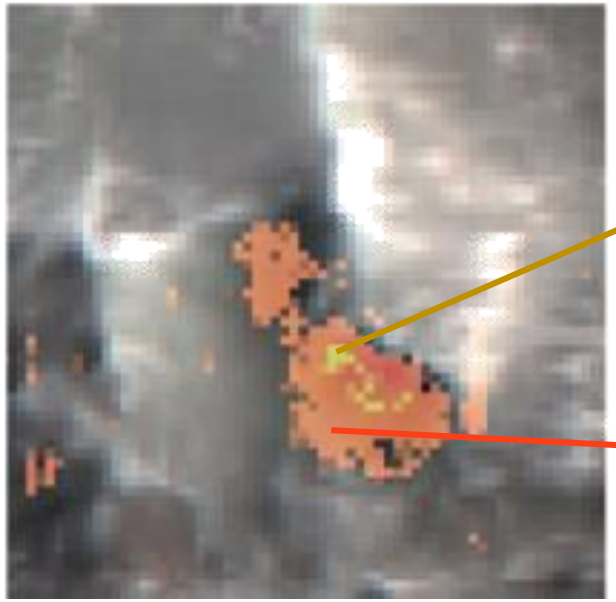
BDa230 (FeMg-clay minerals)

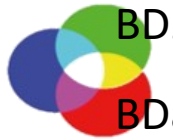



***Talc, carbonates and serpentine on the same outcrop***
***Probably correspond to carbonation of serpentinite***

# Application on Mars data

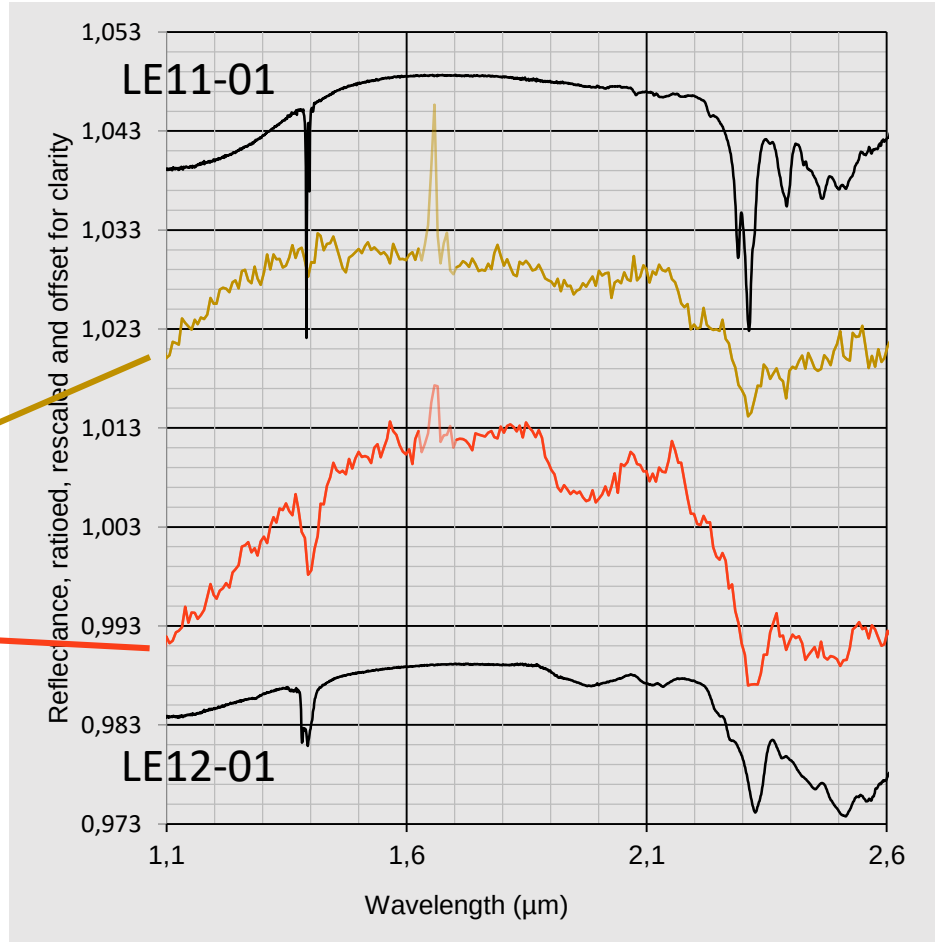






BD239 (Talc)

BDa230 (FeMg-clay minerals)




***Talc, carbonates and serpentine on the same outcrop***
***Probably correspond to carbonation of serpentinite***

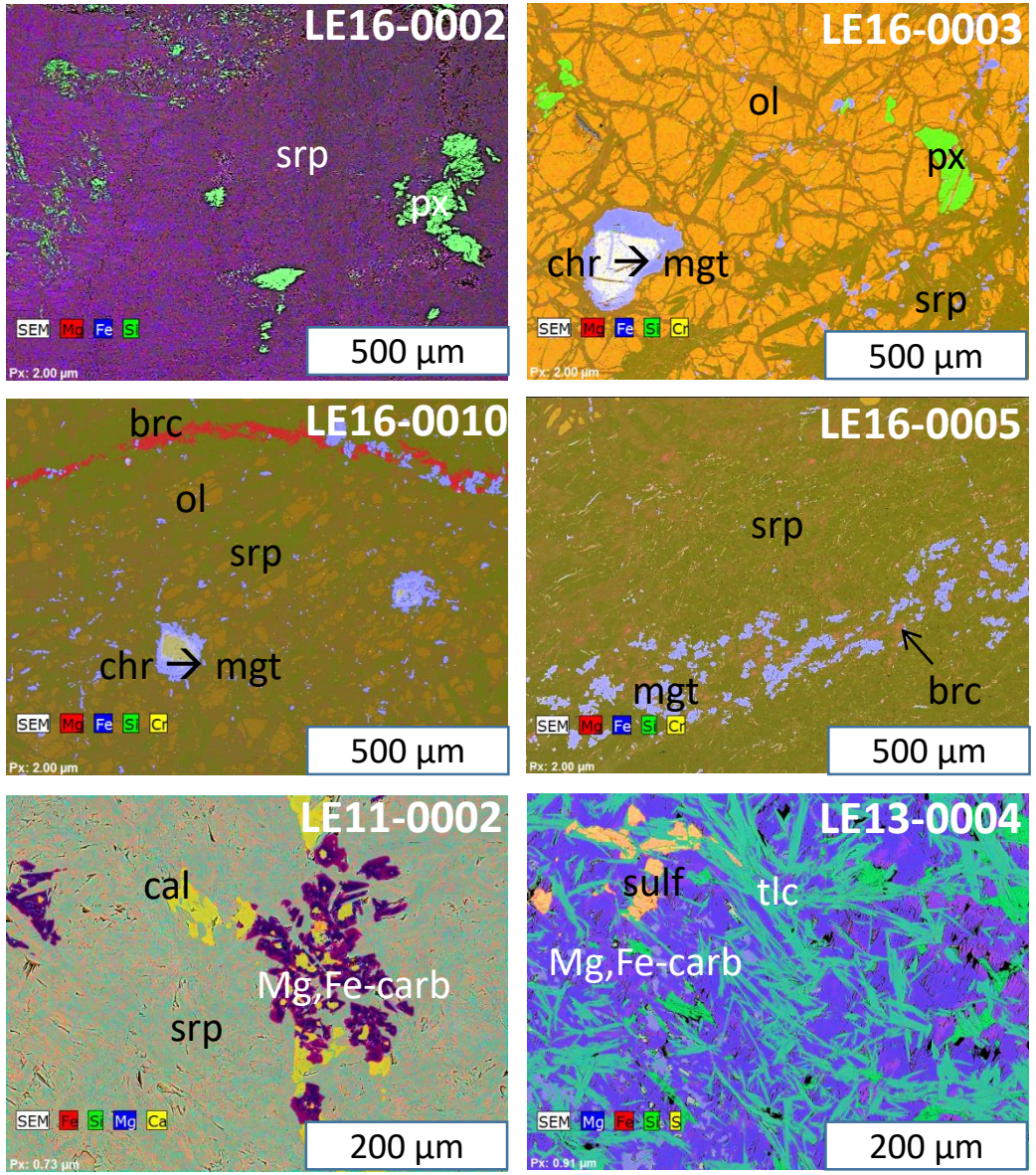
Detailed study of Leka rocks and analogy to Mars available @ Bultel et al., 2021, EGU presentation. And publication in preparation.

# Q2b: Does ‘the same’ aqueous path leave a fingerprint?

## Example of Leka serpentinites

- Brucite, magnetite, carbonates and talc – presence calibrated based on their occurrences in various Leka samples.
- These minerals may be seen in NIR spectra from several locations on Mars.
- More detailed sequence of aqueous alterations on Mars may be reconstructed, if accessory mineral signal is taken into account.

**Detailed mineralogical assemblages by SEM -EDX**




**Importance of accessory minerals**

# Lessons learnt:

- Techniques on board space missions have their limitations and important details may be not retrieved (limited sensitivity to accesory phases and geochemistry).
- Each analogue is always a partial analogue: mineralogical vs setting analogy.
- Mineralogical analogy in aqueous settings usually means at least one physicochemical feature of the process in common e.g., redox state, oxic/anoxic conditions.
- Accessory minerals in aquoeus alteration are needed to reconstruct alteration path.
- Same geodynamic evolution of igenous rocks on different planets does not produce same rock compositions. Mineralogical analogues have limited utility for crustal processes understanding.
- Geochemistry of igneous rocks as important as accessory mineralogy in aqueous conditions.
- Coordination between projects focused on different aspects of analogies (e.g. geomorphologic) with mineralogical and geochemical data on the same sites could bring large benefits.

PTAL collection is available for subsequent studies and precise information on field site locations are accessible for potentially coordinated field works.

# Further resources on PTAL database and rock collection

**PTAL**

Planetary Terrestrial Analogues Library

**Visit our website** ➡

- The PTAL webpage, that provides general information about the project and results. https://ptal.eu/
- Detailed presentation of sampling sites and collected lithologies. https://www.ptal.eu/sites/ptal.eu/files/PTAL-samples.pdf
- PTAL online platform, that gives access to terrestrial analogues info and all spectral data. https://erica.uva.es/PTAL/