The Circum-Isidis Olivine/Carbonate Unit

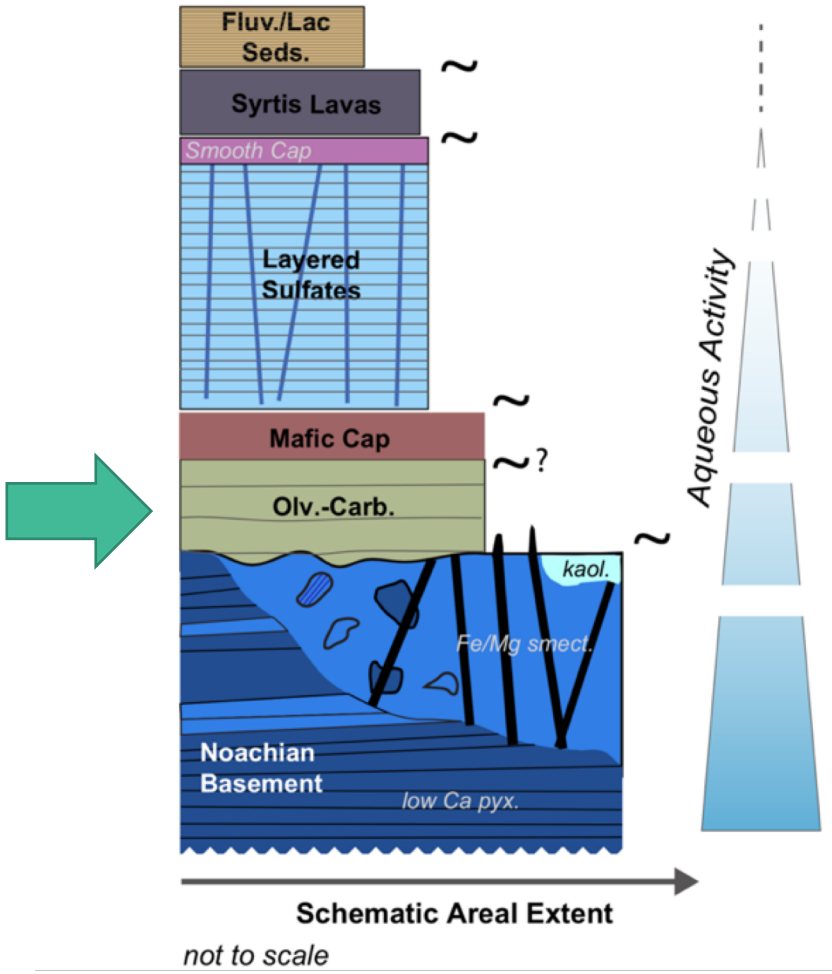
Elena Amador & Bethany Ehlmann

4th Mars 2020 Landing Site Workshop

October 17, 2018

Extensive olivine-enriched unit around Isidis Basin

Nili Fossae - NE Syrtis Stratigraphic Column



Key Points:

1. Circum-Isidis olivine/carbonate unit is globally significant

2. Provides access to primary igneous compositions that have been variably altered in-place to produce habitable subsurface environments during the late-Noachian.

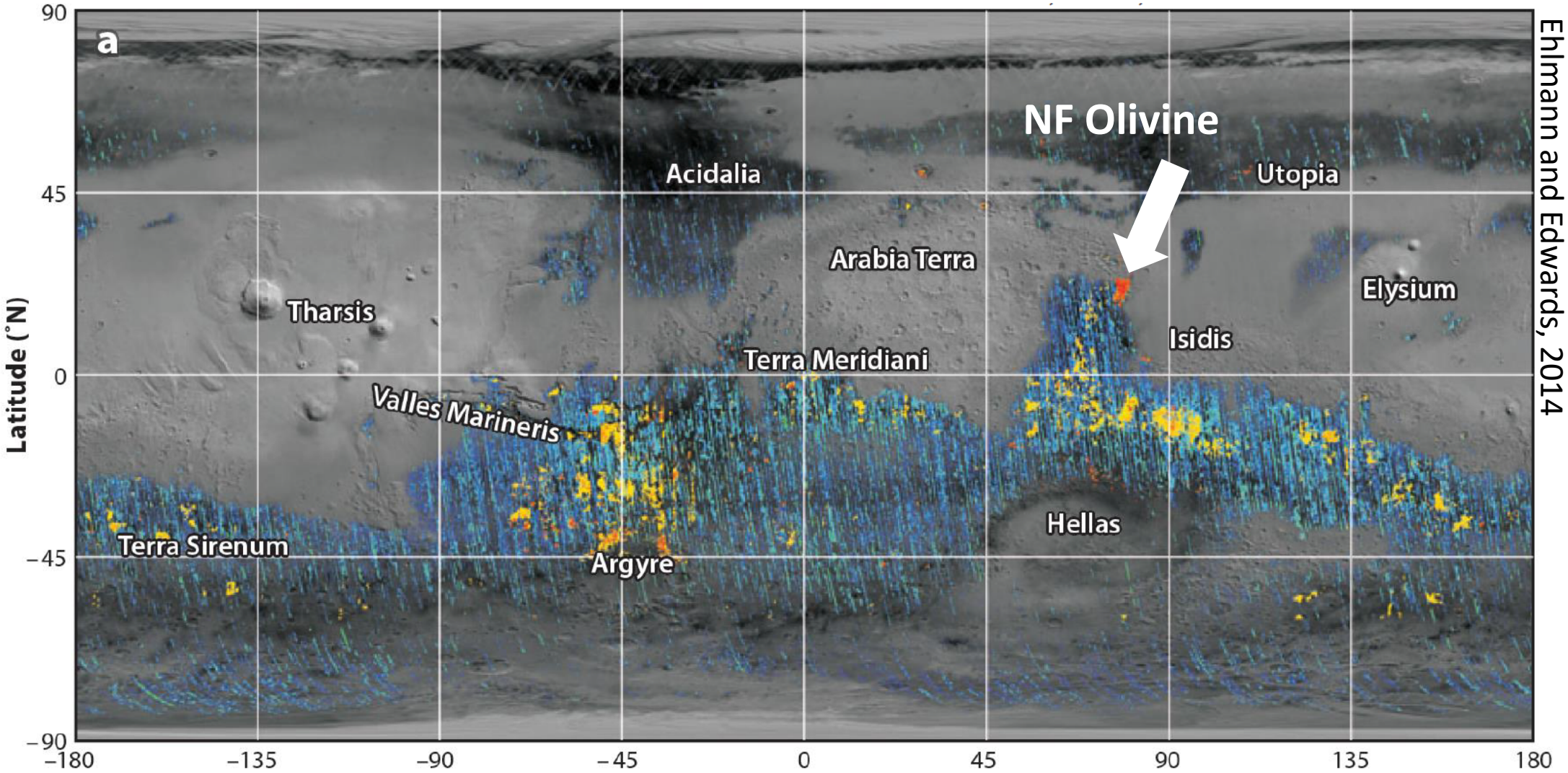
3. Allows for the direct testing and resolution of proposed hypotheses with implications for planetary evolution

The Circum-Isidis Unit has *"glowed"* in every wavelength since studying martian surface mineralogy from orbit.

Historical Context

2003	MGS TES	• Extensive olivine-enriched unit discovered 2003 by MGS TES • ~20-30% olivine • Mg-rich for Mars: Fo numbers ranging from ~70-90 • Hoefen et al., 2003; Koeppen and Hamilton, 2008
2005	THEMIS/ Mars Odyssey	• THEMIS detailed a much more extensive unit, contextualized, and determined thermophysical properties; (layered, highest olivine concentrations in sand, etc.) • Hamilton and Christensen, 2005
2007	Mars Express/ OMEGA	• Showed distinct phyllosilicate basement unit • First proposed that olivine may be associated with the Isidis Impact event • Mustard et al., 2007 & Mangold et al, 2007 • Hinted at the possibility of the aqueous alteration of the olivine unit
2008	CRISM/ MRO	• Evidence for hydrated Mg-carbonate associated with the olivine-unit, variably present with another secondary alteration phase • Ehlmann et al., 2008; 2009; Brown et al., 2010
2009 - present	CRISM/ MRO	• Distributed evidence for serpentine across the Nili Fossae/NE Syrtis region in association with the olivine-unit • Ehlmann et al., 2009; 2010; Ehlmann and Mustard, 2012; Viviano et al., 2013; Amador et al., 2017;2018; Brown et al., submitted; … many others.

Most extensive exposure of high abundance olivine



Ehlmann and Edwards, 2014

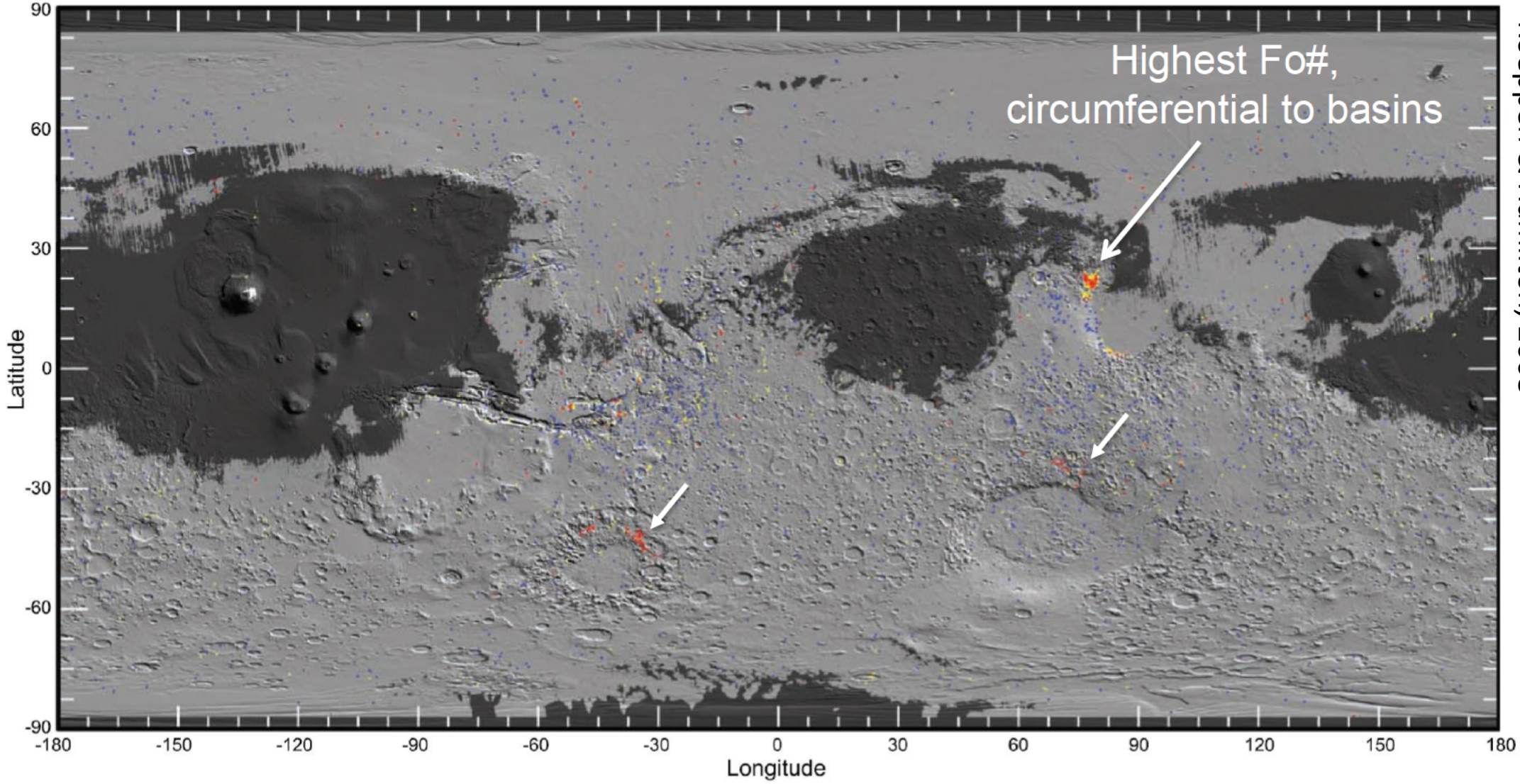
0% TES olivine abundance 20%

Koeppen & Hamilton, 2008, JGR

Low OMEGA total olivine High

Ody et al., 2013, JGR

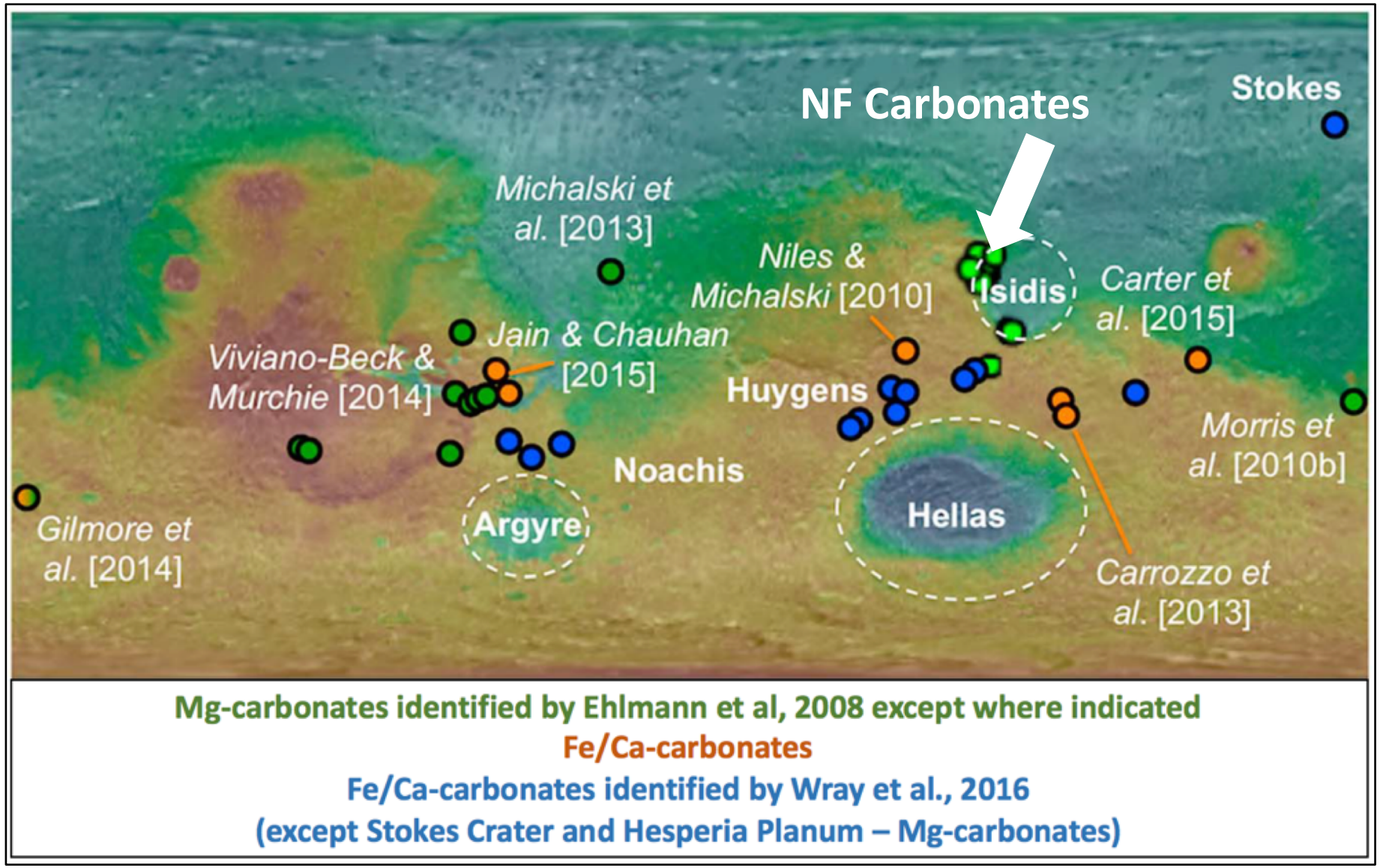
Access to high-Mg olivine likely from primitive melts or mantle



Koeppen & Hamilton, 2008

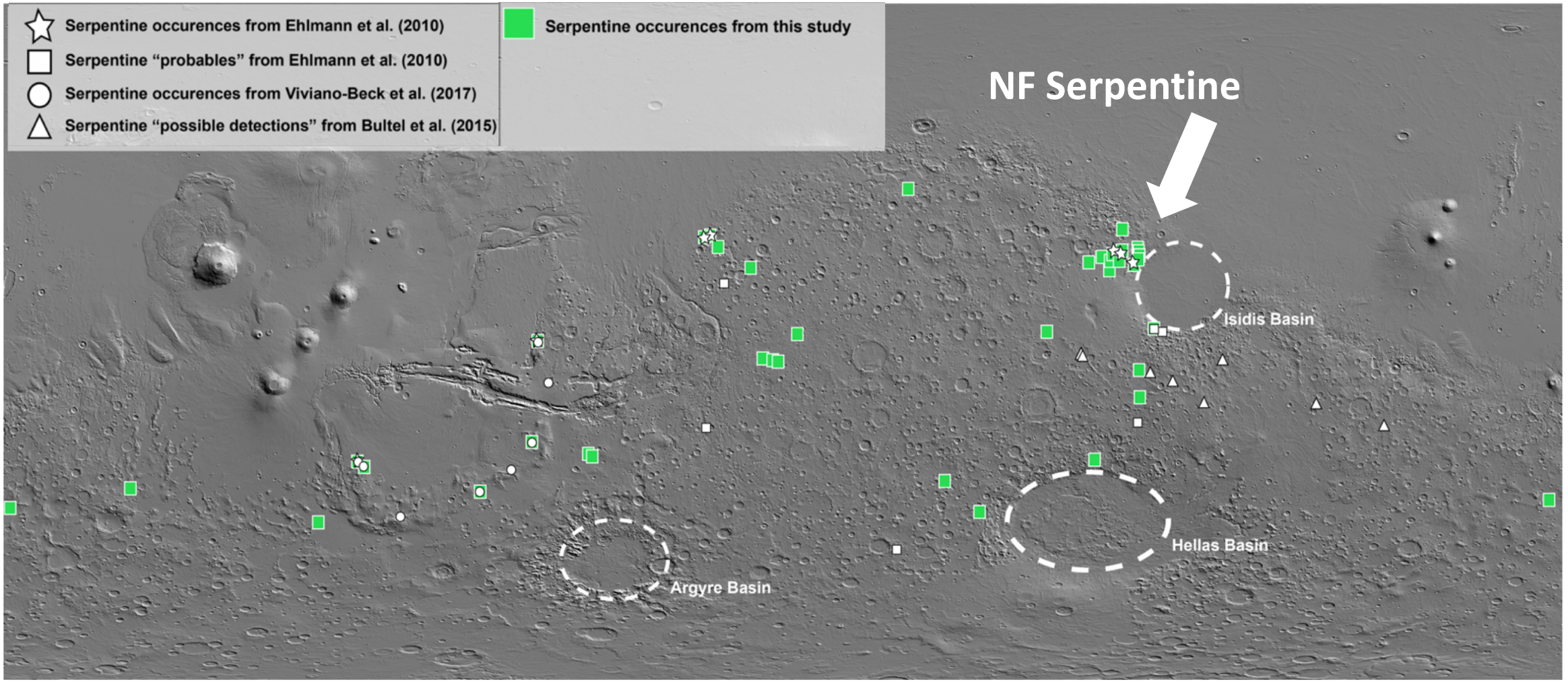
Fo75-100 Fo58-74 Fo42-57

Most extensive and best exposed carbonate-bearing rock unit



Wray et al., 2016

Largest concentration of spectral signatures for serpentine-bearing surfaces



Amador et al., 2018

Key characteristics of the olv.-carb. unit around Nili Fossae

Time constrained: Between Isidis and Syrtis lava flows (~3.9-3.5 Ga) (Mangold et al., 2007; Mustard et al., 2007; 2009)

Olivine-enrichment between ~20-30 wt% (Hoefen et al., 2003; Edwards & Ehlmann, 2015)

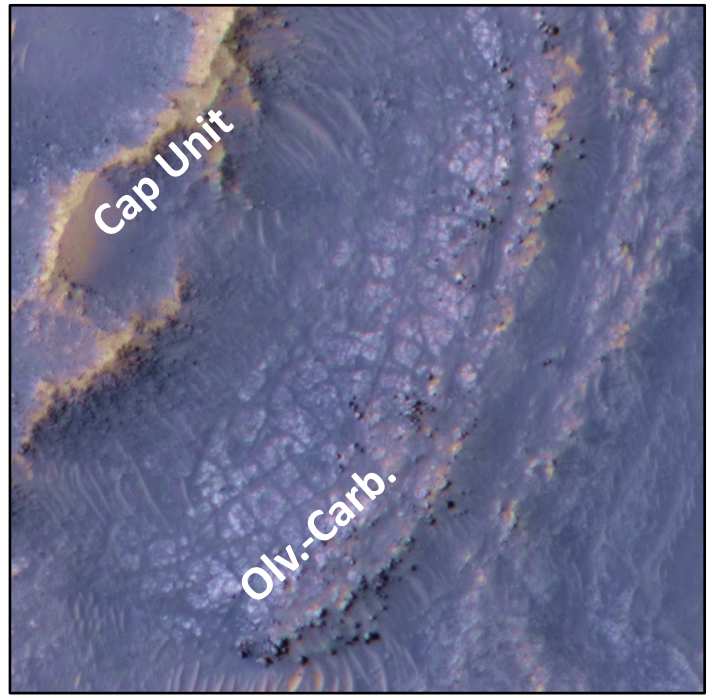
Olivine compositions Fo_{68-91} (i.e., Mg-rich for Mars) (Hamilton & Christensen, 2005; Koeppen & Hamilton, 2008; Edwards & Ehlmann, 2015)

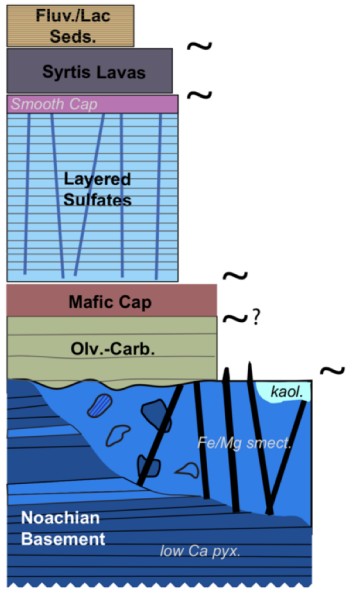
Carbonate abundances ~5-20 wt% (Edwards & Ehlmann, 2015)

Variable evidence for associated serpentine across Nili Fossae region (Ehlmann et al., 2009;2010;2012; Brown et al., 2010; Viviano et al., 2013; Amador et al., 2017;2018; Tarnas, LPSC 2017)

CRISM spectral shape, modeling imply >1 mm olivine grain size in nearby eroded olivine-enriched sands (Edwards & Ehlmann, 2015; Bramble et al., 2017)

Characteristic few meters scale fracturing, moderate thermal inertia (~ 420 TI units) imply altered igneous unit (Hamilton & Christensen, 2005; Edwards & Ehlmann, 2015)





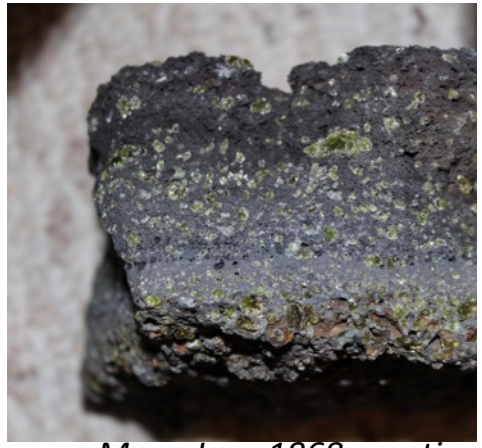
How did this unit get here?
Olivine-enriched unit emplacement scenarios

- **Igneous intrusive complex, pre-dating Isidis impact (Hoefen et al., 2003)** – pretty well ruled out now given flow and draping characteristics

- **Subaerially erupted olivine-rich basalts** (Hamilton and Christensen, 2005; Tornabene et al., 2008)

- **Mantle cumulates** transported in impact melt associated with the Isidis impact basin (e.g., Mustard et al., 2007)

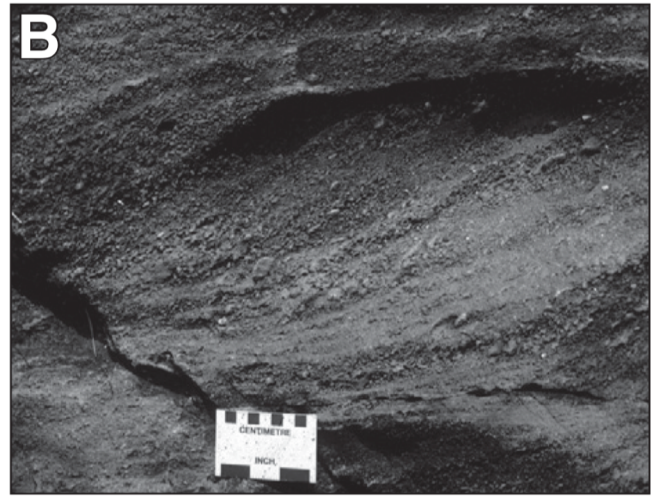
- **Komatiitic lava flow or ash deposit** (e.g., Rogers et al., 2018; Kremer et al., 2018, *in review*)



Mona Loa, 1868 eruption

Komati Valley, Komatiite

San Carlos, AZ



Carbonatized,cross-stratified komatiitic lapilli tuff, Thompson Stiegler, 2011

How did this unit get here?
Olivine-enriched unit emplacement scenarios

- **Igneous intrusive complex, pre-dating Isidis impact (Hoefen et al., 2003)** – pretty well ruled out now given flow and draping characteristics
- **Subaerially erupted olivine-rich basalts** (Hamilton and Christensen, 2005; Tornabene et al., 2008)
- **Mantle cumulates** transported in impact melt associated with the Isidis impact basin (e.g., Mustard et al., 2007)
- **Komatiitic lava flow or ash deposit** (e.g., Rogers et al., 2018; Kremer et al., 2018, *in review*)

These different hypotheses are testable on the ground, straightforwardly with Mars-2020 payload by high-resolution imaging, bulk chemistry, and analysis of mineral assemblages.

Provides access to a key martian primary igneous lithologies with implications for understanding the evolution of the martian interior.

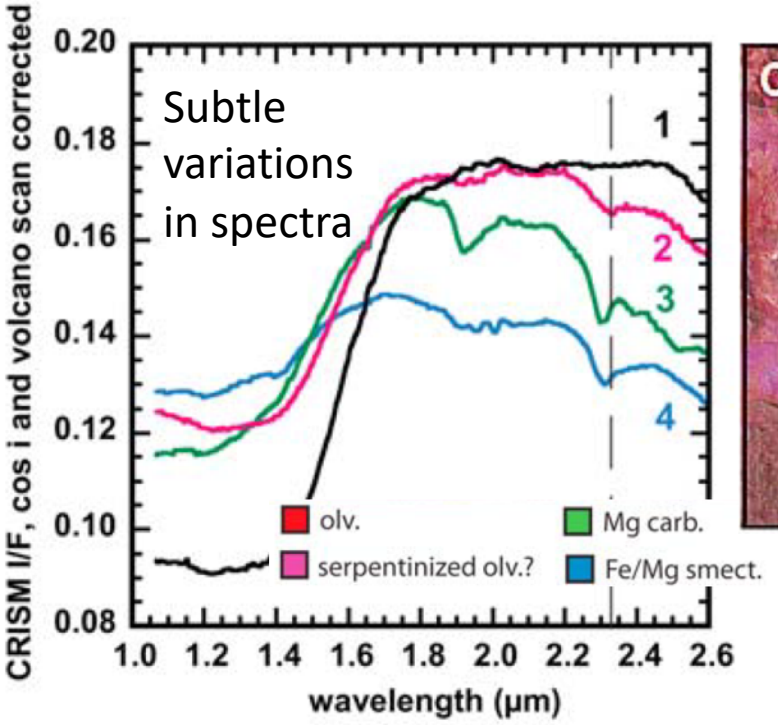
The variably weathered nature of the olivine/carbonate unit

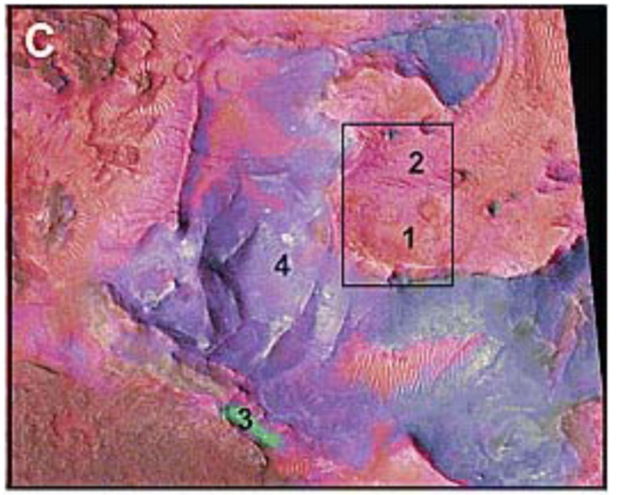
Alteration of olivine leads to mineralogical variability and is an indicator of a once habitable subsurface.

Shown by measuring variability in the **position**, **shape, and depth** of 2.3 and 2.5 *μ*m band centers for Mg-carbonate.

Present:

- **Mg-carbonate** (distinct, extensive evidence)
- **Mg-serpentine** (distinct in several locations, more diffuse regionally)
- **Other Fe/Mg-phyllosilicate (smectite, talc?)** (distinct but variable across region)

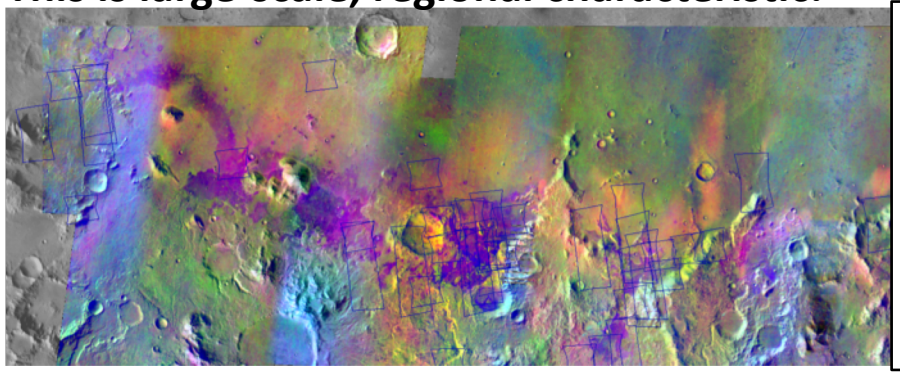




Ehlmann et al., 2009

Subtle variations in spectra that are spatially resolvable, implying variable alteration.

This is large-scale, regional characteristic:



Olivine alteration to Mg-carbonate and serpentine is similarly observed in Libya Montes (e.g., Bishop et al., 2013).

Libya Montes (southern rim of Isidis Basin); THEMIS Bands 8-7-5 (purple == olivine)

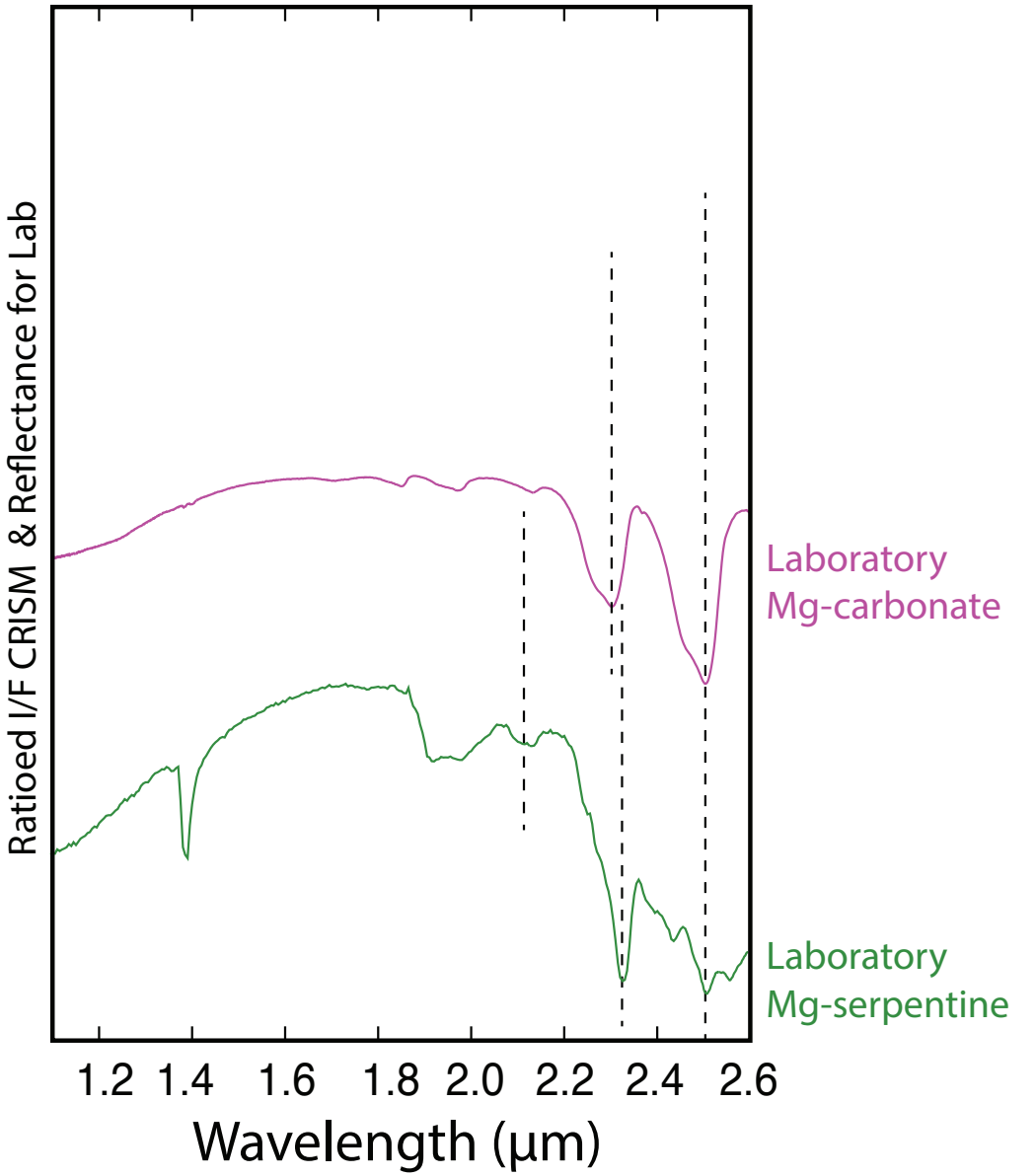
The variably weathered nature of the olivine/carbonate unit

Alteration of olivine leads to mineralogical variability and is an indicator of a once habitable subsurface.

Shown by measuring variability in the **position**, **shape, and depth** of 2.3 and 2.5 μm band centers for Mg-carbonate.

Present:

- **Mg-carbonate** (distinct, extensive evidence)
- **Mg-serpentine** (distinct in several locations, more diffuse regionally)
- **Other Fe/Mg-phyllosilicate (smectite, talc?)** (distinct but variable across region)



These are **spectrally distinct** but can be confounded at CRISM spectral and spatial resolutions compared to lab hand-samples

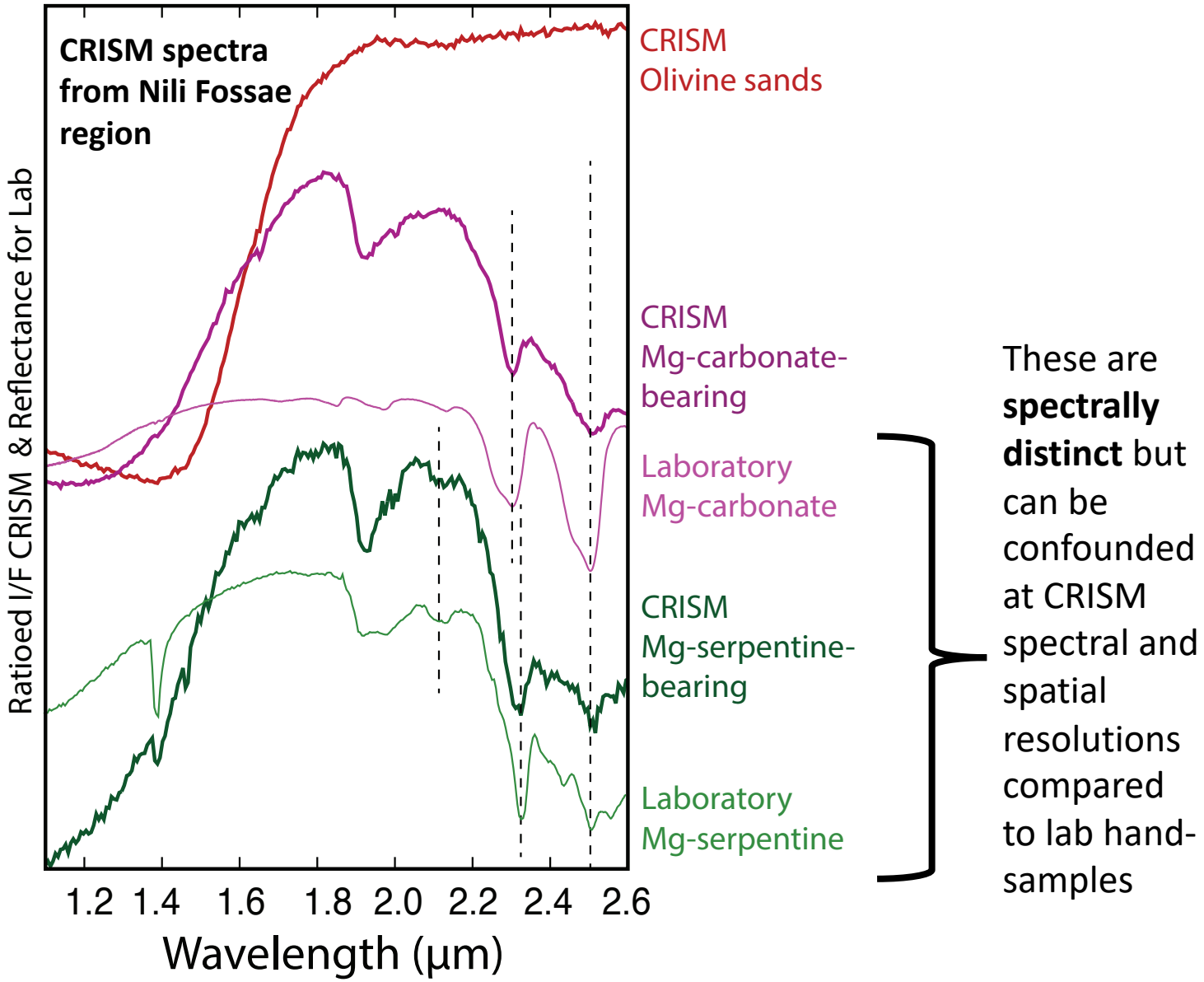
The variably weathered nature of the olivine/carbonate unit

Alteration of olivine leads to mineralogical variability and is an indicator of a once habitable subsurface.

Shown by measuring variability in the **position**, **shape, and depth** of 2.3 and 2.5 μm band centers for Mg-carbonate.

Present:

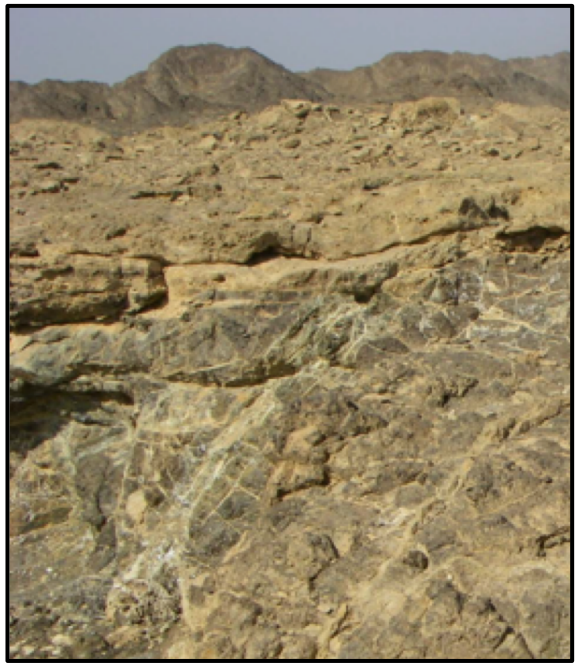
- **Mg-carbonate** (distinct, extensive evidence)
- **Mg-serpentine** (distinct in several locations, more diffuse regionally)
- **Other Fe/Mg-phyllosilicate (smectite, talc?)** (distinct but variable across region)



How did these secondary hydrated phases form?
Sustained aqueous alteration of the protolith by:

Mg-carbonate formation from near-surface weathering of **olivine-enriched protolith** by surface water
Mg-carbonate formation from near-surface weathering of s**erpentine-enriched protolith** by surface water
Mg-serpentine and Mg-carbonate formation by moderate/low-T **serpentinization (20-200 °C)**
Deep hydrothermal convection: *Unlikely, No high T phases detected, though found elsewhere regionally*

Left:
White carbonate veins in altered peridotite, Oman, (Keleman & Matter, 2008)



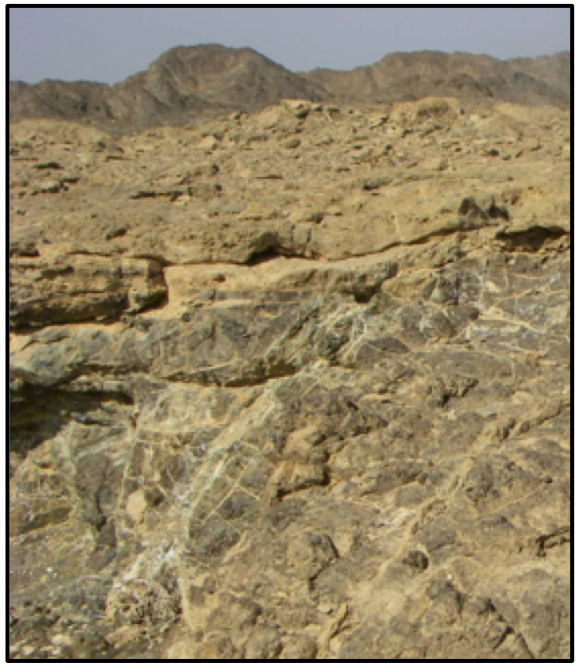
Right:
Samail Ophiolite, Oman
Serpentine, talc, magnesite, olivine found together

How did these secondary hydrated phases form?
Sustained aqueous alteration of the protolith by:

Mg-carbonate formation from near-surface weathering of **olivine-enriched protolith** by surface water
Mg-carbonate formation from near-surface weathering of s**erpentine-enriched protolith** by surface water
Mg-serpentine and Mg-carbonate formation by moderate/low-T **serpentinization (20-200 °C)**
Deep hydrothermal convection: *Unlikely, No high T phases detected, though found elsewhere regionally*

Left:
White carbonate veins in altered peridotite, Oman, (Keleman & Matter, 2008)

These different hypotheses can be tested with *in-situ* scale context and detailed petrology



Right:
Samail Ophiolite, Oman
Serpentine, talc, magnesite, olivine found together.

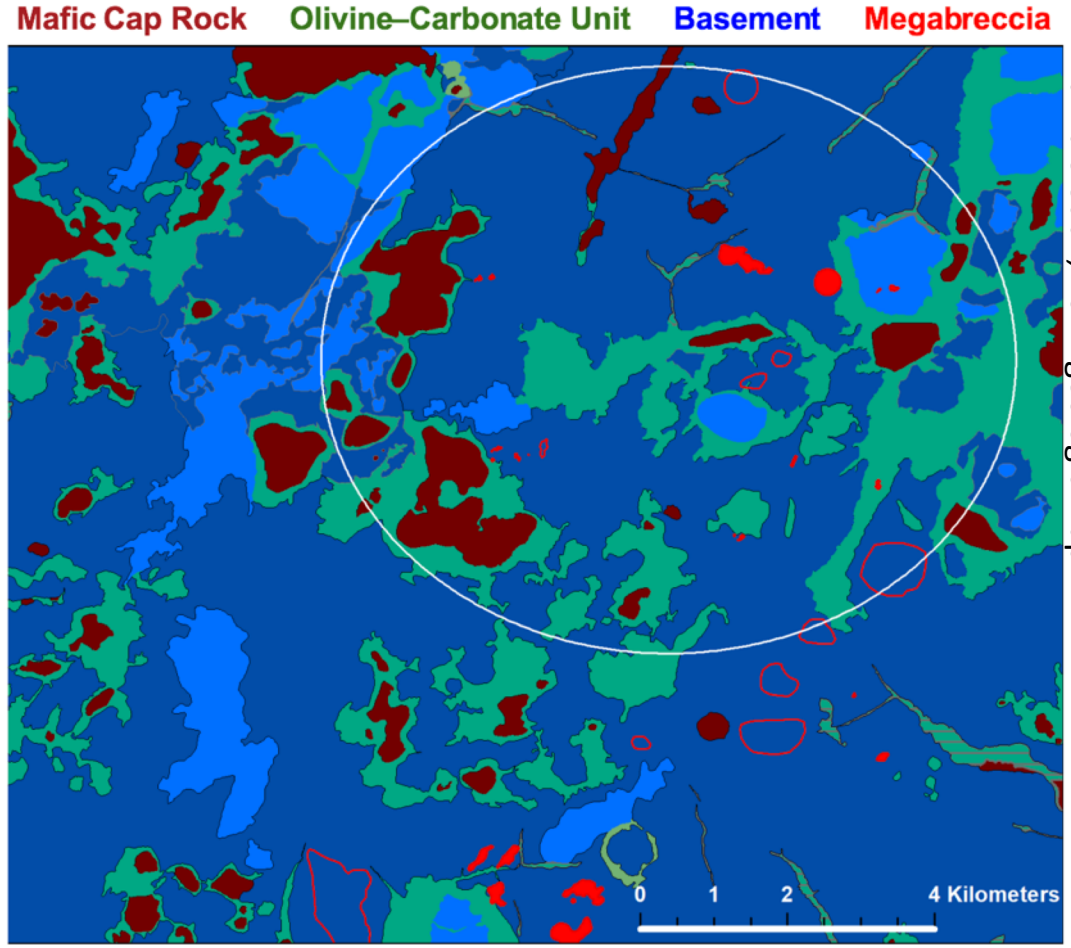
Why is this important?
These alteration/hydrous phases have important planetary scale implications…

Carbonates	Olivine alteration/serpentine
Informs our understanding of Noachian **atmospheric composition and processes** (e.g., mechanisms of atmospheric carbon sequestration); on site petrology, measure $\delta^{13}C$, $\delta\ ^{18}O$	• Direct H_2 production is common • CH_4 (and other short-chained hydrocarbons) can form indirectly
The nature and fate of the early Noachian to early Hesperian atmosphere is a key outstanding question for Mars. In NES, carbonates are found in-place and allow for the direct interrogation of this question.	Terrestrially known to be **inhabited environments** on early and modern Earth with diverse communities of chemoautotrophic life
They represent 0.25-12 mbar of atm. CO_2 (Edwards and Ehlmann, 2015)	Serpentinizing systems have been connected to origin of life scenarios

We have access to this diversity at and around the NES and Midway ellipses.

Compositional diversity at and around the NES and Midway ellipses

- Goal for sampling olivine/carbonate unit:
  - *To sample a diverse set of compositions*

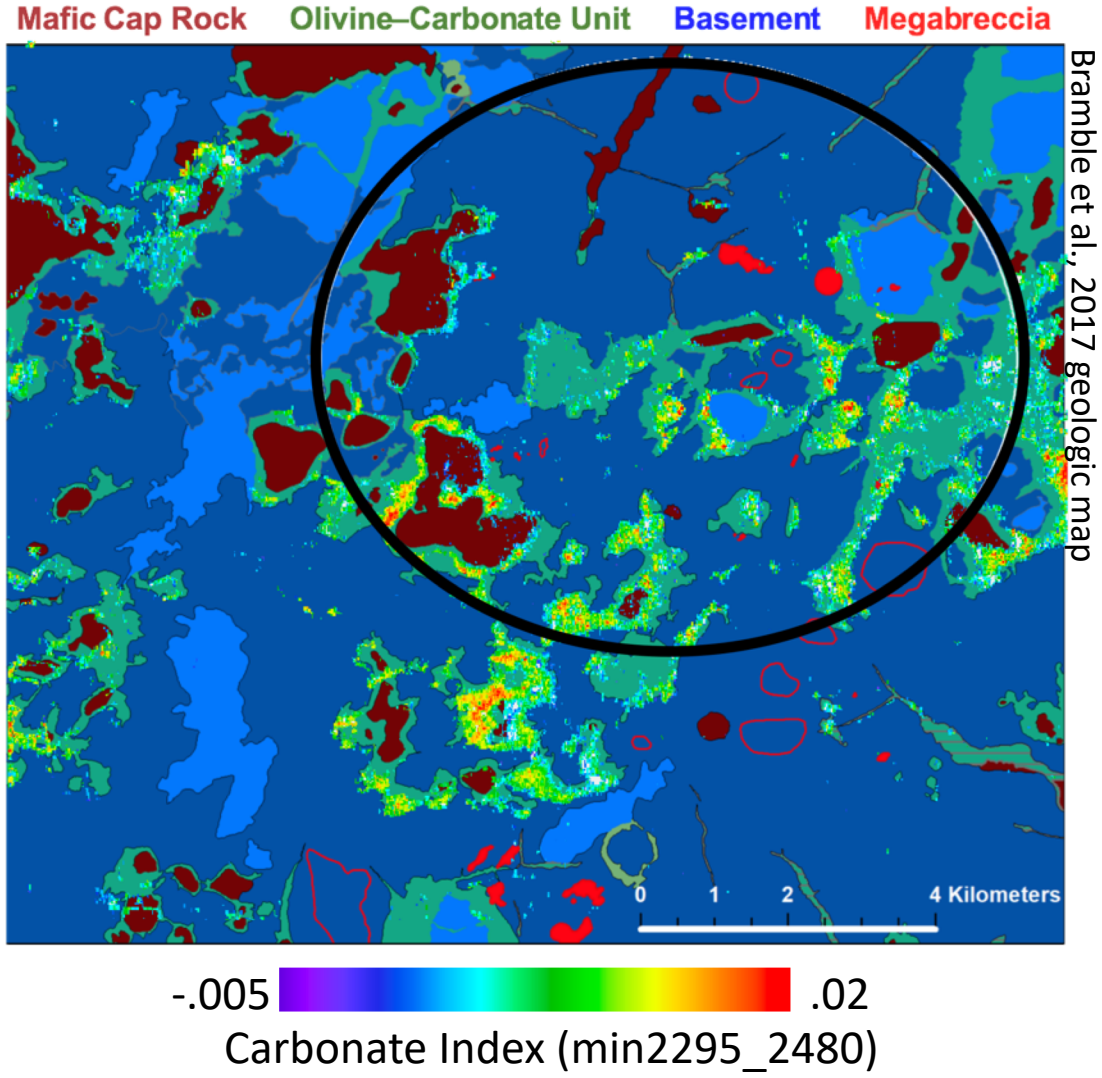


Bramble et al., 2017 geologic map

Compositional diversity at and around the NES and Midway ellipses

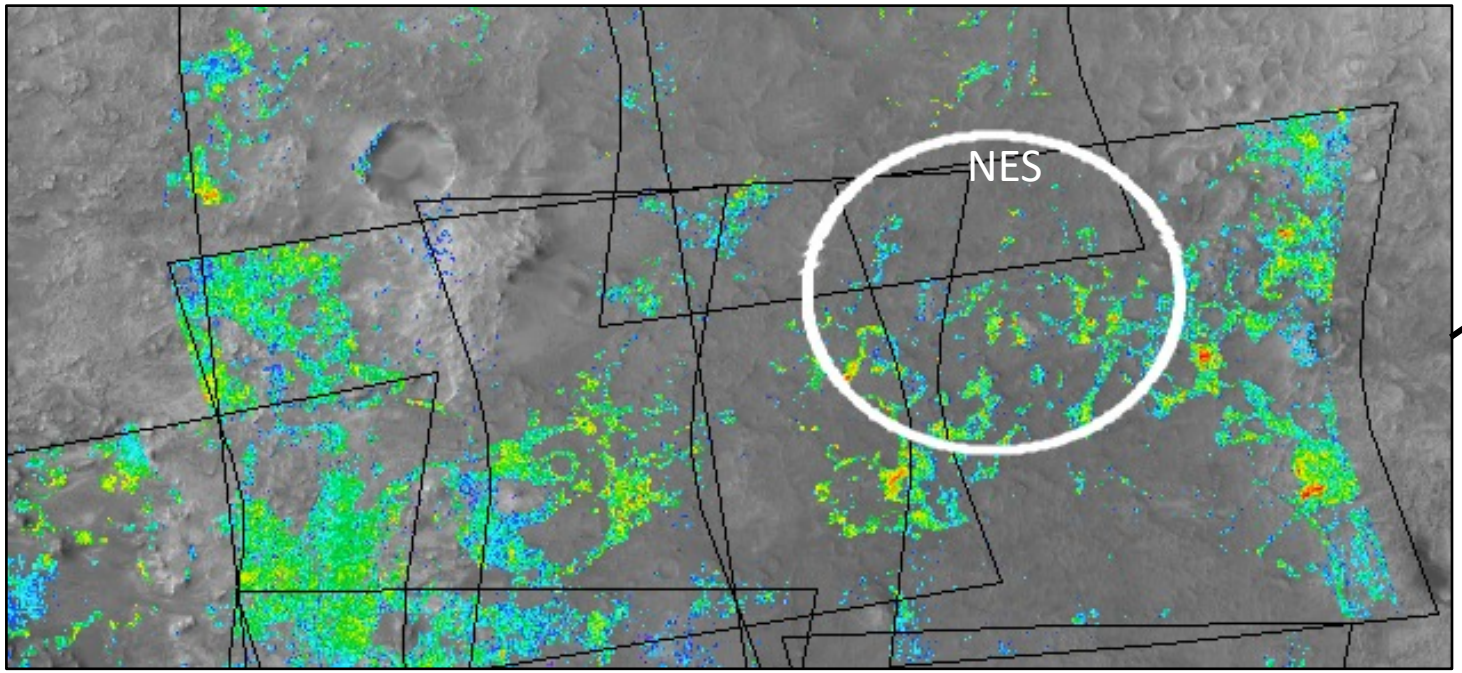
- Goal for sampling olivine/carbonate unit:
  - *To sample a diverse set of compositions*

1. *Map of locales with best spectral signatures for carbonate (red hotspots, right) correlate very well with the geomorphic mapping of the fractured olivine unit.*

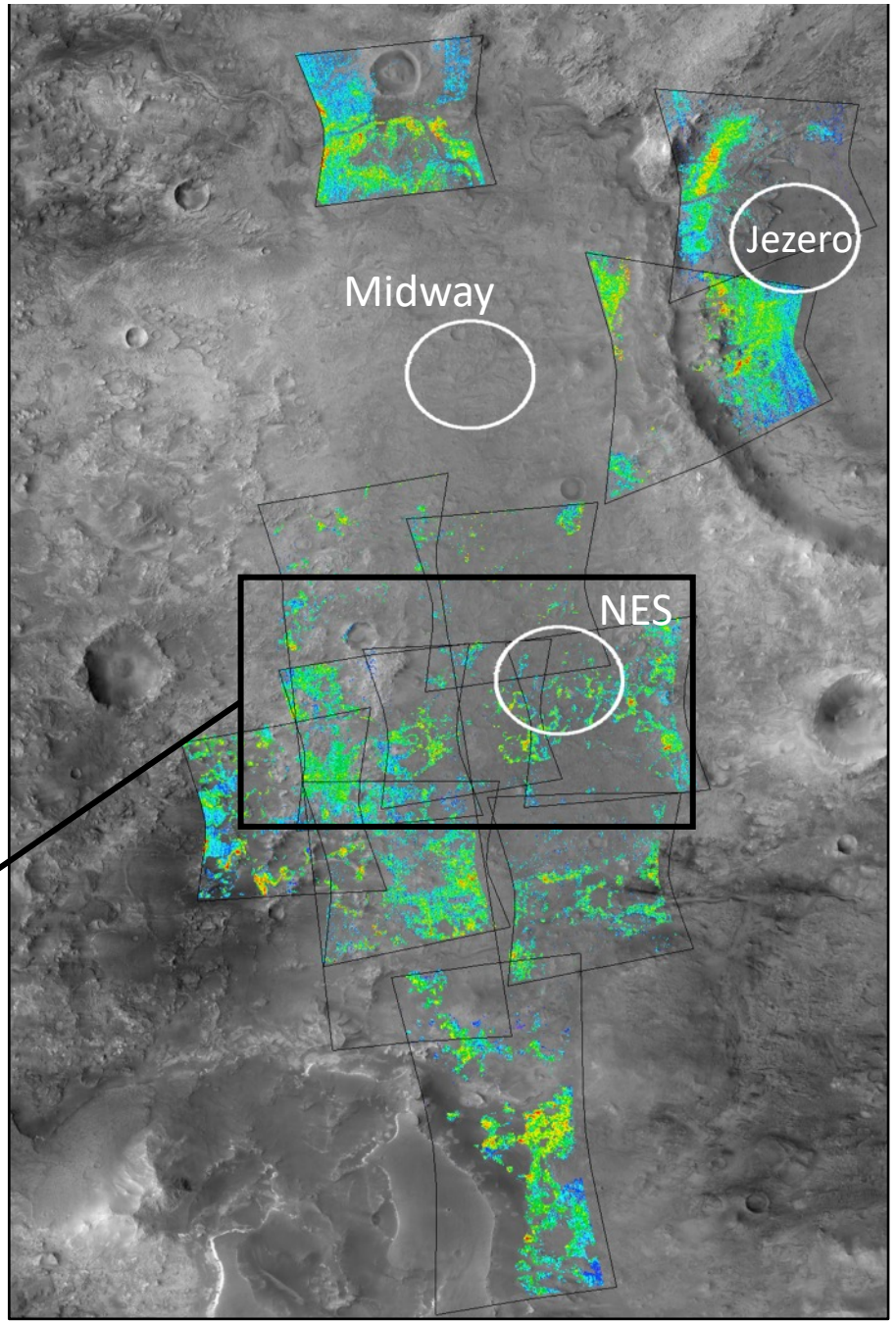


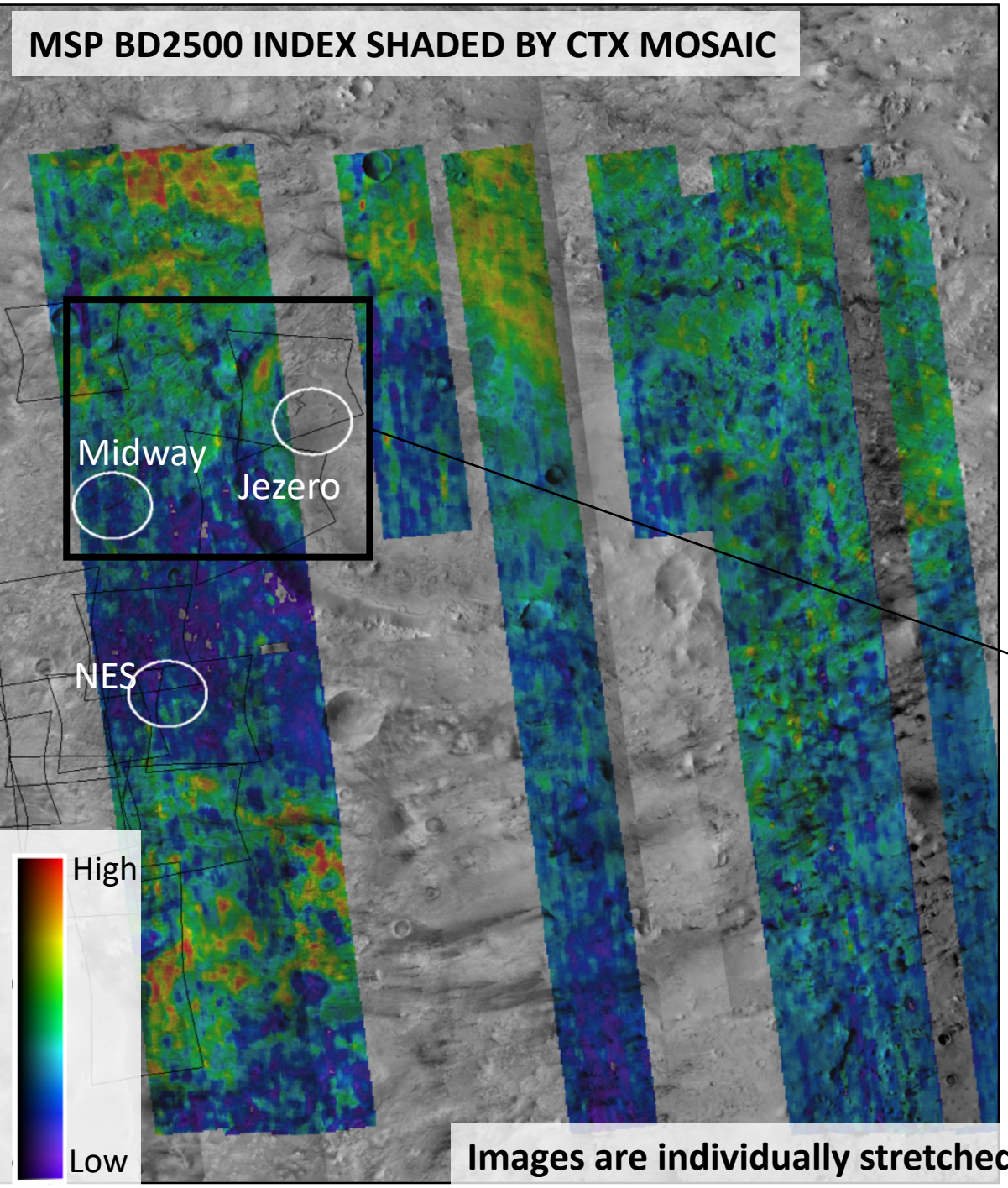
Regional extent of carbonate unit

- Carbonate is found regionally and always associated with the olivine-rich unit with significant opportunity to target within and around NES ellipse.



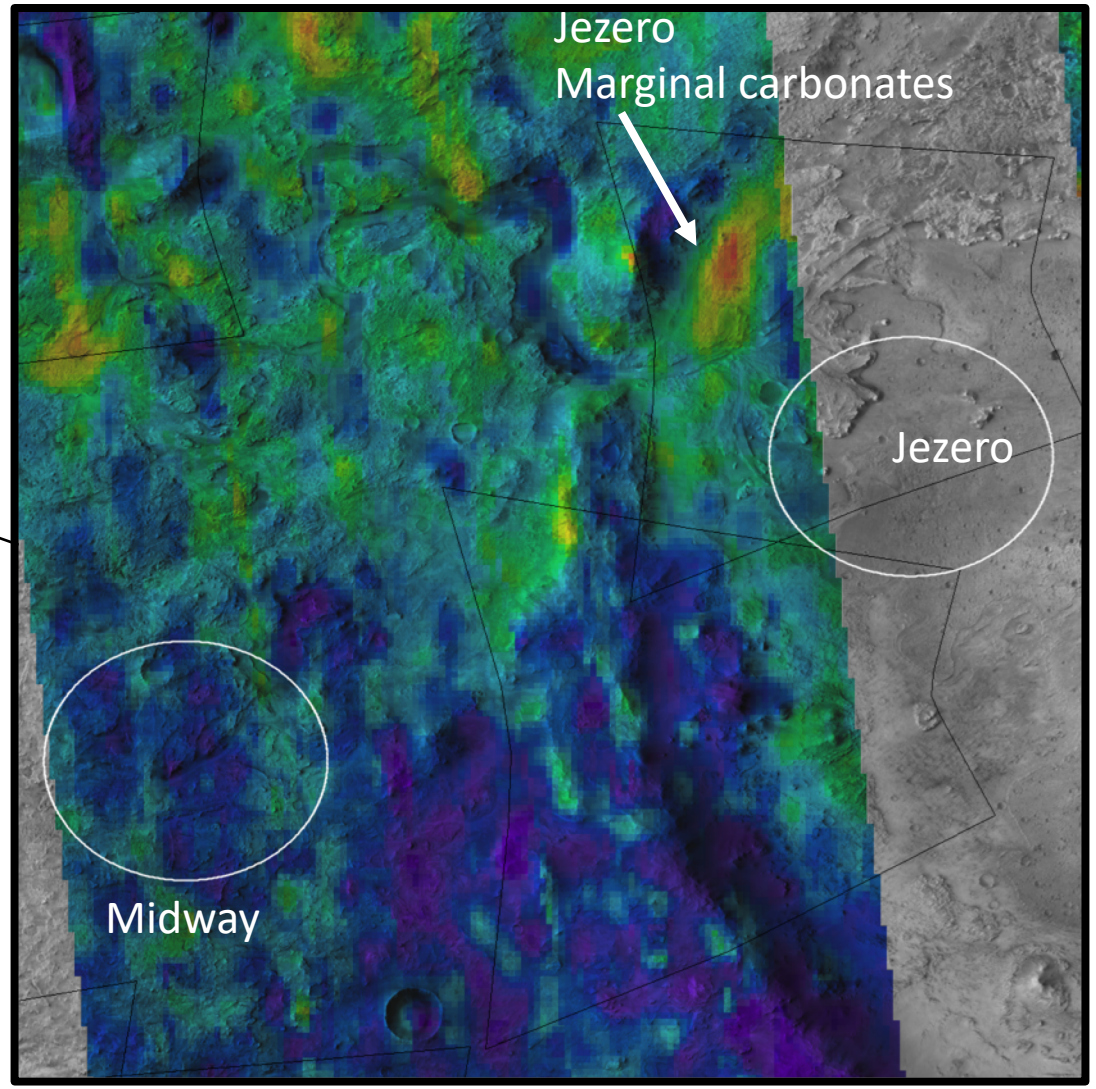
Regional carbonate mapping from Full-resolution CRISM





Access to carbonate around Midway ellipse:

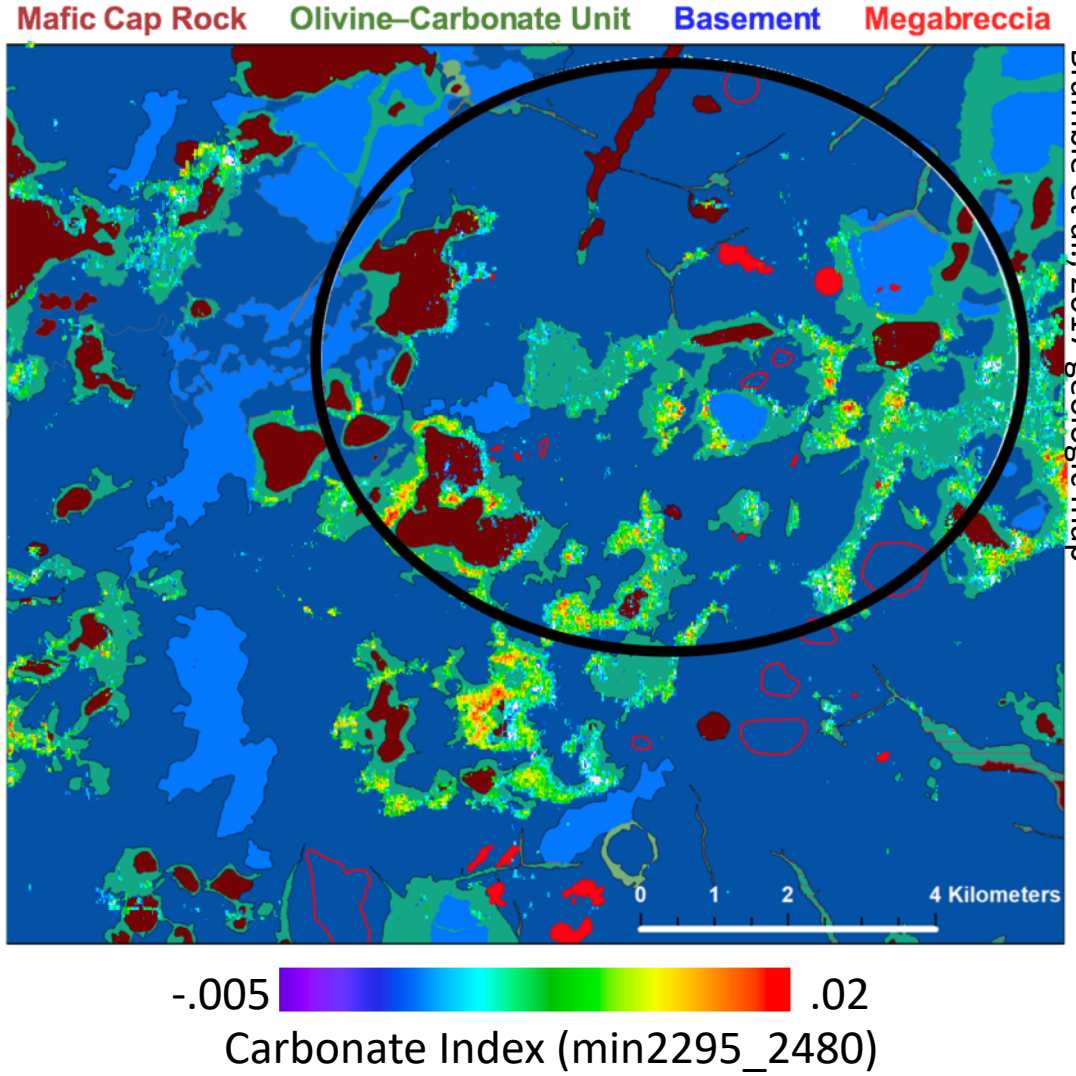
May be pushing the limits of the MSP data but it does clearly map NES and Jezero carbonates



Compositional diversity at and around the NES and Midway ellipses

- Goal for sampling olivine/carbonate unit:
  - *To sample a diverse set of compositions*

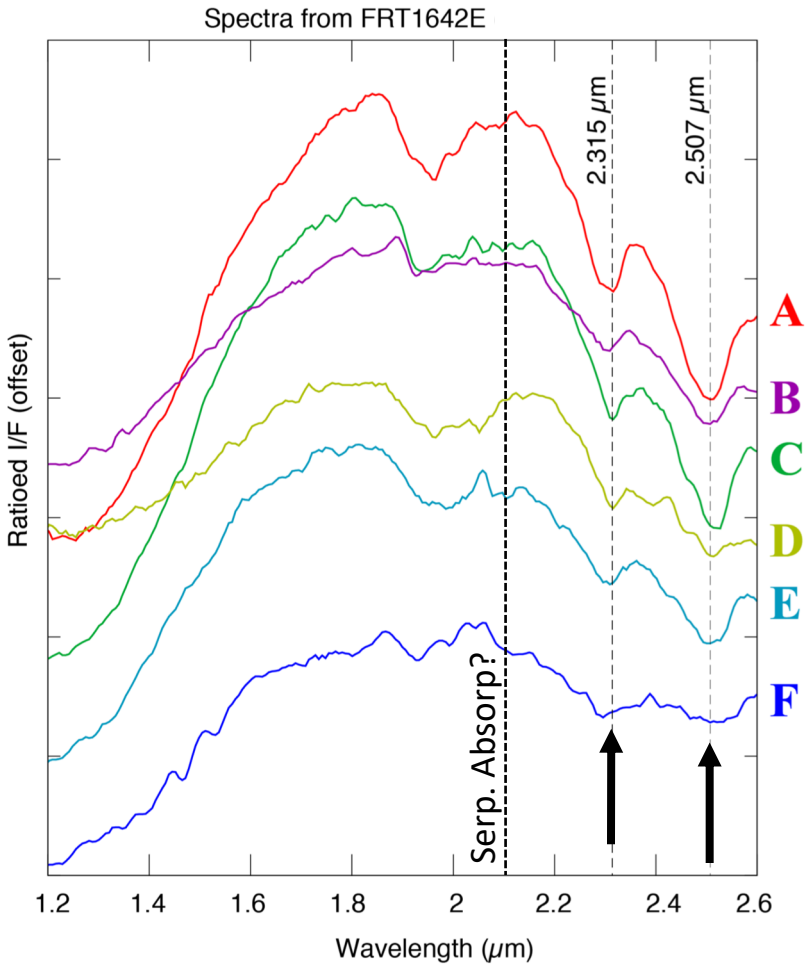
2. ***Are all these carbonate hotspots the same?***

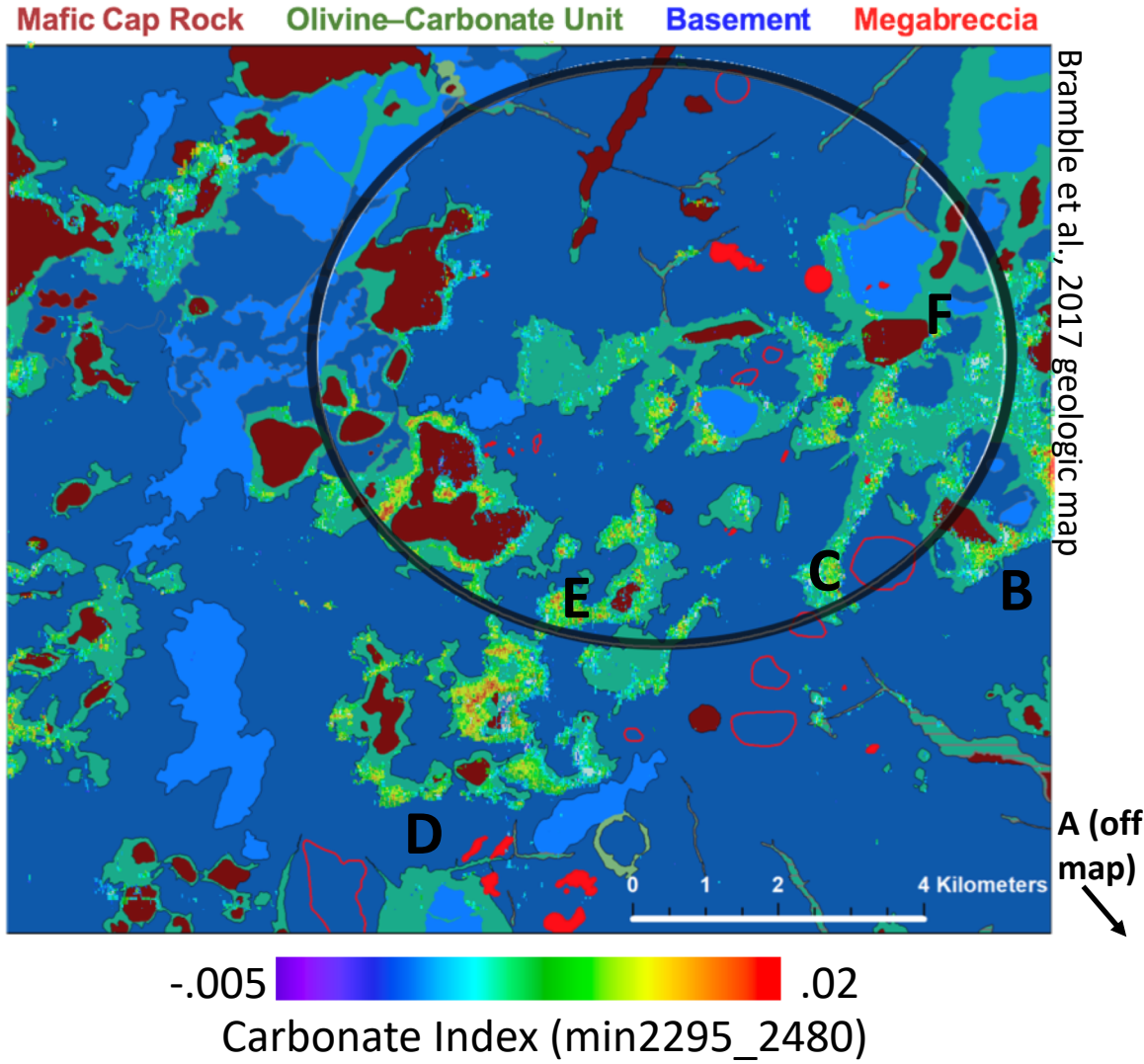


Compositional diversity at and around the NES ellipse

2. Are all these carbonate hotspots the same?

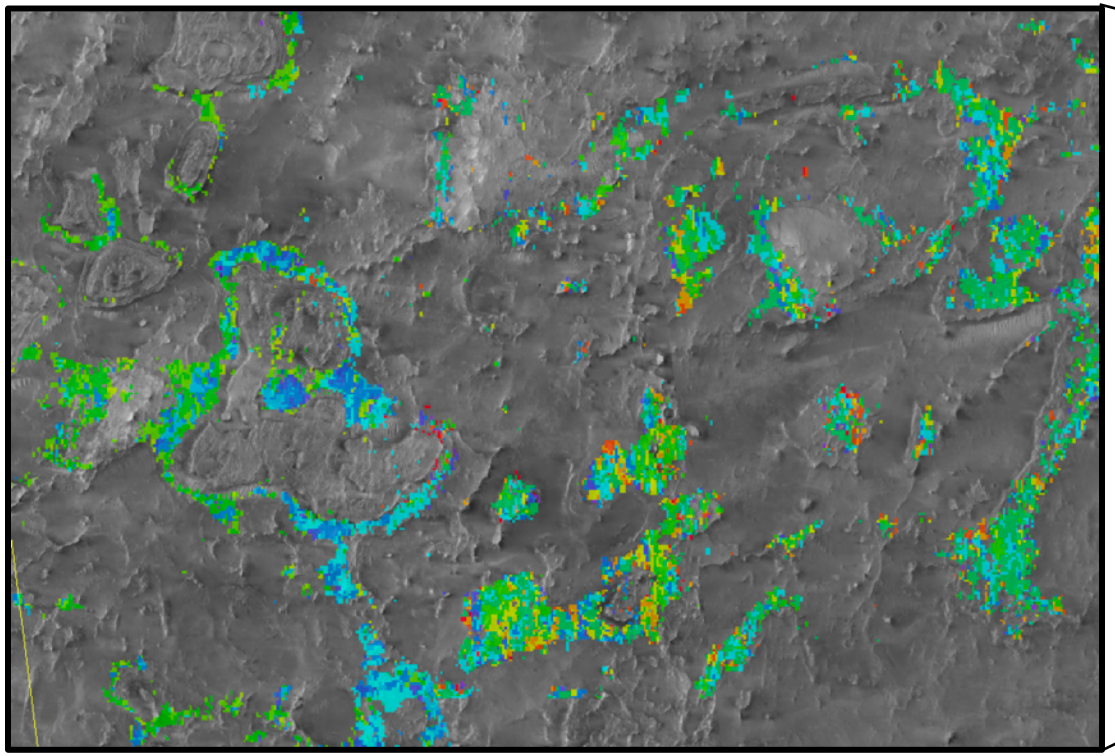
No, as elsewhere in the region, spectra within the NES ellipse show subtle variations in band centers/shapes that imply compositional variability and mixtures





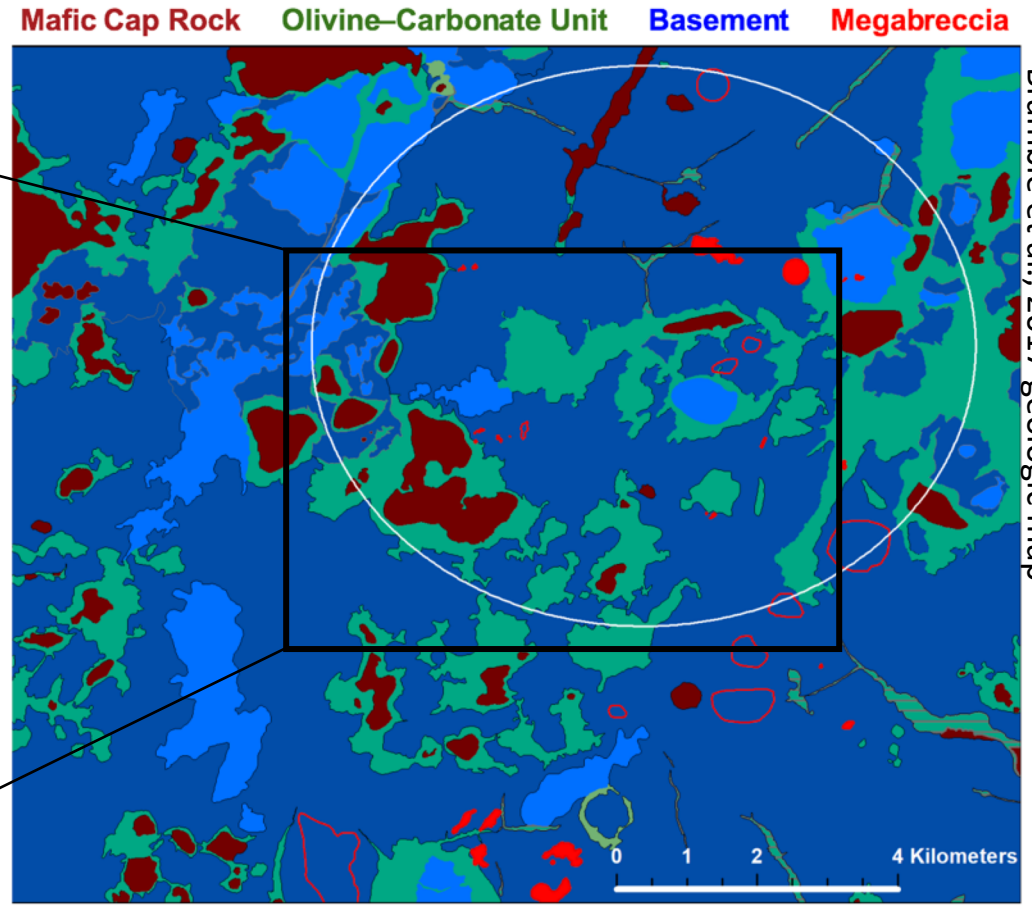
This diversity can be accessed by Mars2020 in ellipse

Map variability in carbonate absorption centers



2.260 µm — 2.340 µm

Continuum removed band center ~2.3
(average in scene =2.306 µm)

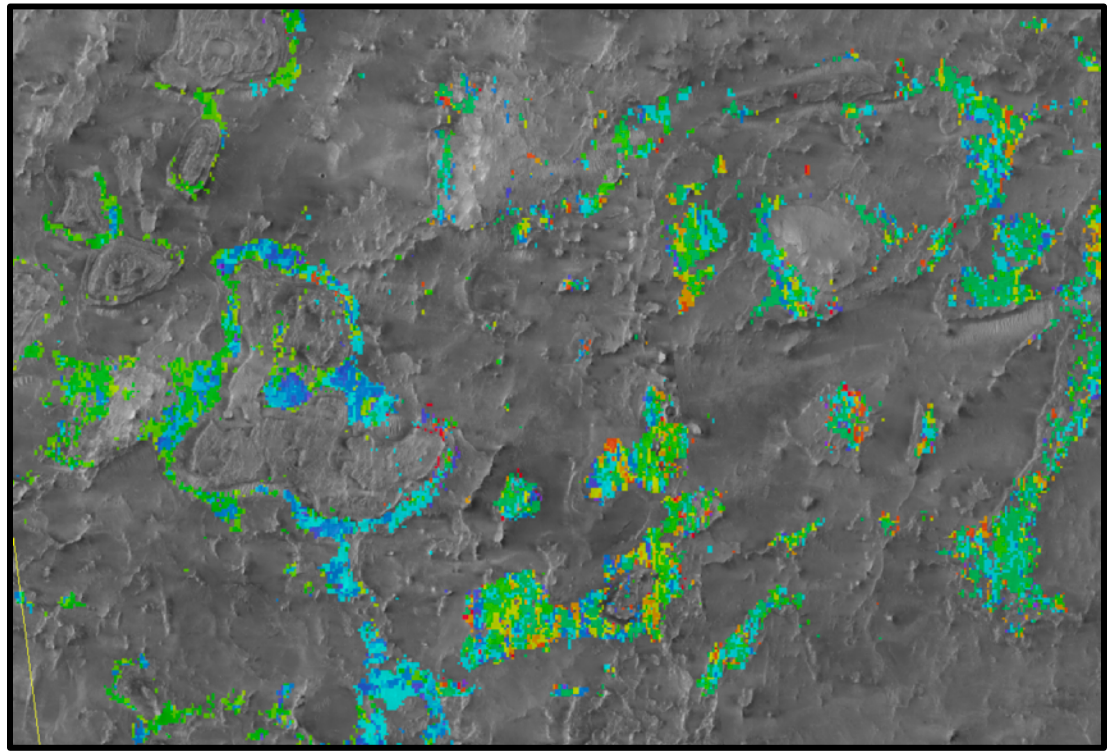


Bramble et al., 2017 geologic map

Analysis of MTRDR data

This diversity can be accessed by Mars2020 in ellipse

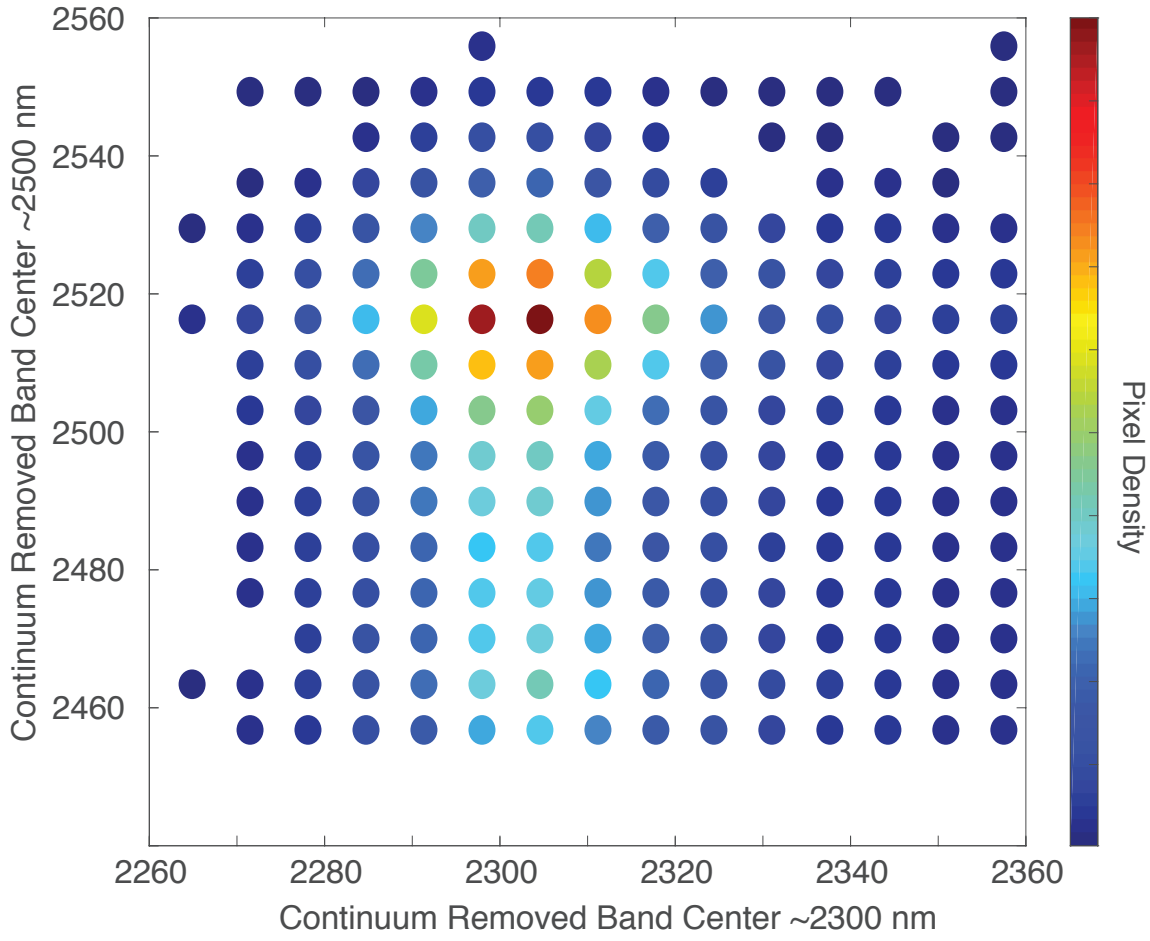
Map variability in carbonate absorption centers



2.260 µm — 2.340 µm

Continuum removed band center ~2.3
(average in scene =2.306 µm)

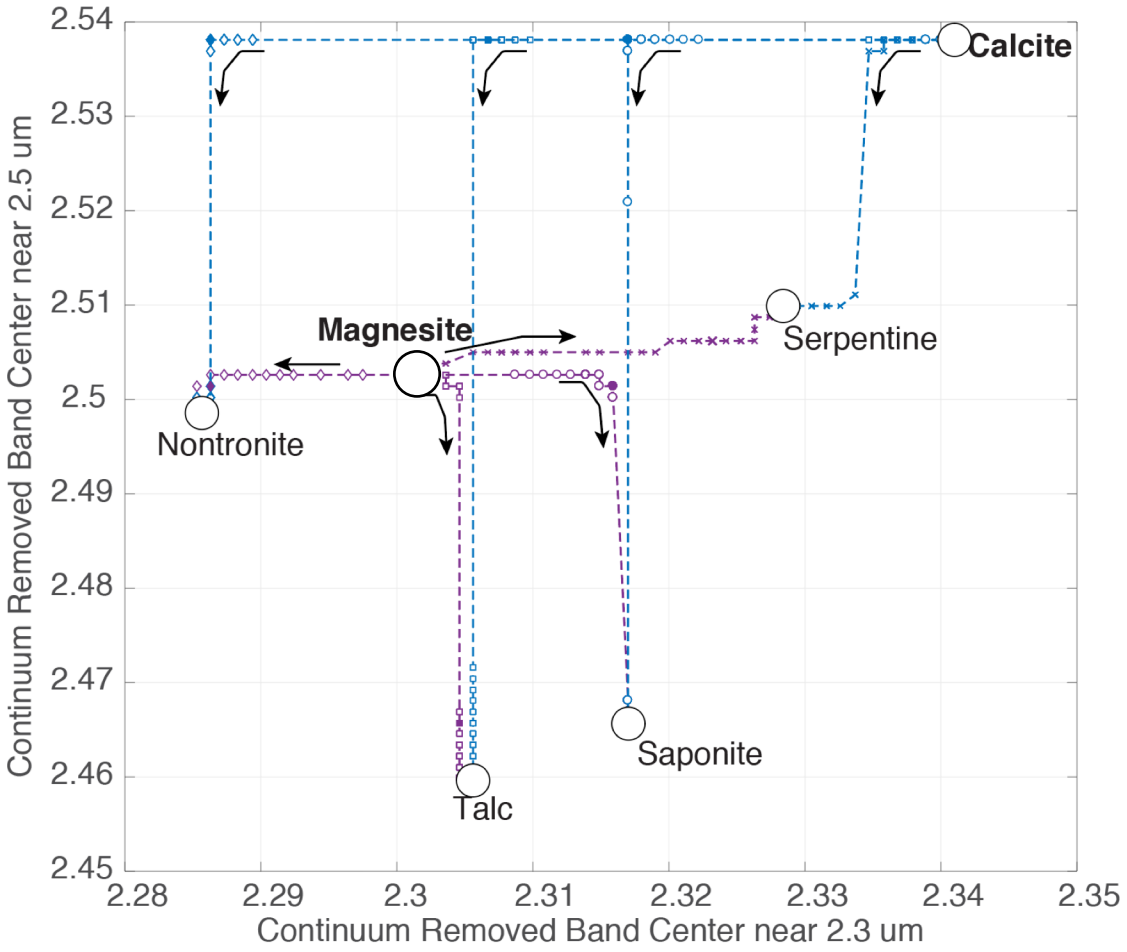
CRISM MTRDR carbonate data
(FRT1642E) – note limits of spectral sampling



Analysis of MTRDR data

This diversity can be accessed by Mars2020 in ellipse

Laboratory synthetic mixtures to show changes in band centers with mixtures between carbonate + Fe/Mg-phyllosilicate phases

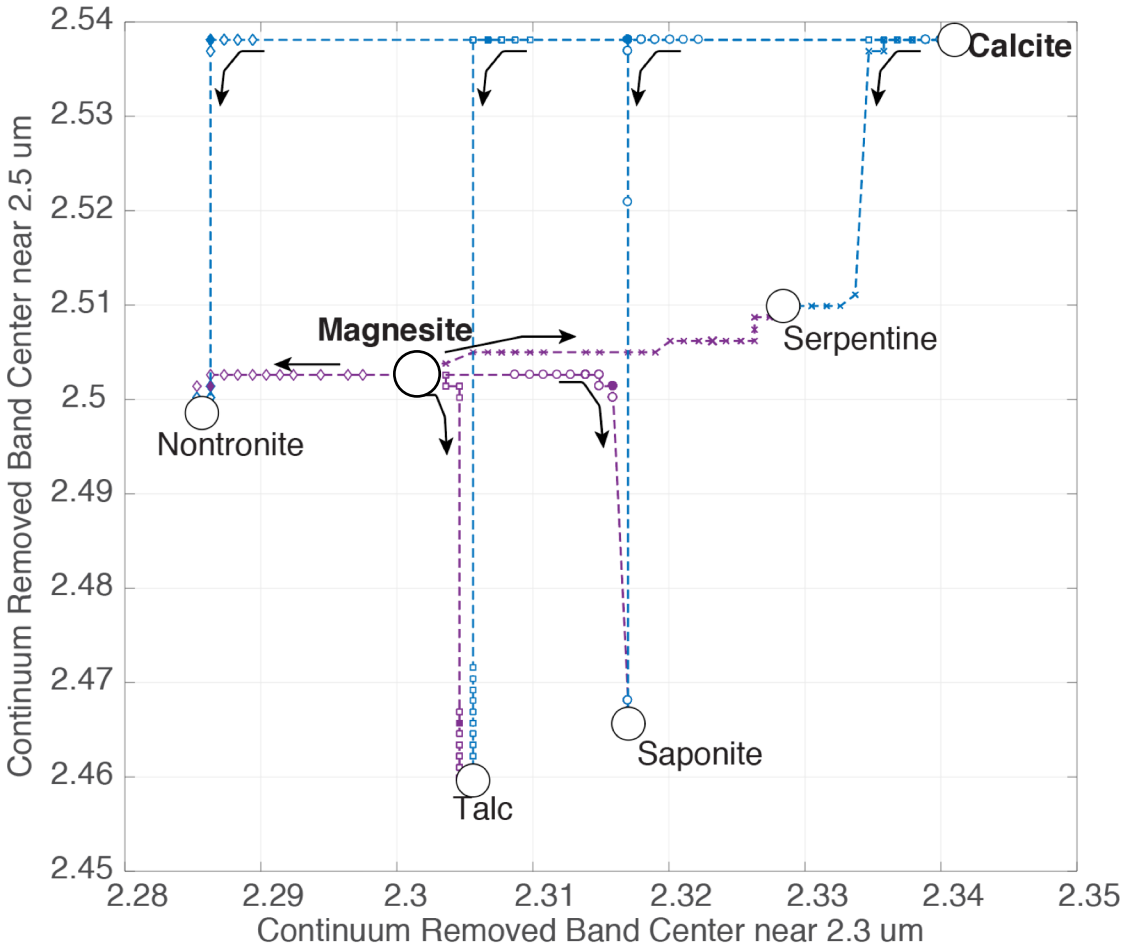


Relative 2.3/2.5 µm band centers for all carbonate-bearing pixels in image 1642E

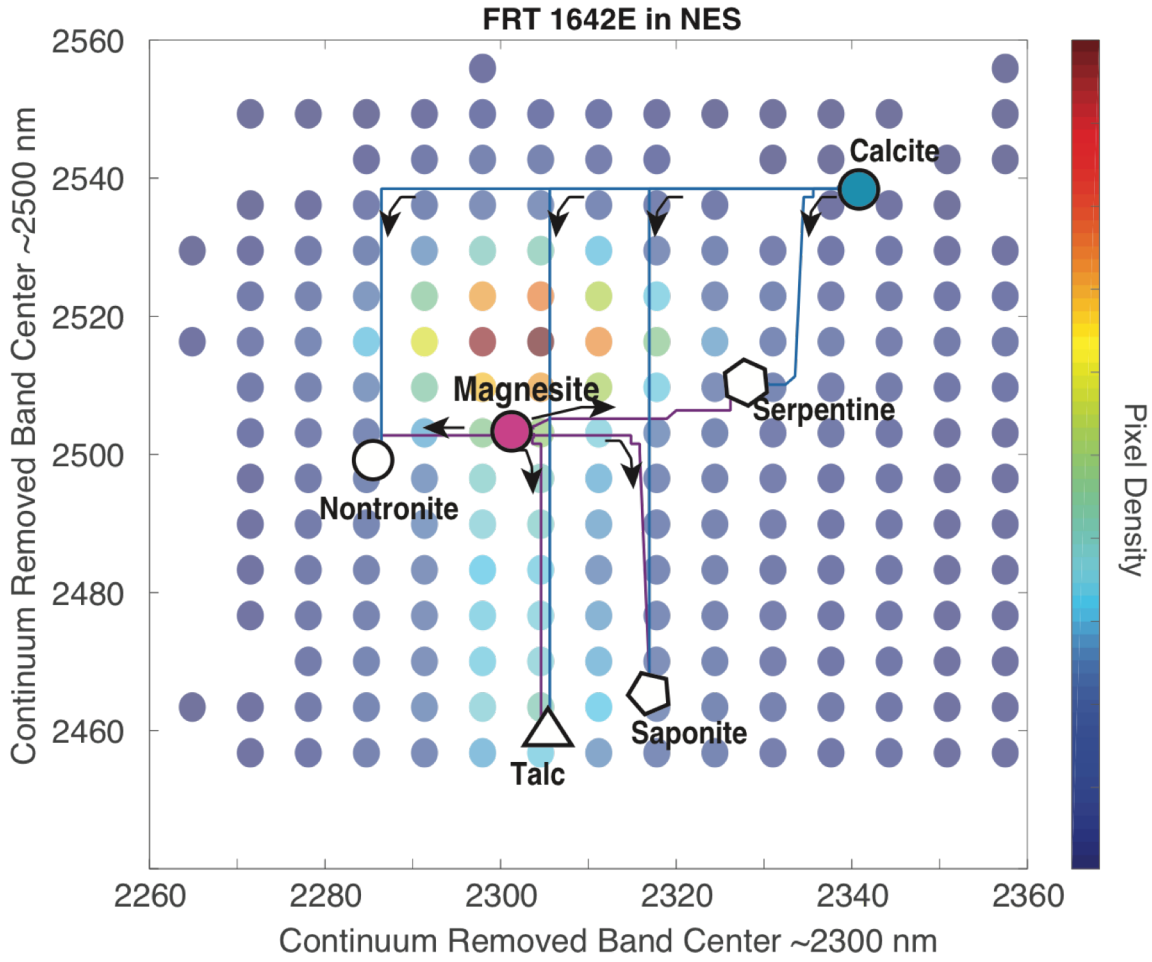
Analysis of MTRDR data

This diversity can be accessed by Mars2020 in ellipse

Laboratory synthetic mixtures to show changes in band centers with mixtures between carbonate + Fe/Mg-phyllosilicate phases



Relative 2.3/2.5 µm band centers for all carbonate-bearing pixels in image 1642E



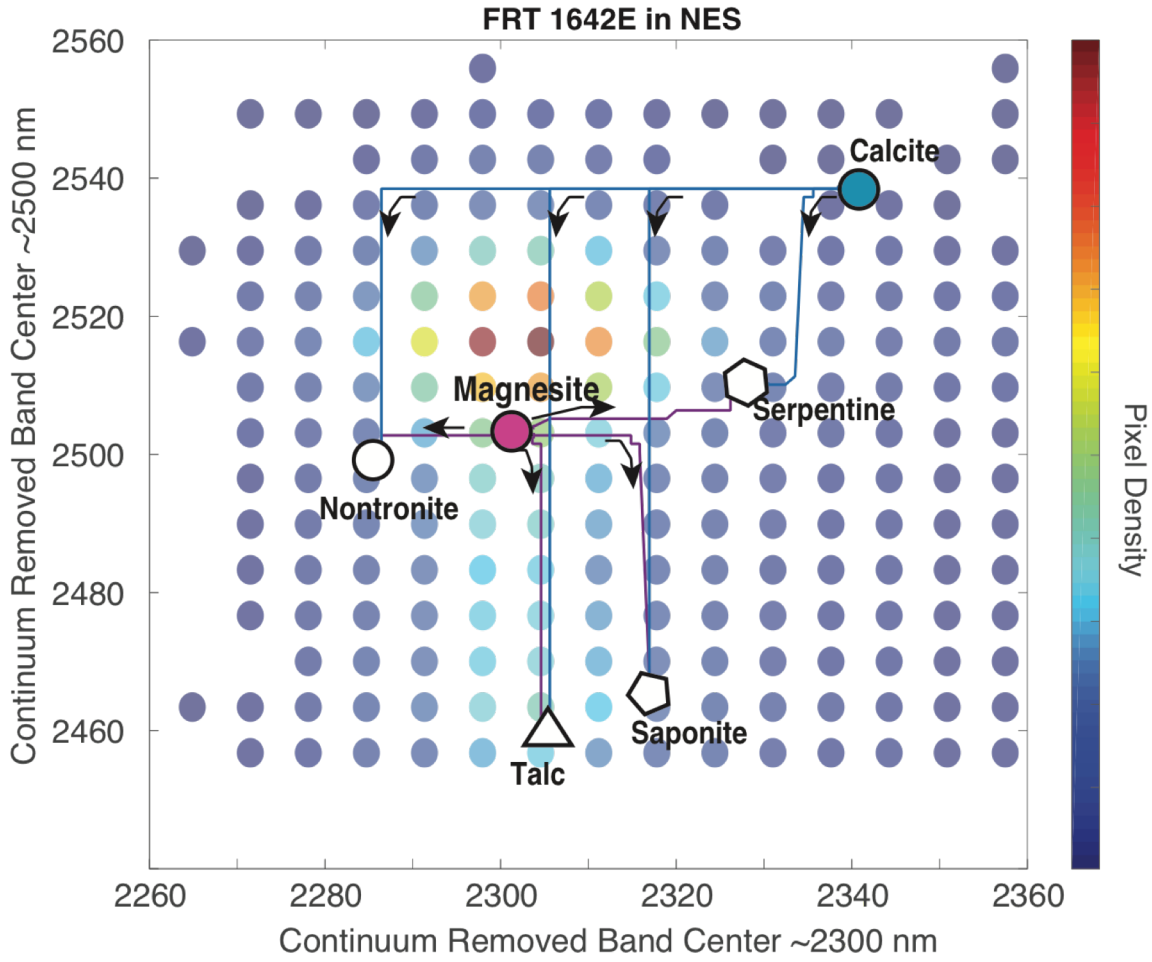
Analysis of MTRDR data

This diversity can be accessed by Mars2020 in ellipse

Pixels are dominated by a Mg-carbonate endmember, as previously recognized, but with subtle but correlated band center variations that likely imply spectral/compositional mixtures including **magnesite+serpentine** and **magnesite+talc/saponite**

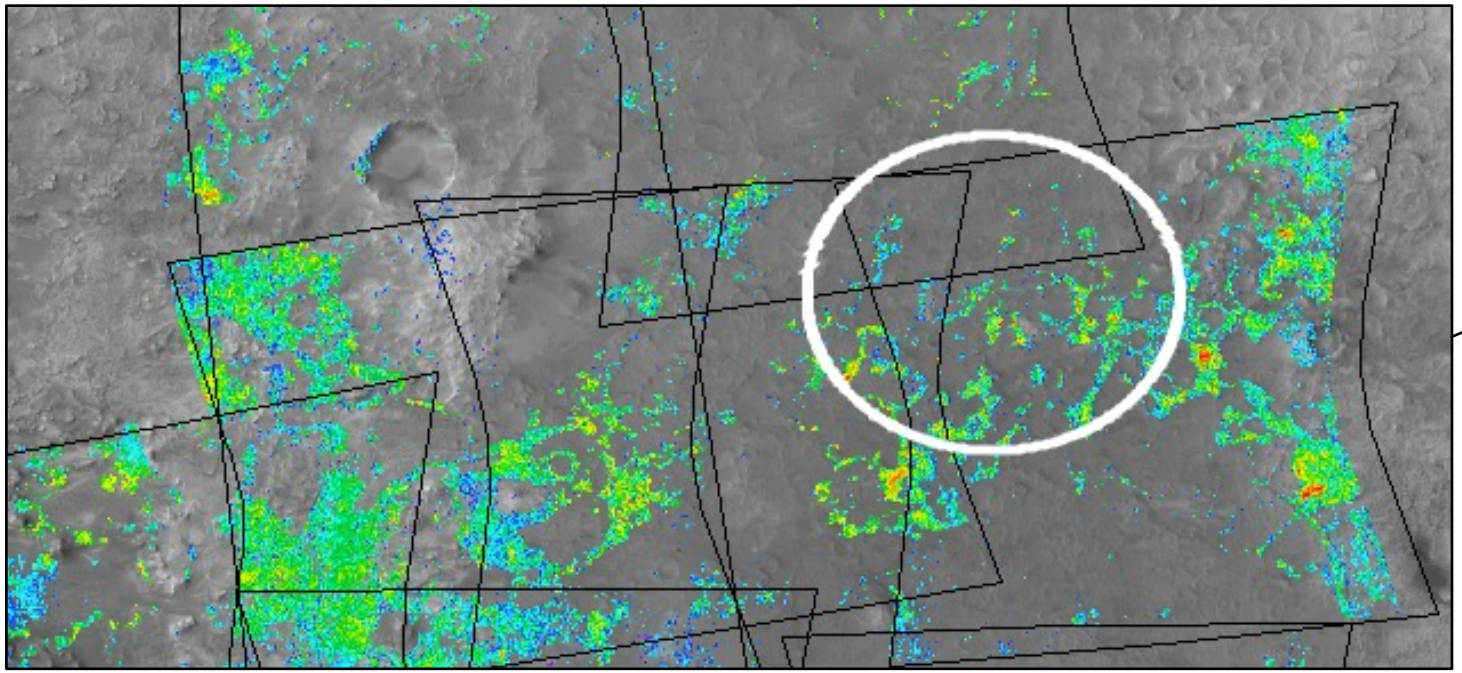
Consistent with factor analysis and target transformation results from Amador et al., 2018

Relative 2.3/2.5 µm band centers for all carbonate-bearing pixels in image 1642E

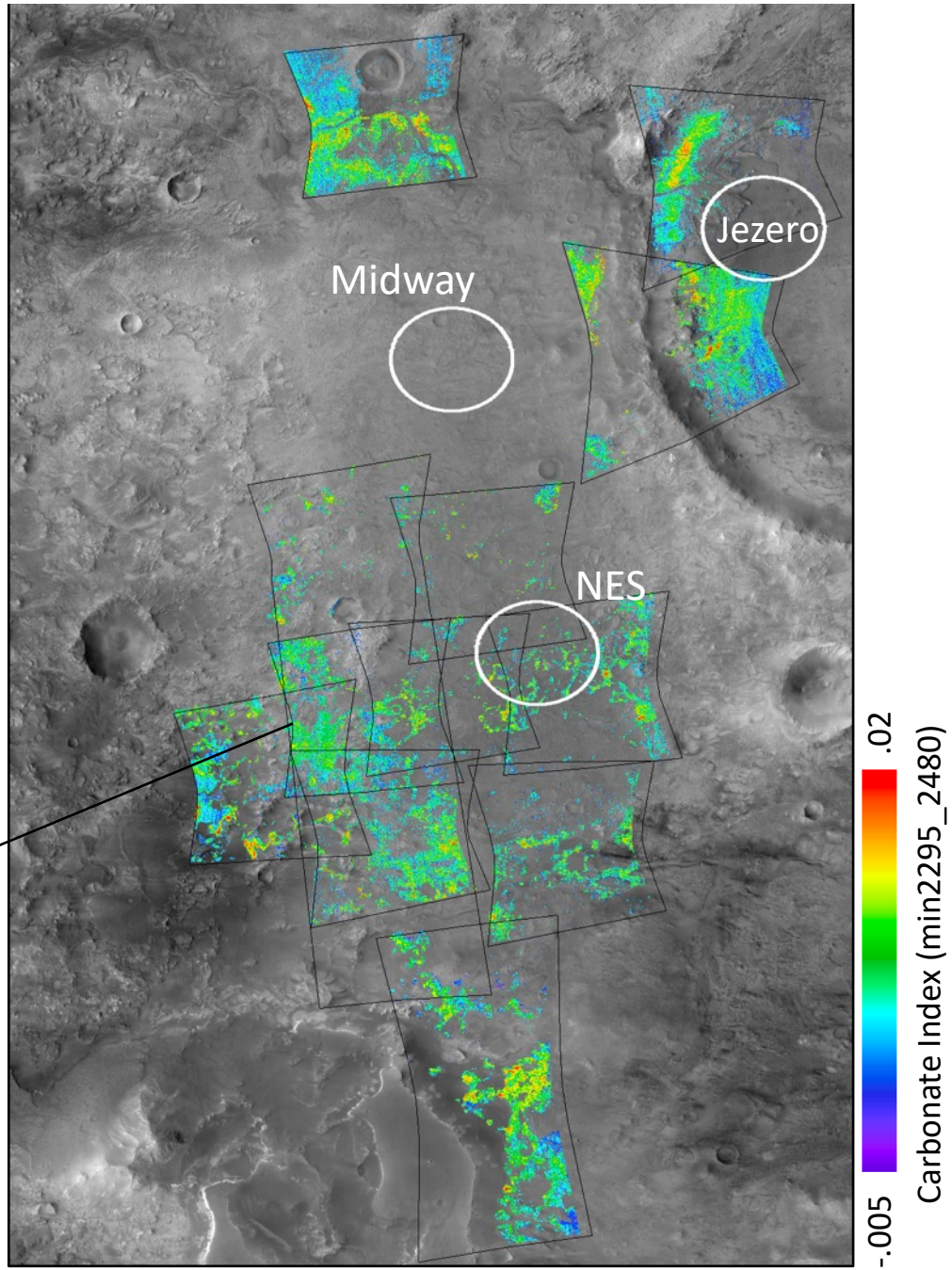


Analysis of MTRDR data

This compositional variability exists wherever we observe the olivine-carbonate unit.



Regional carbonate mapping from Full-resolution CRISM



Science value of assessing the circum-Isidis olivine/carbonate unit

1. **Circum-Isidis olivine/carbonate unit is globally significant.**
   - Most extensive and best exposures for many significant phases:
     High-Fo olivine; carbonate; serpentine

2. **Provides access to primary igneous compositions that have been variably altered in-place to produce habitable subsurface environments during the late-Noachian.**
   - Hydrous alteration of olivine-enriched unit including evidence for mod/low-temperature serpentinization; in ellipse access to a diverse set of compositions

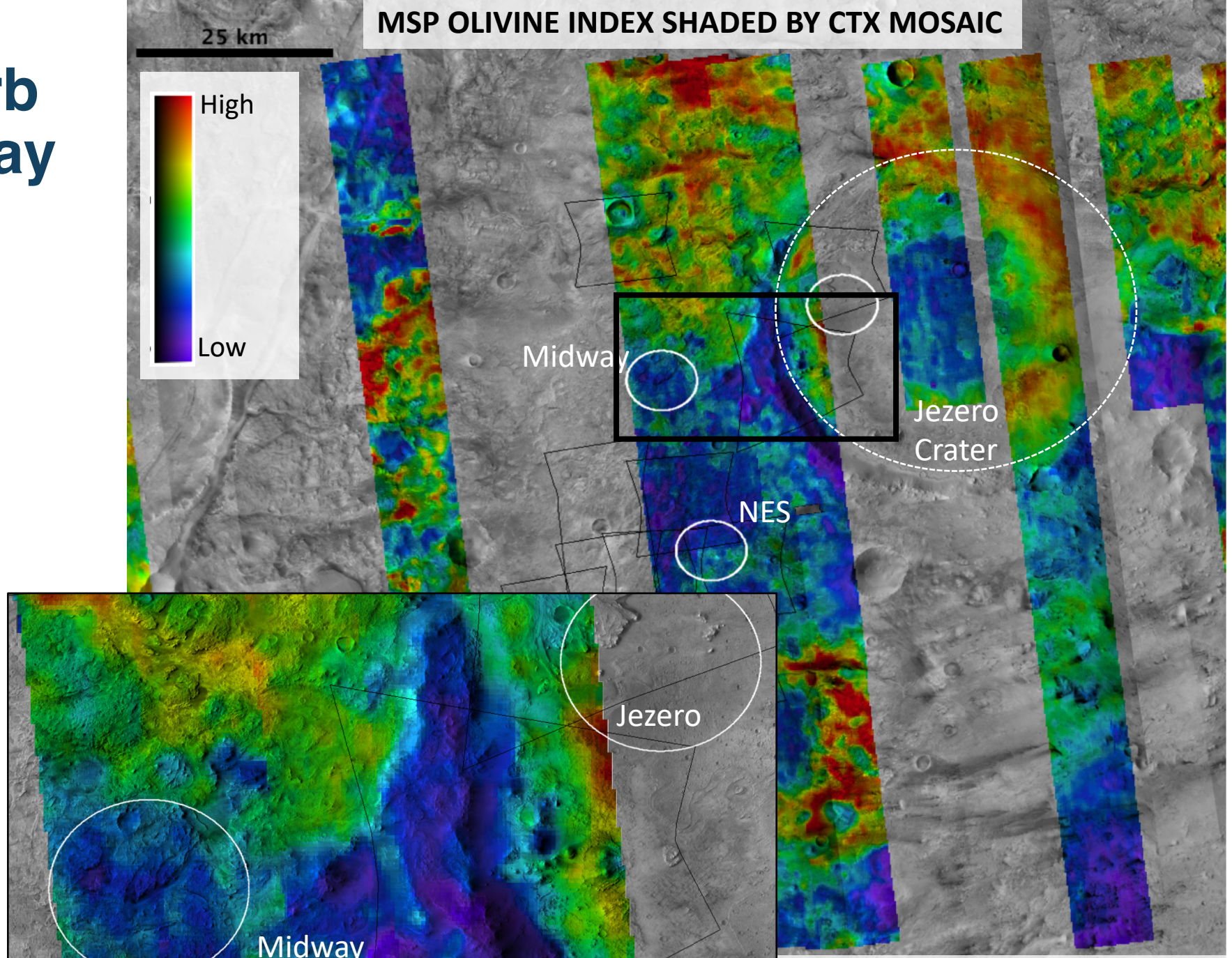
3. **Allows for the direct testing and resolution of proposed hypotheses with implications for our fundamental understanding planetary evolution.**
   - Crater chronology
   - Petrogenesis of circum-basin high-Fo olivine units
   - Early martian igneous processes
   - Fate and evolution of the martian atmosphere

EXTRAS

Access to olv.-carb unit around Midway

Mineralogical evidence

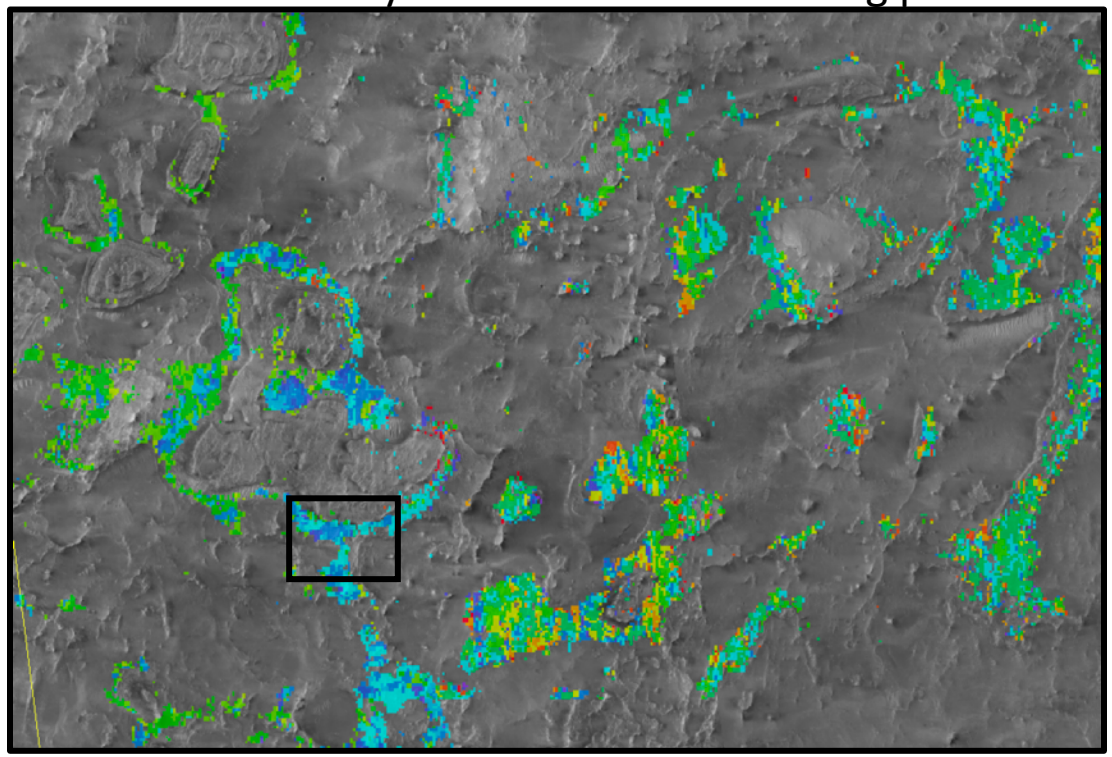
- CRISM multispectral mapping images show olivine in Midway region that would be accessible by rover and certainly on a traverse between Midway and Jezero



Images are individually stretched

This diversity can be accessed by Mars2020 in ellipse

FRT 17103 and FRT1642E 2300 nm band center
Masked to only show carbonate-bearing pixels



2.260 µm — 2.340 µm

Continuum removed band center ~2.3
(average in scene =2.306 µm)