Supporting Materials for **"Widespread clay–carbonate co-occurrence reveals advanced aqueous alteration on Mars"**

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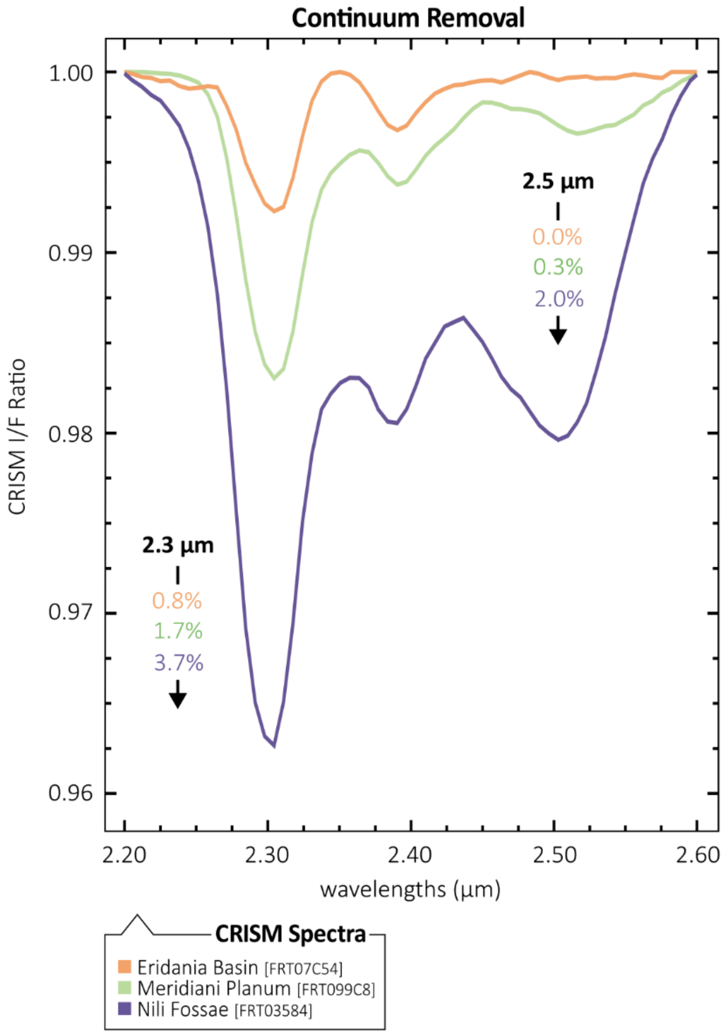
A. Continuum Removal & Band Depth Classification

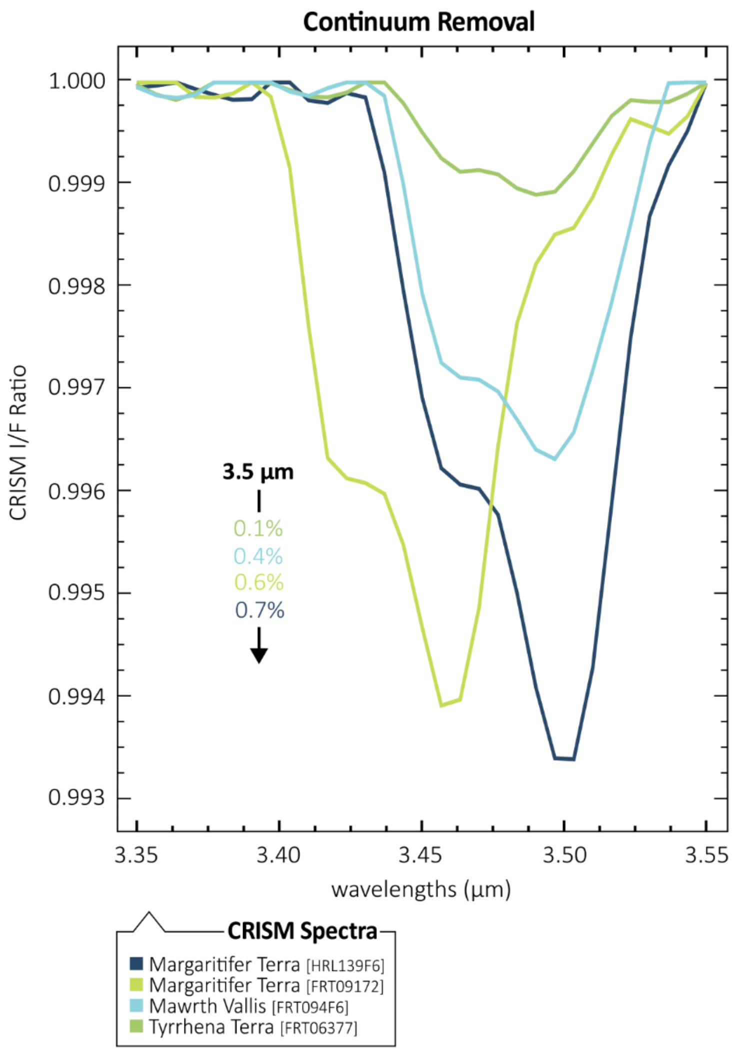
Figure S1.1 – Selected spectra of denoised CRISM reflectance after continuum removal over the 2.2 to 2.6 µm range, emphasizing the diagnostic absorptions at 2.3 and 2.4 µm typical of ferromagnesian clays, as well as the 2.5 µm feature possibly associated with carbonates. The 2.5 µm band exhibits variable intensities, enabling a straightforward classification according to band depth (BD25; **Table S1**): strong absorptions (BD25 > 2%) are observed in 13 cubes, intermediate values (1–2%) in 127 cubes, and low values (0.3–0.9%) in 278 cubes. Continuum-removal also allows accurate determination of band center (BC) positions. A comparable approach was employed by ref. (28) to characterize and compare an extensive suite of carbonate samples.

Figure S1.2 – Examples of denoised, continuum-removed CRISM reflectance spectra over the 3.35–3.55 µm range for clay-rich deposits, illustrating the possible absorption near 3.5 µm identified in 342 targeted cubes. In most instances, this feature remains weak, with band depths generally below 1% (BD35; **Table S1**). The band is tentatively identified in 103 cubes with very low values (0.1–0.2%), while it is clearly resolved in 239 cubes with intermediate values (0.3–1%) or higher values (above 1%).



Continuum Removal
CRISM I/F Ratio
1.00
0.99
0.98
0.97
0.96
2.20
2.30
2.40
2.50
2.60
wavelengths (µm)
2.5 µm
0.0%
0.3%
2.0%
2.3 µm
0.8%
1.7%
3.7%
CRISM Spectra
Eridania Basin [FRT07C54]
Meridiani Planum [FRT099C8]
Nili Fossae [FRT03584]

Figure S1.1



Continuum Removal
1.000
0.999
0.998
0.997
0.996
0.995
0.994
0.993
CRISM I/F Ratio
3.5 µm
0.1%
0.4%
0.6%
0.7%
3.35
3.40
3.45
3.50
3.55
wavelengths (µm)
CRISM Spectra
Margaritifer Terra [HRL139F6]
Margaritifer Terra [FRT09172]
Mawrth Vallis [FRT094F6]
Tyrrhena Terra [FRT06377]

Figure S1.2

B. Additional Spectral Indexes

We also computed additional spectral criteria to emphasize the carbonate-clay associations. In the following example figures, we present several CRISM indices commonly used to identify clays and carbonates.

Figure S2.1 – Maps of clay-carbonates outcrops derived from unprojected CRISM cubes acquired at three sites of interest: Lunae Planum (FRT1957D), McLaughlin crater (FRT0A5AA), and Nili Fossae (FRT186FA). (A) False-color (RGB) composites (R: 2.53 µm, G: 1.51 µm, B: 1.08 µm). (B) Maps of the reflectance drop near 2.3 µm ("*D2300*" index, shown in blue), frequently used to indicate ferromagnesian clays and, in some cases, carbonates (2,38). (C) Maps of the spectral slope between 1.1 and 1.8 µm ("*FeSlope*" index, purple), often referred to as ferrous slope due to contributions from ferrous (Fe^{2+}) -bearing phases such as olivine, carbonates, or even smectites. (D) Maps of the spectral slope from 2.1 to 2.5 µm ("*HdSlope*" index, green), commonly induced by hydrated minerals including smectites, sulfates, chlorites, and carbonates. (E) Maps of the "*BD3900*" index (yellow), revealing a convex spectral feature centered near 3.6–3.7 µm together with a reflectance drop near 3.9 µm (3,23,25). Both the "*D2300*" and "*BD3900*" index maps suggest a spatial correlation between clay-related absorptions (combined bands near 1.4, 1.9, 2.3, and 2.4 µm) and the carbonate-related features (absorption at 2.5 µm and broad bulge-like feature near 3.6–3.7 µm induced by paired absorptions around 3.4–3.5 µm and 3.9 µm).

Figure S2.2 – Scatterplots comparing the "*D2300*" and "*BD3900*" parameters for the three cubes. They indicate a strong correspondence between clay-related and carbonate-related spectral features in specific areas (ROIs).

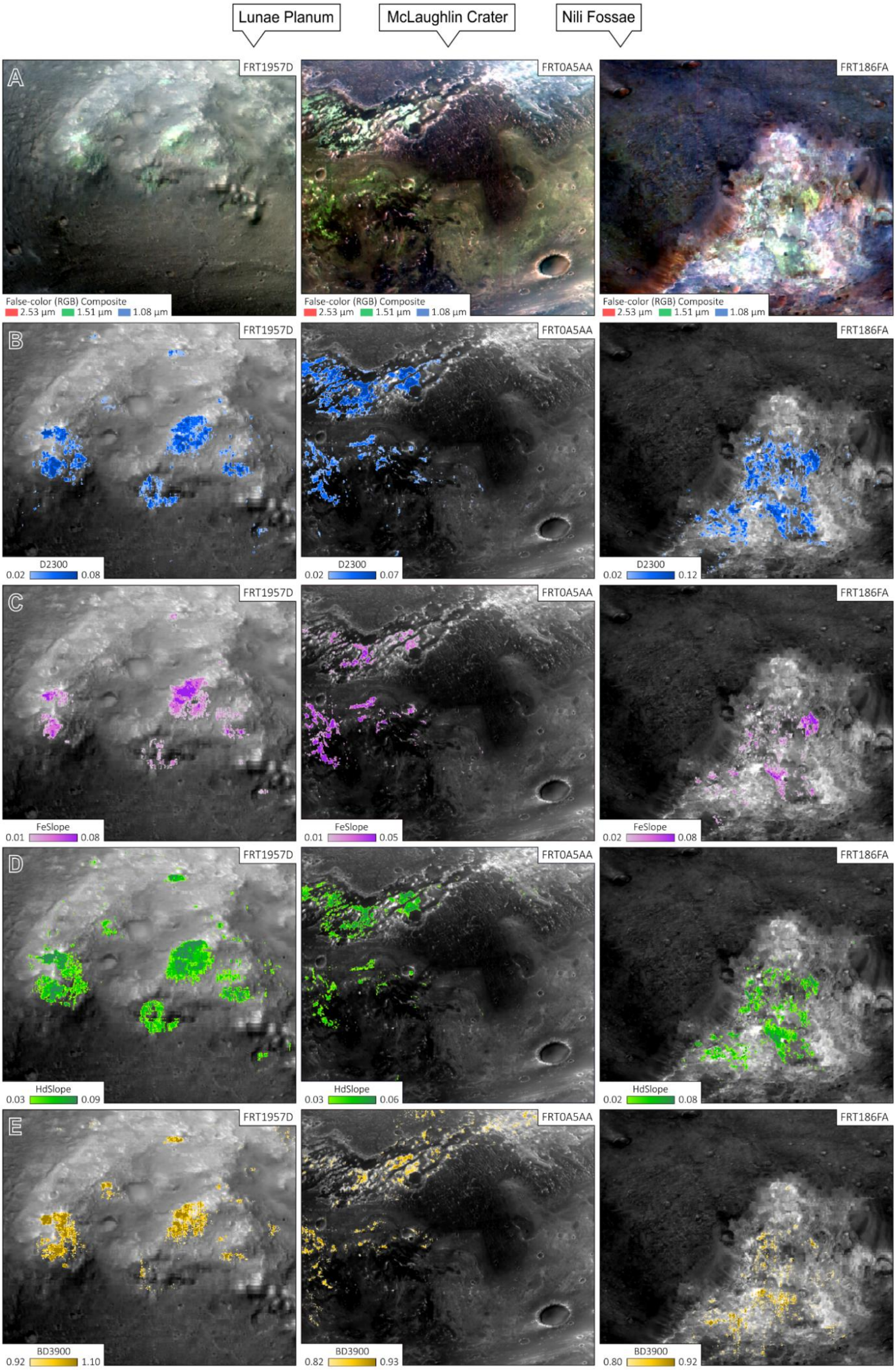
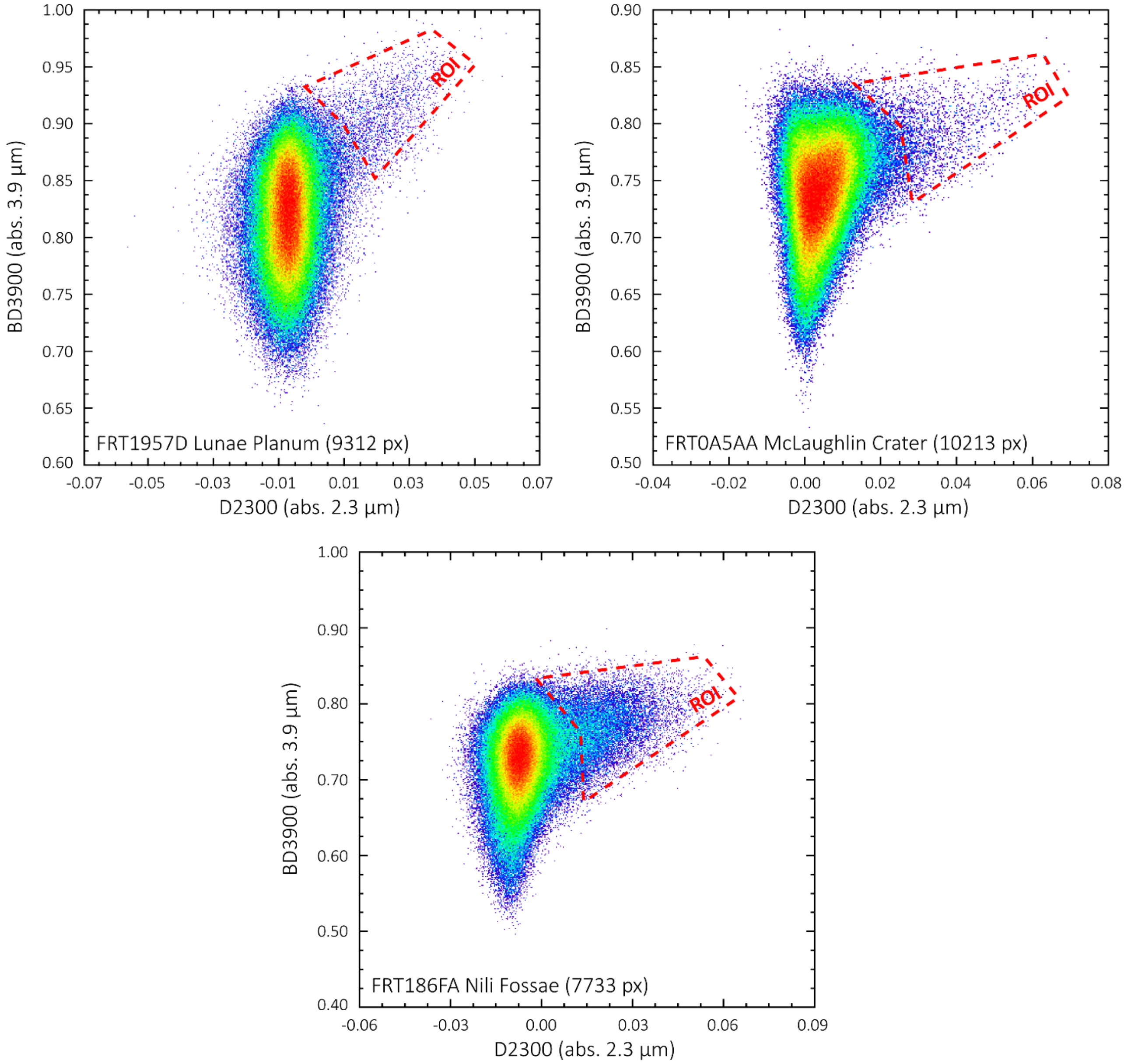

Lunae Planum
McLaughlin Crater
Nili Fossae
A
B
C
D
E
FRT1957D
FRT0A5AA
FRT186FA
False-color (RGB) Composite
2.53 μm 1.51 μm 1.08 μm
D2300
0.02 0.08
0.02 0.07
0.02 0.12
FeSlope
0.01 0.08
0.01 0.05
0.02 0.08
HdSlope
0.03 0.09
0.03 0.06
0.02 0.08
BD3900
0.92 1.10
0.82 0.93
0.80 0.92

Figure S2.1



BD3900 (abs. 3.9 µm)
D2300 (abs. 2.3 µm)
ROI
FRT1957D Lunae Planum (9312 px)
FRT0A5AA McLaughlin Crater (10213 px)
FRT186FA Nili Fossae (7733 px)

Figure S2.2

C. Uneven Distribution of CRISM data

Some regions, notably Mawrth Vallis, Nili Fossae and Meridiani Planum, were heavily observed during the nominal phase of the Mars Reconnaissance Orbiter mission (43). Consequently, these areas contain a disproportionately large number of targeted observations acquired by the CRISM instrument. In our dataset, Mawrth Vallis, Nili Fossae, and Meridiani Planum account for 71, 106, and 47 cubes, respectively, together representing roughly 40% of all analyzed cubes in this survey. Given this uneven spatial distribution of CRISM cubes Mars, we evaluated whether such sampling bias could influence the global interpretation of the results. To do so, we produced additional histograms and pie charts excluding these heavily sampled regions for the 2.3, 2.5, and 3.5 µm absorption bands. The results indicate that the relative proportions of these bands and their precise positions remain largely unchanged.

Figure S3.1 – (A,B) Band centers for the 2.3 and 2.5 µm absorptions were determined after continuum removal to enhance band contrast and improve readability. Values are subdivided according to the intensity of the 2.5 µm band observed in this survey, expressed as band depth values (BD25; **Table S1**): none (below 0.3%), weak (0.3-0.9%), moderate (1-2%), and strong (above 2%). In the 2.3 µm window, band centers range from 2.29 to 2.32 µm, whereas in the 2.5 µm window they span 2.50 to 2.54 µm. The mean values are 2.304 ± 0.007 µm and 2.516 ± 0.009 µm, respectively. (C) Pie chart showing the relative frequencies of clays and possible carbonates identified in this study, excluding oversampled regions (i.e., Mawrth Vallis, Nili Fossae, and Meridiani Planum). Paired absorptions at 2.3 and 2.5 µm are clearly detected in 215 cubes. Numbers labeled in each segment indicate the corresponding detection counts.

Figure S3.2 – (A) Band centers for the 3.5 µm absorption were determined, where present, after continuum removal to enhance band contrast and improve readability. Values are subdivided according to the intensity of the 3.5 µm band, expressed as band depth values (BD35; **Table S1**): tentative detection (0.1–0.2%), weak (0.3–1%), and strong (above 1%). In this window, values range from 3.44 to 3.50 µm, with a mean value of 3.480 ± 0.020 µm. (B) Pie chart illustrating the relative frequencies of absorptions identified in this study, excluding heavily sampled regions. All three bands (2.3, 2.5, and 3.5 µm) are collectively detected in 177 cubes.

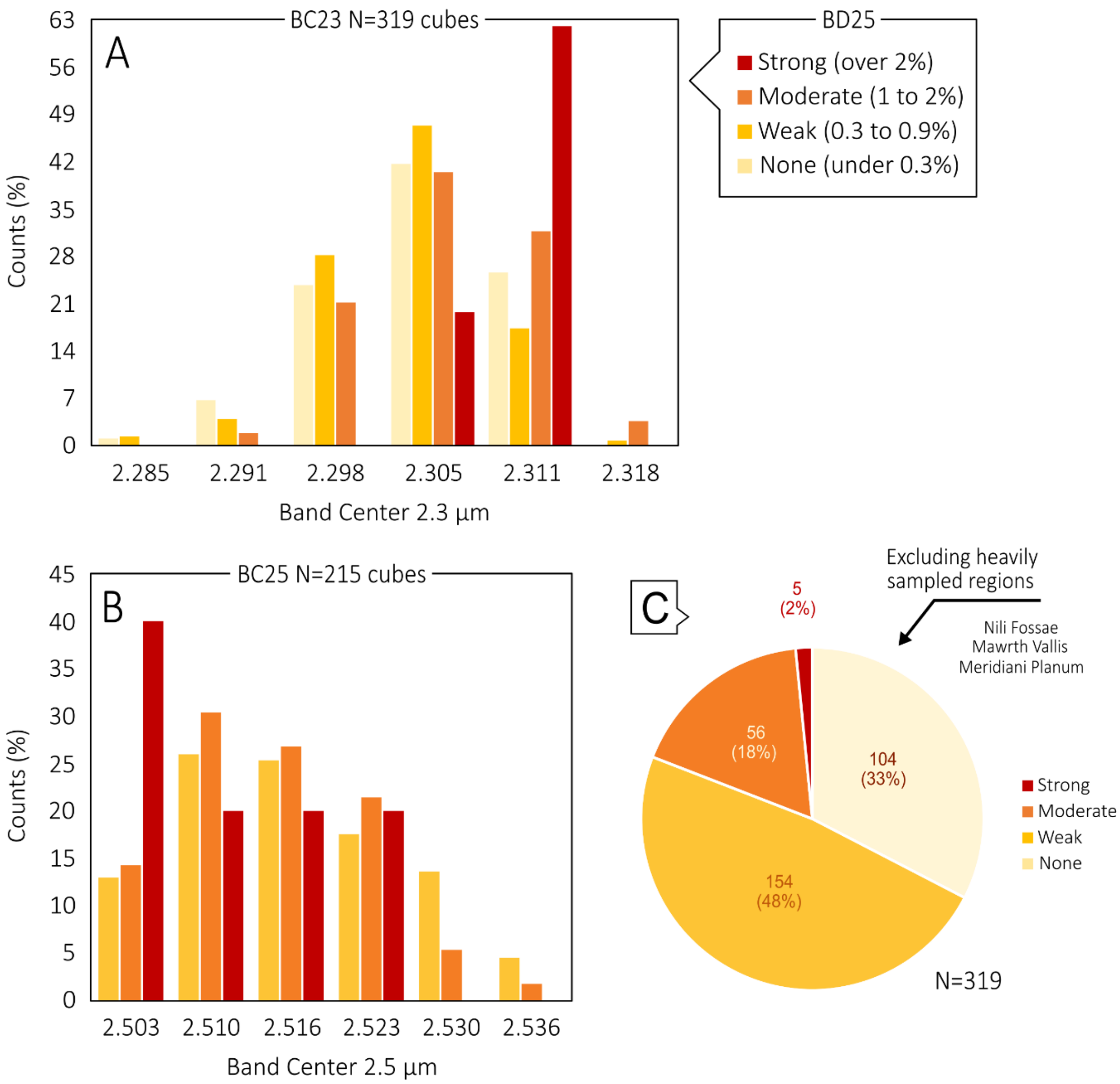

BC23 N=319 cubes
A
Counts (%)
63
56
49
42
35
28
21
14
7
0
2.285
2.291
2.298
2.305
2.311
2.318
Band Center 2.3 µm
BD25
Strong (over 2%)
Moderate (1 to 2%)
Weak (0.3 to 0.9%)
None (under 0.3%)
BC25 N=215 cubes
B
Counts (%)
45
40
35
30
25
20
15
10
5
0
2.503
2.510
2.516
2.523
2.530
2.536
Band Center 2.5 µm
C
Excluding heavily sampled regions
Nili Fossae
Mawrth Vallis
Meridiani Planum
5 (2%)
56 (18%)
104 (33%)
154 (48%)
Strong
Moderate
Weak
None
N=319

Figure S3.1

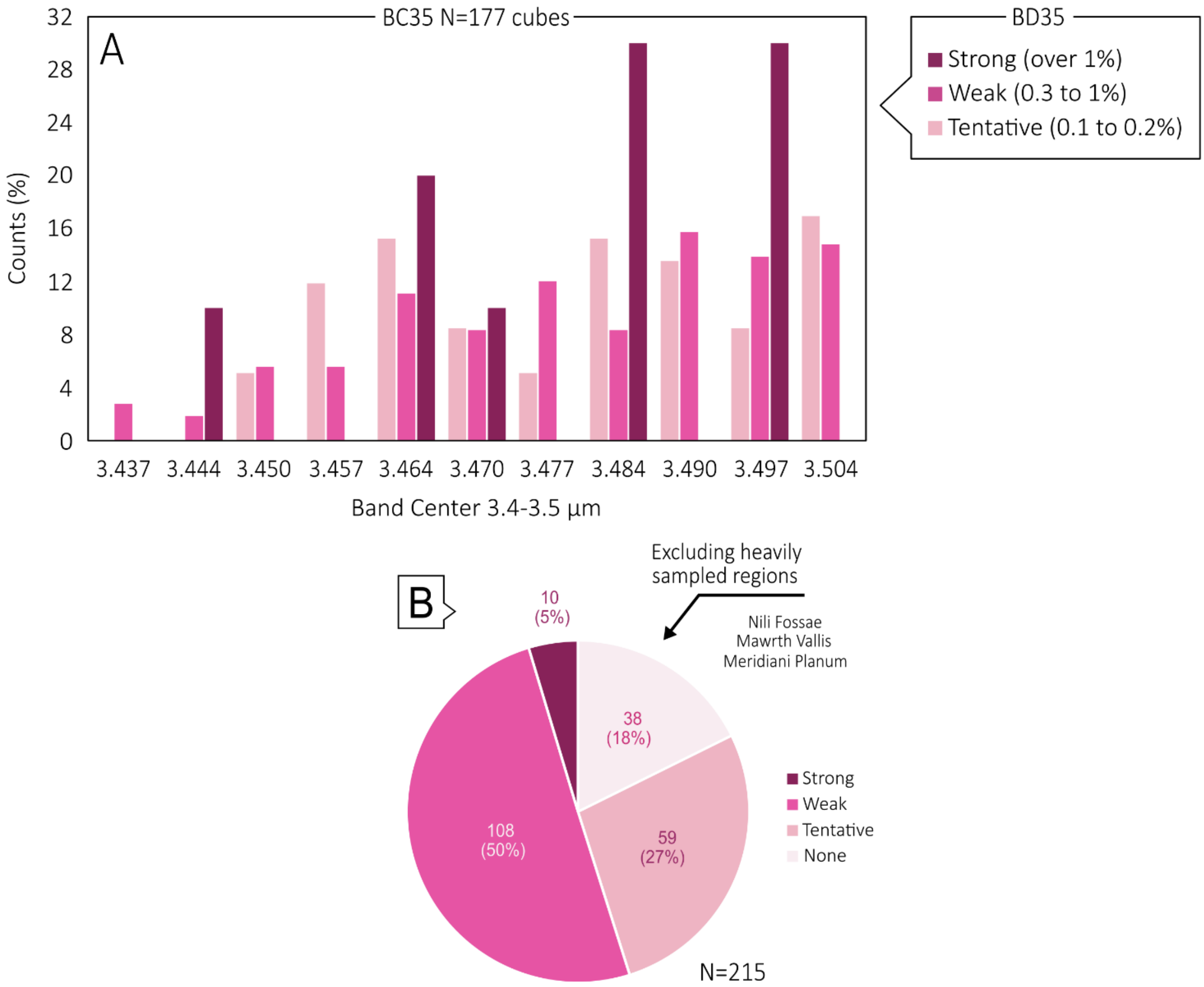


Figure S3.2

References:

See numbered references in main text.