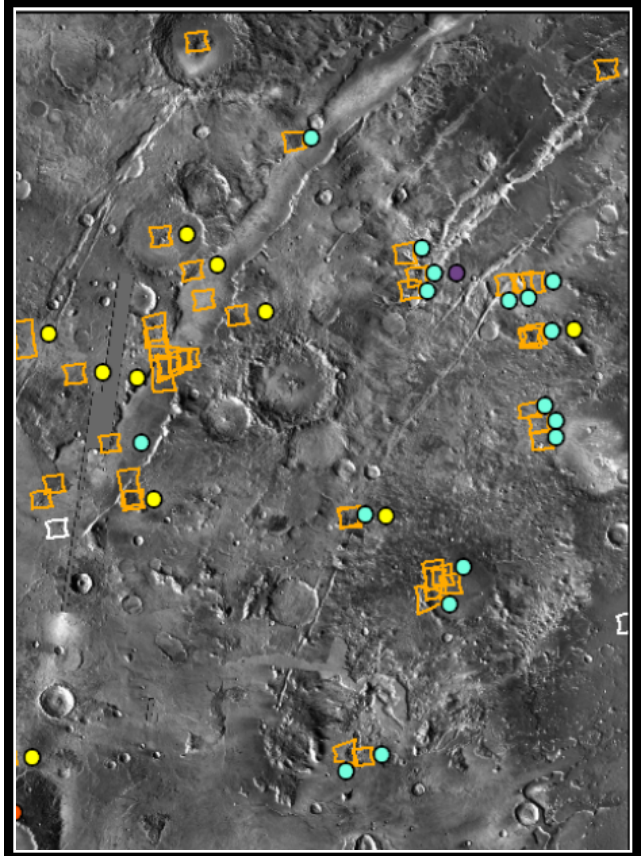
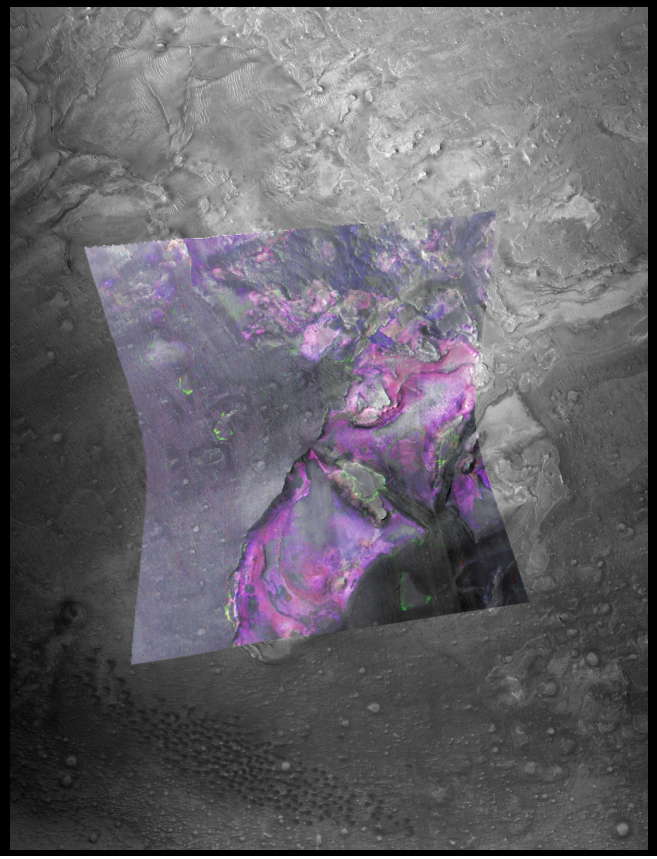
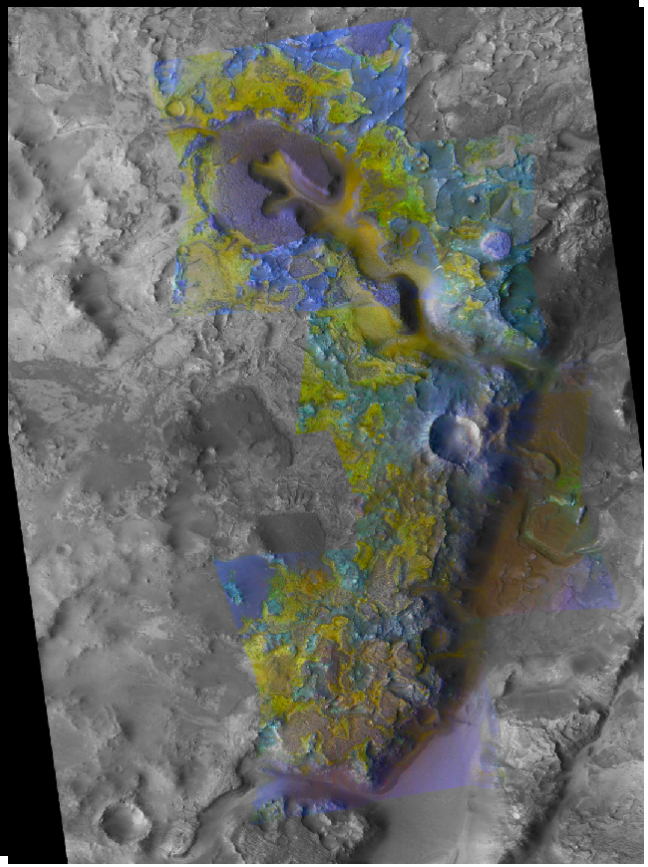
Mineralogy of the Nili Fossae Region

Evidence for sustained water-rock interaction in multiple potentially habitable environments

B.L. Ehlmann, J.F. Mustard
with many collaborators on the CRISM, HiRISE, and OMEGA teams

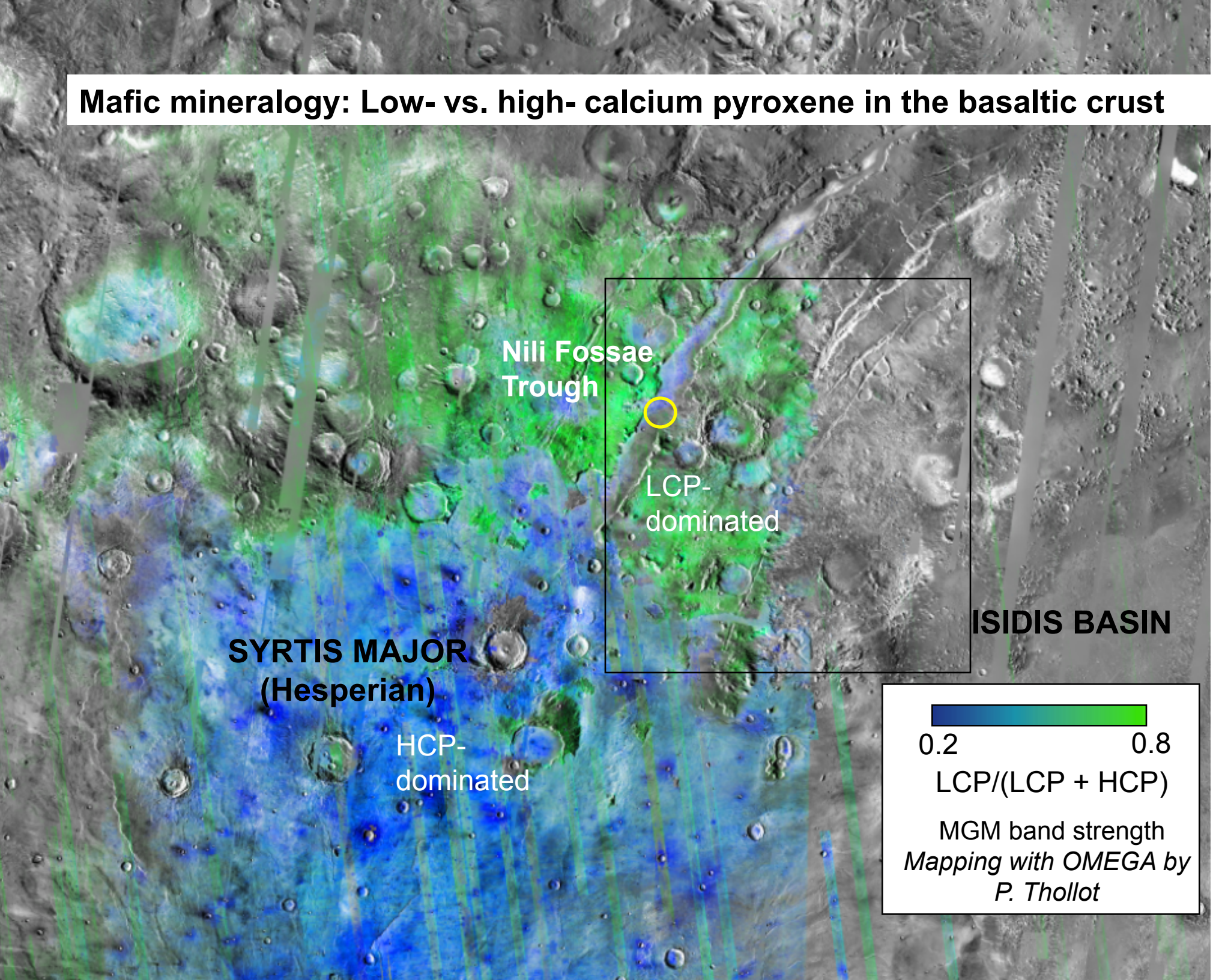






Outline

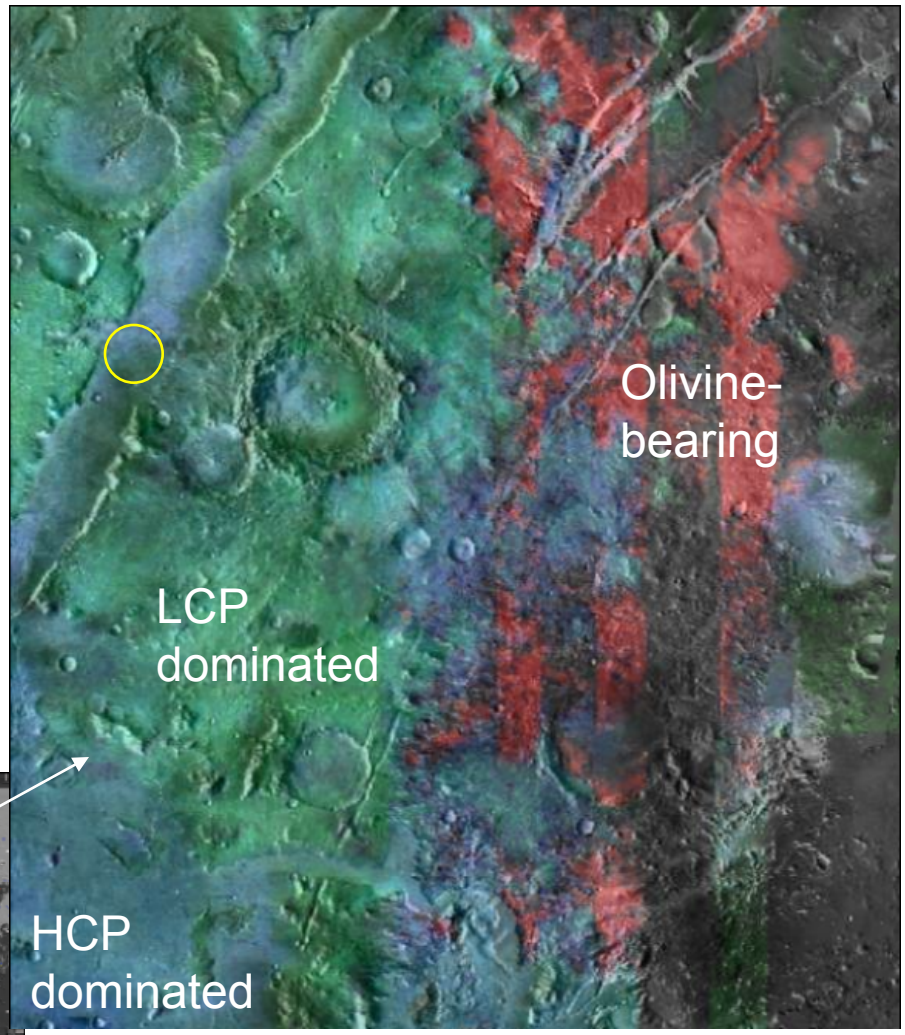
- Mafic mineral variation
- Diverse secondary minerals formed by aqueous processes
  - Fe/Mg smectite – in-situ, basement
  - Fe/Mg smectite – transported, fluvially
  - Carbonate – alteration product assoc. with olivine
  - Kaolinite – on top of smectites
- Regional mineralogic-geomorphic stratigraphic section
  - →Multiple episodes indicate long-term action of liquid water in both alteration and transport
  - → Recording neutral to high pH aqueous conditions

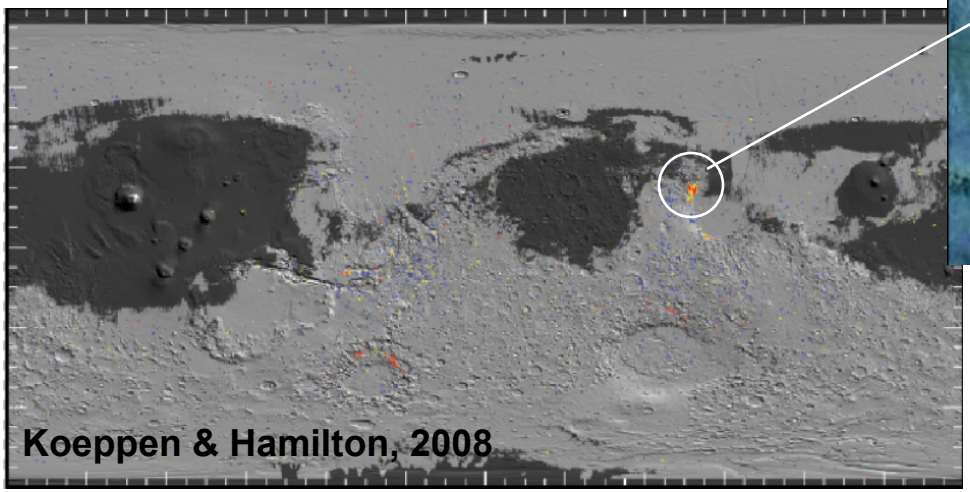

Mafic mineralogy: Low- vs. high- calcium pyroxene in the basaltic crust
Nili Fossae Trough
LCP-dominated
ISIDIS BASIN
SYRTIS MAJOR (Hesperian)
HCP-dominated
0.2
0.8
LCP/(LCP + HCP)
MGM band strength
Mapping with OMEGA by P. Thollot

Mafic mineralogy Olivine

- Largest exposure of olivine on the planet
- Fo_{68-75}, with some variation (Hoefen et al., 2003; Hamilton & Christensen, 2005)
- Pre-date the fossae
- Opportunity to test hypotheses for origin:
  - Impact melt (Mustard et al., 2007)
  - Extrusive lavas (Hamilton & Christensen, 2005)

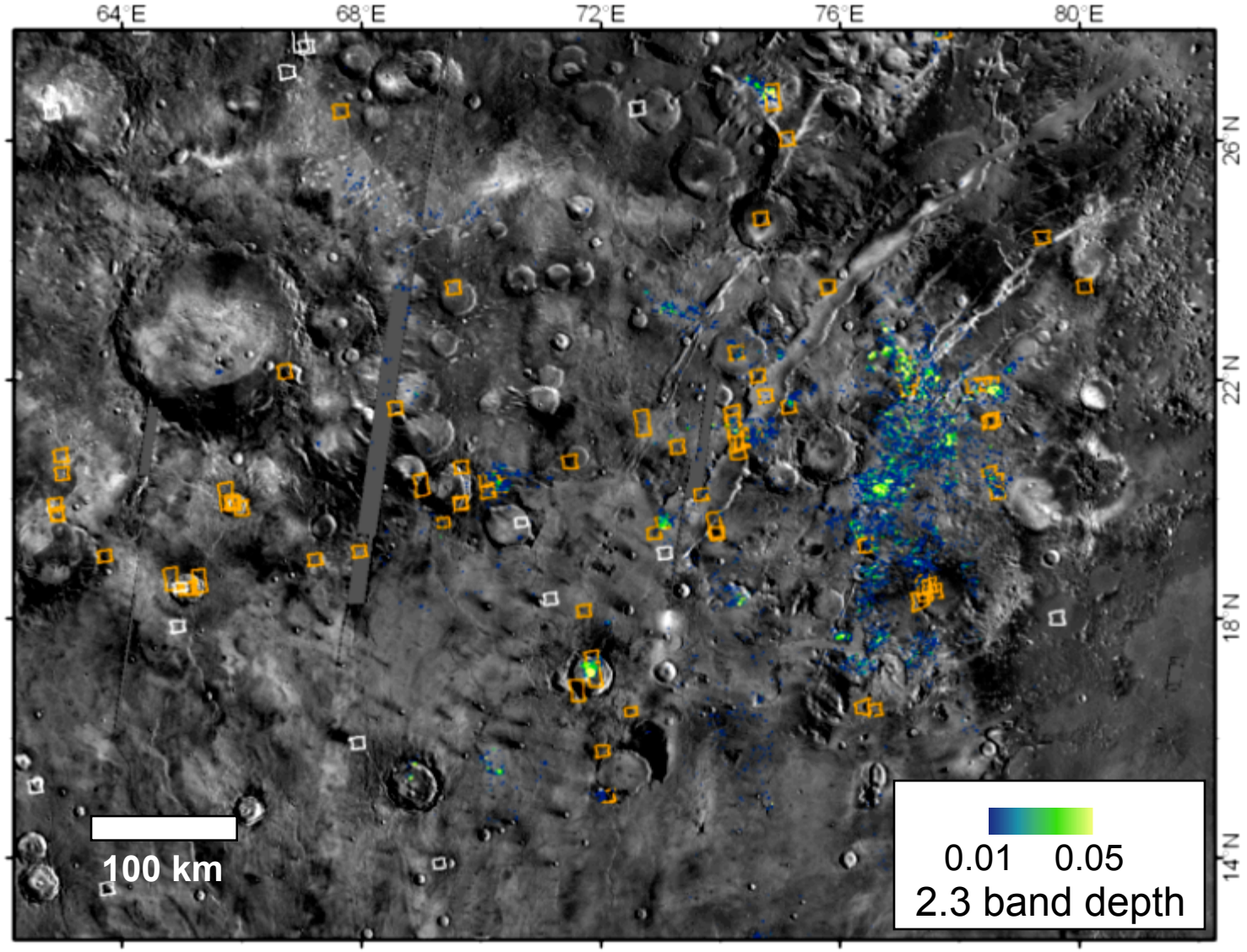
OMEGA parameter map



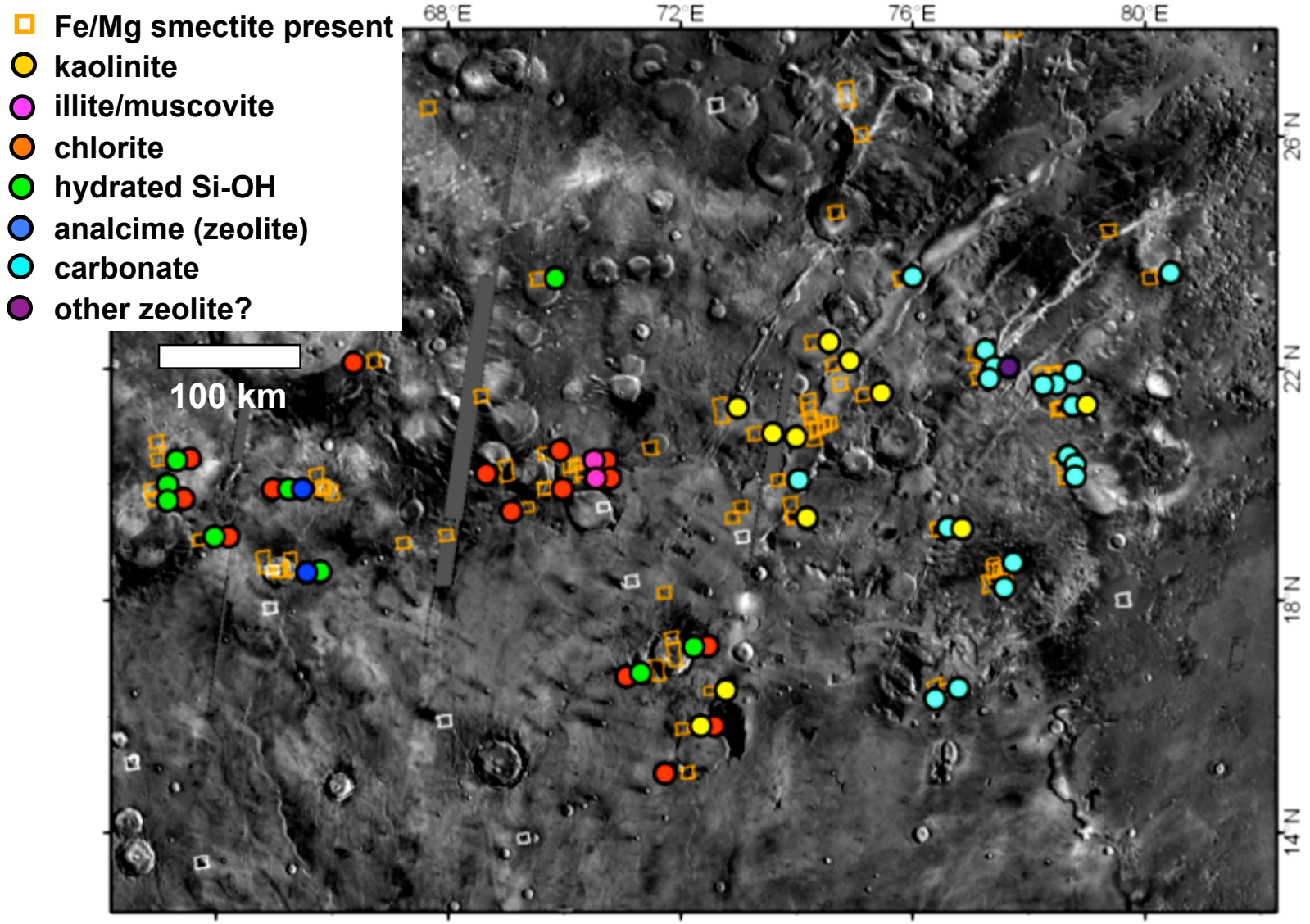


Secondary mineralogy: Fe/Mg phyllosilicates (OMEGA, 300m/pixel)

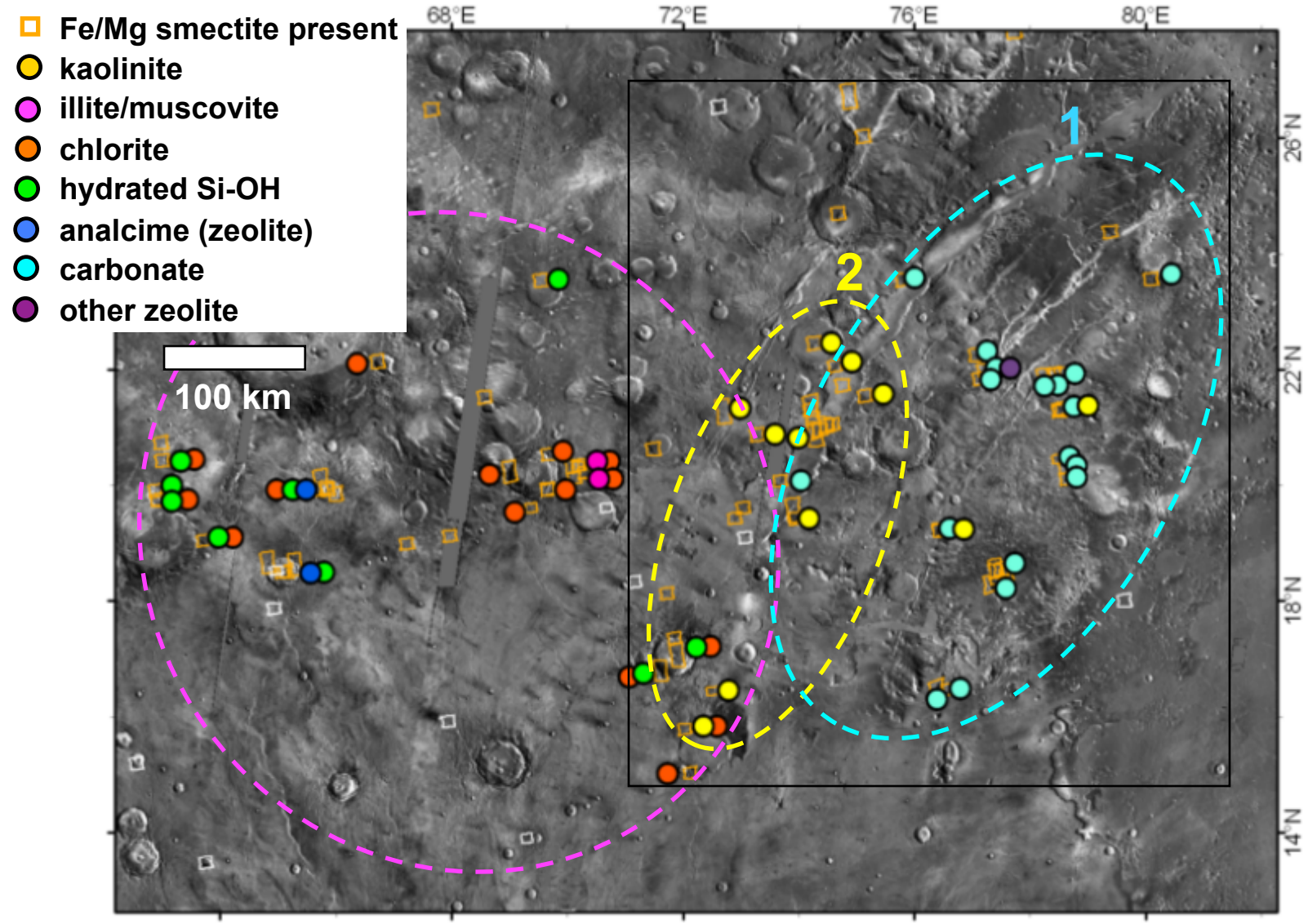
w/ CRISM targeted observations with Fe/Mg smectites (orange if present)



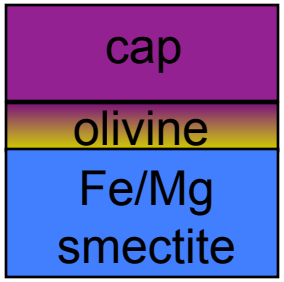
Secondary mineralogy: CRISM targeted observations (18m/pixel)



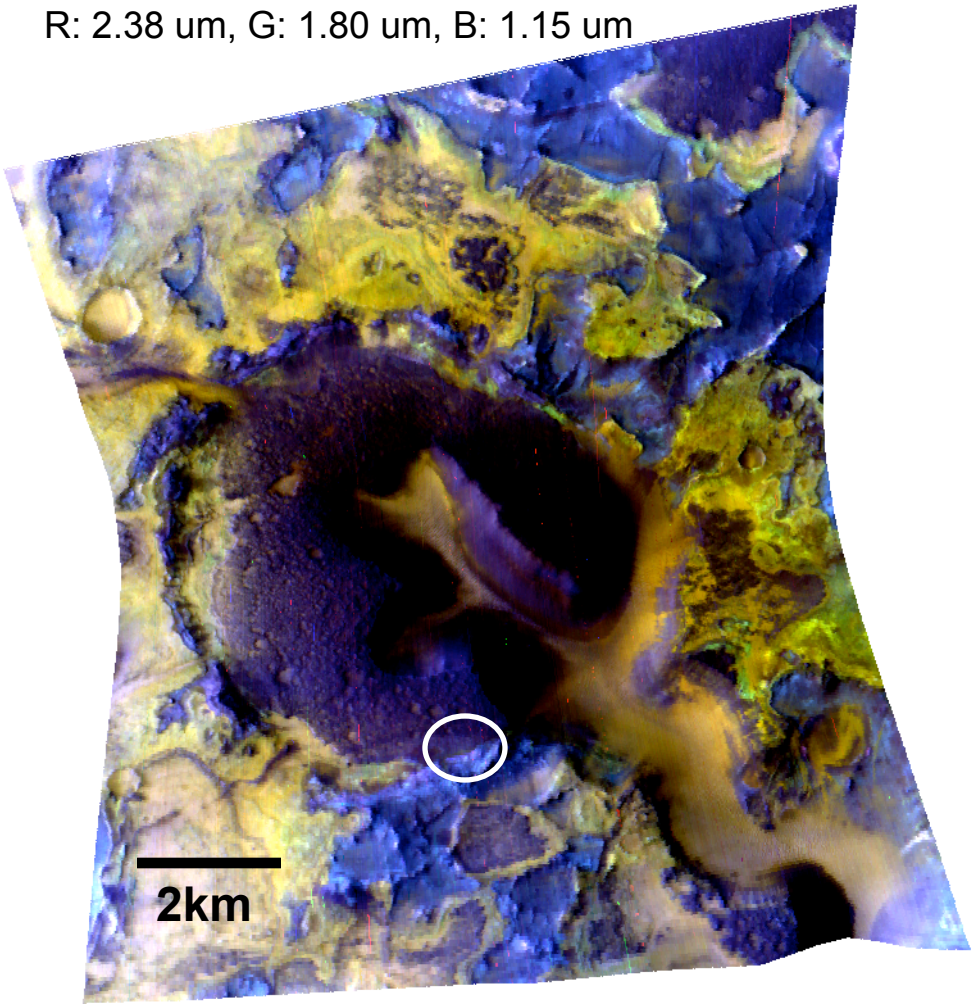
Secondary mineralogy: Fe/Mg phyllosilicates, OMEGA D2300(300 m/pixel) w/ CRISM targeted observations with Fe/Mg smectites (orange if present)

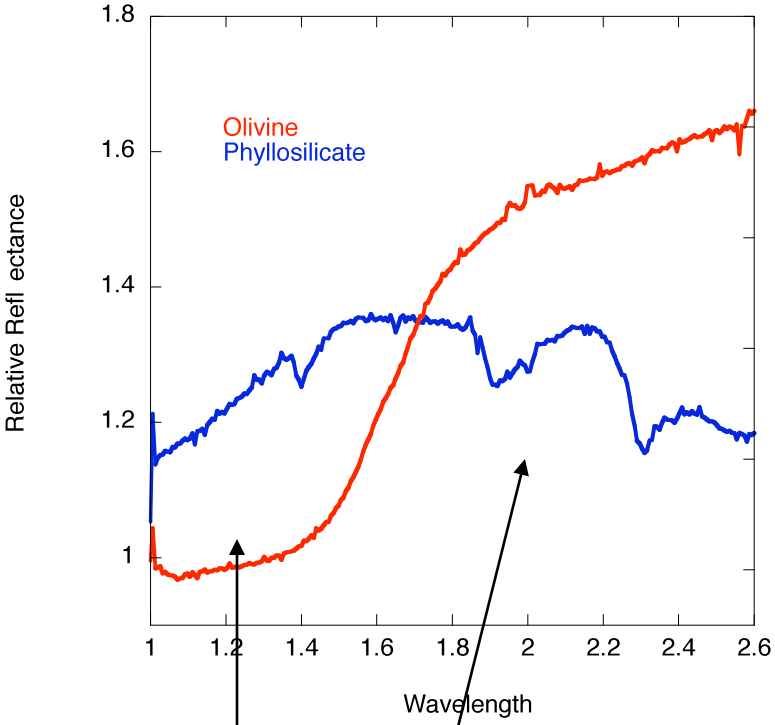


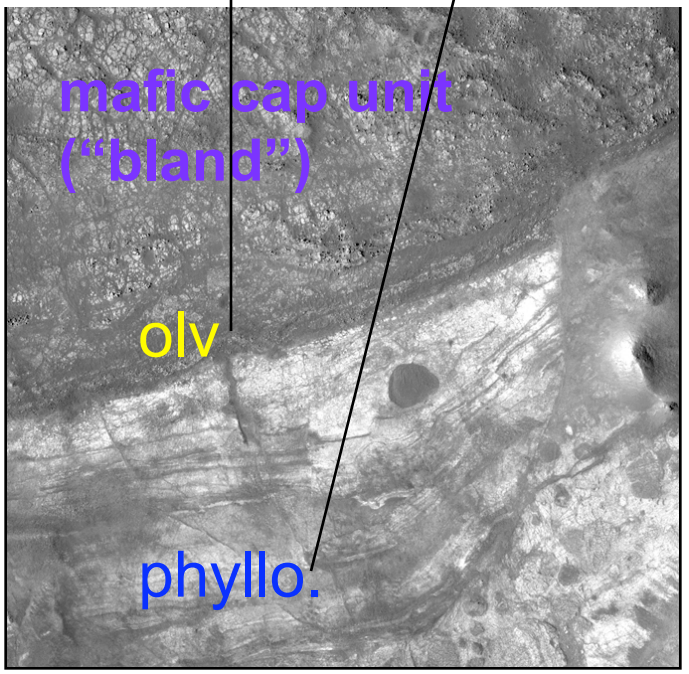
Fe/Mg smectite-olivine stratigraphy



FRT00003E12
R: 2.38 um, G: 1.80 um, B: 1.15 um

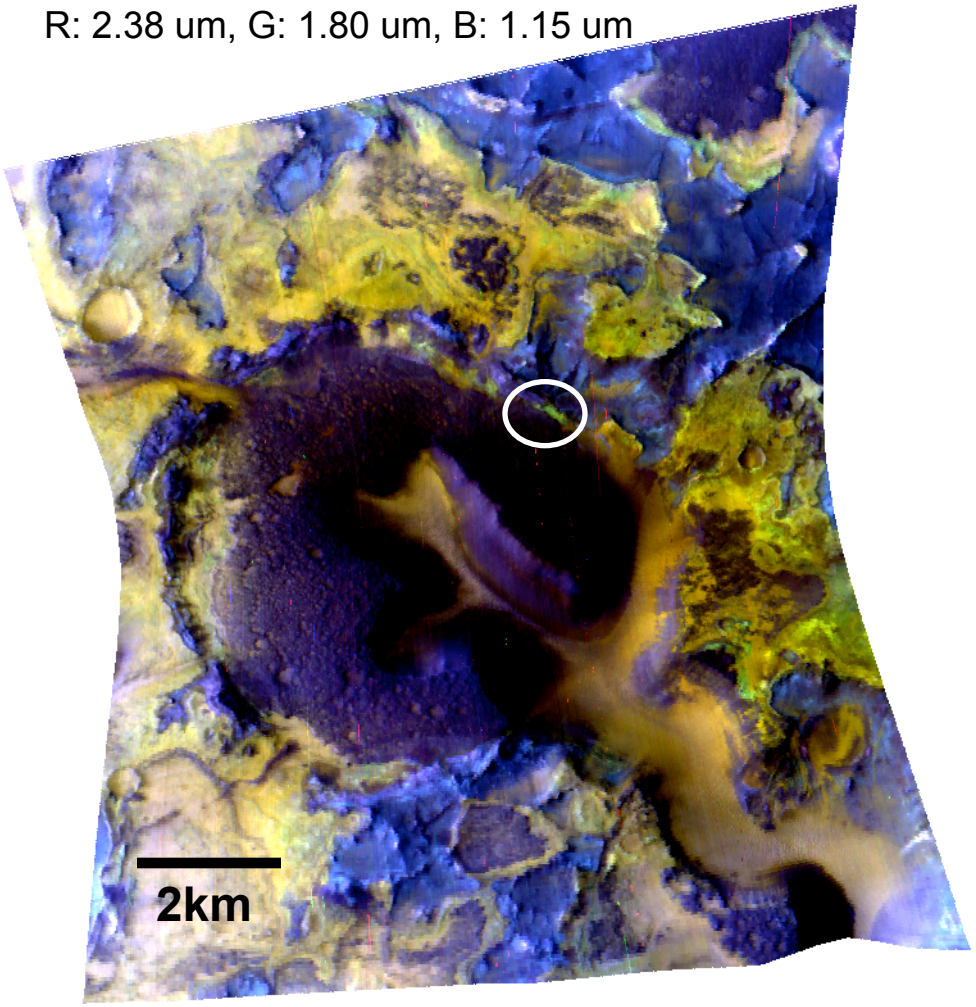


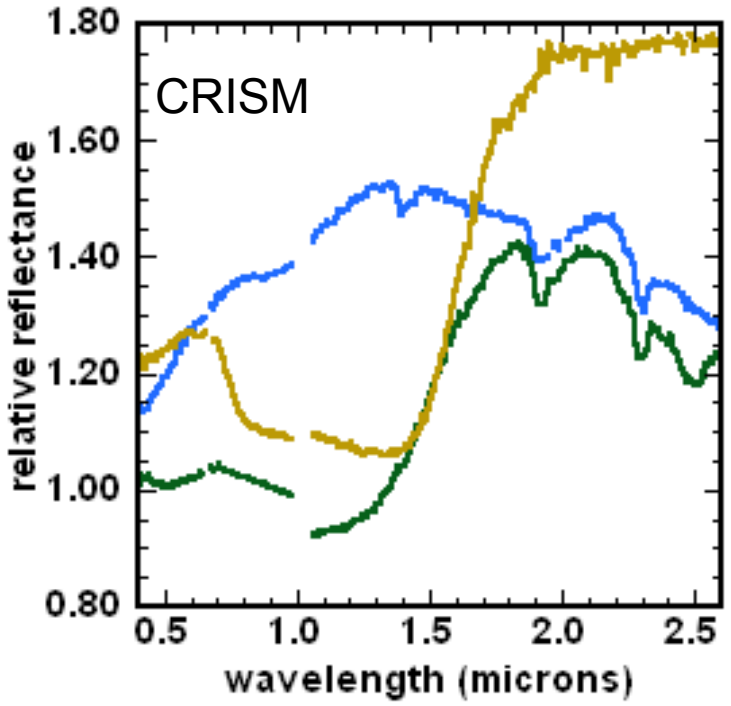




Carbonate-Fe/Mg smectite-olivine stratigraphy

FRT00003E12
R: 2.38 um, G: 1.80 um, B: 1.15 um

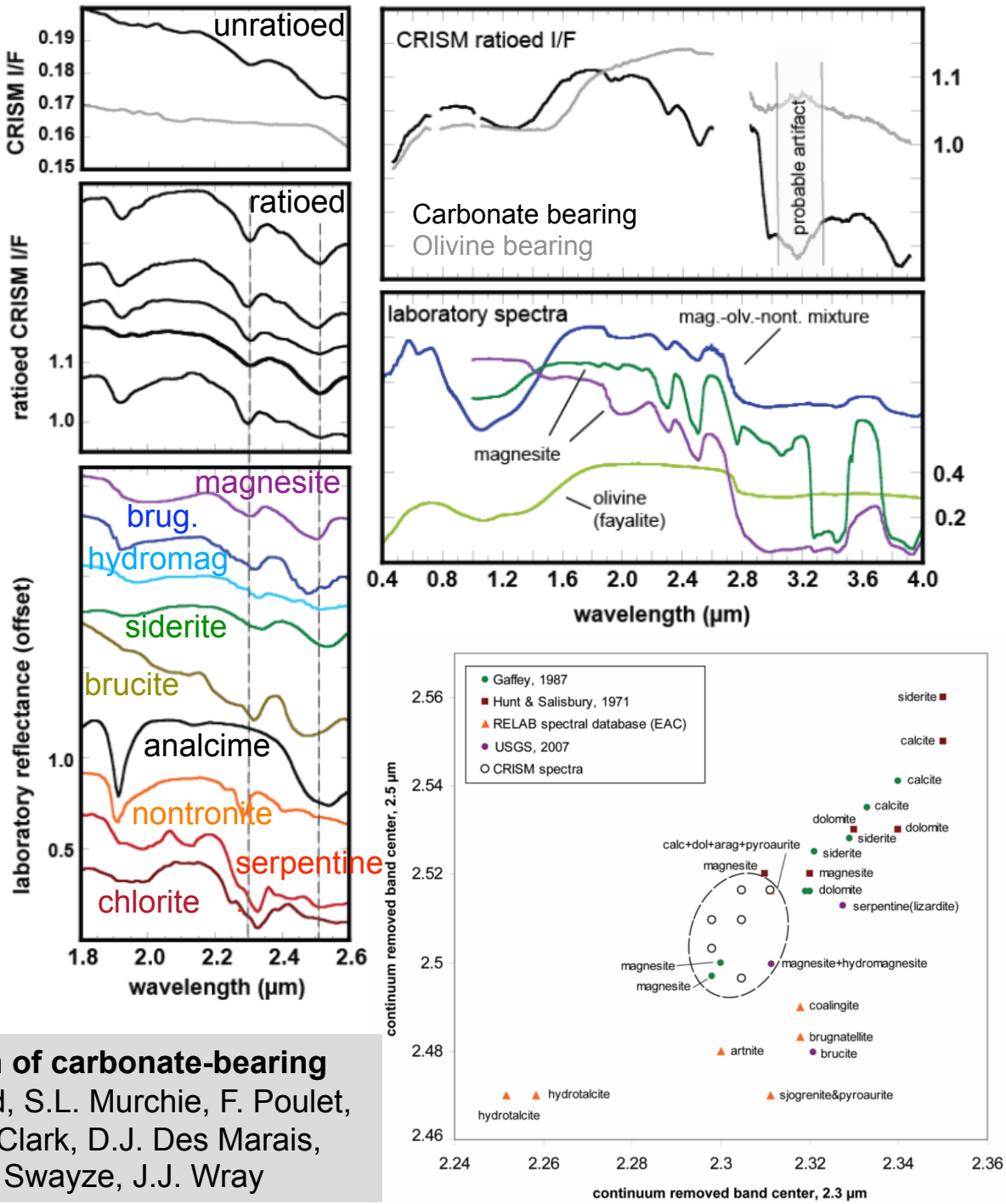




Olivine
Bland or with small amounts of pyroxene
Phyllosilicate: Fe/Mg smectite
Carbonate

Carbonate? -Most likely

- Distinct hydrated phase with absorptions at 2.3 and 2.5 um and a broad 1 um band
- Present in mappable geomorphic units (< 4km^2) within 20+ targeted CRISM images in Nili Fossae. Also seen by OMEGA.
- The most probable mineral to explain these spectral features is magnesium carbonate in a mixture including hydrated materials



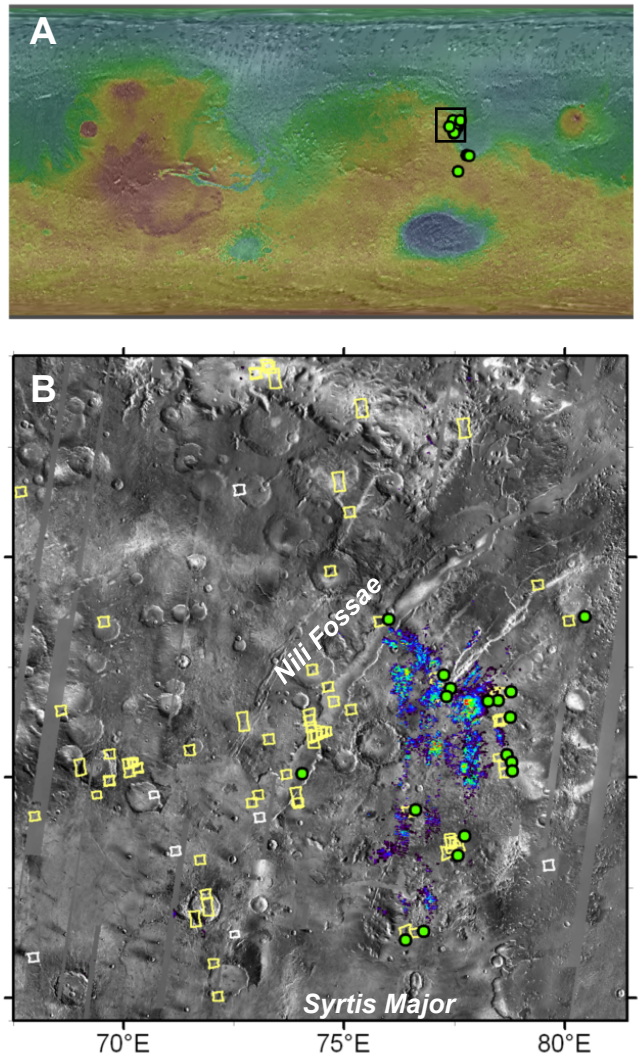
(in review, *Science*) Orbital identification of carbonate-bearing rocks on Mars. B.L. Ehlmann, J.F. Mustard, S.L. Murchie, F. Poulet, J.L. Bishop, A.J. Brown, W.M. Calvin, R.N. Clark, D.J. Des Marais, R.E. Milliken, L.H. Roach, T.L. Roush, G.A. Swayze, J.J. Wray

Carbonate Distribution and Formation

- Well-exposed carbonate bedrock is restricted to the Eastern portion of Nili Fossae
  - To date, significant outcrops have not been observed elsewhere on Mars
- Why so limited? Required: much olivine (for detection from orbit) and its extensive interaction with water
- Magnesium carbonate formation scenarios:

  <u>Subsurface (hydrothermal or serpentinization)</u>
  - Percolation of groundwater through ultramafic rocks
  - Contact metamorphism of olivine-hydrated smectite

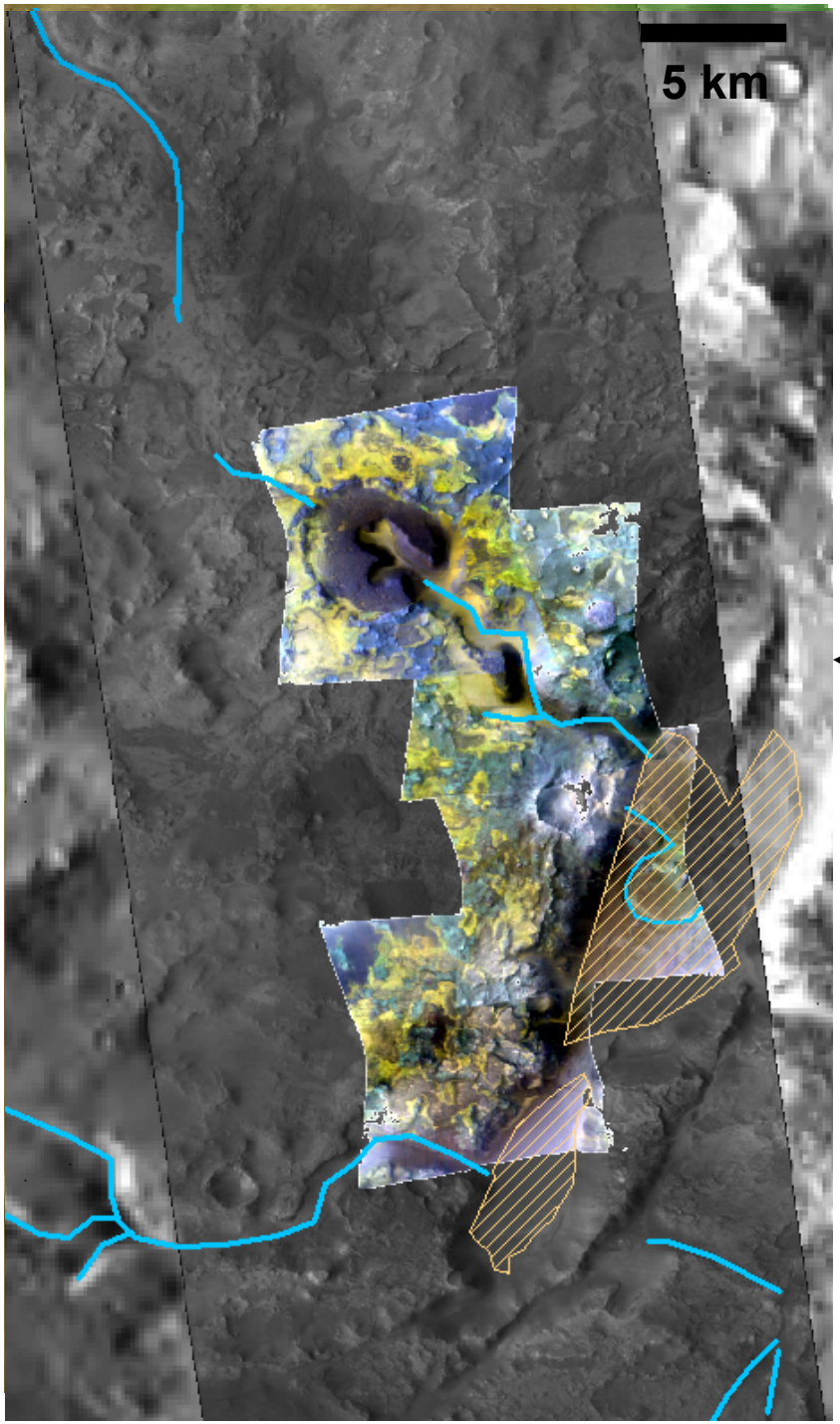
  <u>Surface</u>
  - Playa lakes fed by ultramafic catchments
  - Weathering of olivine/serpentinized bodies
- Significance? Exclusively neutral to high pH aqueous conditions in carbonate rocks are implied
  - Regional fluvial activity extended into the Hesperian
  - Carbonates persist to the present, were not dissolved

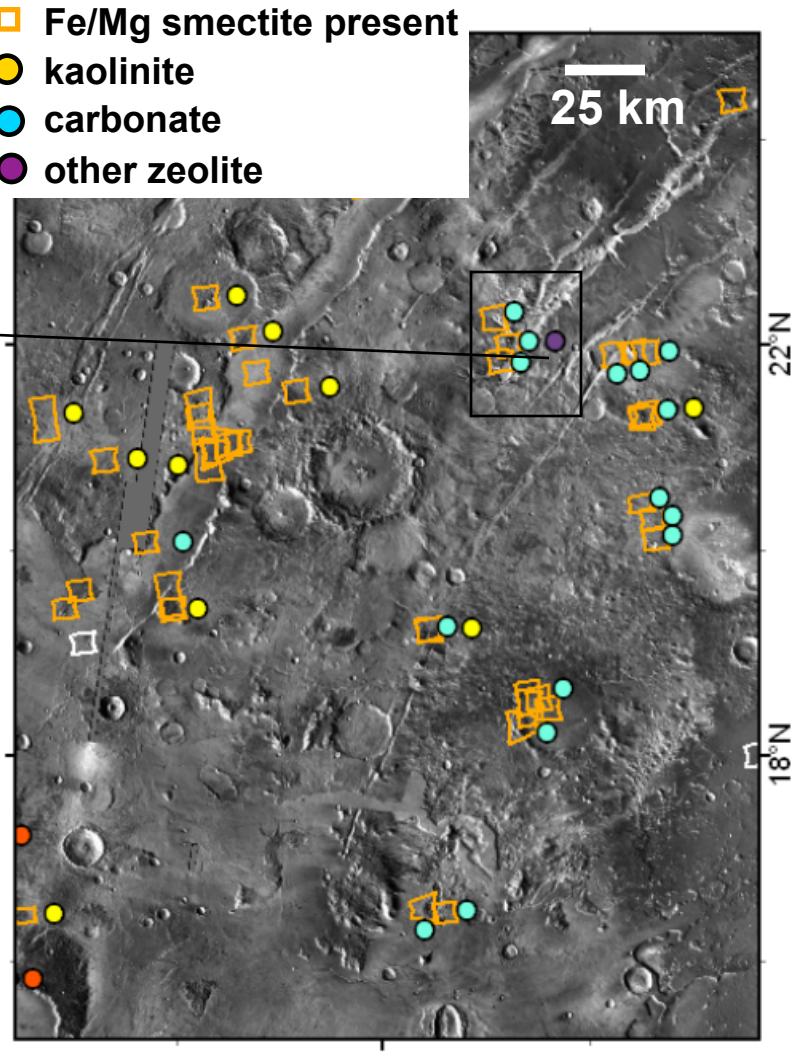


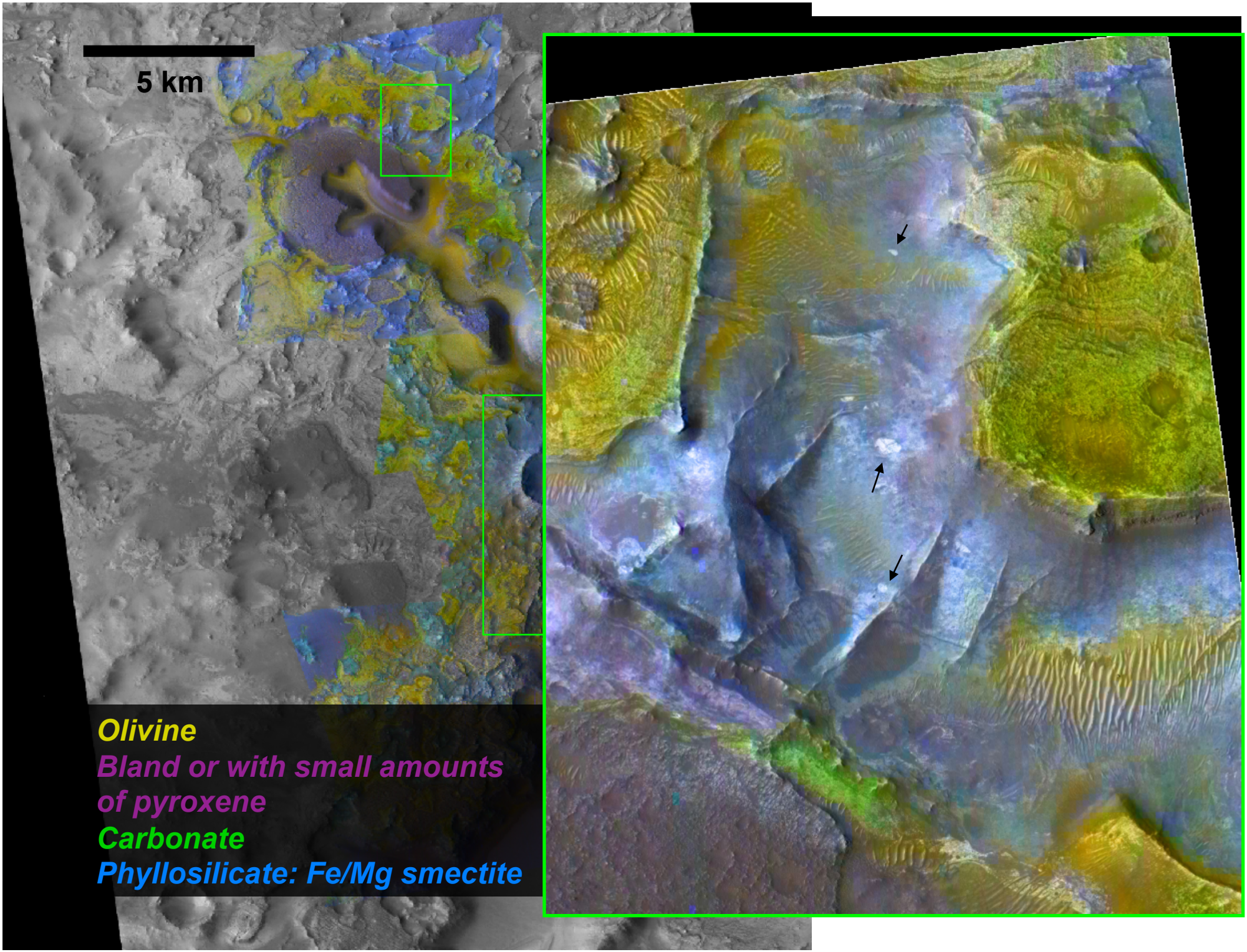
Carbonate-Olivine-Smectite Stratigraphy

MOLA (elevation range 400 to -1500 m)

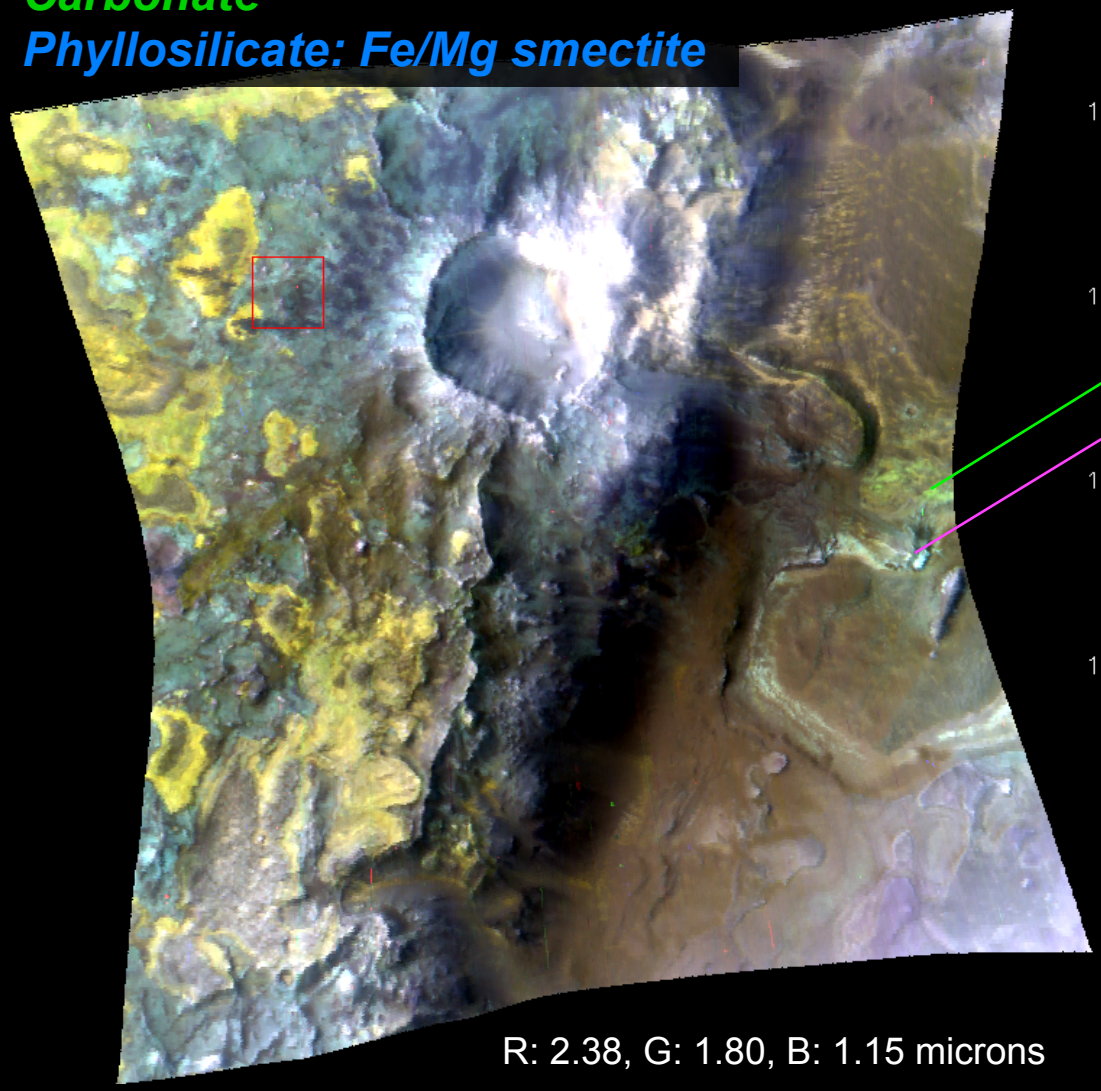
on CTX (P03_002176_2024_XI_22N283W_070113)



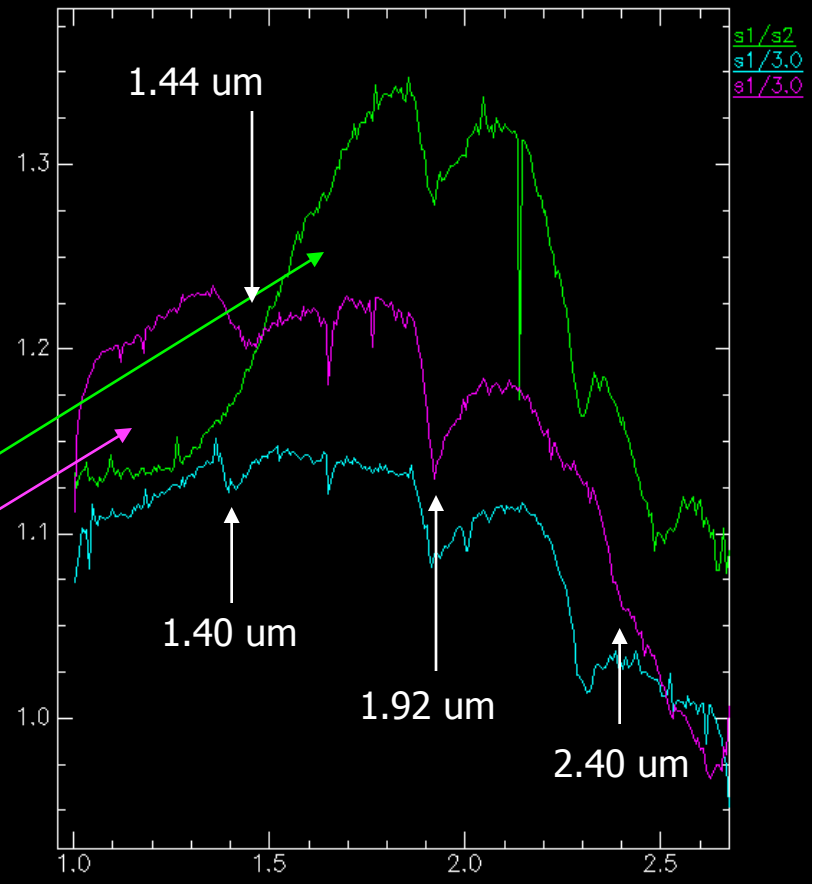



5 km
Olivine
Bland or with small amounts of pyroxene
Carbonate
Phyllosilicate: Fe/Mg smectite

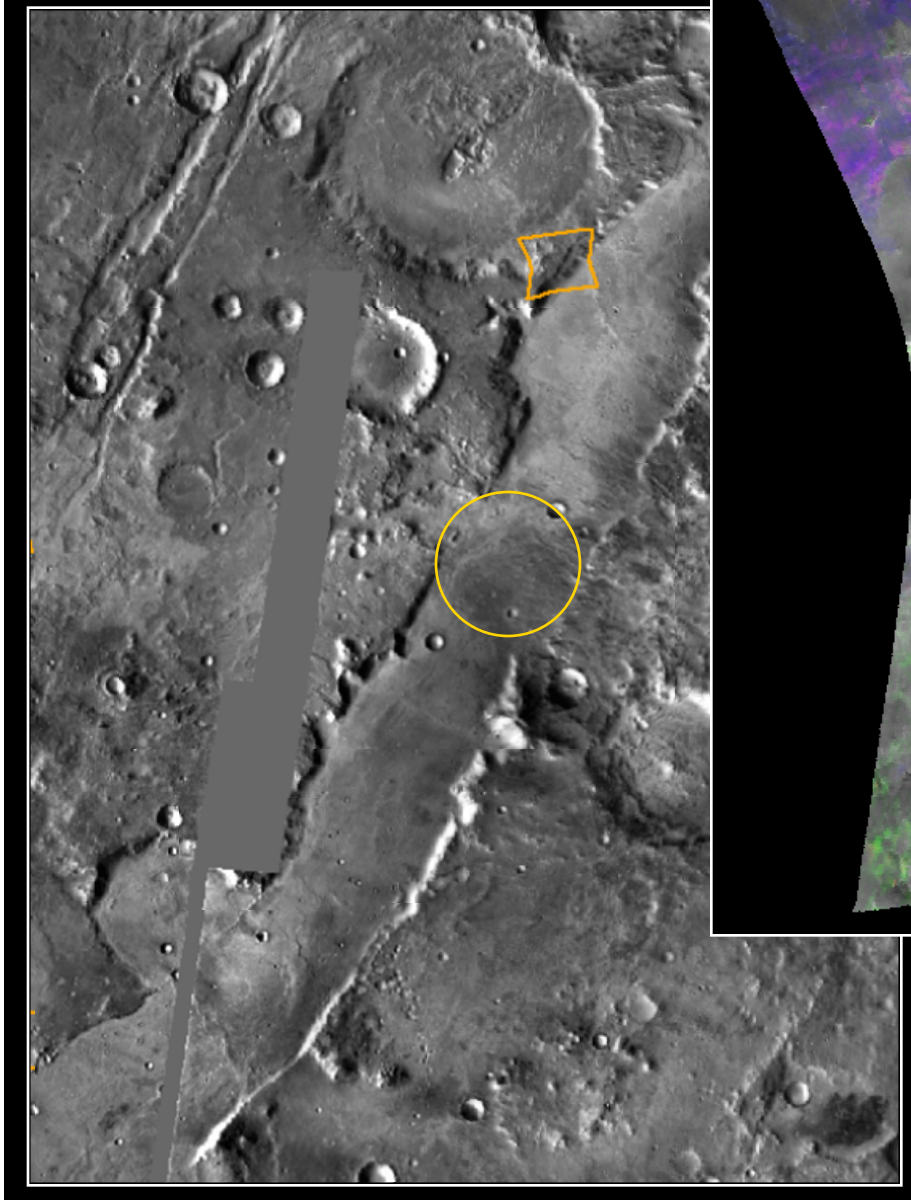
Olivine
Bland or with small amounts of pyroxene
Carbonate
Phyllosilicate: Fe/Mg smectite



R: 2.38, G: 1.80, B: 1.15 microns



Kaolinite-smectite stratigraphy



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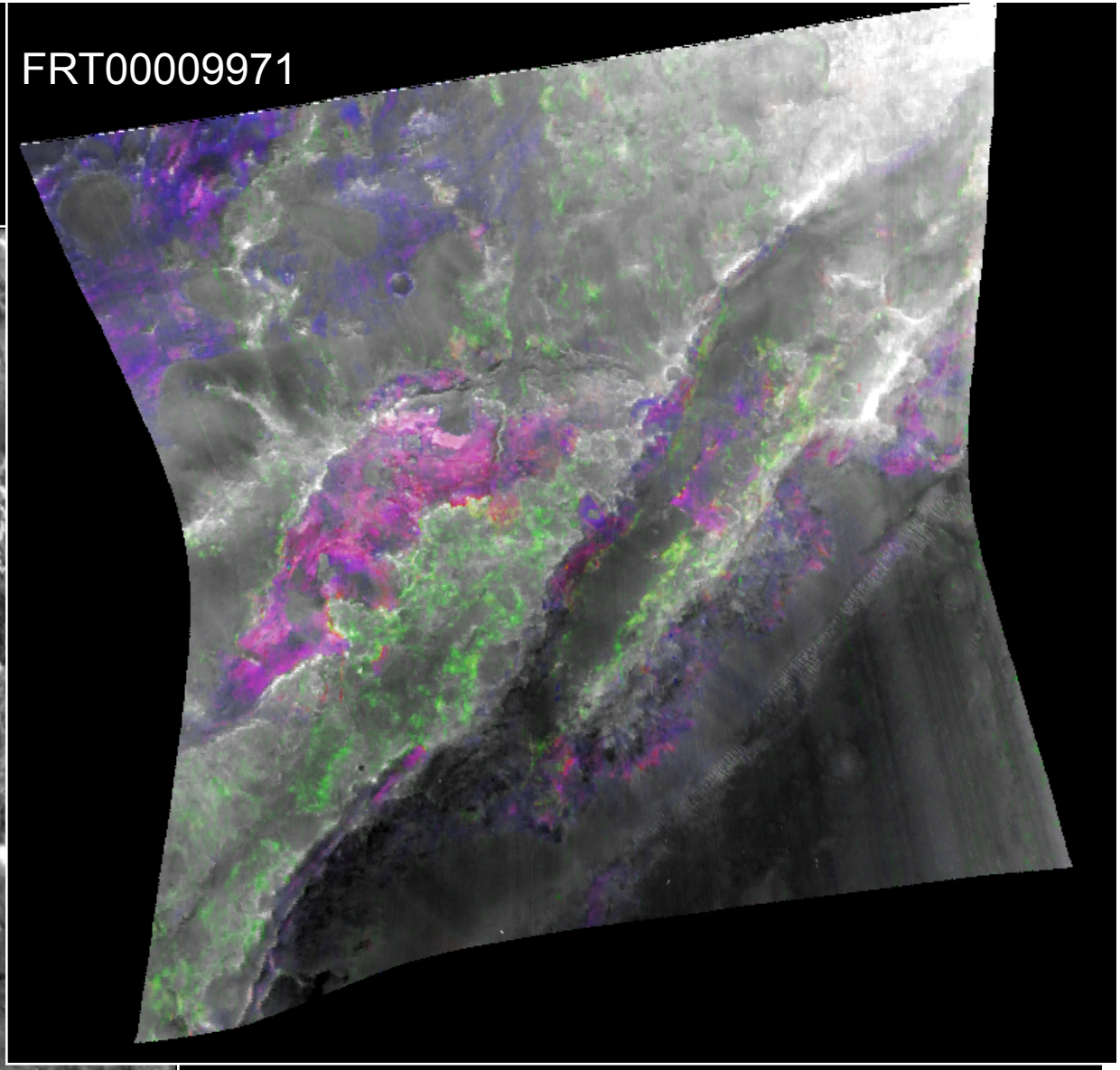
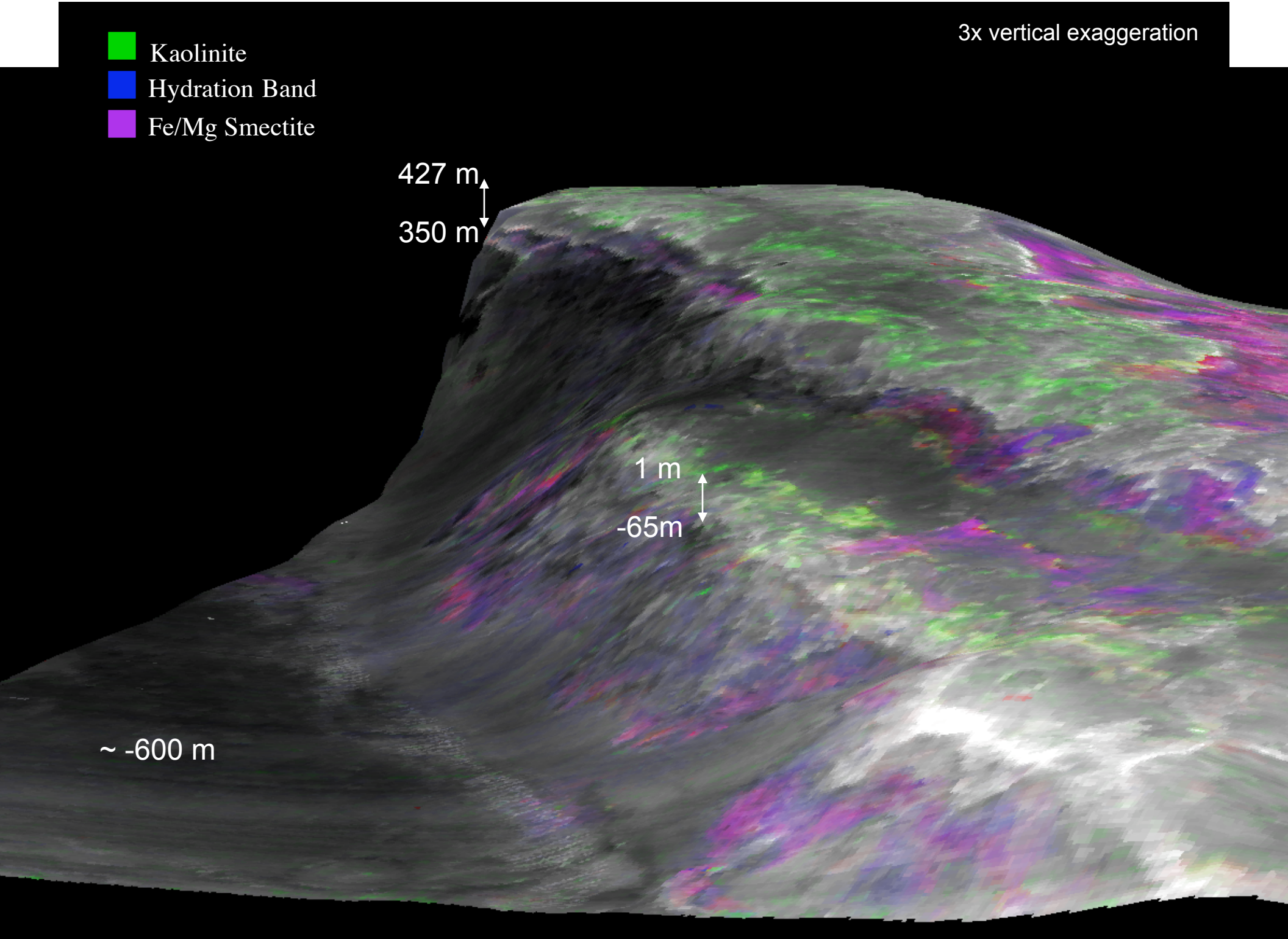


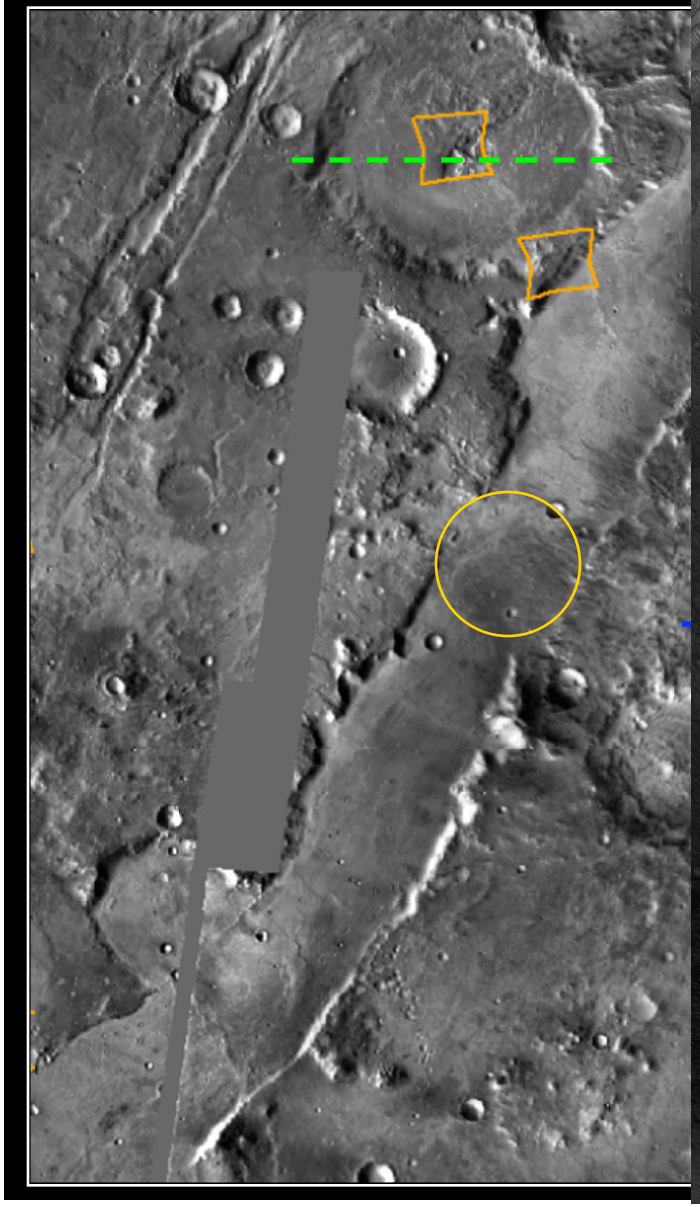
Kaolinite (BD2200)

Hydration Band (BD1900)

Fe/Mg Smectite (BD1900, D2300)


Kaolinite
Hydration Band
Fe/Mg Smectite
3x vertical exaggeration
427 m
350 m
1 m
-65m
~ -600 m

Kaolinite-smectite stratigraphy



Kaolinite
Hydration Band
Fe/Mg Smectite

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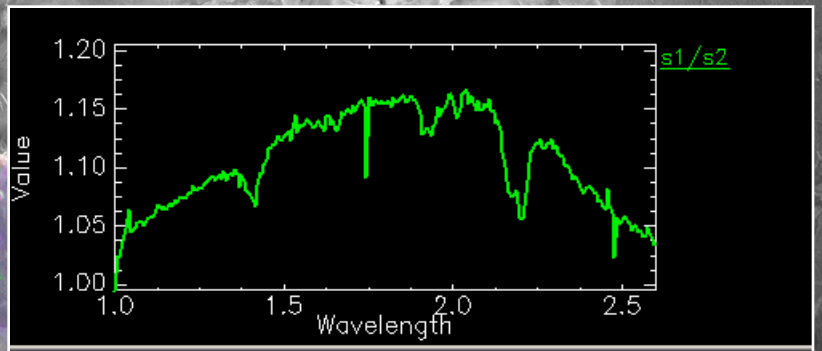
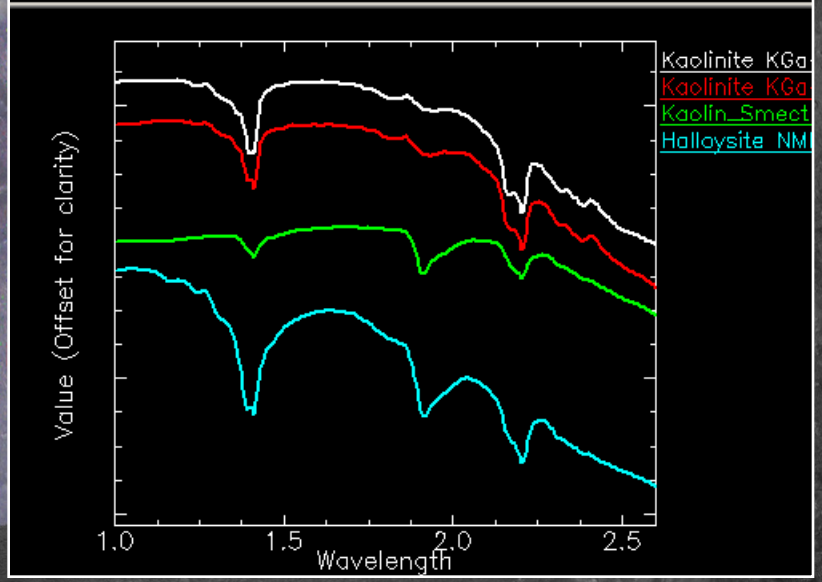
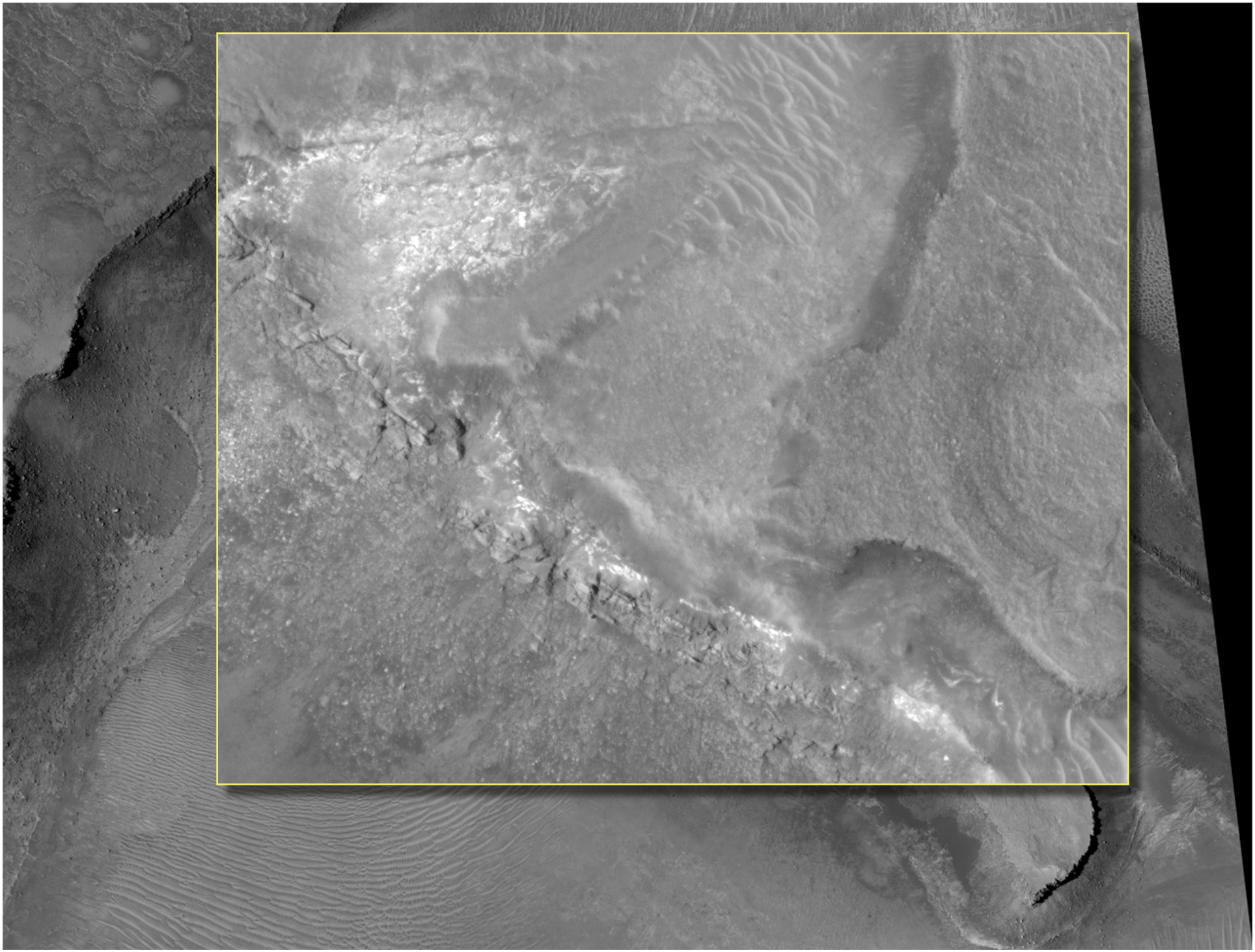
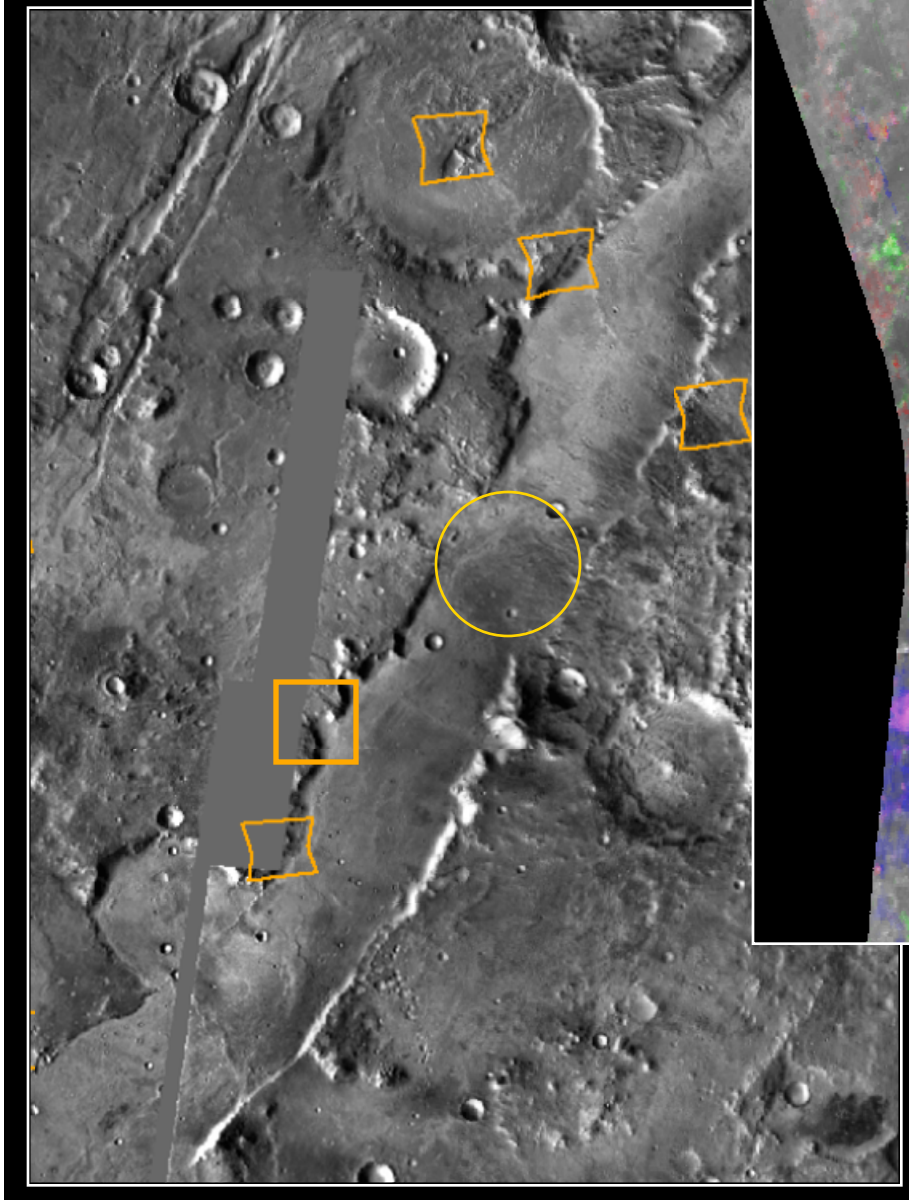


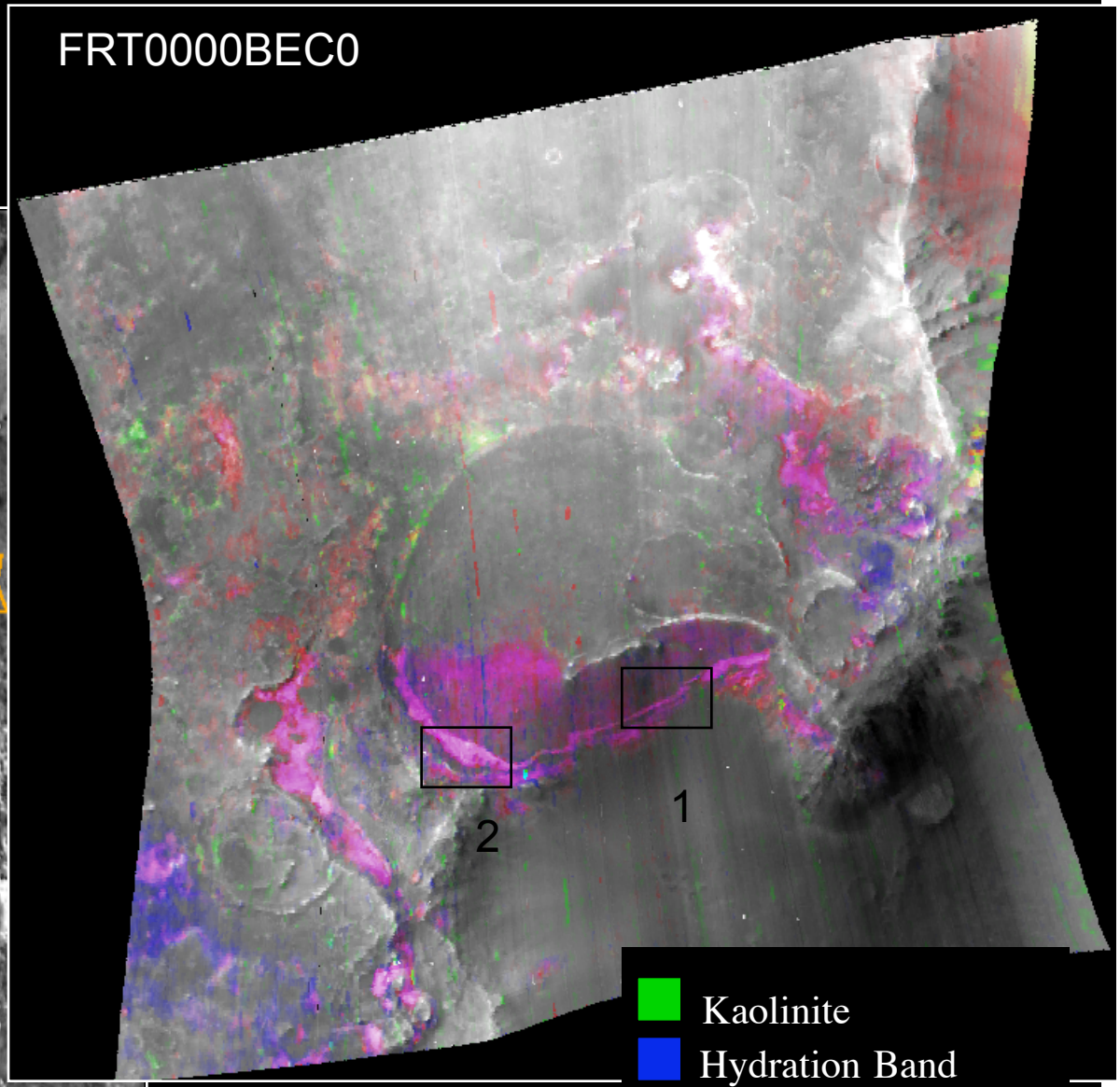


10 km



Kaolinite-smectite stratigraphy





PSP_009494_2010_RED


60 m
PSP_009494_2010_RED

Kaolinite-smectite stratigraphy - hypotheses

Why do we see a distinct kaolinite layer capping both in-situ and transported smectite?

- Enhanced weathering

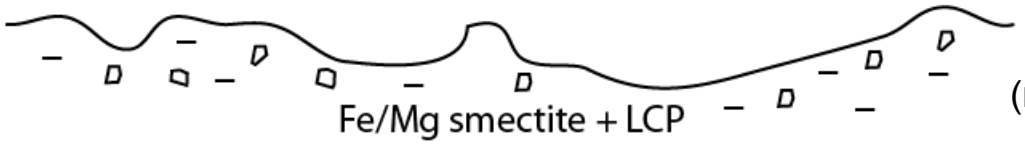
  1) basalt → Fe/Mg smectite [e.g. $(Fe, Mg)_2(Si, Al)_4O_{10}(OH)_2$]

  2) more leaching → loss of Ca^{2+}, Mg^{2+}, Fe^{2+} ions → kaolinite - $Al_2Si_2O_5(OH)_4$

  Terrestrial analog: soil formation

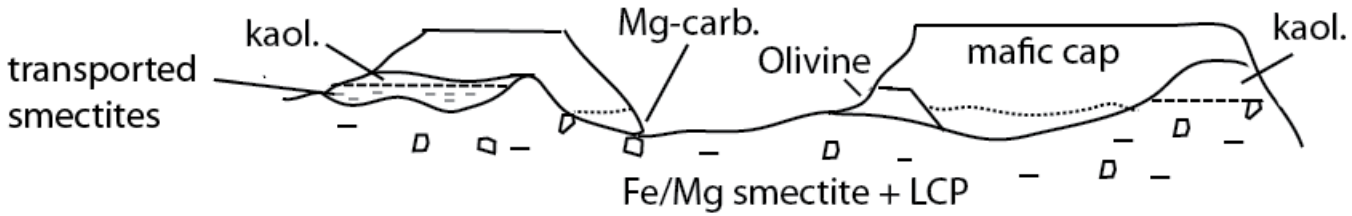
- Further east, the presence of olivine changes the dominant alteration mineral from kaolinite to magnesium carbonate

(1) Noachian crust -aqueously altered

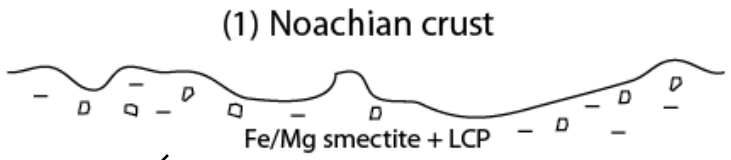


(regional slope removed)

Mineralogic-geomorphic units exposed today

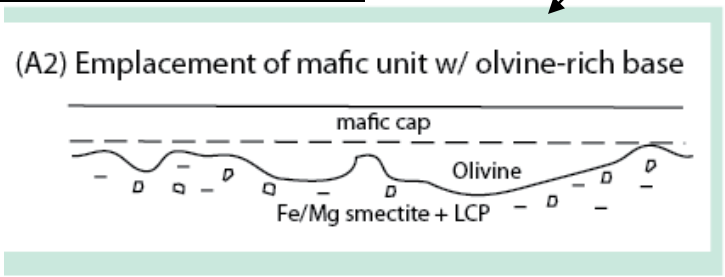


Testing potential geologic histories

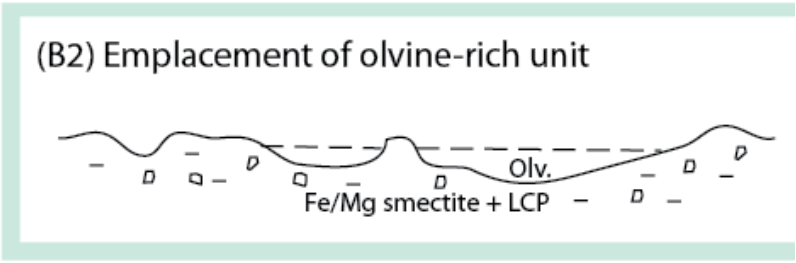


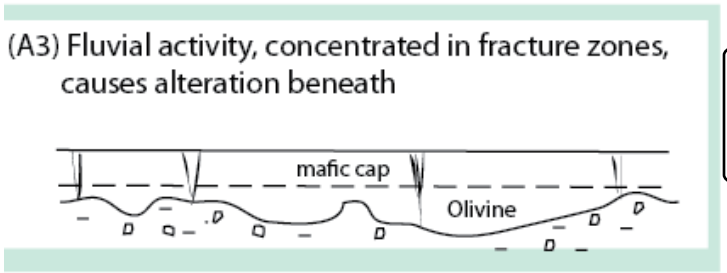
(A) alteration in subsurface

(B) alteration at surface

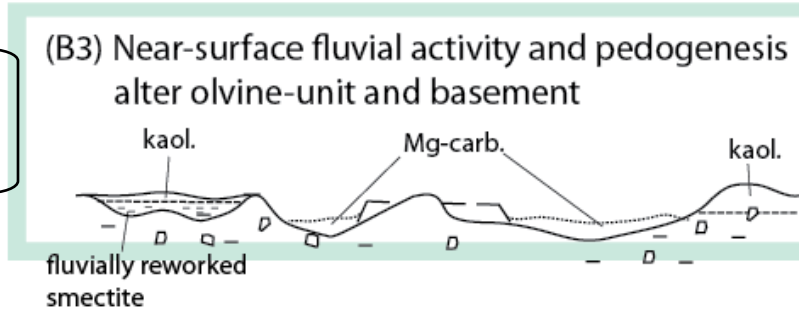


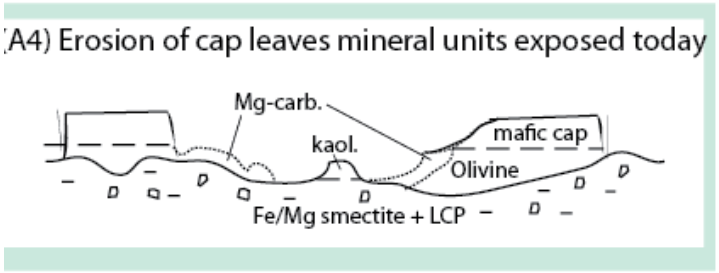
ISIDIS IMPACT



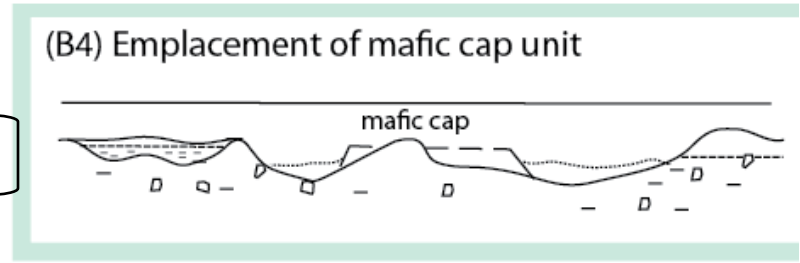


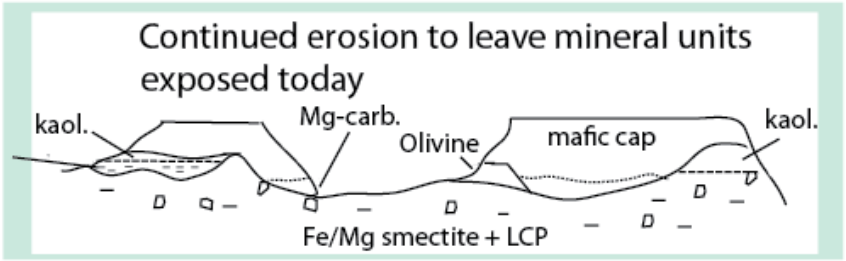
AQUEOUS ACTIVITY multiple episodes/ settings





EROSION





Reasonably accessible by MSL?

- In-situ stratigraphic section
  - LCP, Fe/Mg smectite in-situ
  - Fe/Mg smectite transported
  - Kaolinite on trough wall? (extended mission)
- Breccia blocks: samples from the east
  - More layered Fe/Mg smectite
  - Kaolinite
  - Carbonate

Closing thoughts – Nili Fossae mineralogy and MSL (I)

DIVERSITY

- Opportunity to understand ancient Mars as a system—cratering, volcanic processes, fluvial processes, climate → water-rich environments
  - *phyllo*$_i$ and *phyllo*$_t$
- Igneous petrology: LCP-HCP crust, olivine provenance
- Secondary minerals in Nili Fossae show sustained interaction of water with crust over extended period of time in multiple settings
  - 1) Fe/Mg smectites and precursors (e.g. hisingerite, oxyhydroxides) form in bedrock (>10^5 yrs)
  - 2) Fe/Mg smectites transported → distinct (fluvial?) bedforms (>10^3 yrs)
  - 3) Formation of kaolinite (and carbonate) (>10^5 yrs)

CONTEXT

- Clear context: stratigraphy is distinguishable, consistent, and findings in the landing ellipse are relatable to orbital data for regional exposures of hydrated minerals
  - At smaller scales, more amounts of alteration are present in Noachian bedrock (same lesson as Columbia Hills)

Closing thoughts – Nili Fossae mineralogy and MSL (II)

HABITABILITY

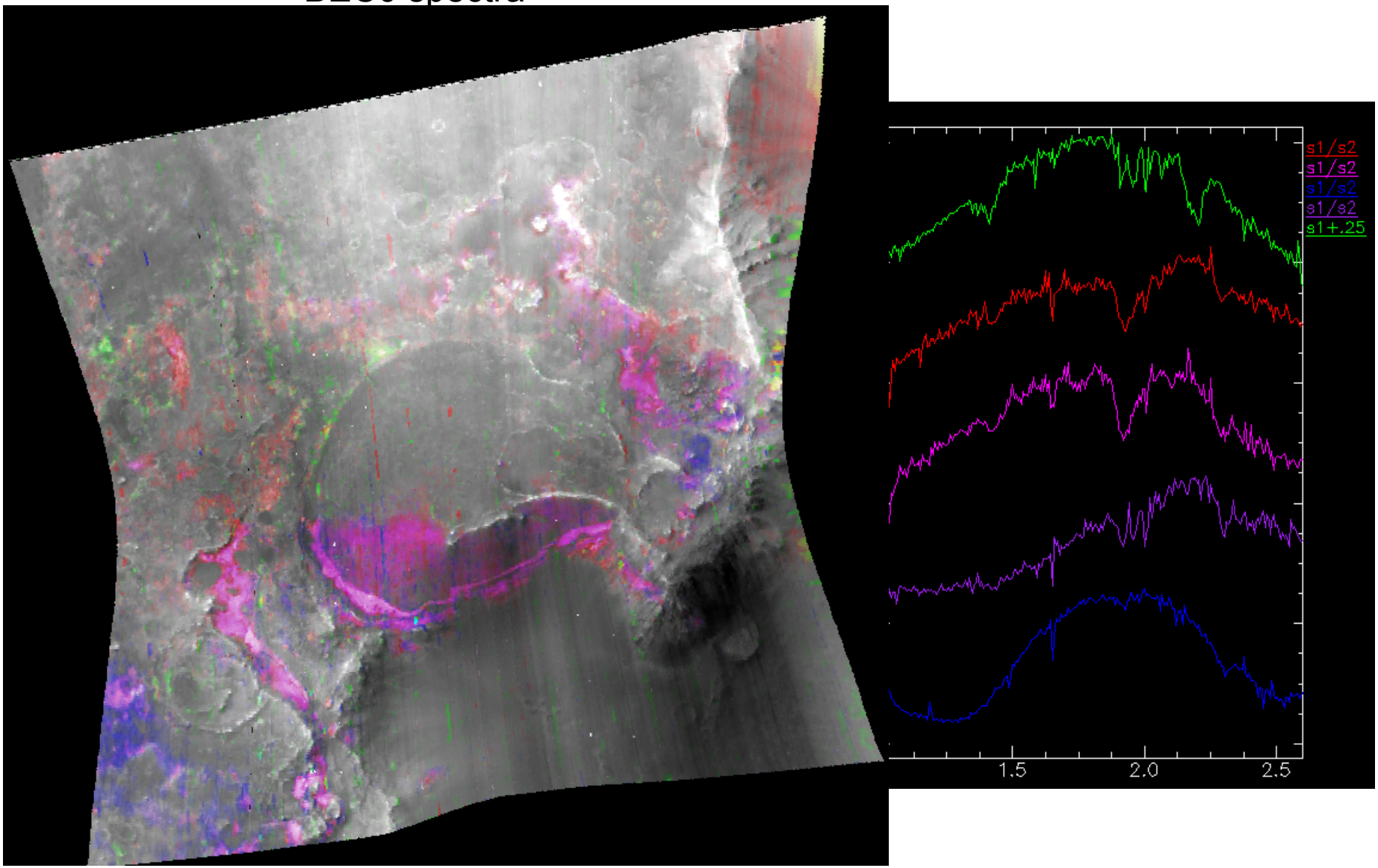
- Follow the (sustained) water a good strategy for identifying habitable environments -- presence of life a necessary step for its preservation
- Data indicate Nili Fossae was persistently wet and it is extremely well-exposed.
    - Is it uniquely/unusually wet for Mars? Or was evidence for multiple, sequential water-rich environments simply better preserved and exposed here?

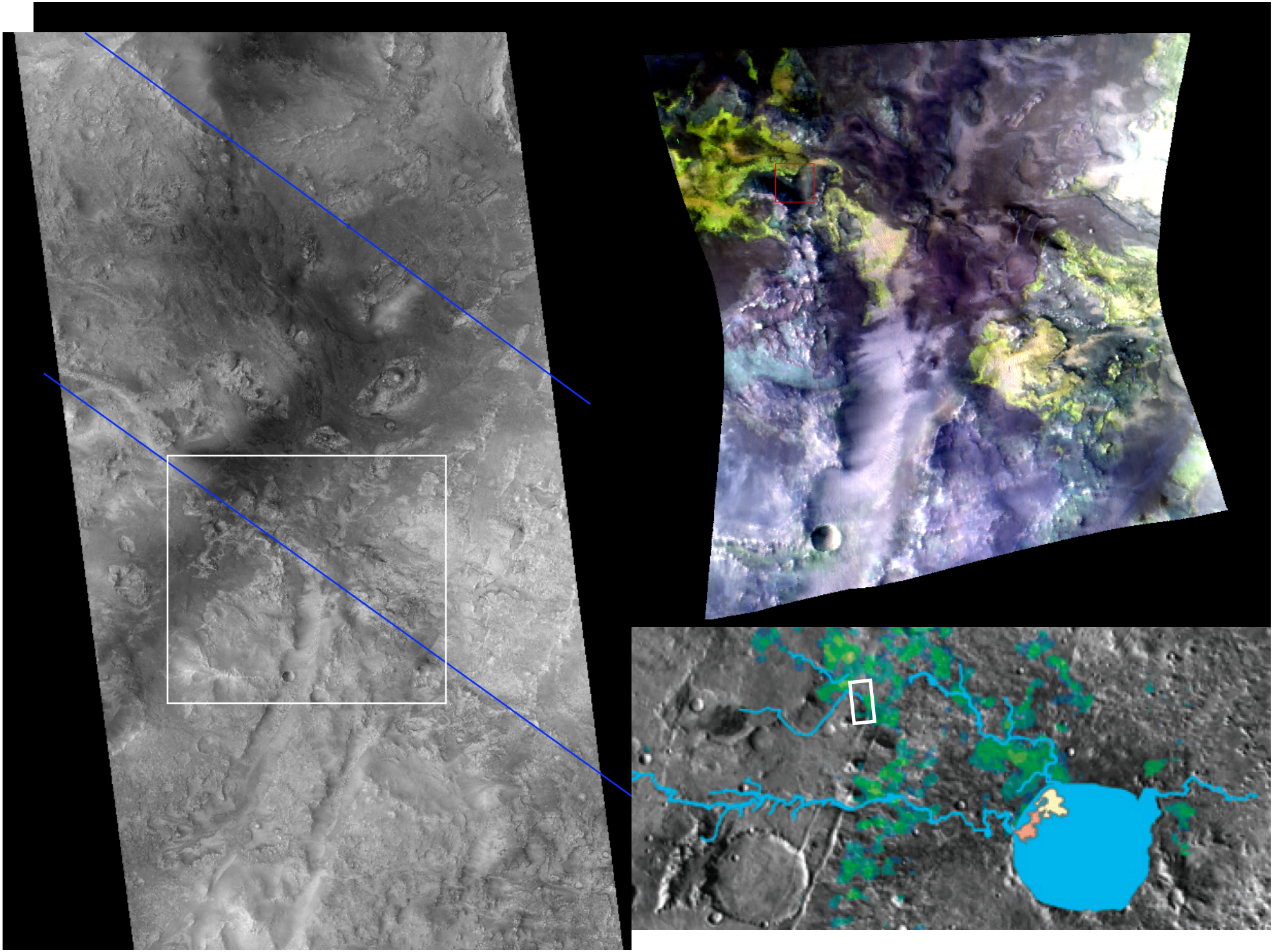
PRESERVATION

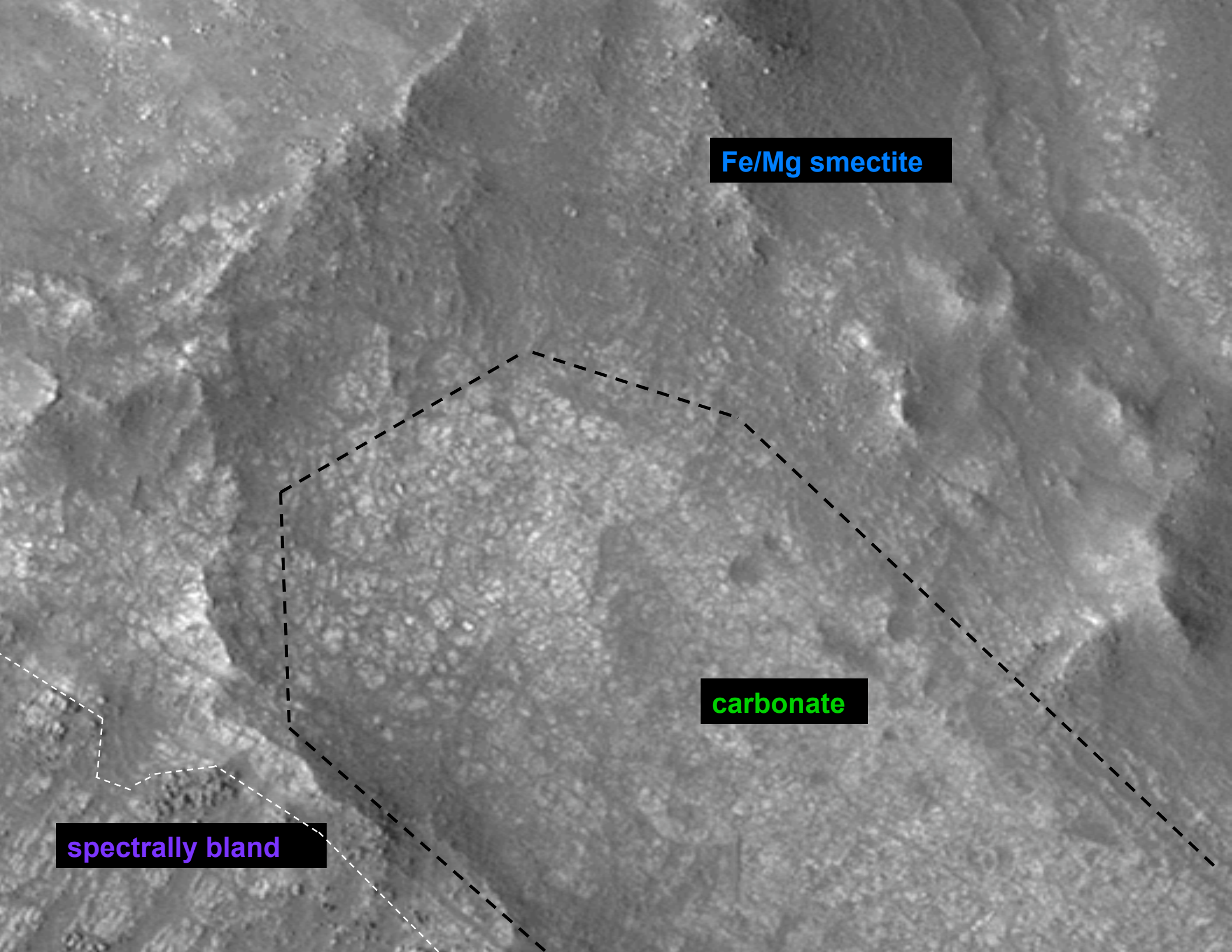
- Neutral to high pH aqueous environment is preserved
- The interlayer of smectities and the surface of associated oxyhydroxides trap organic material.
- Mineralized fractures in smectites, transported smectites, and carbonates are great places to look for life, especially chemical evidence of life

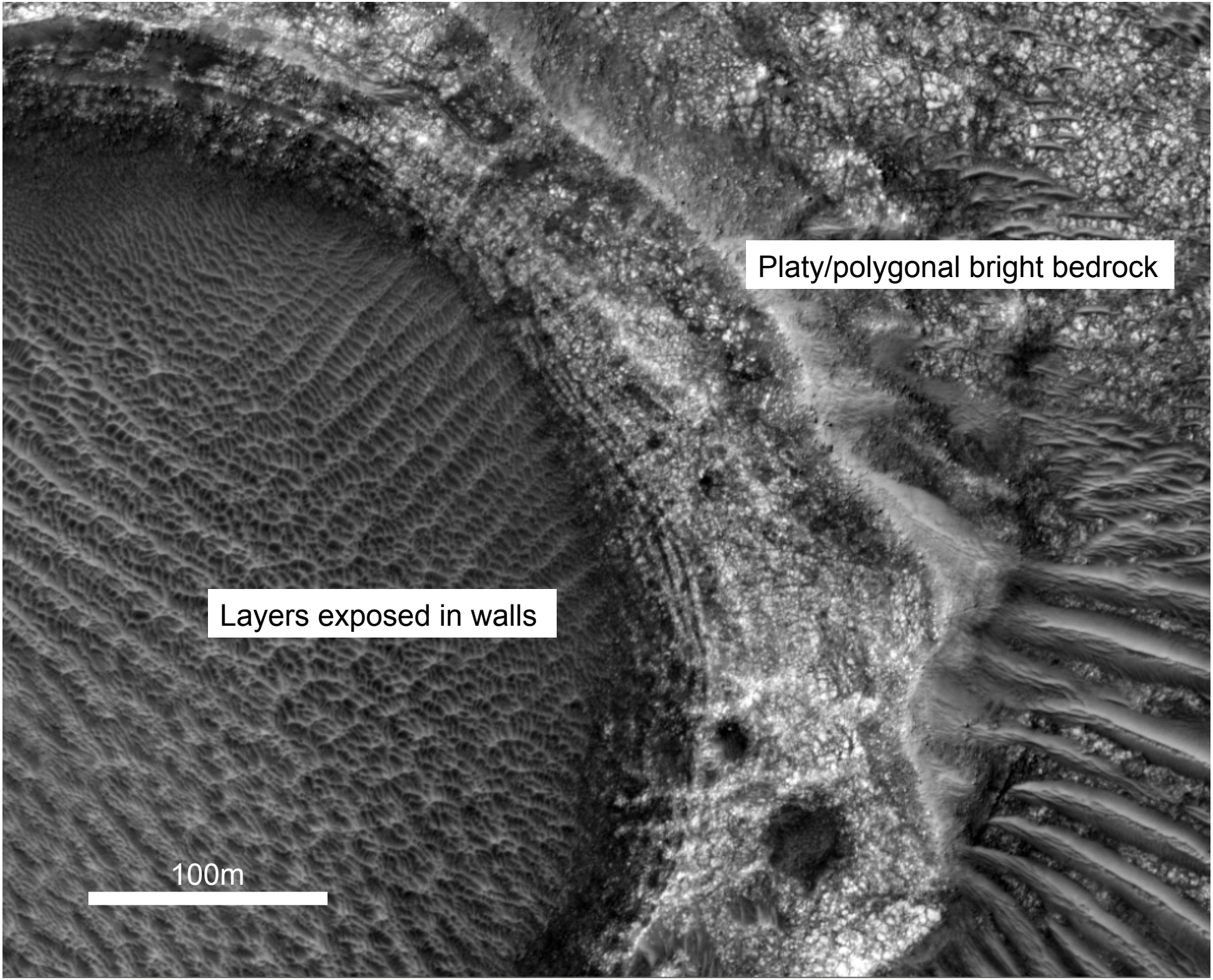
Extras

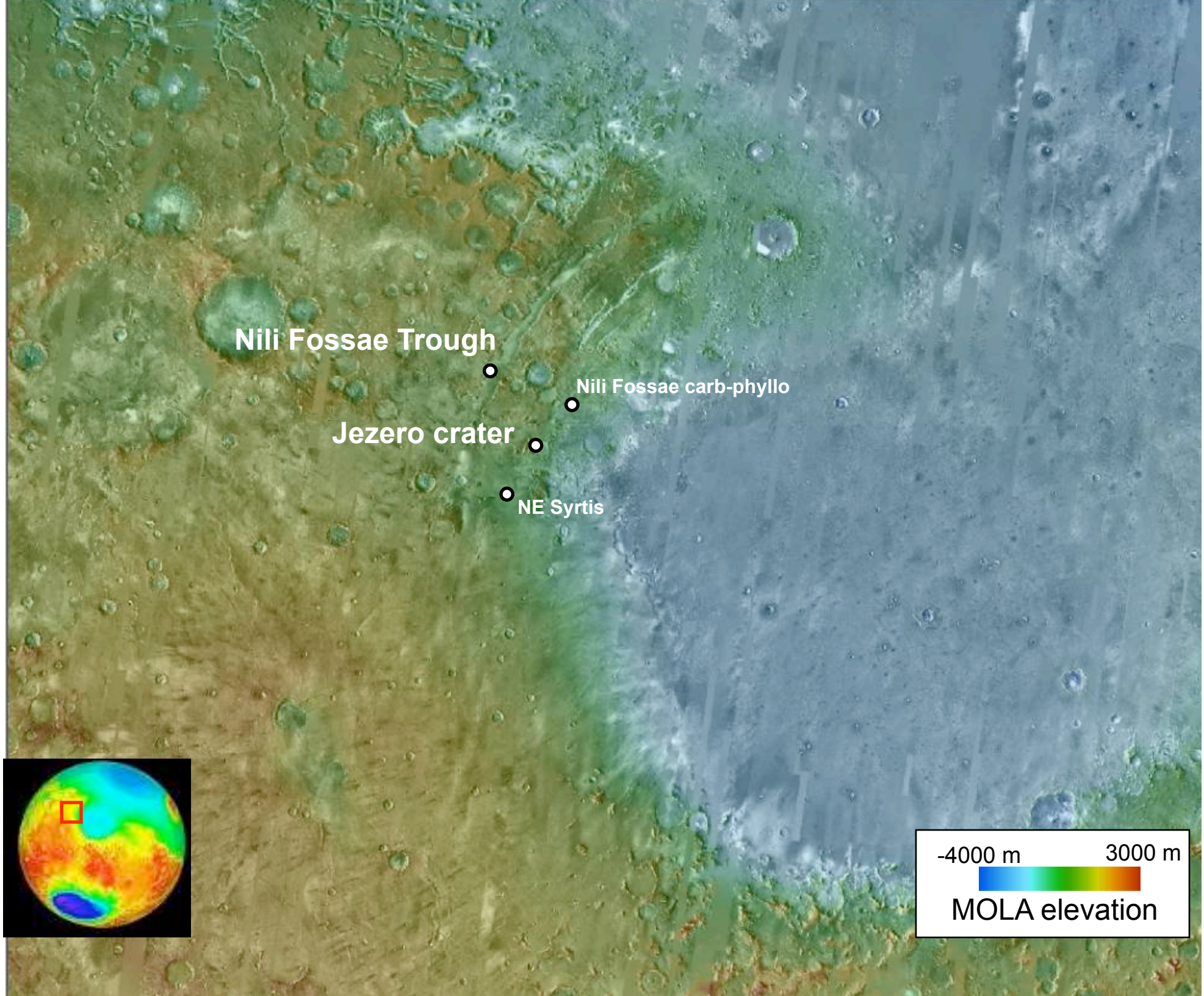
BEC0 spectra



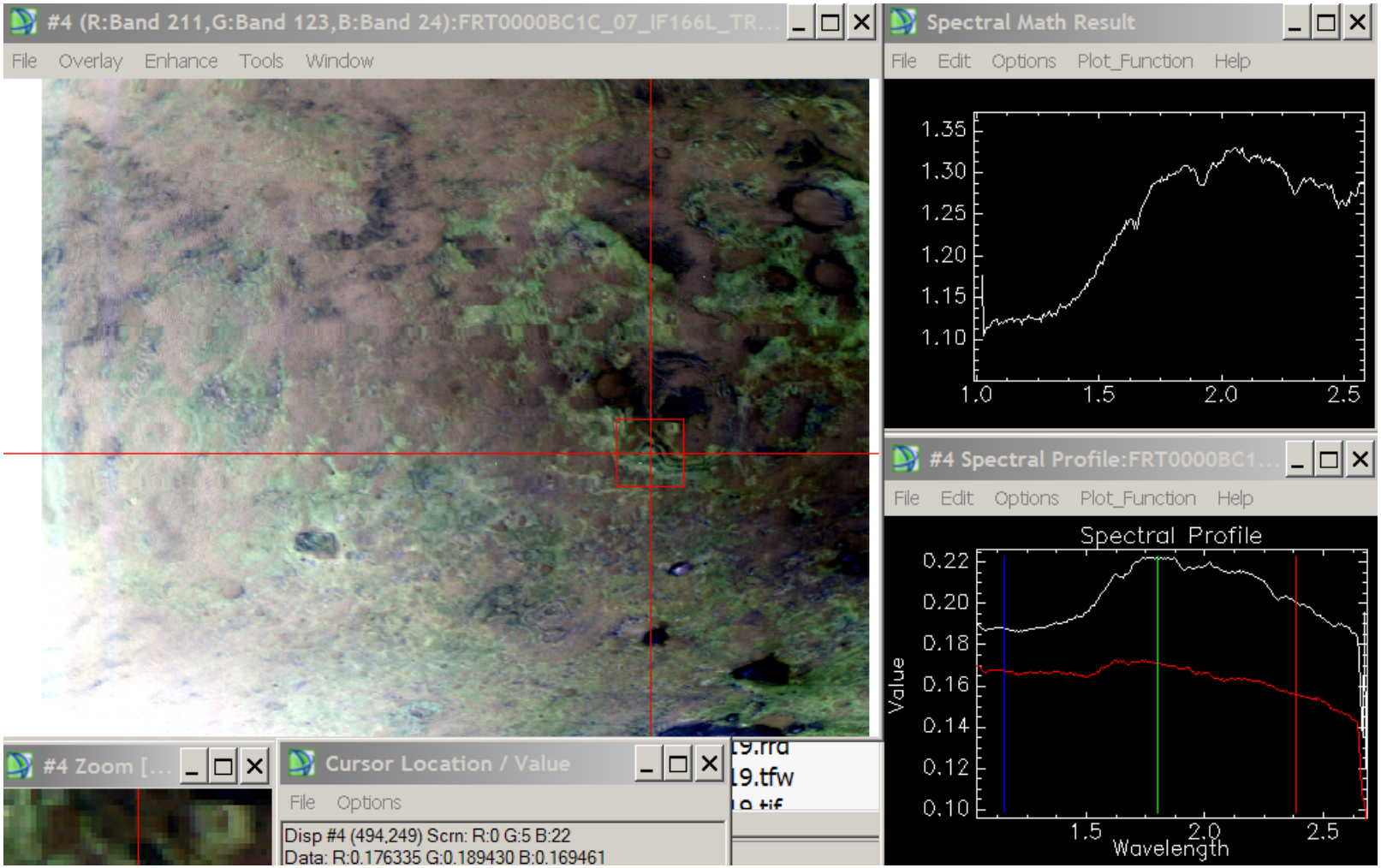


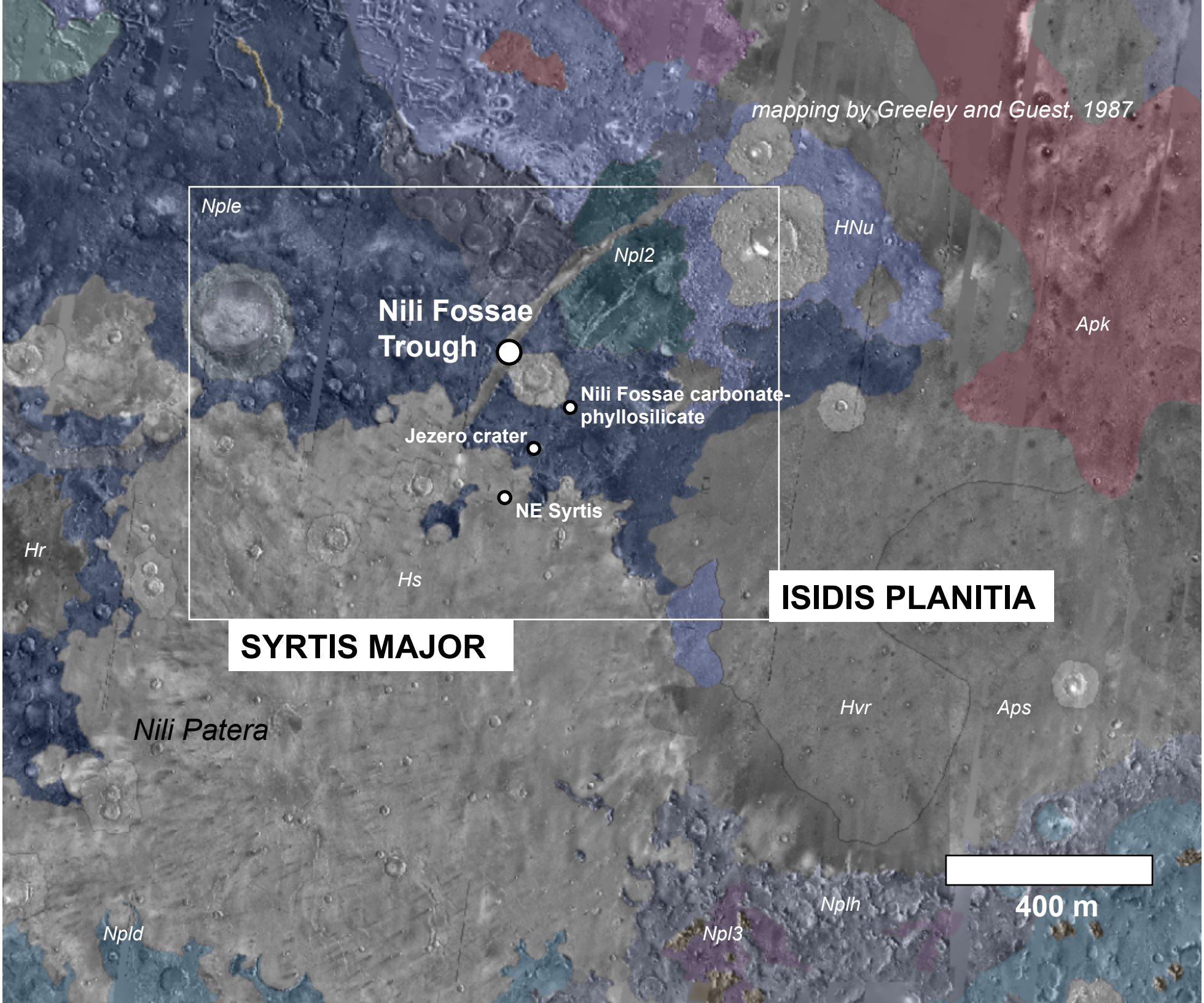

Fe/Mg smectite
carbonate
spectrally bland


Platy/polygonal bright bedrock
Layers exposed in walls
100m


Nili Fossae Trough
Nili Fossae carb-phyllo
Jezero crater
NE Syrtis
-4000 m
3000 m
MOLA elevation

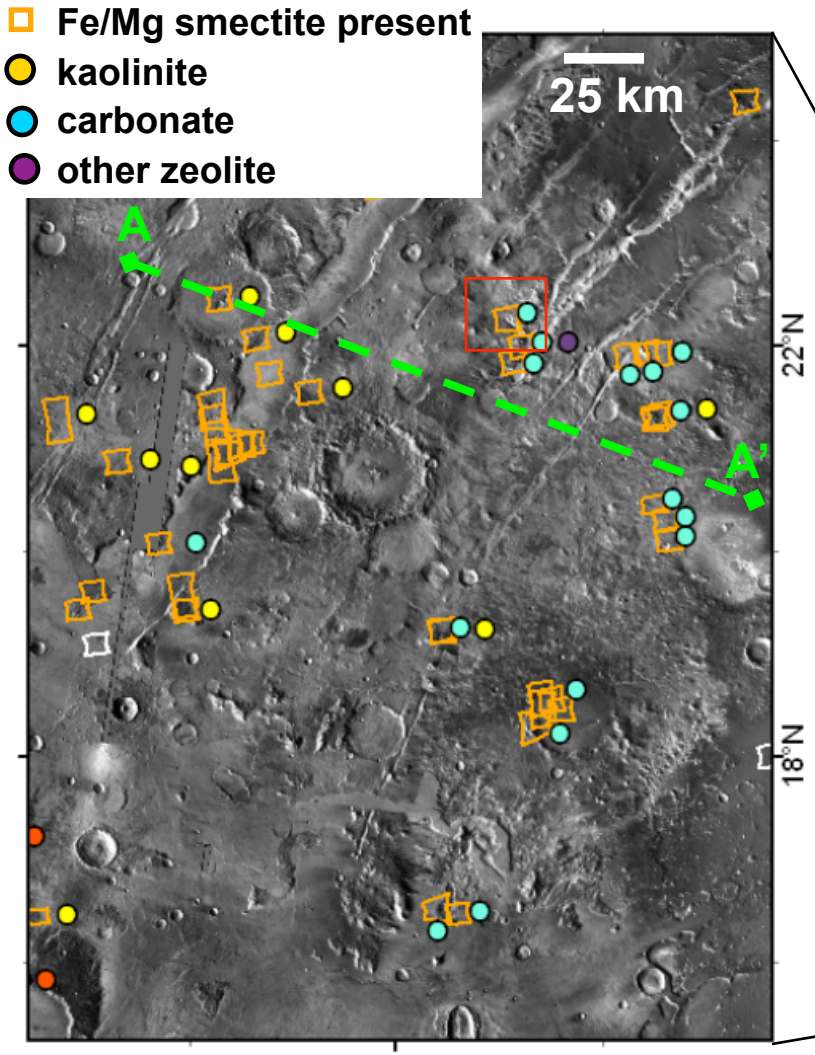
FRT BC1C-NF Carb landing site spectra

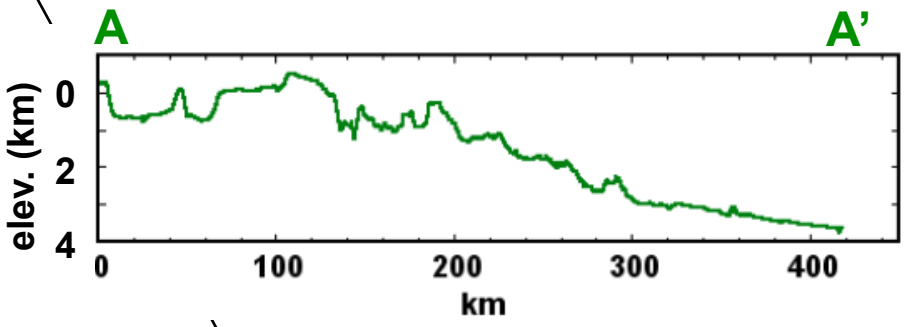


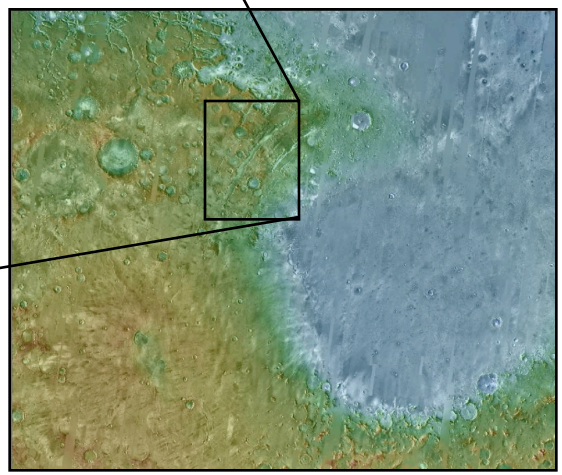

mapping by Greeley and Guest, 1987
Nple
Npl2
HNu
Apk
Nili Fossae Trough
Nili Fossae carbonate-phyllosilicate
Jezero crater
NE Syrtis
Hr
Hs
ISIDIS PLANITIA
SYRTIS MAJOR
Nili Patera
Hvr
Aps
Nplh
Npl3
Npld
400 m

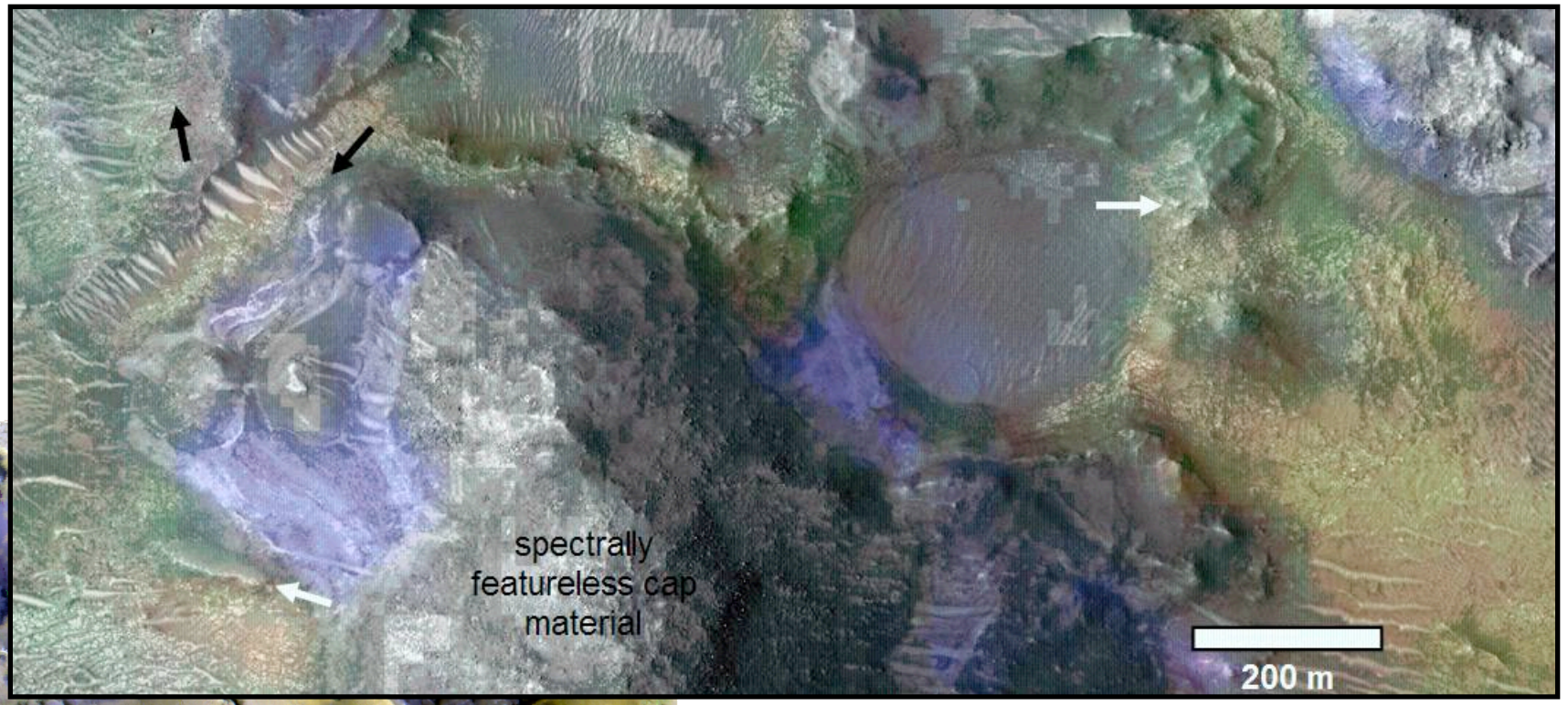
Eastern Nili Fossae

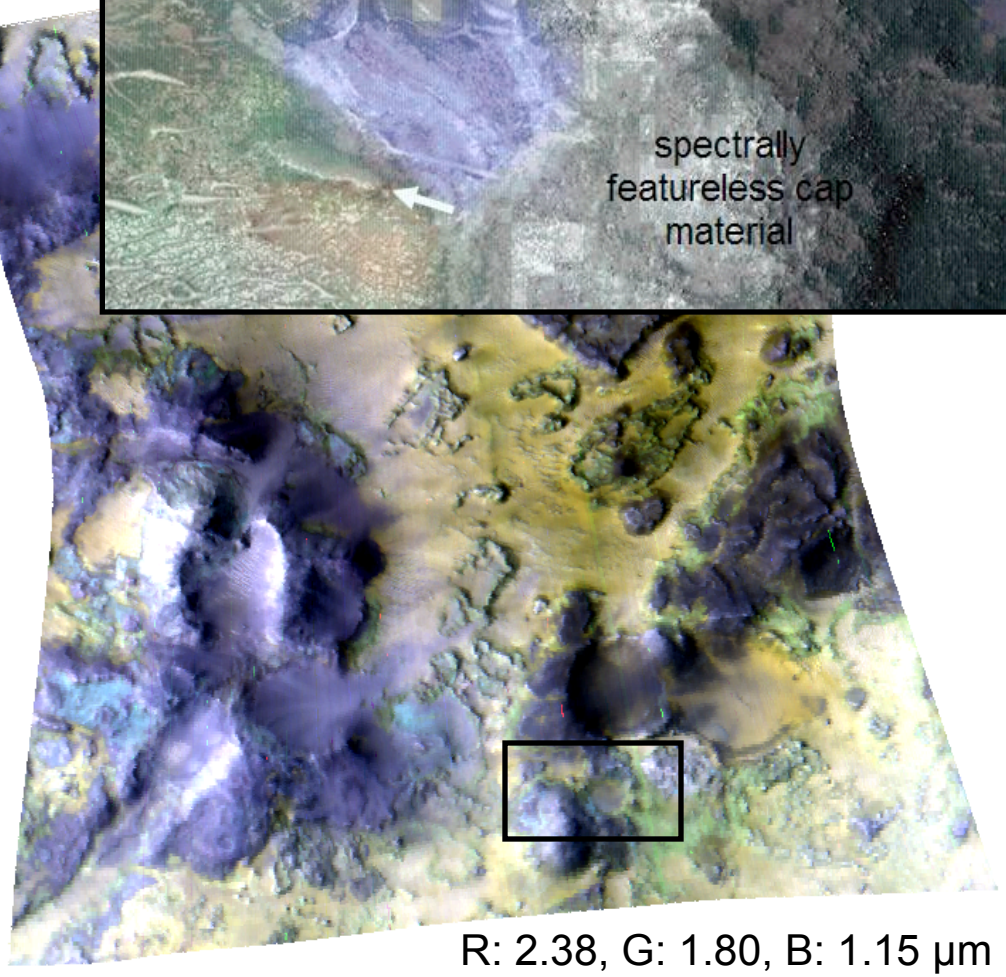
- Examining erosion and redistribution of material within a large basin
- Some (much?) of this was accomplished by fluvial activity
- Multiple layers are well exposed allowing investigation of a stratigraphic sequence





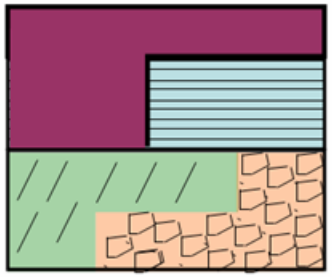






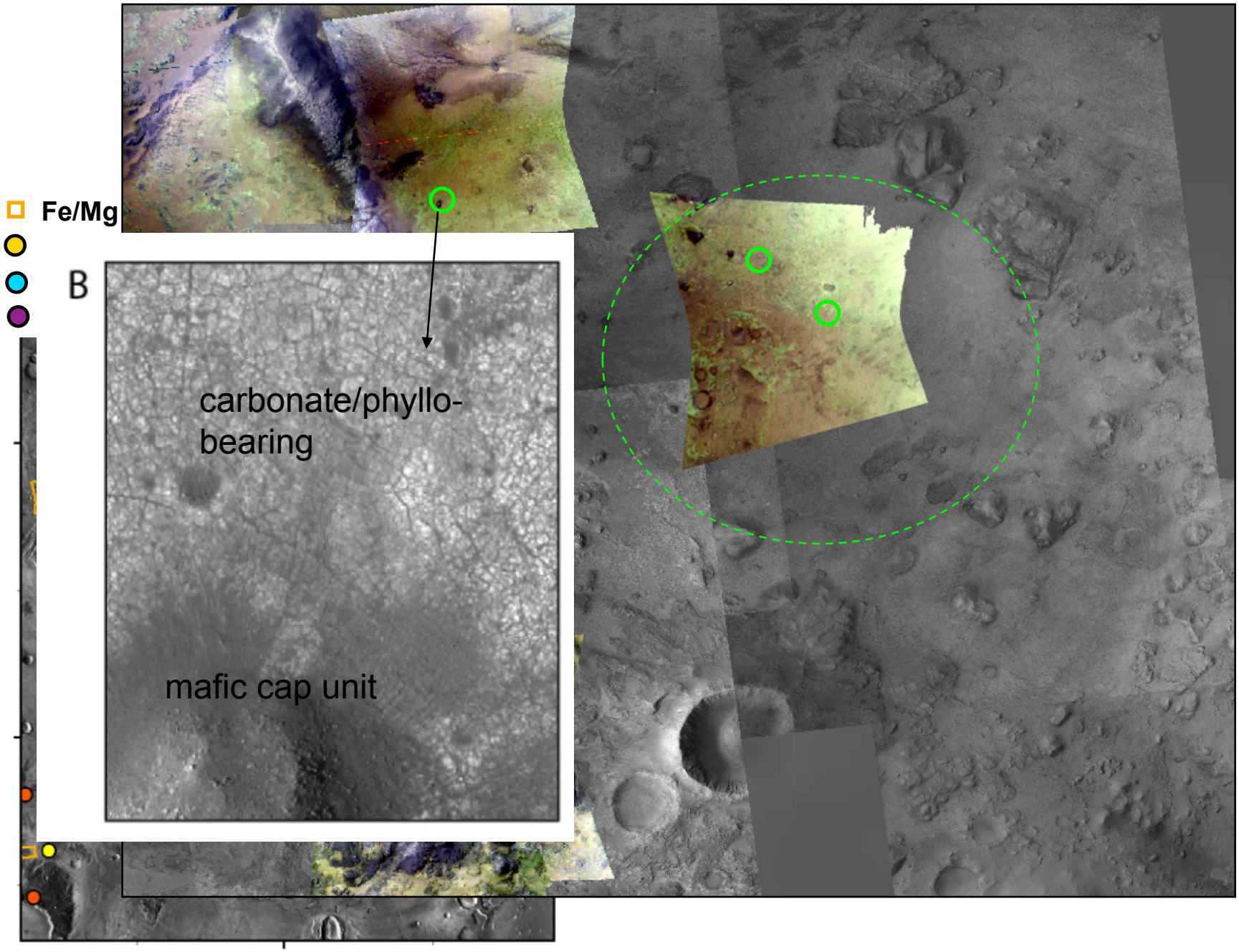
R: 2.38, G: 1.80, B: 1.15 μm

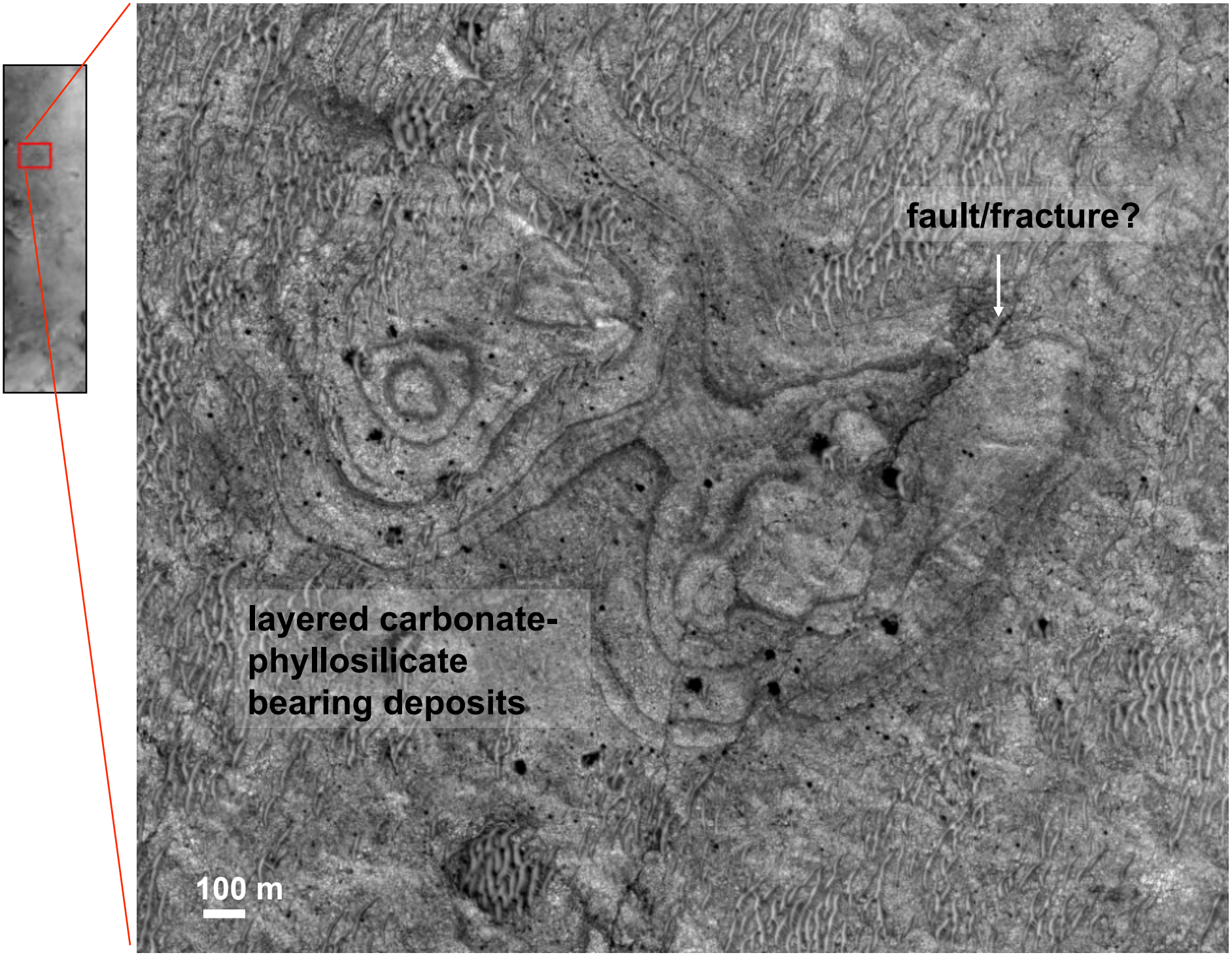
Kaolinite
Olivine
Fe/Mg smectite
Hydrated material



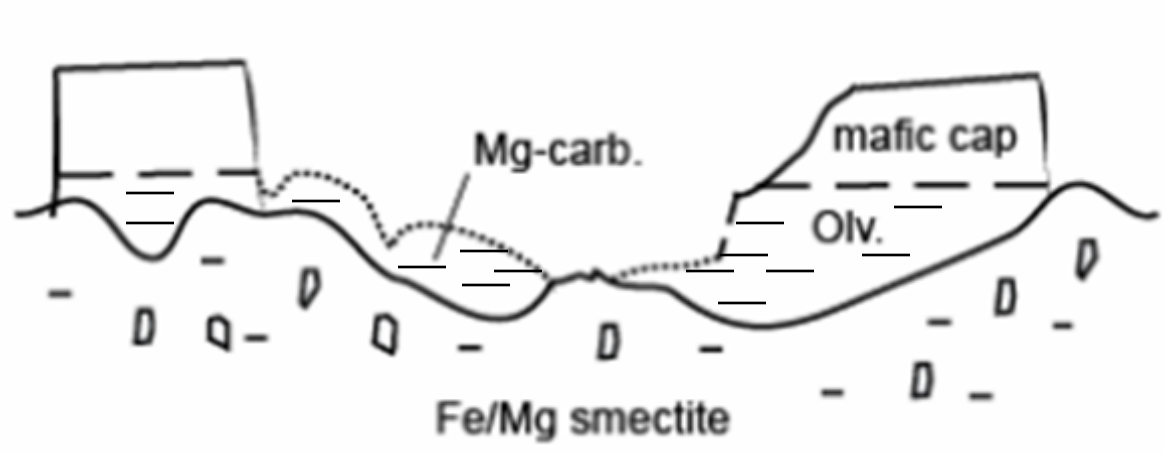
Bland cap unit
Kaolinite-bearing unit
Ridged Fe/Mg smectites
Fractured 2.3/2.5 μm-ite

(2b-no olv)

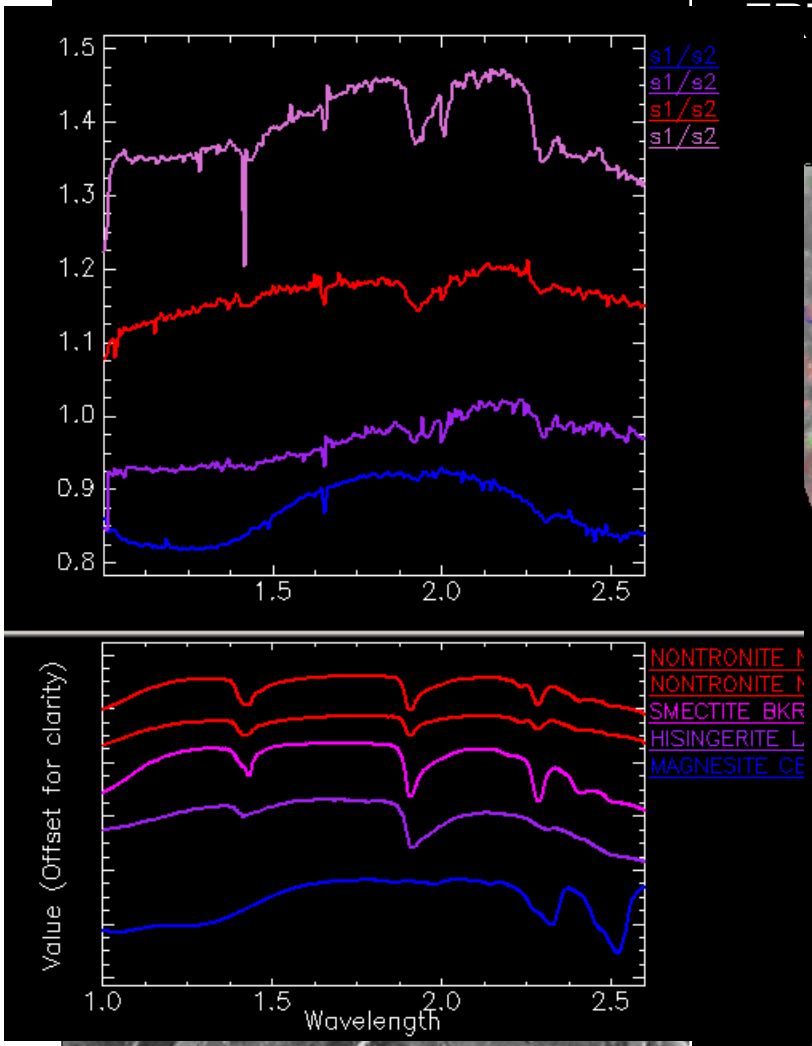

Fe/Mg
B
carbonate/phyllo-
bearing
mafic cap unit


fault/fracture?
layered carbonate-phyllosilicate bearing deposits
100 m

Stratigraphy of carbonate-phyllosilicate-olivine mineral assemblages



Kaolinite-smectite stratigraphy



FRT000088D0

FRT00009D44

T0000BEC0

2-Light crater 57m

1-Top layer 36m

Kaolinite

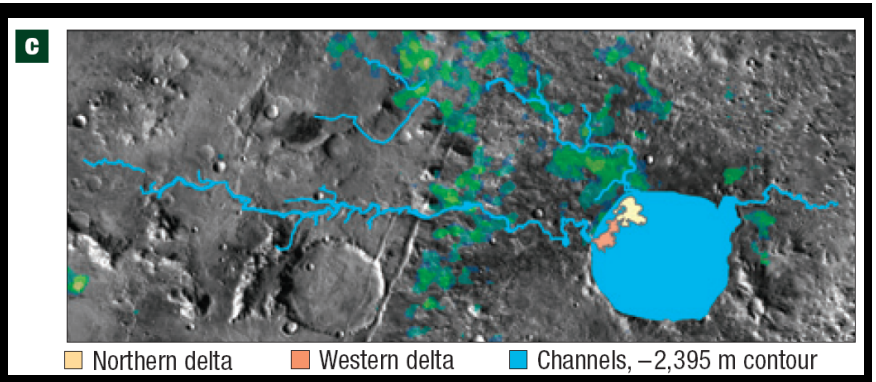
Hydration Band

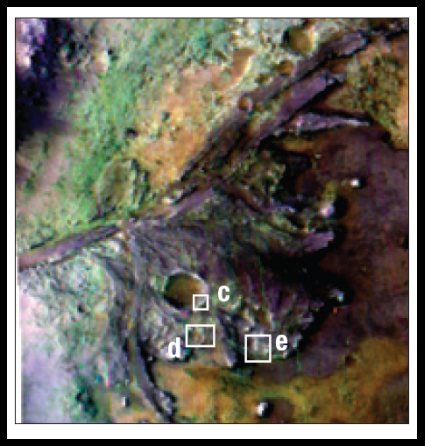
Fe/Mg Smectite

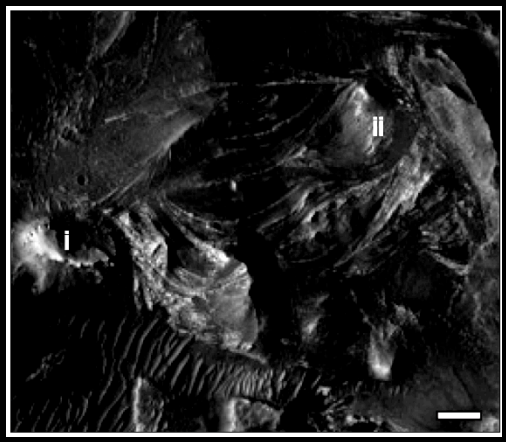
3. Jezero crater

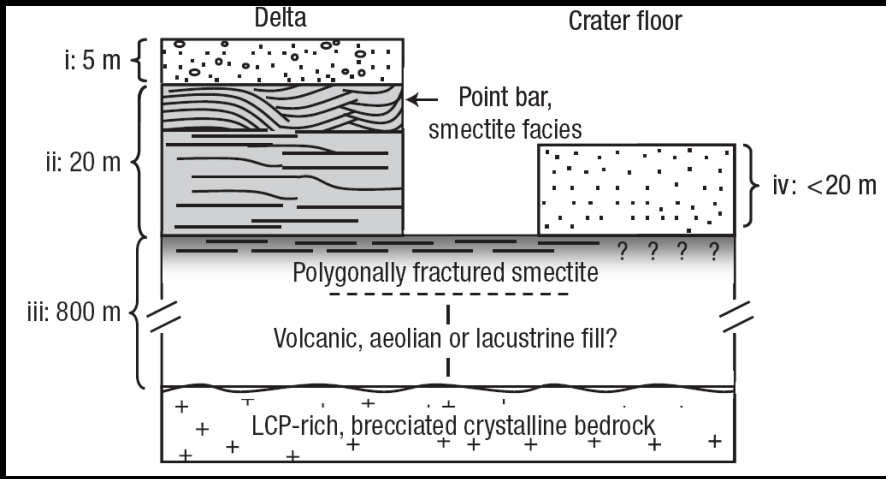
Ehlmann, et al., 2008, *Nature Geoscience*

- Transported smectites (+2.3/2.5 um ite) make up the Jezero deltas.
  - More coherent cap unit which is spectrally bland has helped to preserve the delta against erosion
- Two periods of regional aqueous activity:
  - (in agreement with Mangold et al., 2007)
  - 1) Early smectite forming period
  - 2) Post-Isidis period of fluvial activity (?- to Late Hesperian) which transported the smectites into Jezero
- May be ideal setting for sequestering any organics









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