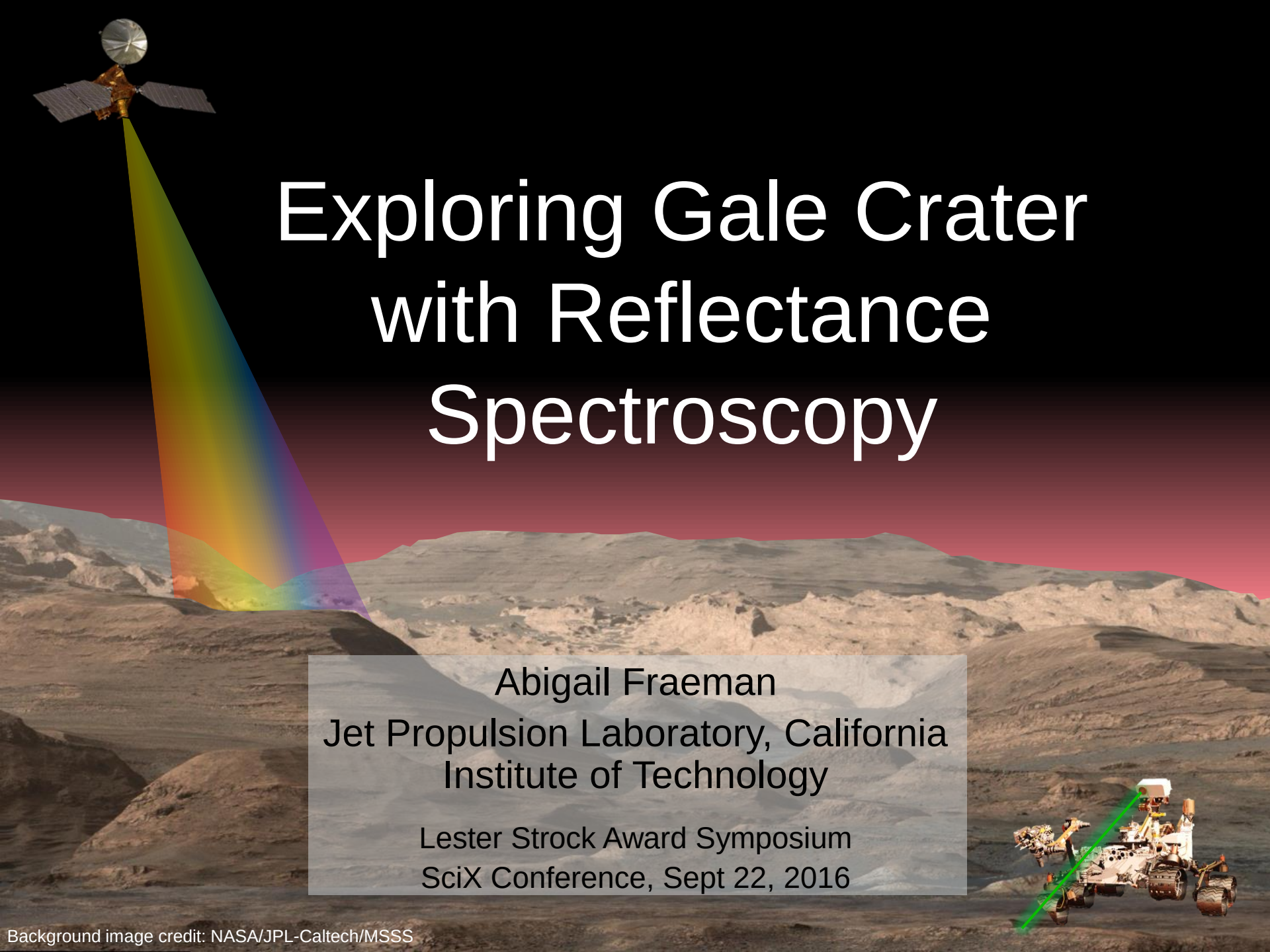


Exploring Gale Crater with Reflectance Spectroscopy

Abigail Fraeman
Jet Propulsion Laboratory, California Institute of Technology

Lester Strock Award Symposium
SciX Conference, Sept 22, 2016

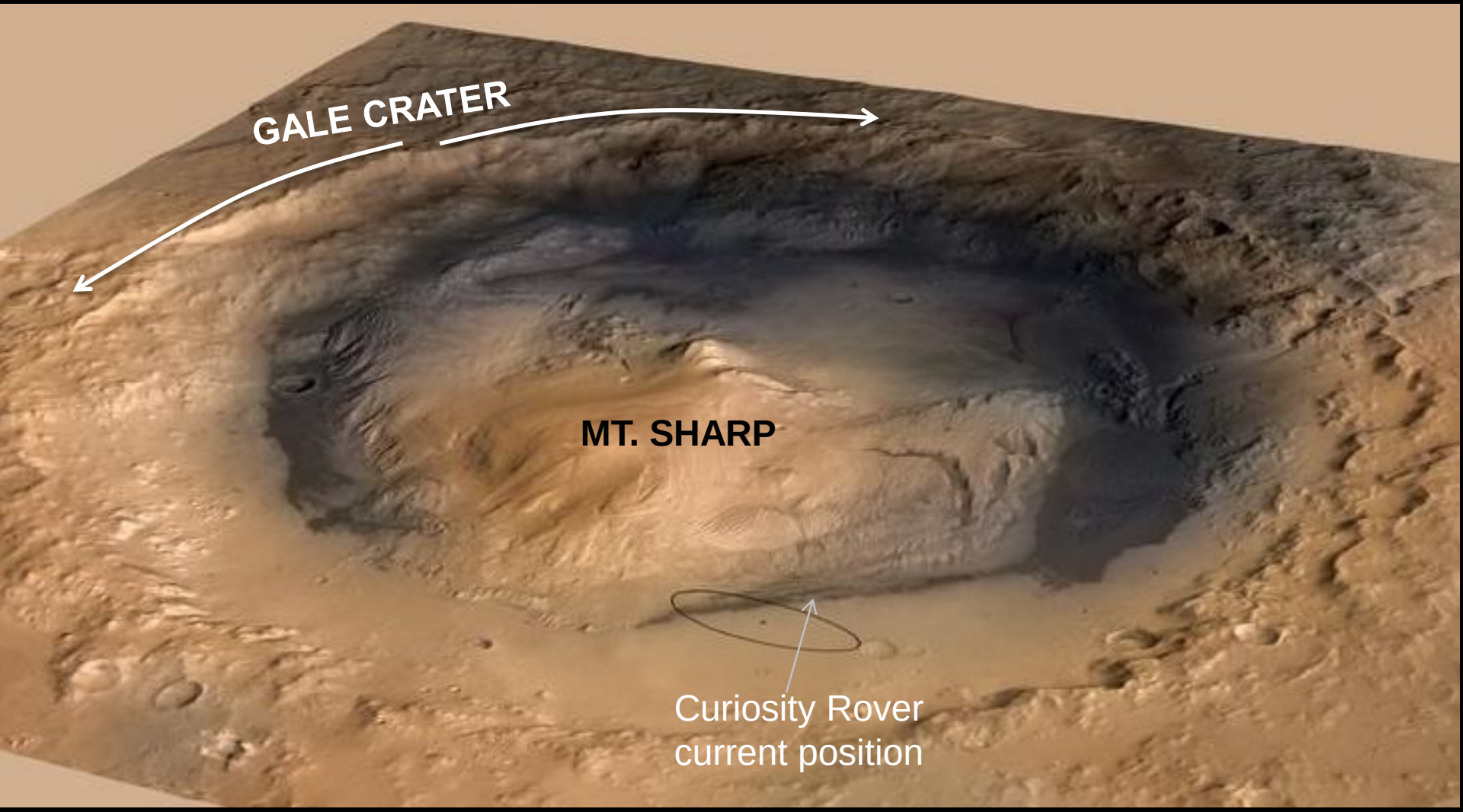
Background image credit: NASA/JPL-Caltech/MSSS

Acknowledgments

- This work would not be possible without the discussion and support from hundreds of people on the Curiosity and Mars Reconnaissance Orbiter science and engineering teams
- … of course need to single out one team member in particular!

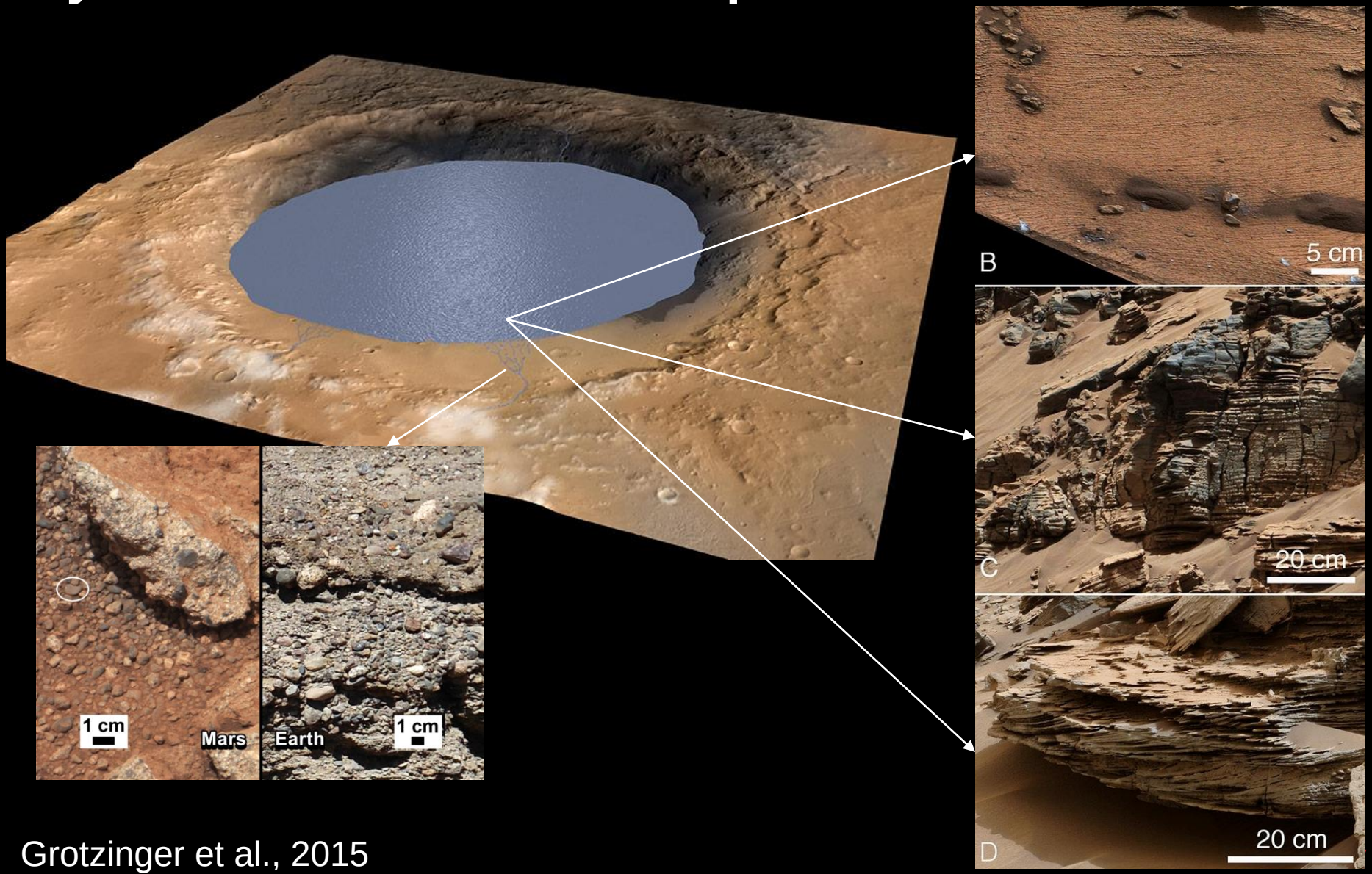
August 2012, 1 day to Curiosity landing

Setting the Scene: Gale Crater and Mt. Sharp



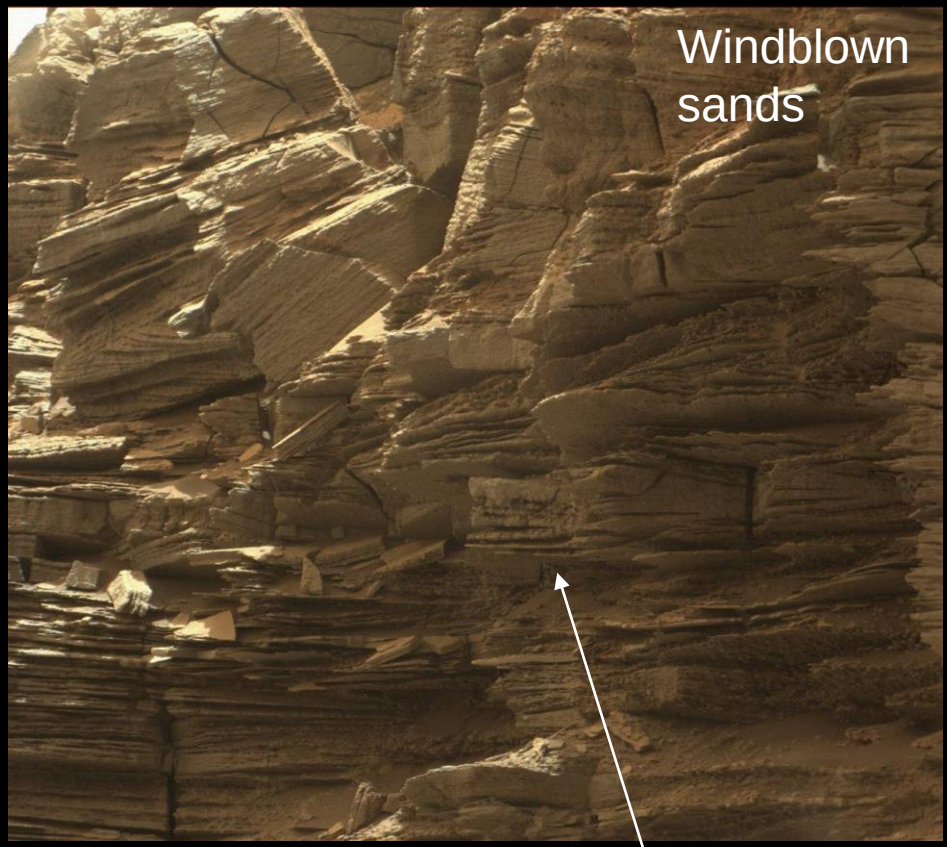
Curiosity's primary scientific goal is to explore and quantitatively assess a local region on Mars' surface as a potential habitat for life, past or present

Curiosity observations have shown lower layers are river and lake deposits

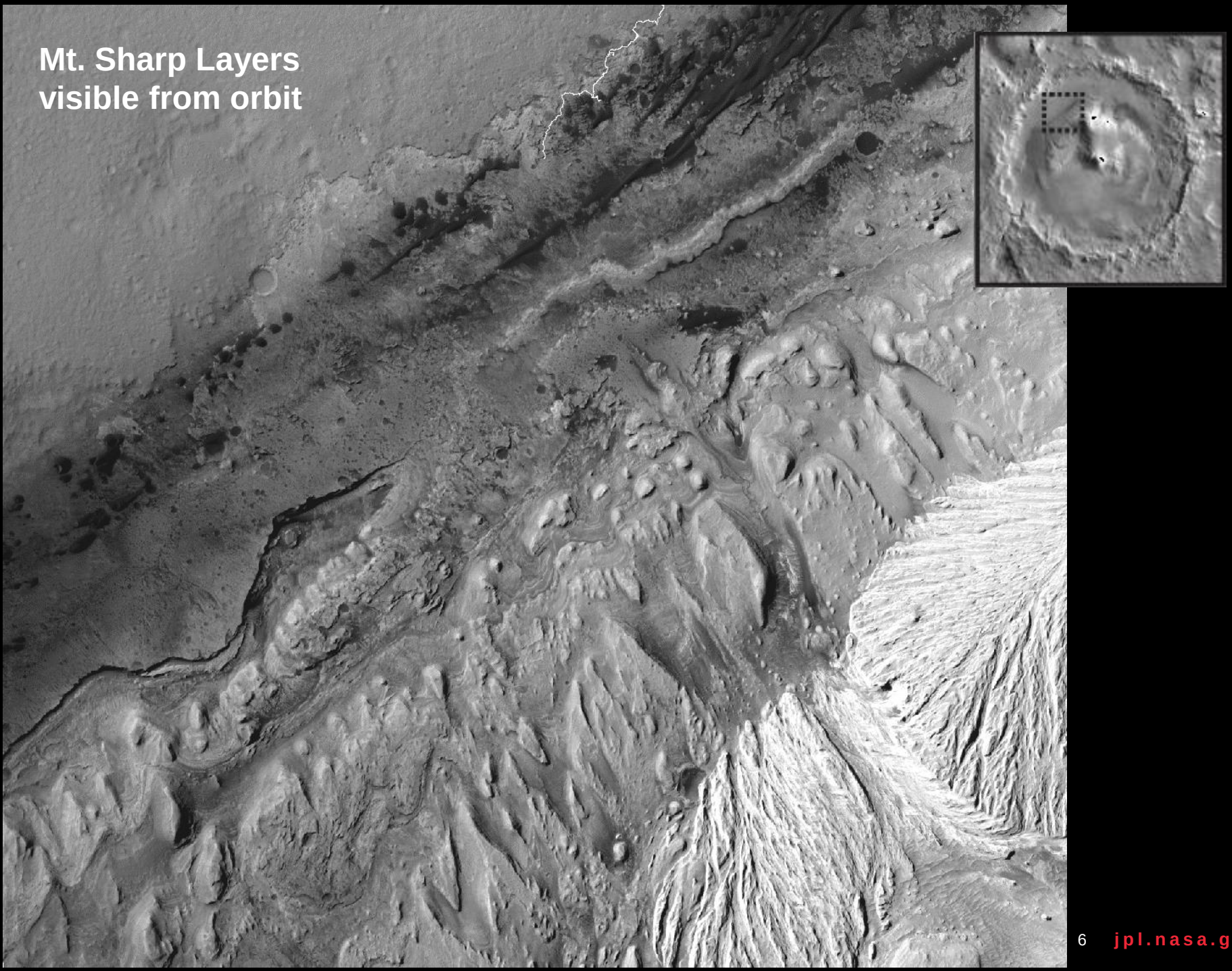


Grotzinger et al., 2015

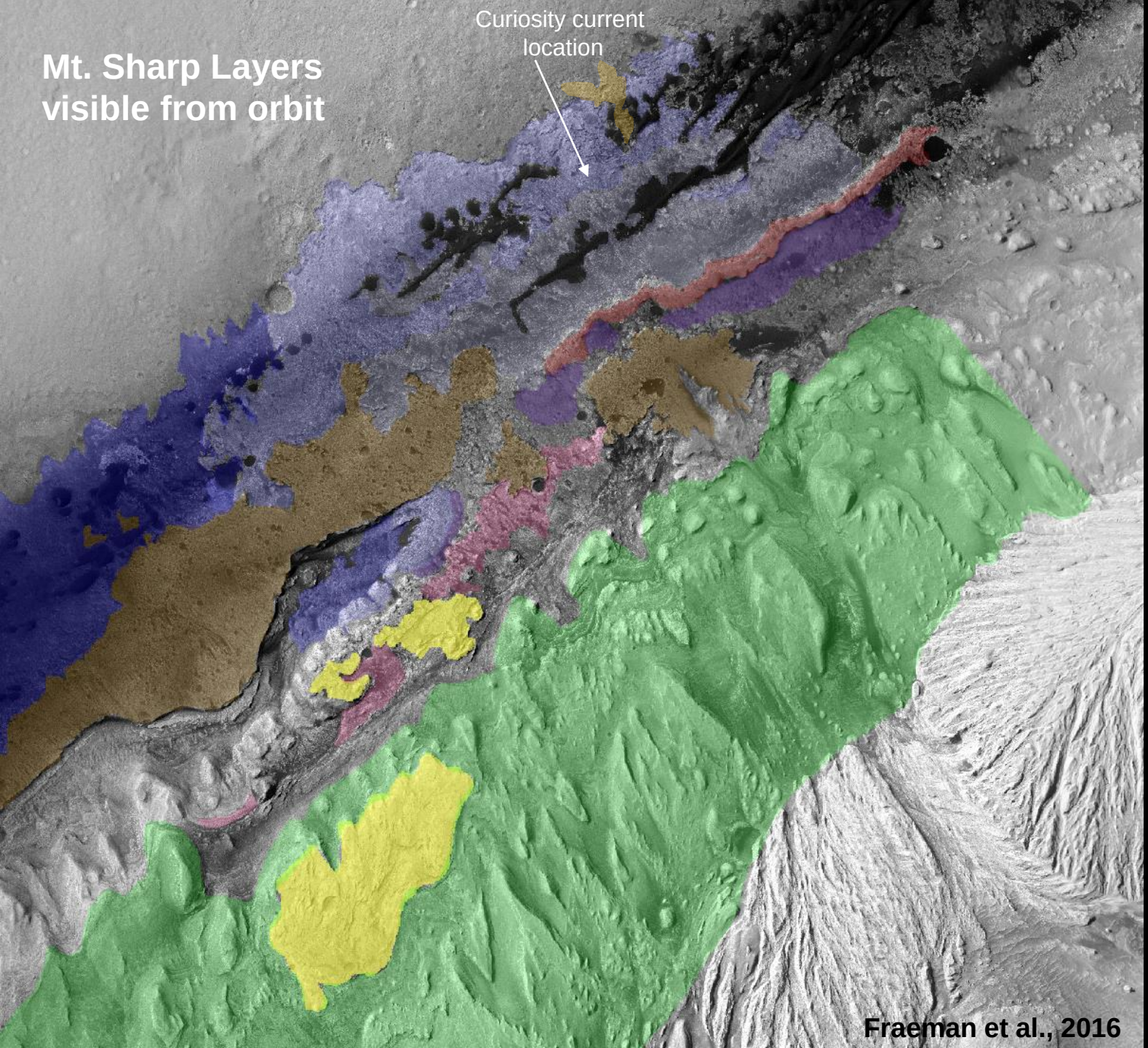
Lake beds are overlain by fossilized, windblow sands implying complex history of burial and erosion



Mt. Sharp Layers visible from orbit

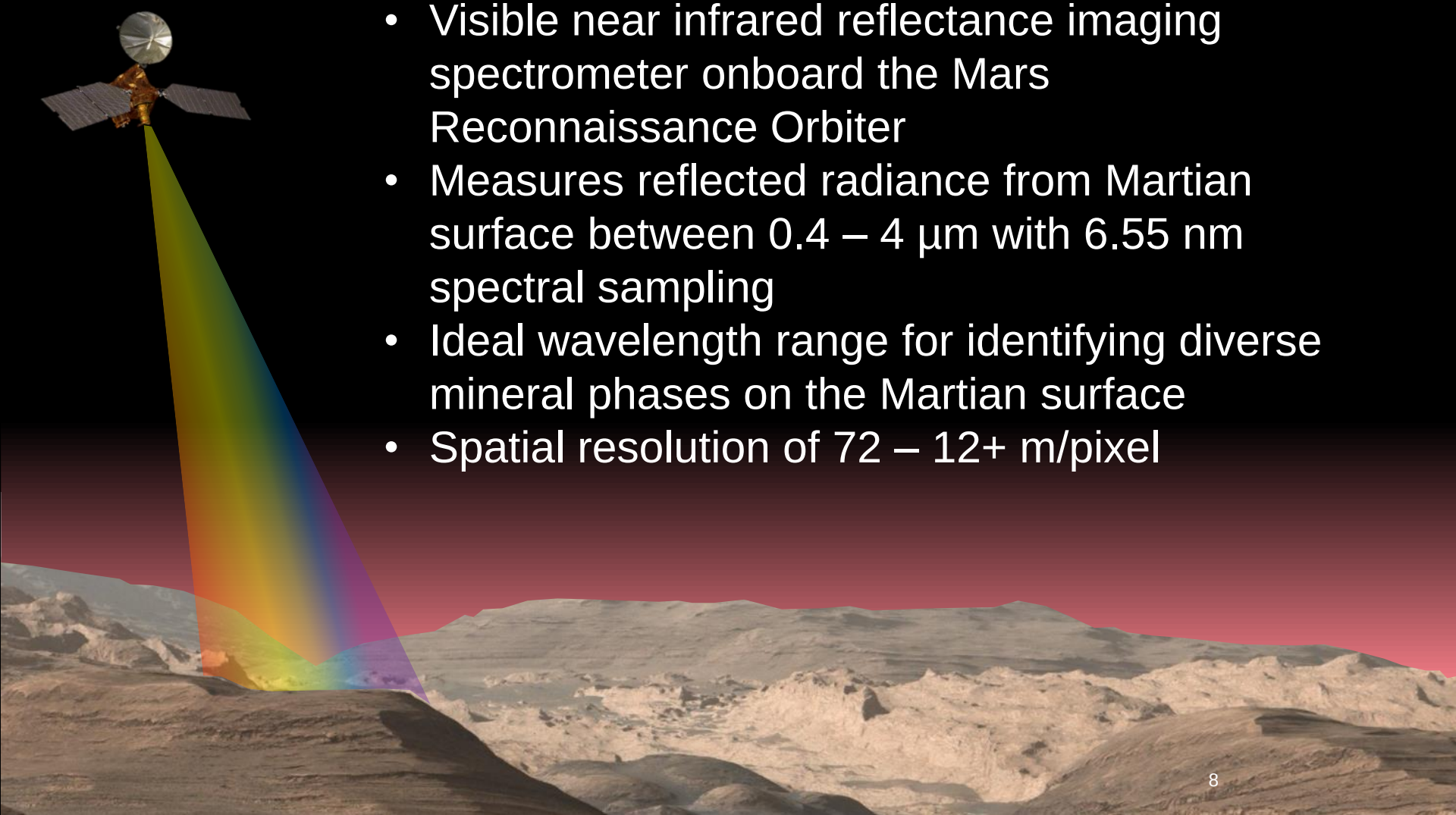


Mt. Sharp Layers visible from orbit



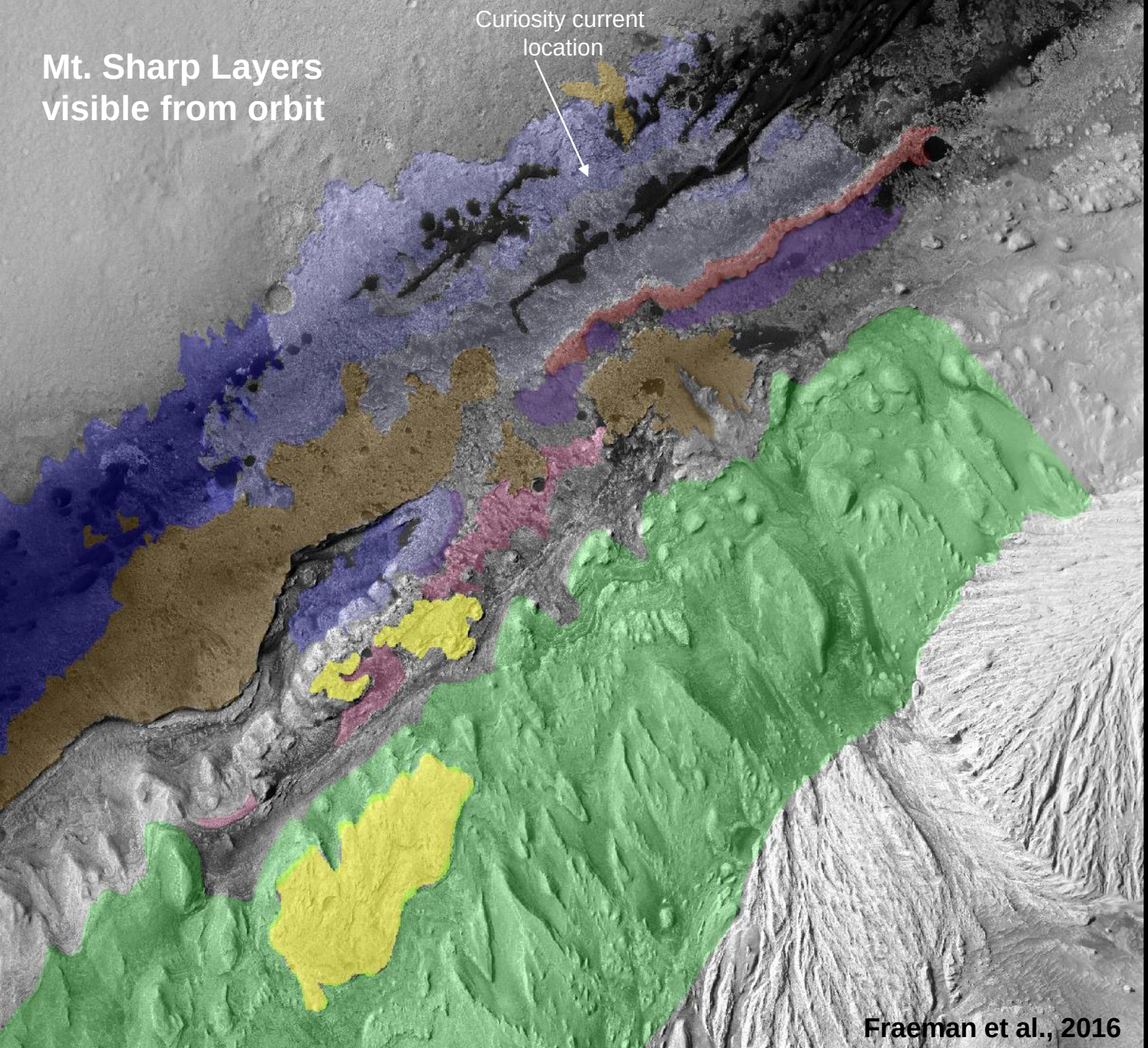
Fraeman et al., 2016

Compact Reconnaissance Imaging Spectrometer for Mars (CRISM)



- Visible near infrared reflectance imaging spectrometer onboard the Mars Reconnaissance Orbiter
- Measures reflected radiance from Martian surface between 0.4 – 4 µm with 6.55 nm spectral sampling
- Ideal wavelength range for identifying diverse mineral phases on the Martian surface
- Spatial resolution of 72 – 12+ m/pixel

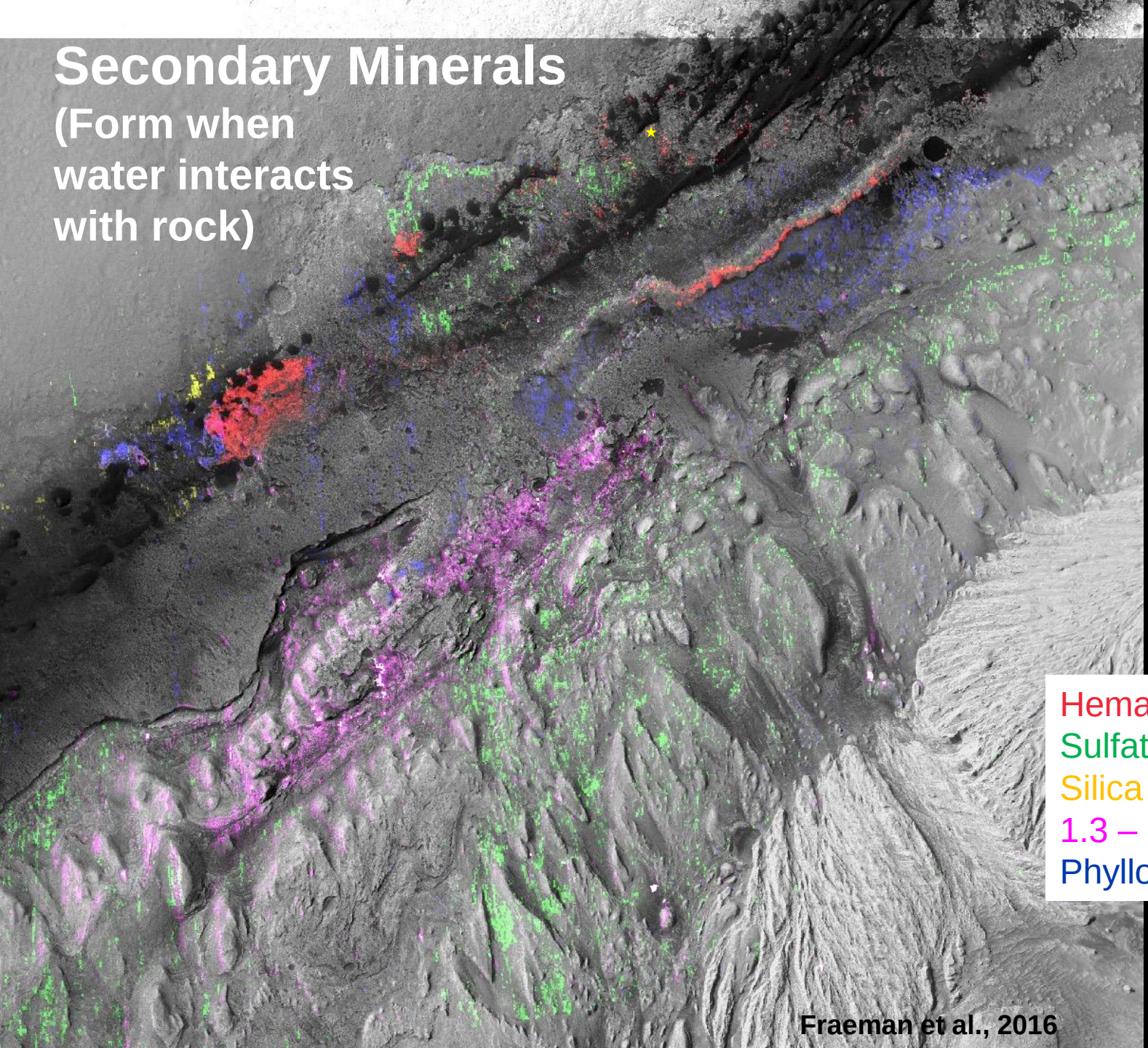
Mt. Sharp Layers visible from orbit



Fraeman et al., 2016

Secondary Minerals

(Form when water interacts with rock)

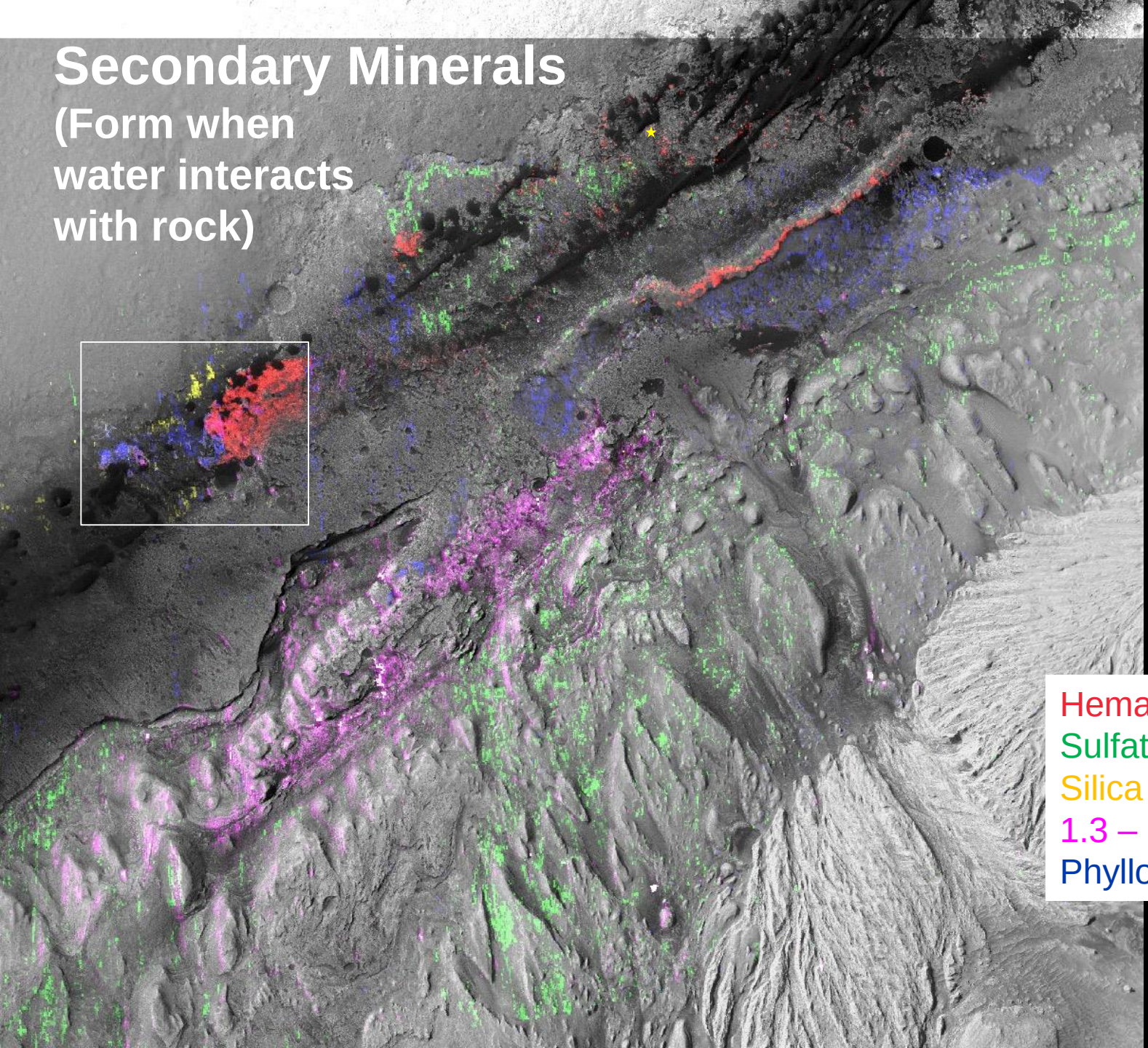


Hematite
Sulfate
Silica
1.3 – 1.6 um slope
Phyllosilicate

Fraeman et al., 2016

Secondary Minerals

(Form when water interacts with rock)



Hematite
Sulfate
Silica
1.3 – 1.6 um slope
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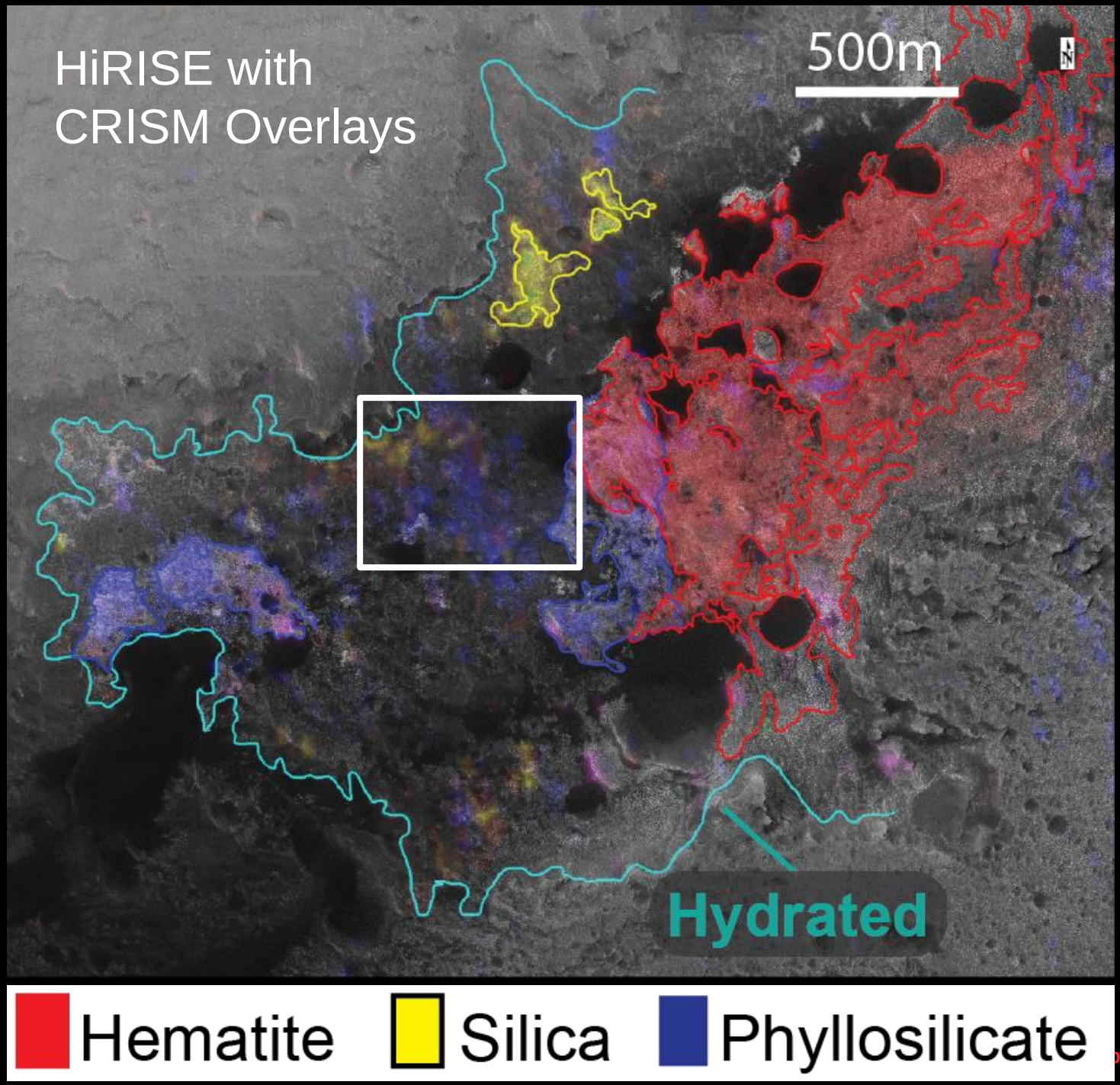
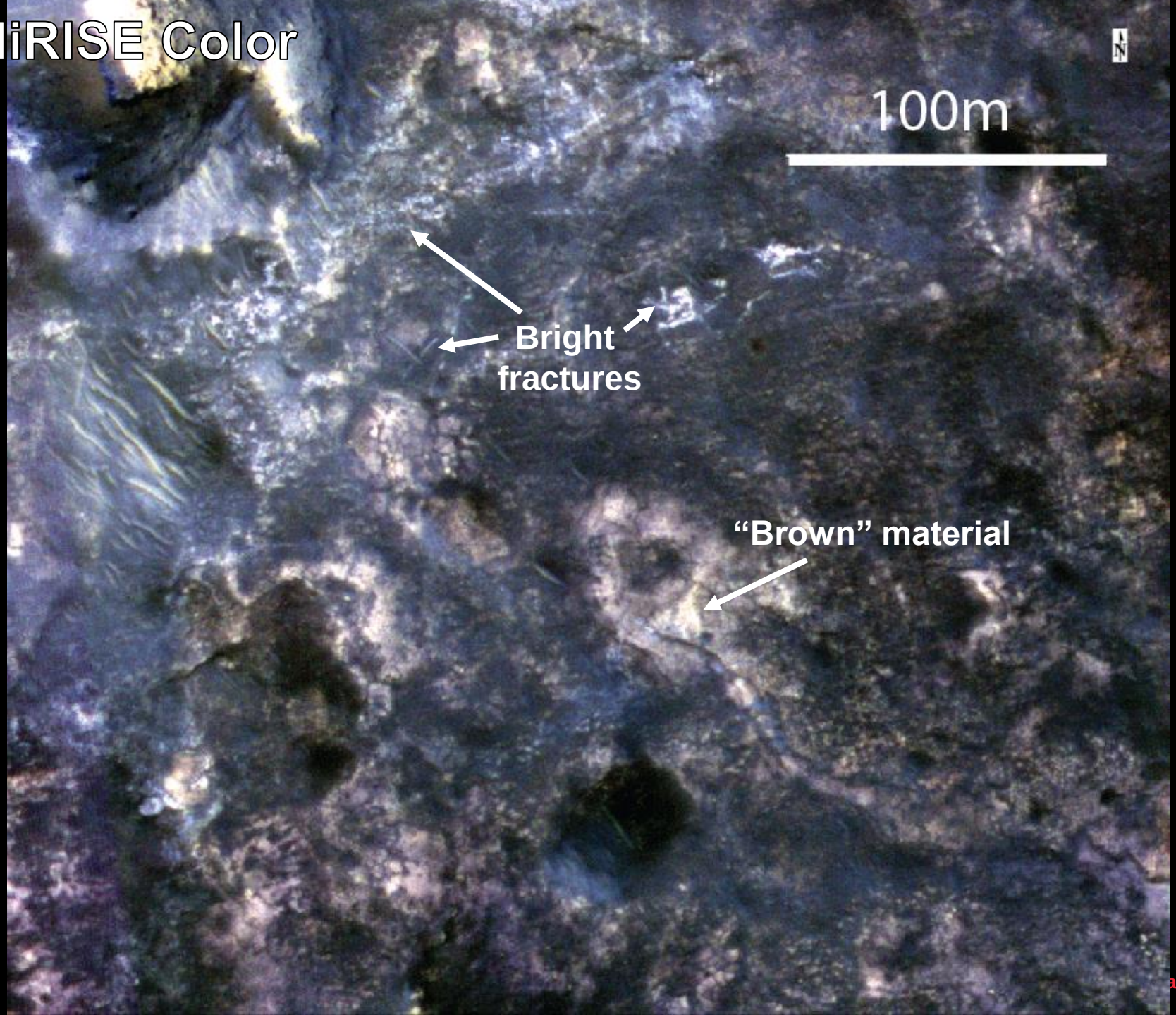
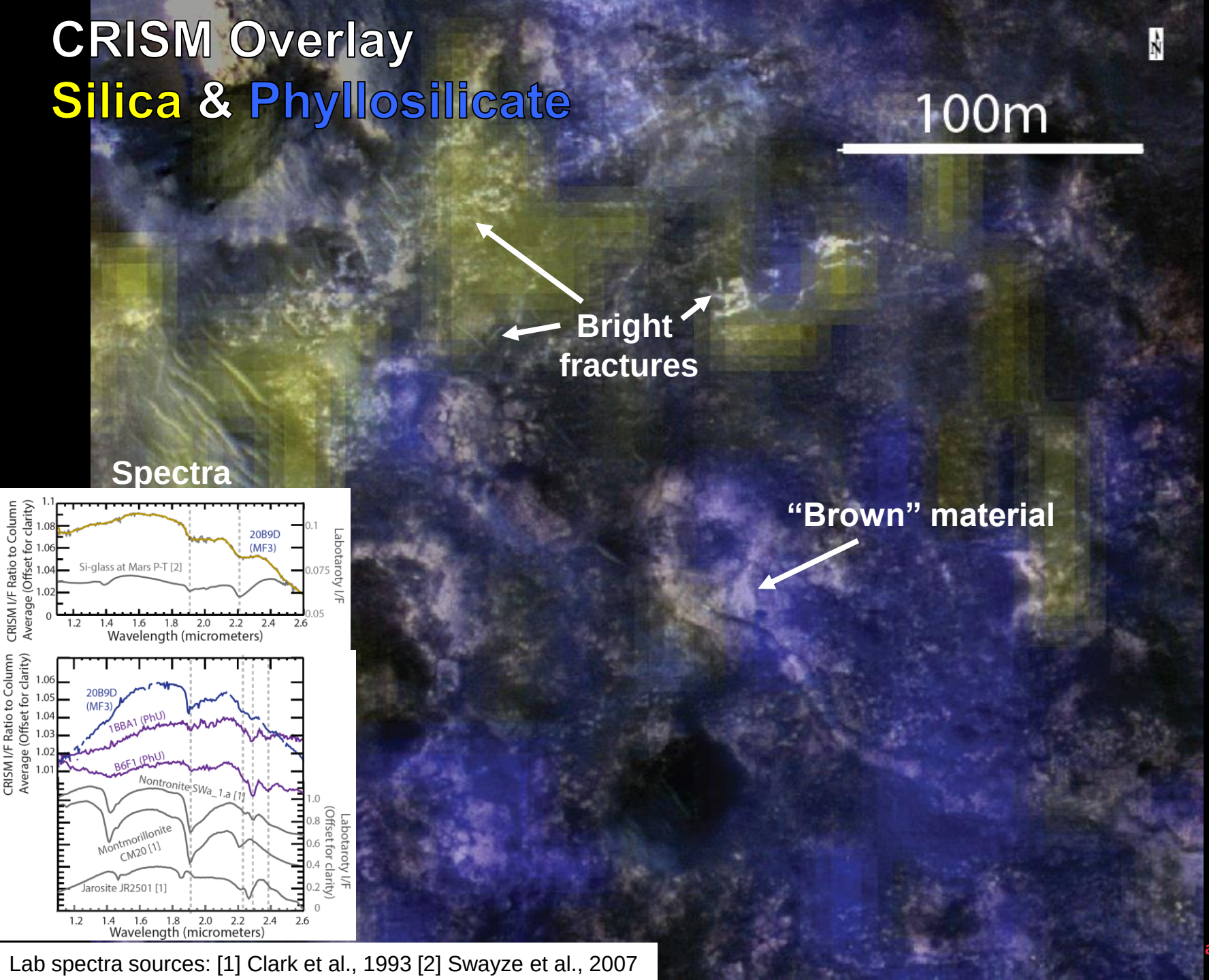

HiRISE with
CRISM Overlays
500m
N
Hydrated
Hematite
Silica
Phyllosilicate

HiRISE Color



a.gov

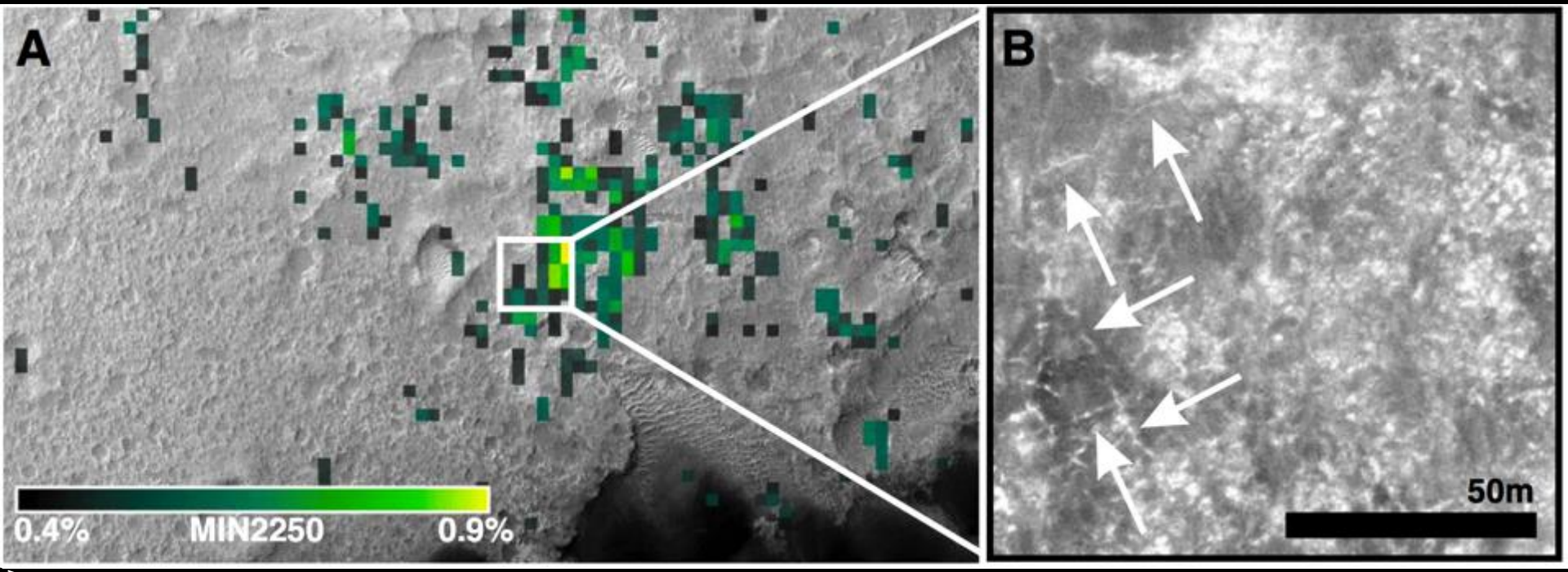
CRISM Overlay
Silica & Phyllosilicate



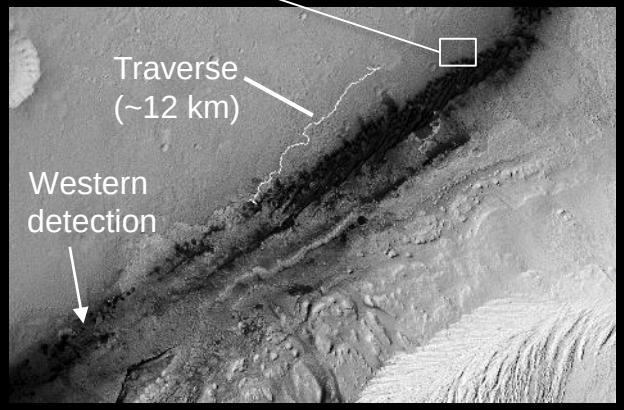
Lab spectra sources: [1] Clark et al., 1993 [2] Swayze et al., 2007

a.gov

Similar Hydrated Si-textures in the NE

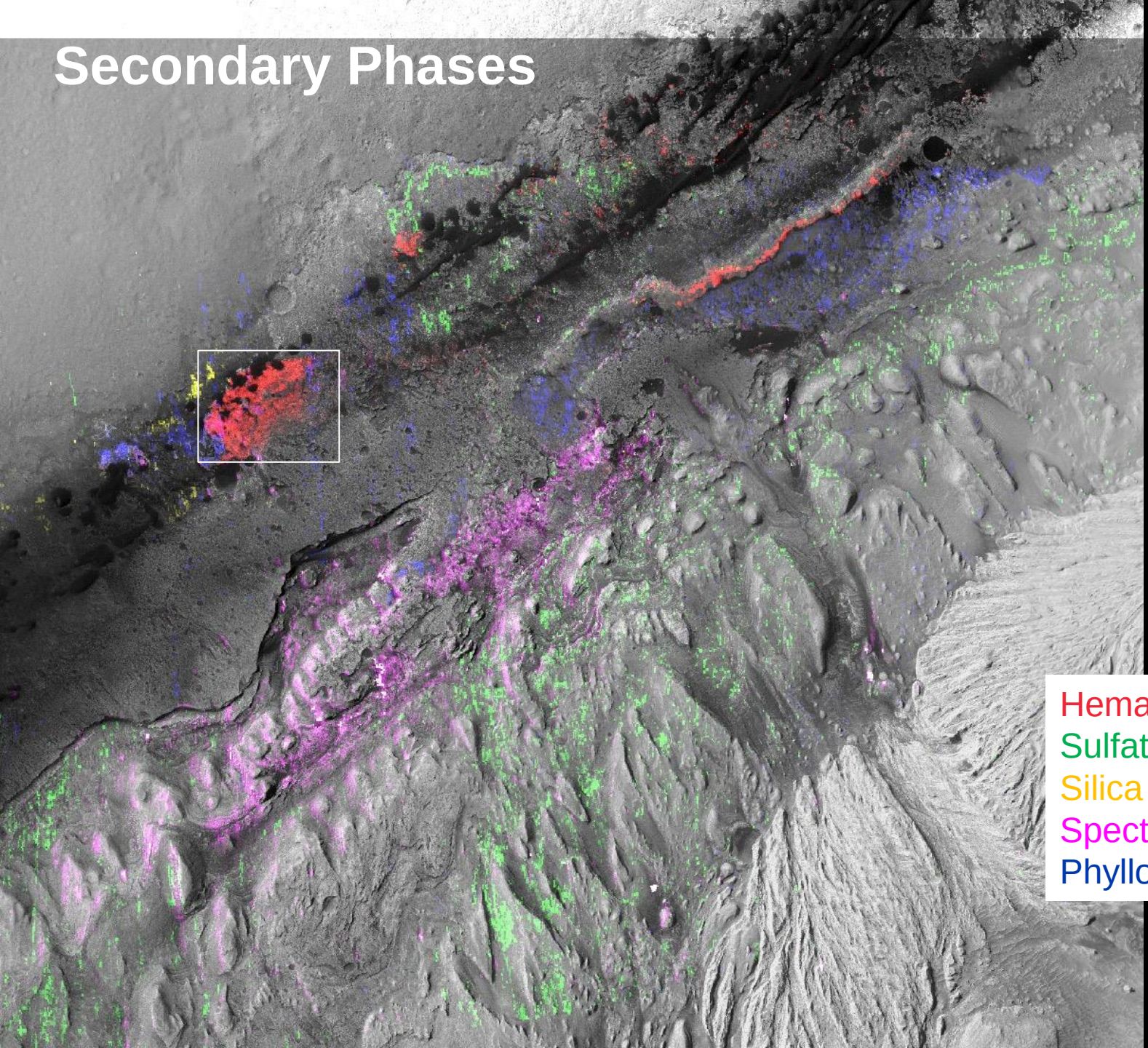


2.2 µm band depth map, Seelos et al., 2014

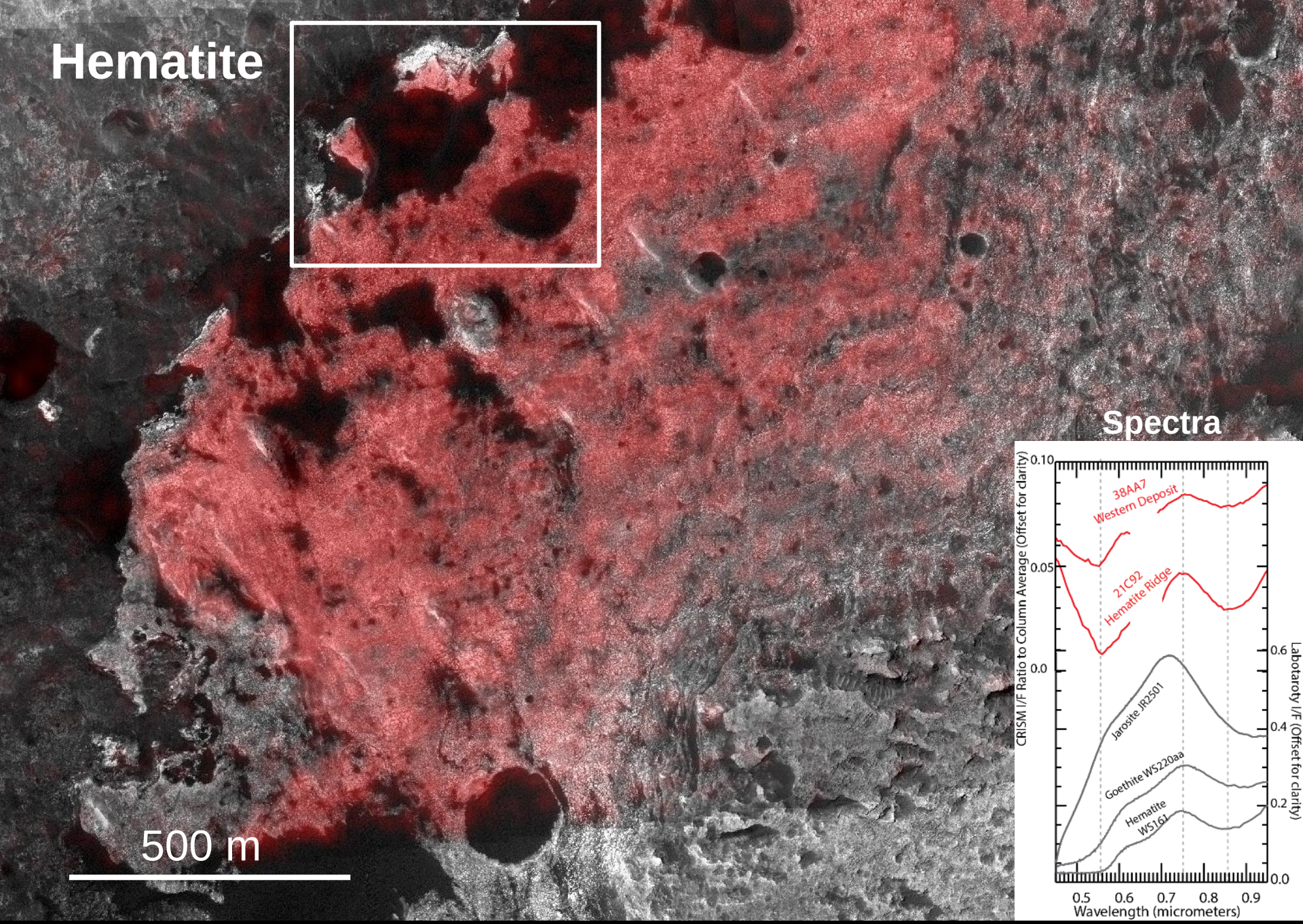


- Spectral signature of hydroxylated silica associated with polygonal fractured light toned terrain near base of Murray formation
- Outcrop large enough to resolve with FRT CRISM data
- Relationship between this outcrop and Murray formation unclear due to dune field cover

Secondary Phases

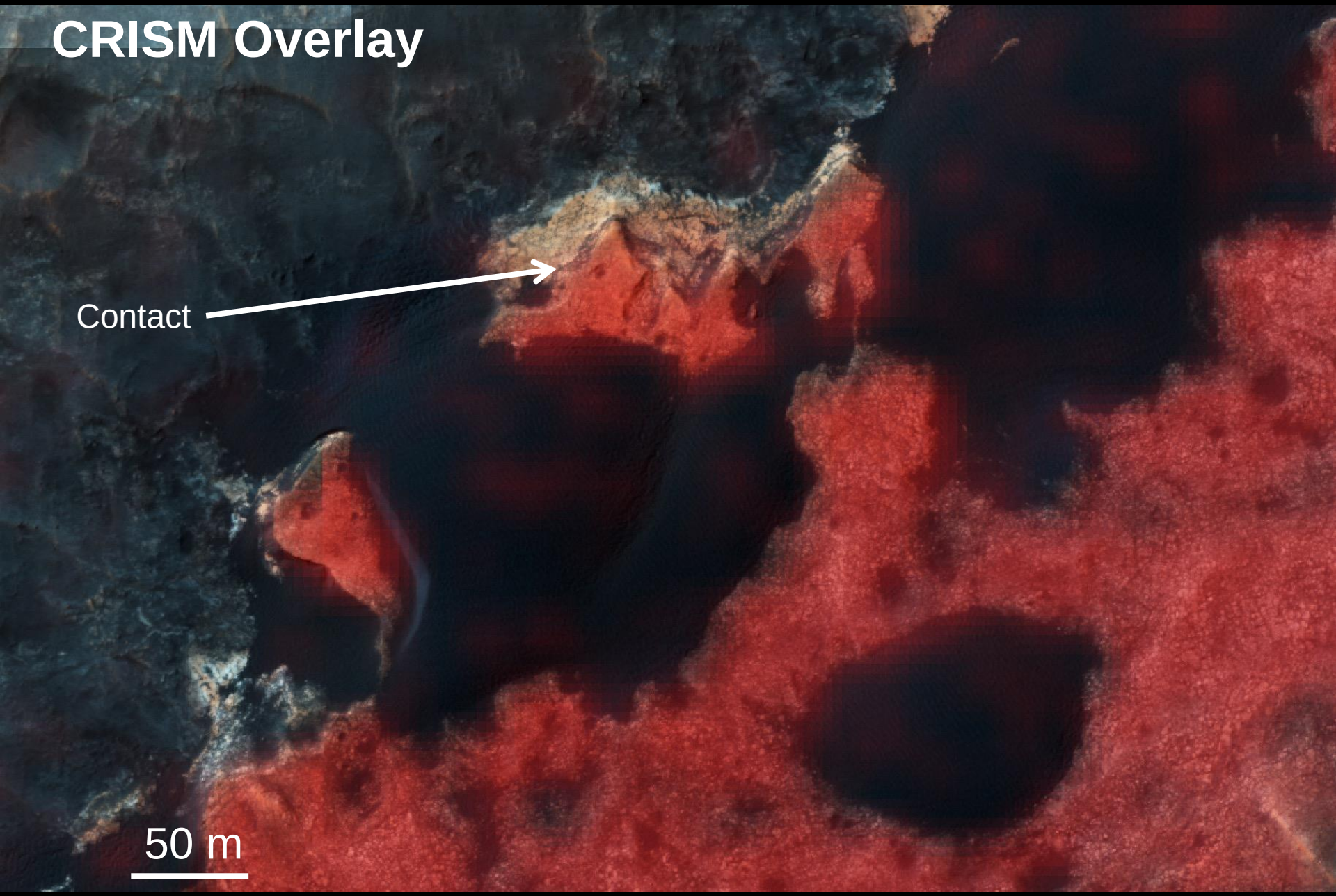


Hematite

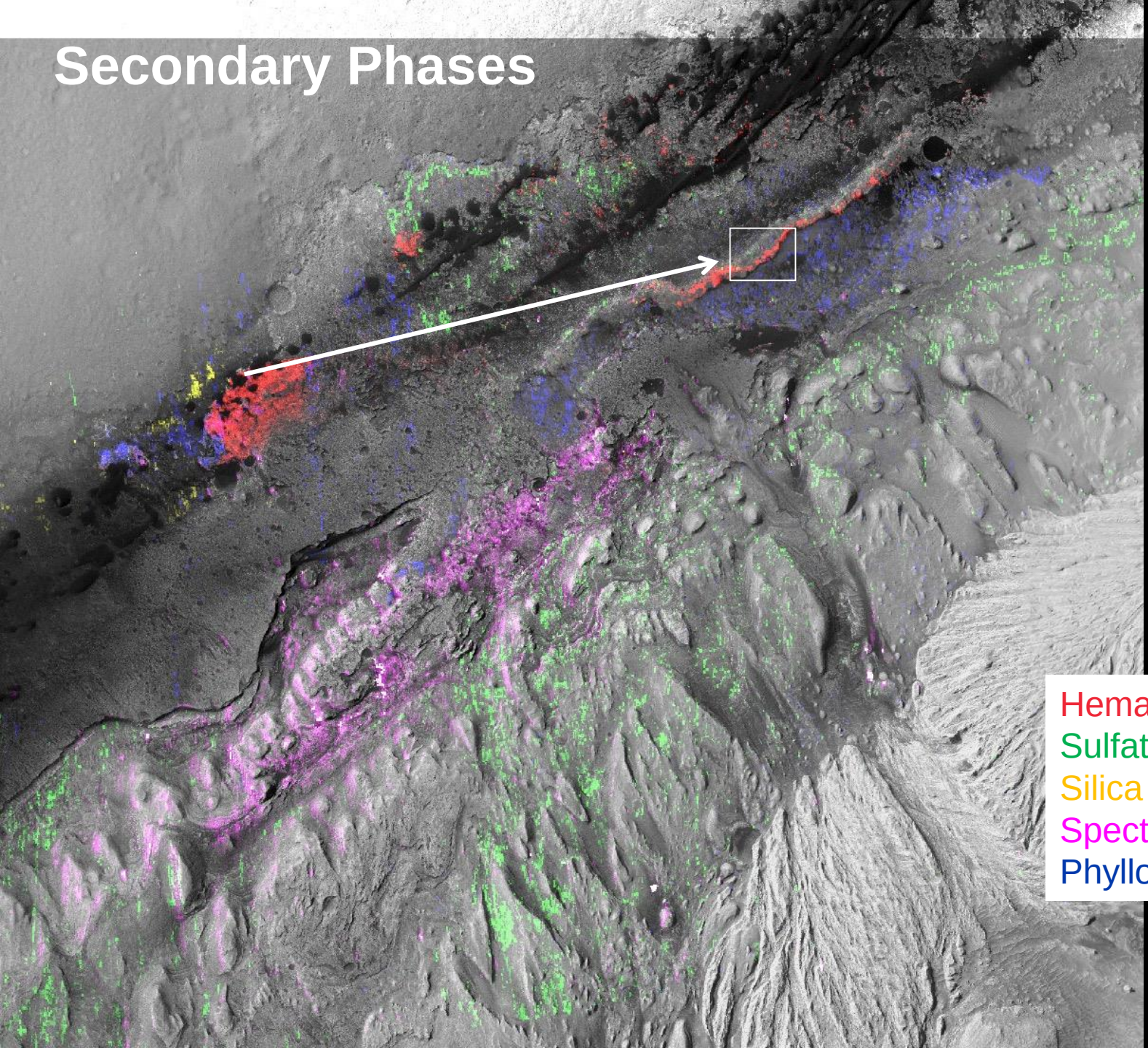

500 m
Spectra
38AA7
Western Deposit
21C92
Hematite Ridge
Jarosite JR2501
Goethite WS220aa
Hematite
WS161
CRISM I/F Ratio to Column Average (Offset for clarity)
Labotaroty I/F (Offset for clarity)
Wavelength (micrometers)
0.10
0.05
0.0
0.6
0.4
0.2
0.0
0.5
0.6
0.7
0.8
0.9

HiRISE Color

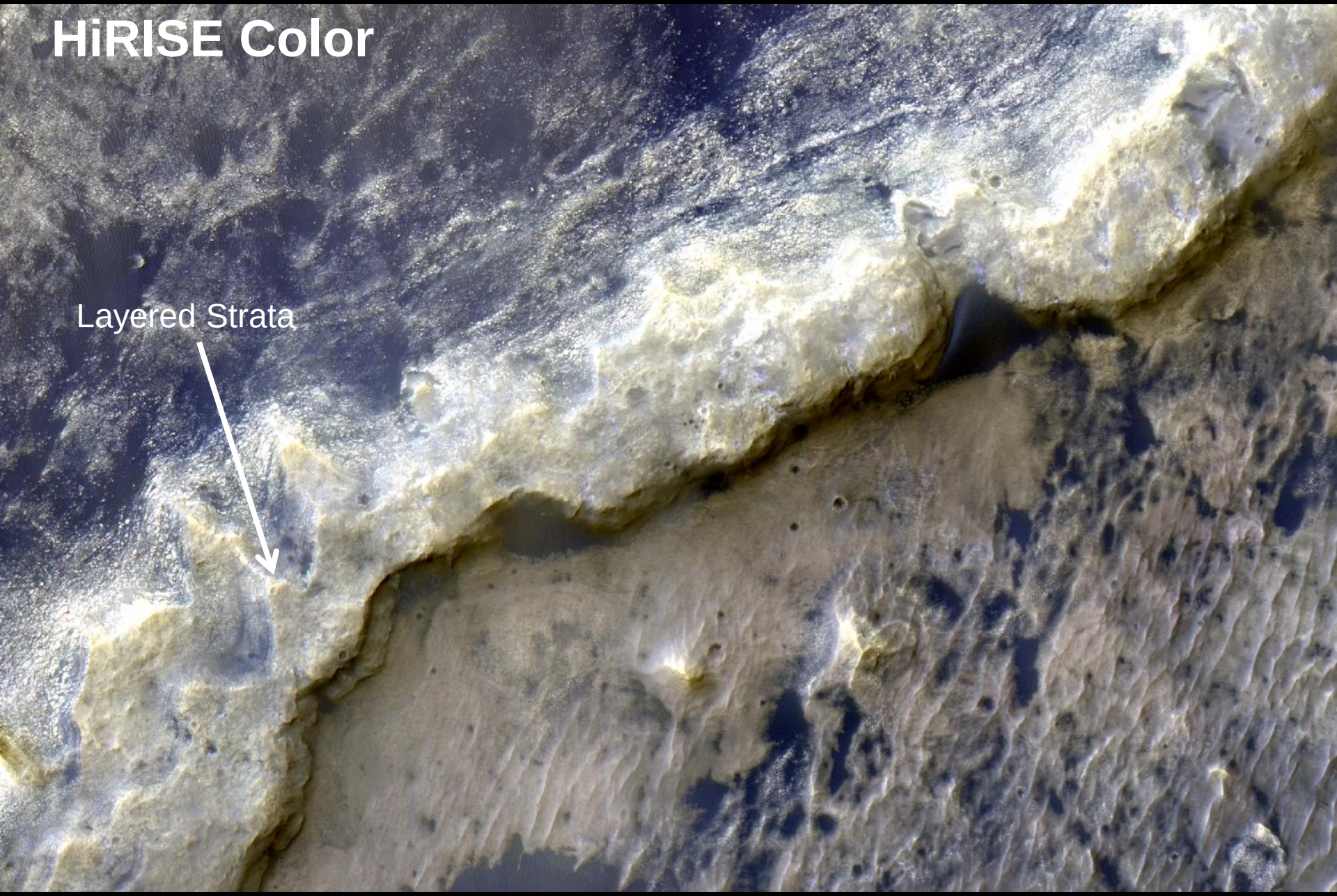
CRISM Overlay



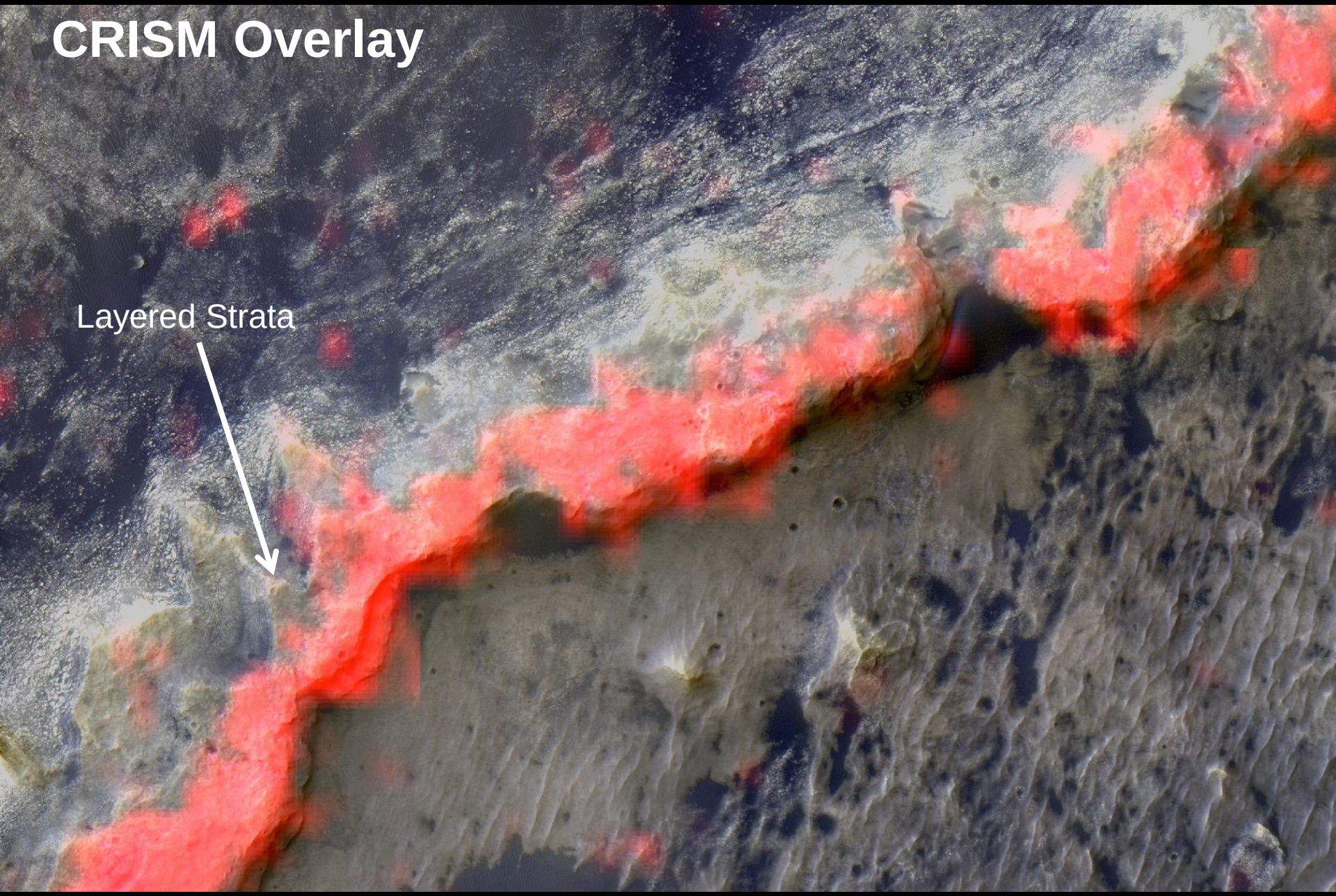
Secondary Phases

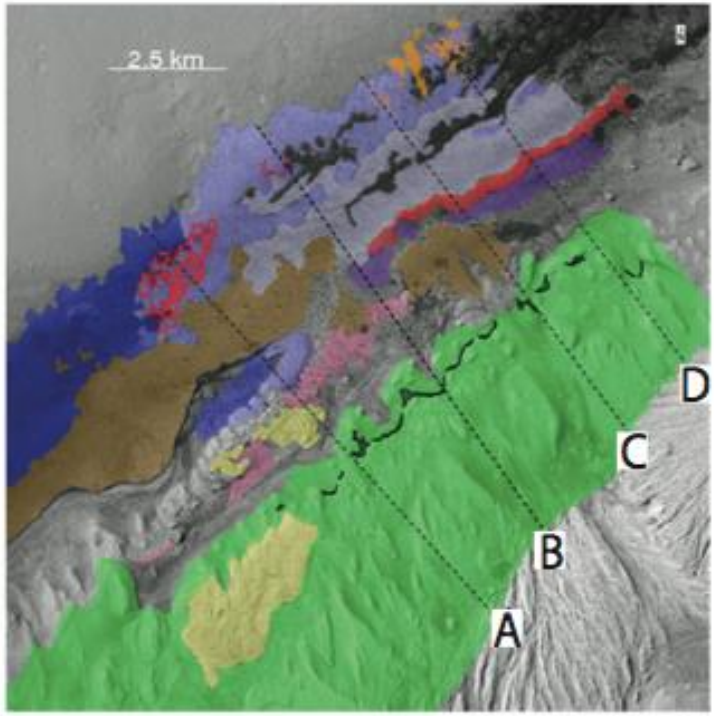


HiRISE Color



CRISM Overlay





SICCAR POINT GROUP

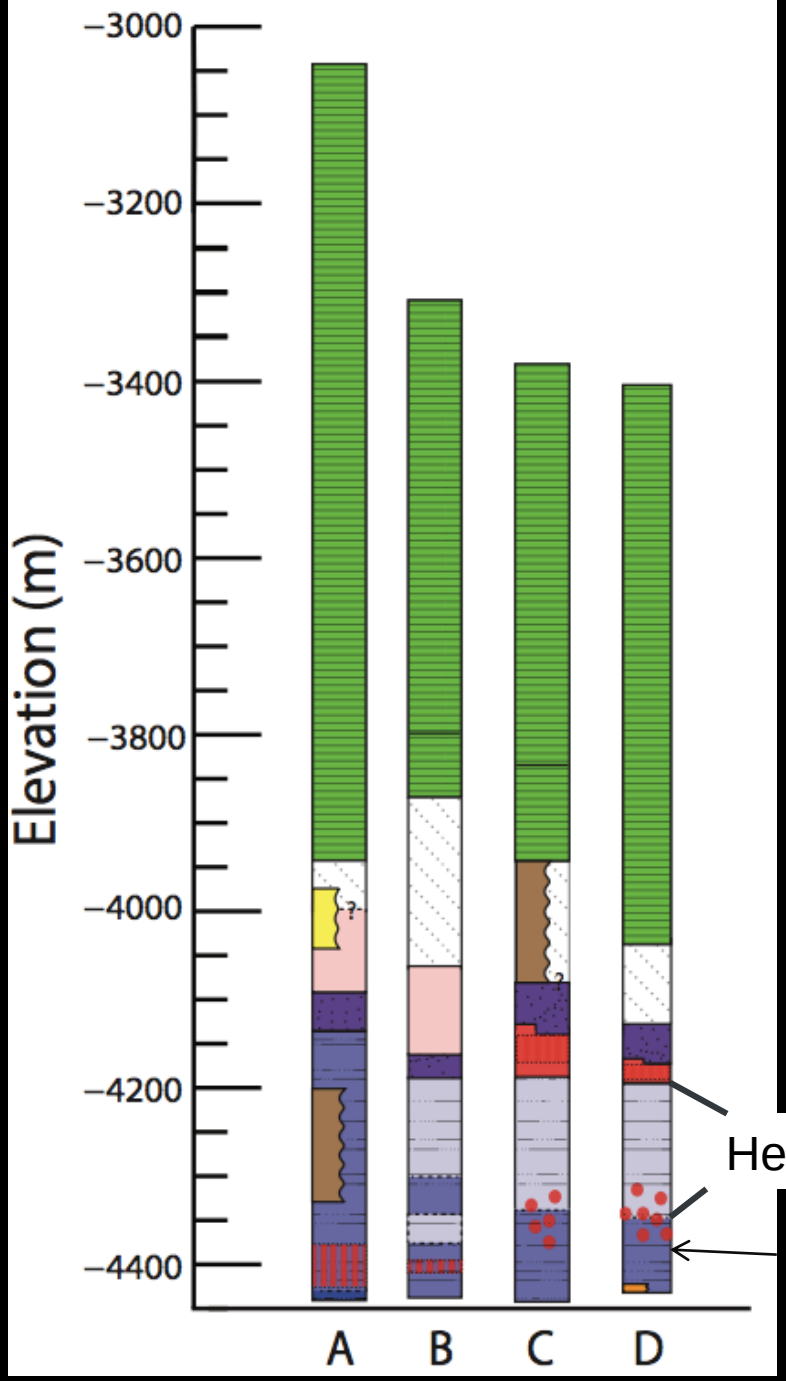
- High TI Unit 1 (HTI1)
- High TI Unit 2 (HTI2)
- Stimson formation*

MT SHARP GROUP

- Layered Sulfate (LS)
- Sub-sulfate (SS)
- Hematite Ridge (HR)
- Phyllosilicate Unit (PhU)
- Murray 2 (MF2)
- Murray 1 (MF1)
- Murray 3 (MF3)

- Marker bed (Milliken et al., 2010)
- Large hematite deposits
- Weak hematite signature
- Not mapped
- Unconformity
- Relative timing uncertain

*Stimson formation defined based on mapping using Curiosity imaging data in *Grotzinger et al.*, 2015 & *Watkins et al.*, 2016.



Fraeman et al., submitted

Key Questions:

1. What process drove localized iron oxide formation?
2. What is the timing of iron oxide formation with respect to Mt. Sharp?
3. Are the iron oxide site indicative of previously habitable environments?

Forming oxidized iron deposits

- Key facts:
  - Reduced iron (Fe^{2+}) is soluble at a range of pH
  - Oxidized iron (Fe^{3+}) is insoluble except in very acidic conditions

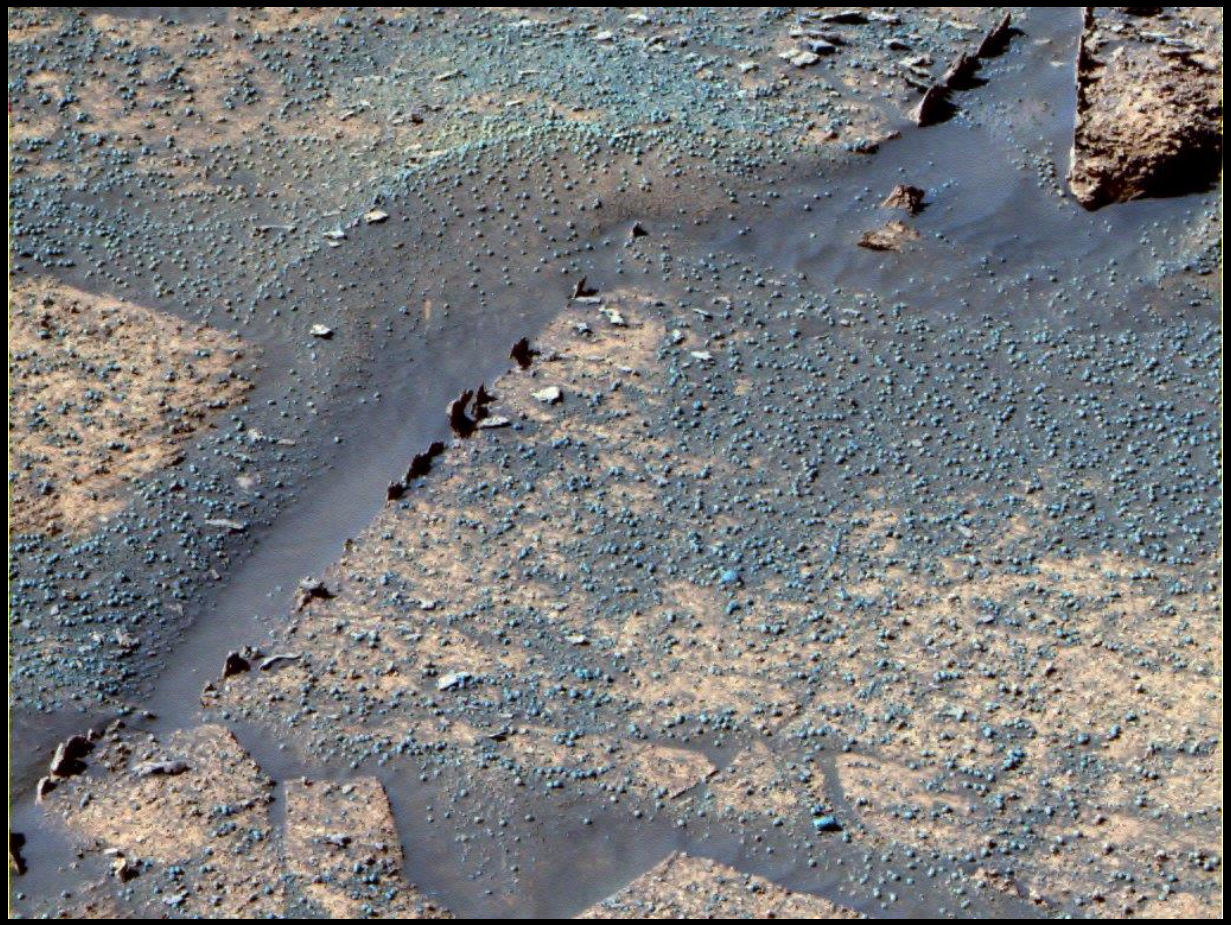
Anoxic groundwater becomes exposed to oxidizing atmosphere

Chalybeate spring along cedar creek trail in Petit Jean State Park in Arkansas
https://arkansasgeological.wordpress.com/2014/05/

Forming oxidized iron deposits

- Key facts:
  - Reduced iron (Fe^{2+}) is soluble at a range of pH
  - Oxidized iron (Fe^{3+}) is insoluble except in very acidic conditions

Upwelling anoxic groundwater becomes exposed to oxidizing atmosphere



Hematite "blueberries" at Meridiani Planum

Forming oxidized iron deposits

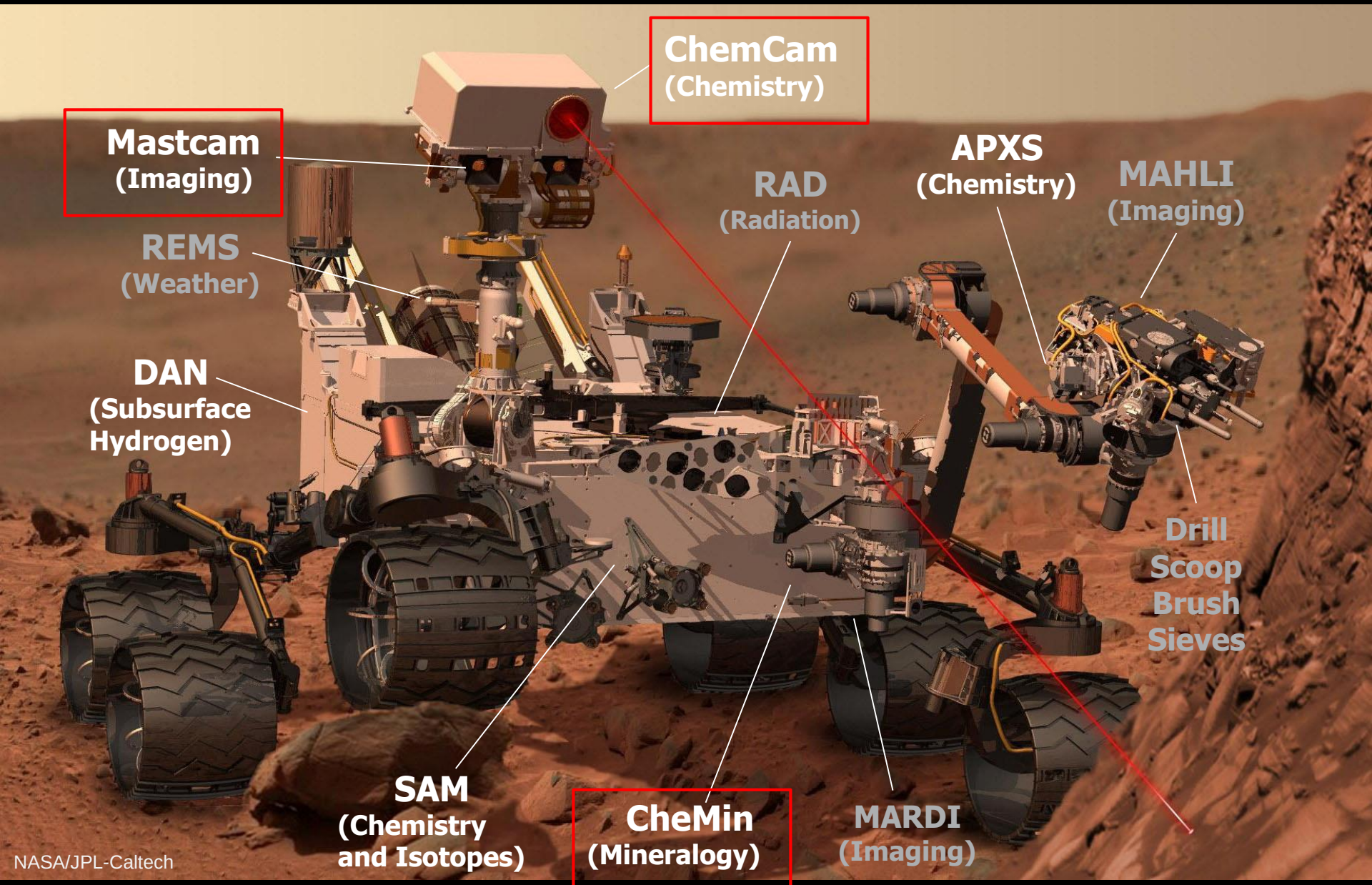
- Key facts:
  - Reduced iron (Fe^{2+}) is soluble at a range of pH
  - Oxidized iron (Fe^{3+}) is insoluble except in very acidic conditions

Banded iron formation = direct precipitation of iron in early earth oceans that were initially reducing but became oxidizing?

Banded iron formation in Karijini National Park in western Australia (Wikipedia)

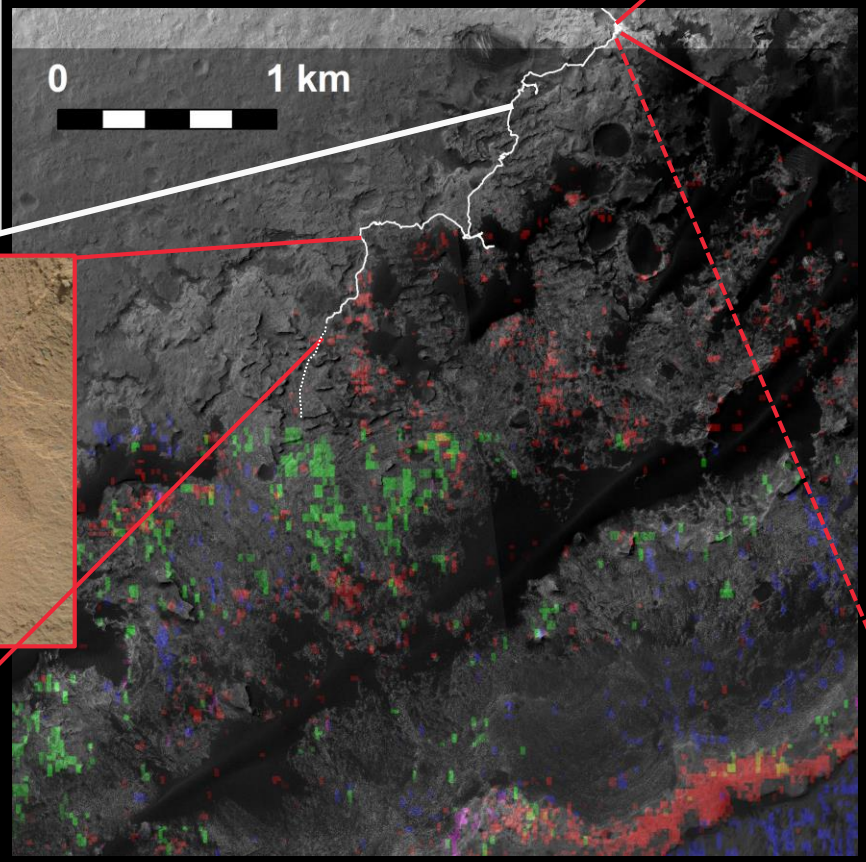
Enter Curiosity

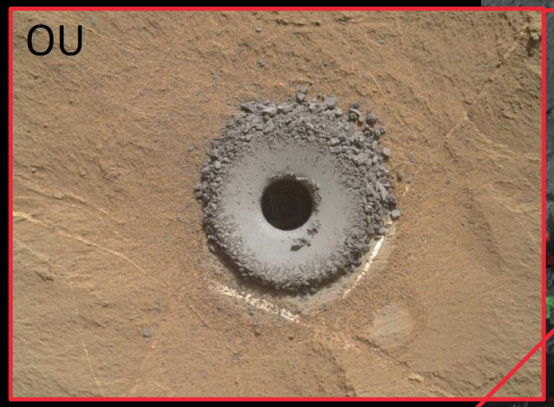
Curiosity Payload (6 spectrometers!)



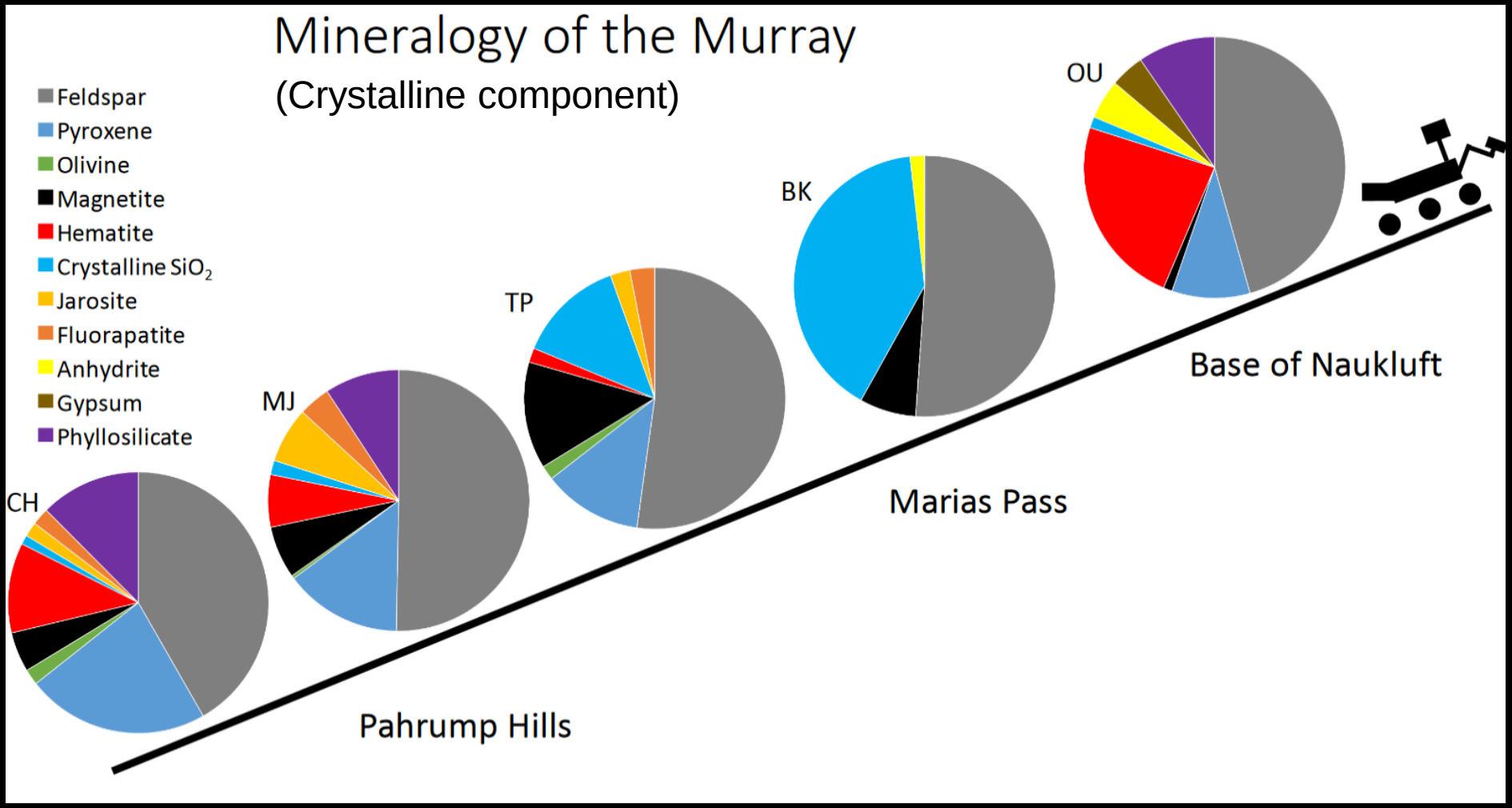
NASA/JPL-Caltech

Mineralogy changes with elevation





CheMin shows 8-20 wt.% hematite in at least four drill locations in Murray (+ minor amounts in Telegraph Peak drill hill)

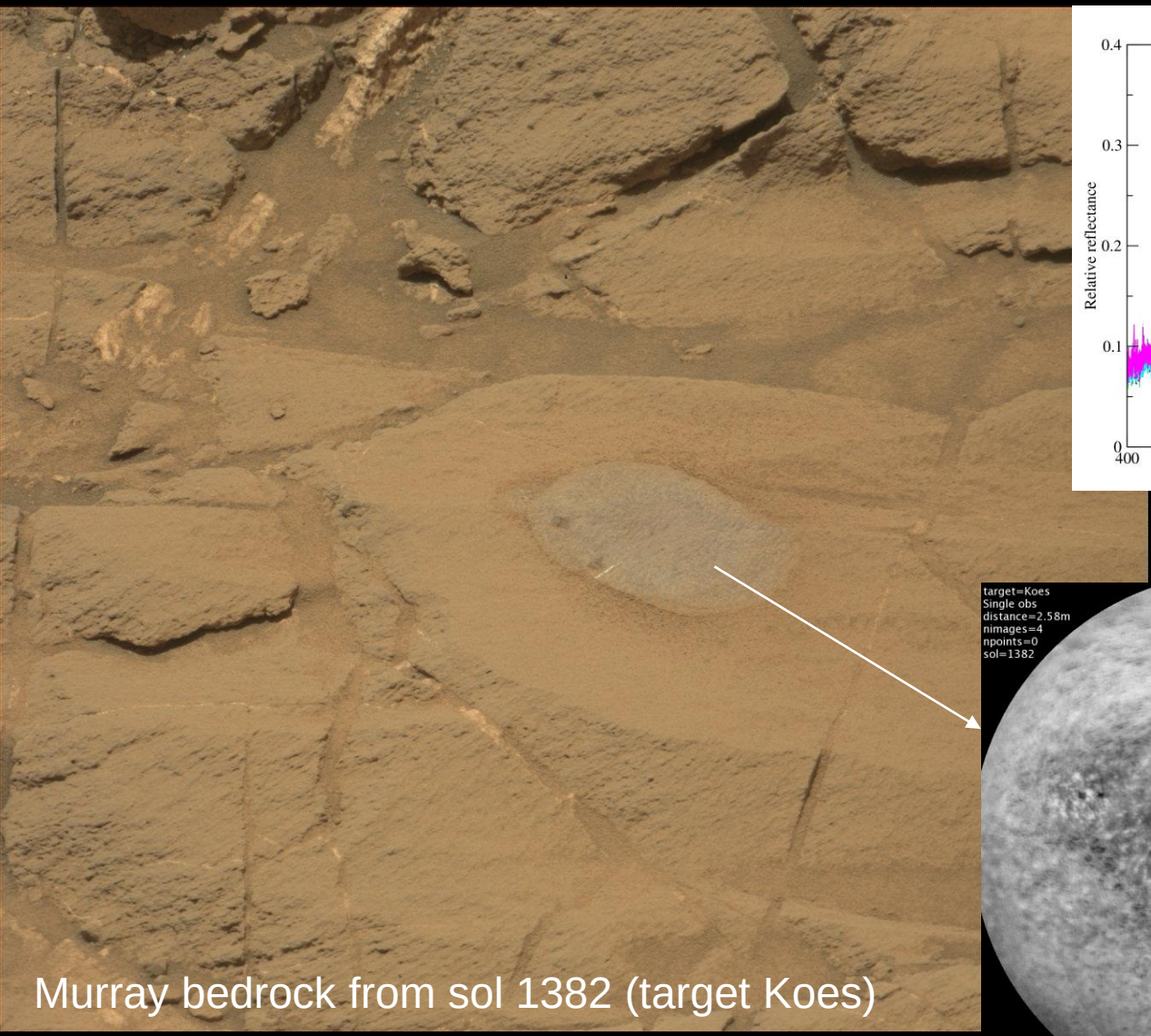


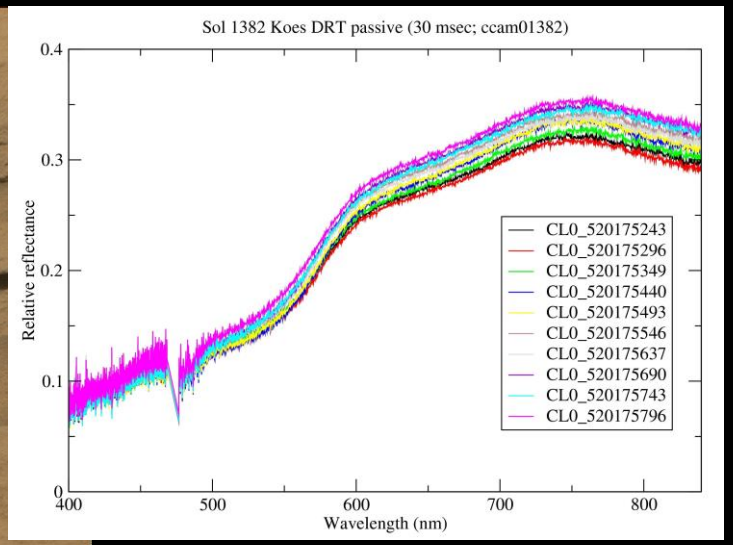
E. Rampe and the CheMin team

Mastcam and ChemCam

- Mastcam: Color imager with 13 filters capable of multispectral imaging. Ideal for mapping distribution of ferric materials while maintaining geologic context.
- ChemCam: LIBS instrument with capability to collect high spectral resolution reflectance point spectra in “passive mode”

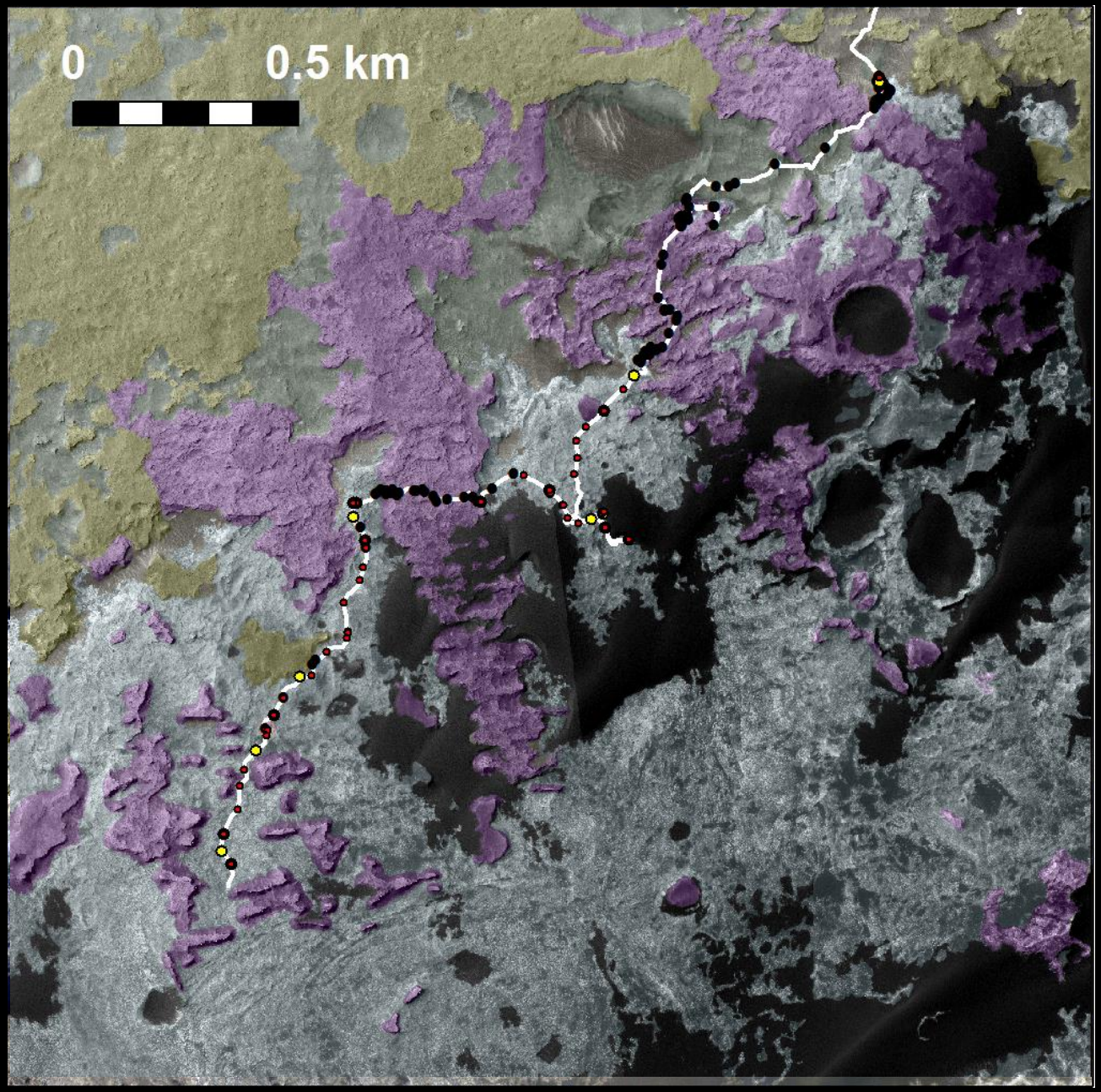
ChemCam passive spectroscopy



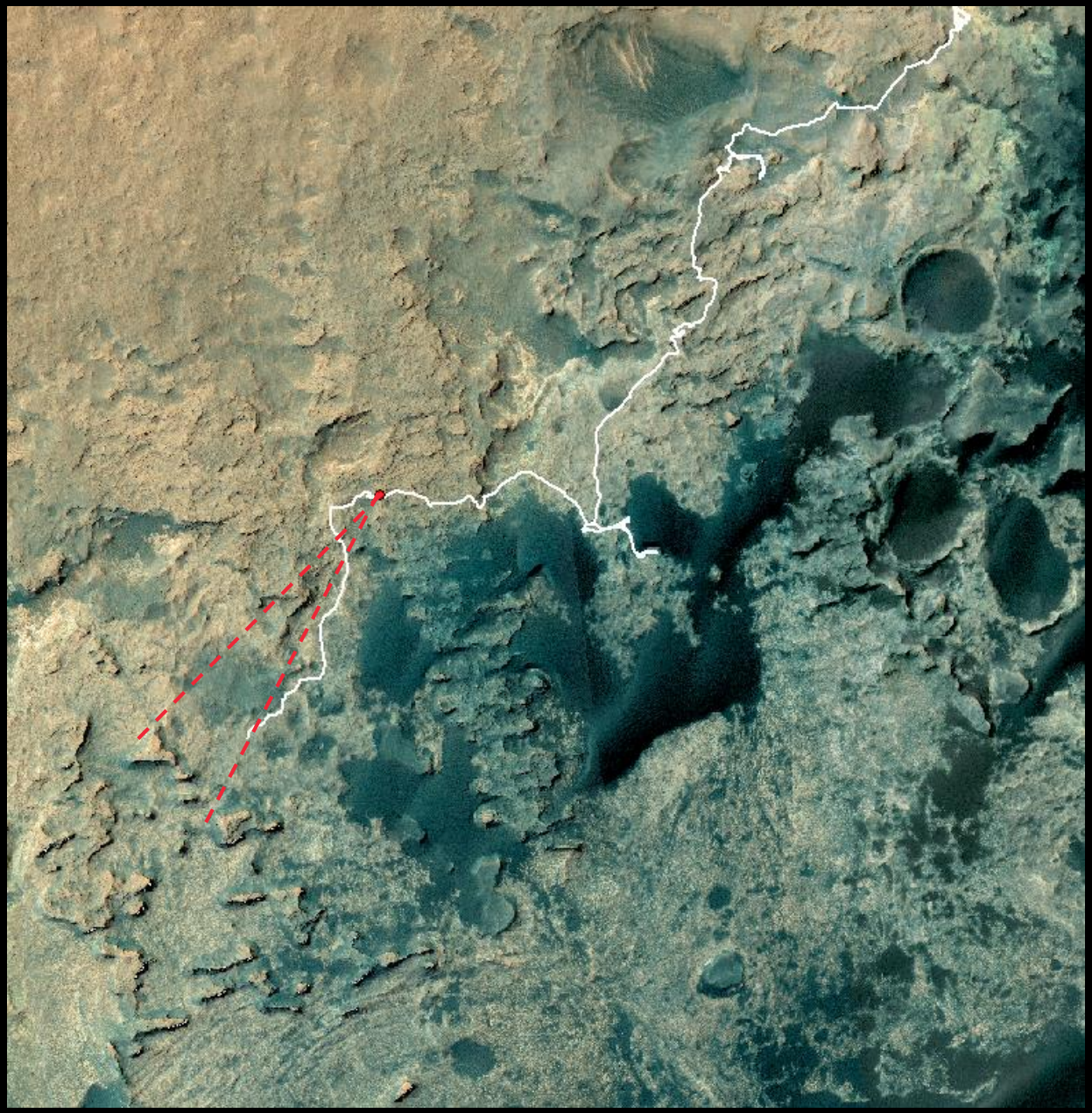


Spectra courtesy J. Johnson

ChemCam passive spectroscopy



Mastcam multispectral mapping

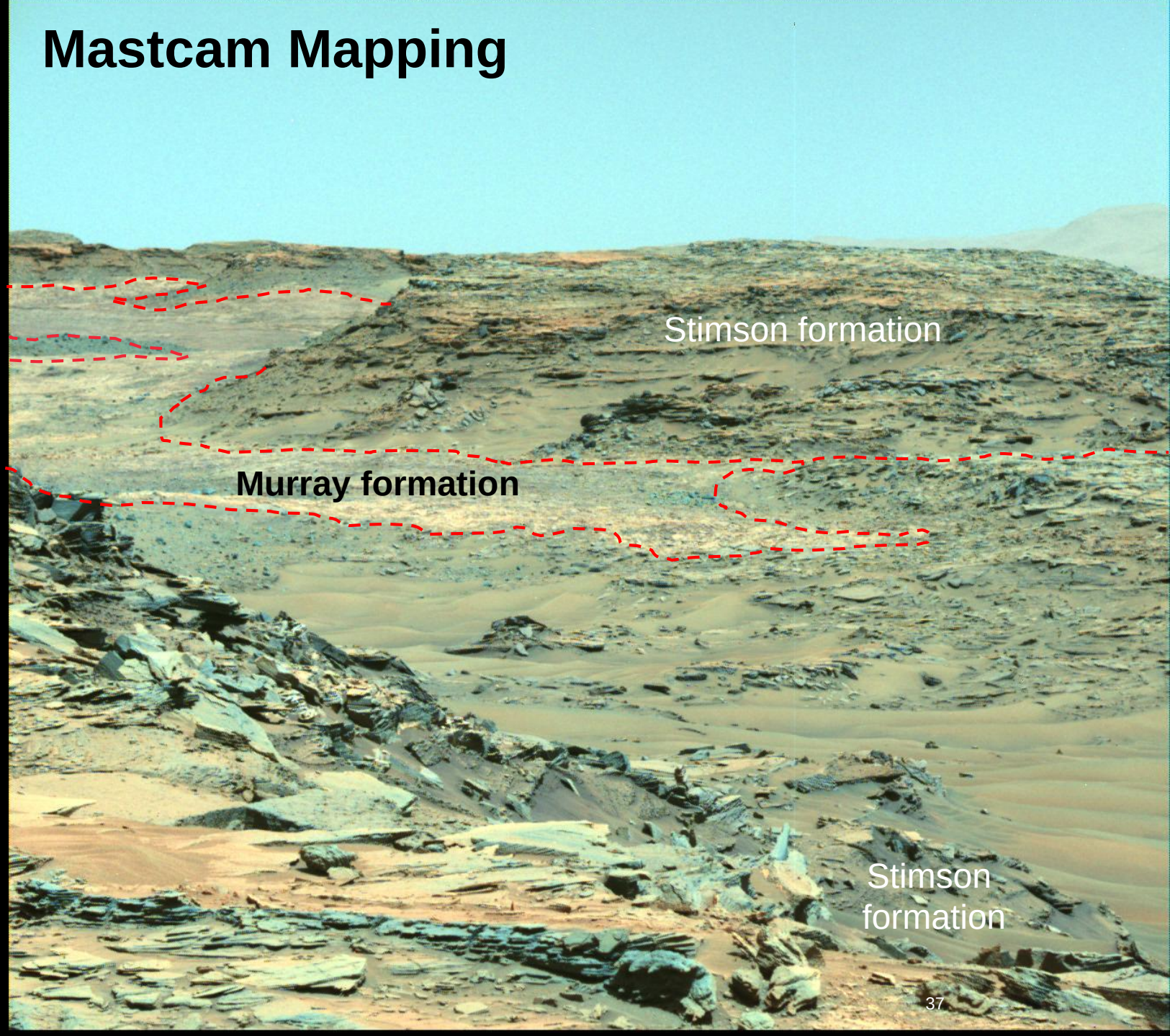


Sol 1309
Ruacana
L312

Mastcam Mapping

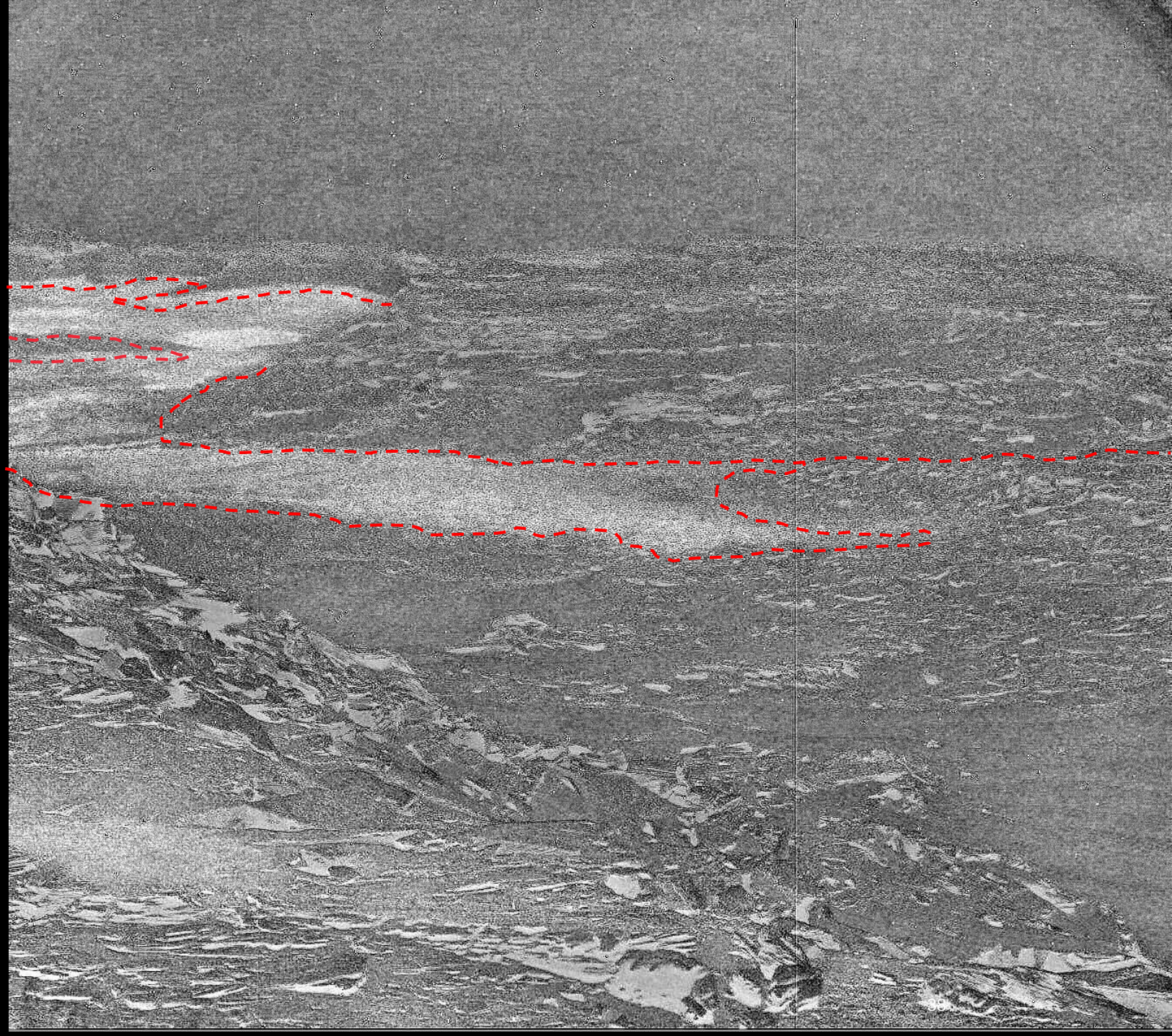
Sol 1309
Ruacana
L312

Mastcam Mapping

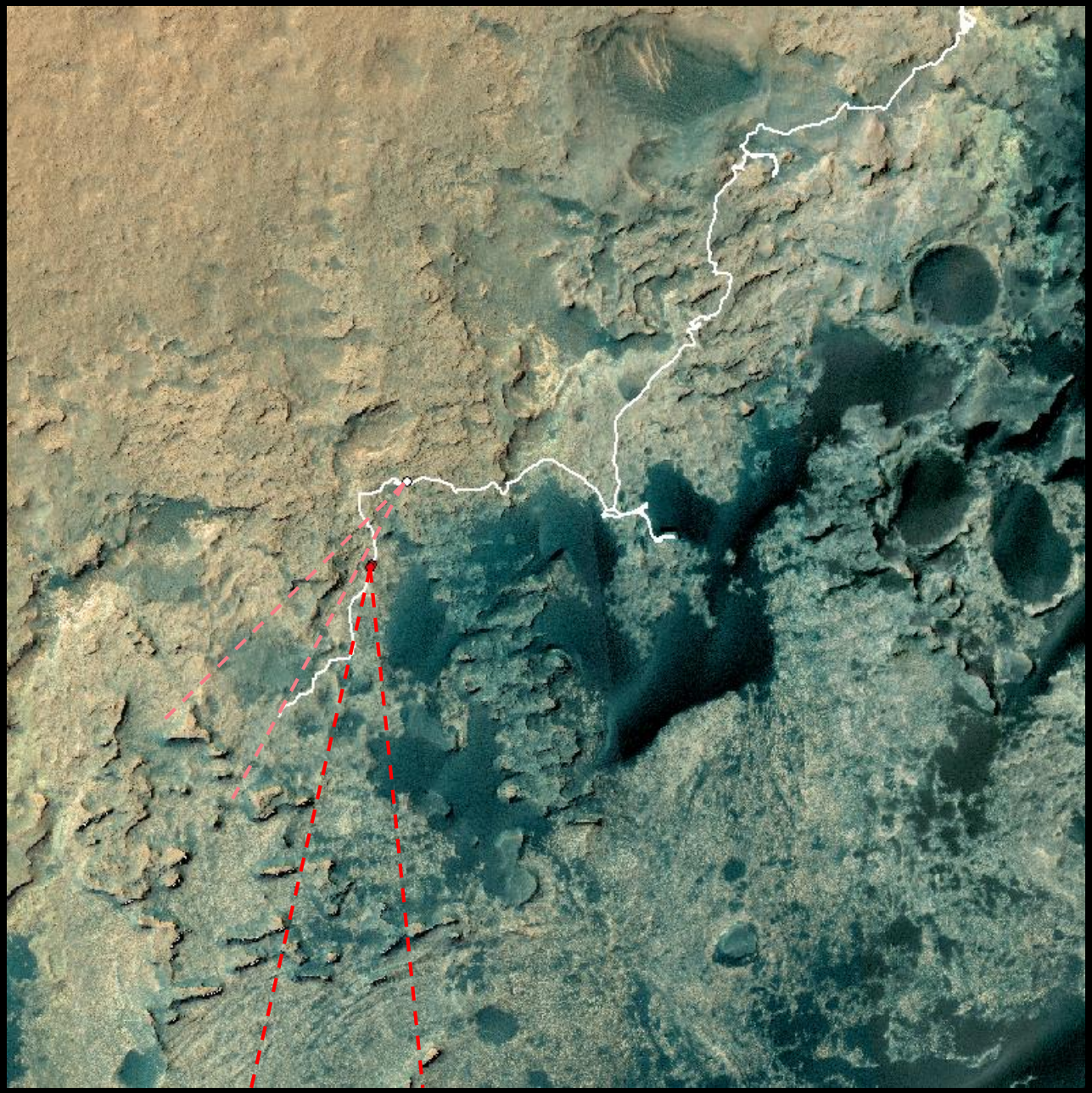


867-1013 nm slope

Brighter = more iron oxide like



Mastcam multispectral mapping

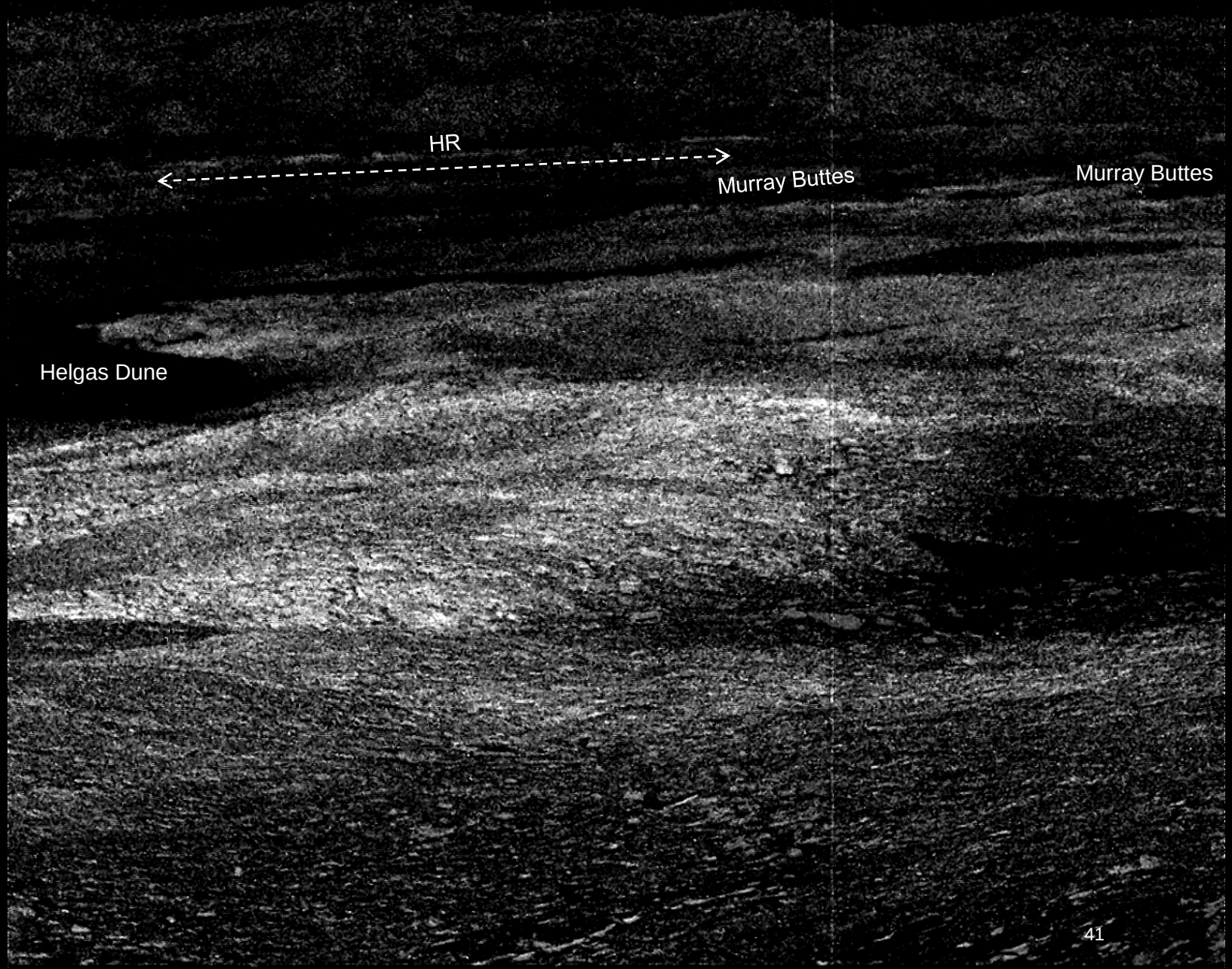


mcam06720, Red:751 nm, Green: 554 nm, Blue: 495 nm

(Wow!)

mcam06720, 867 nm to 1012 nm slope. More hematite like = brighter.

3x3 median filter applied to image to reduce noise



mcam06720, 867 nm to 1012 nm slope. More hematite like = brighter.

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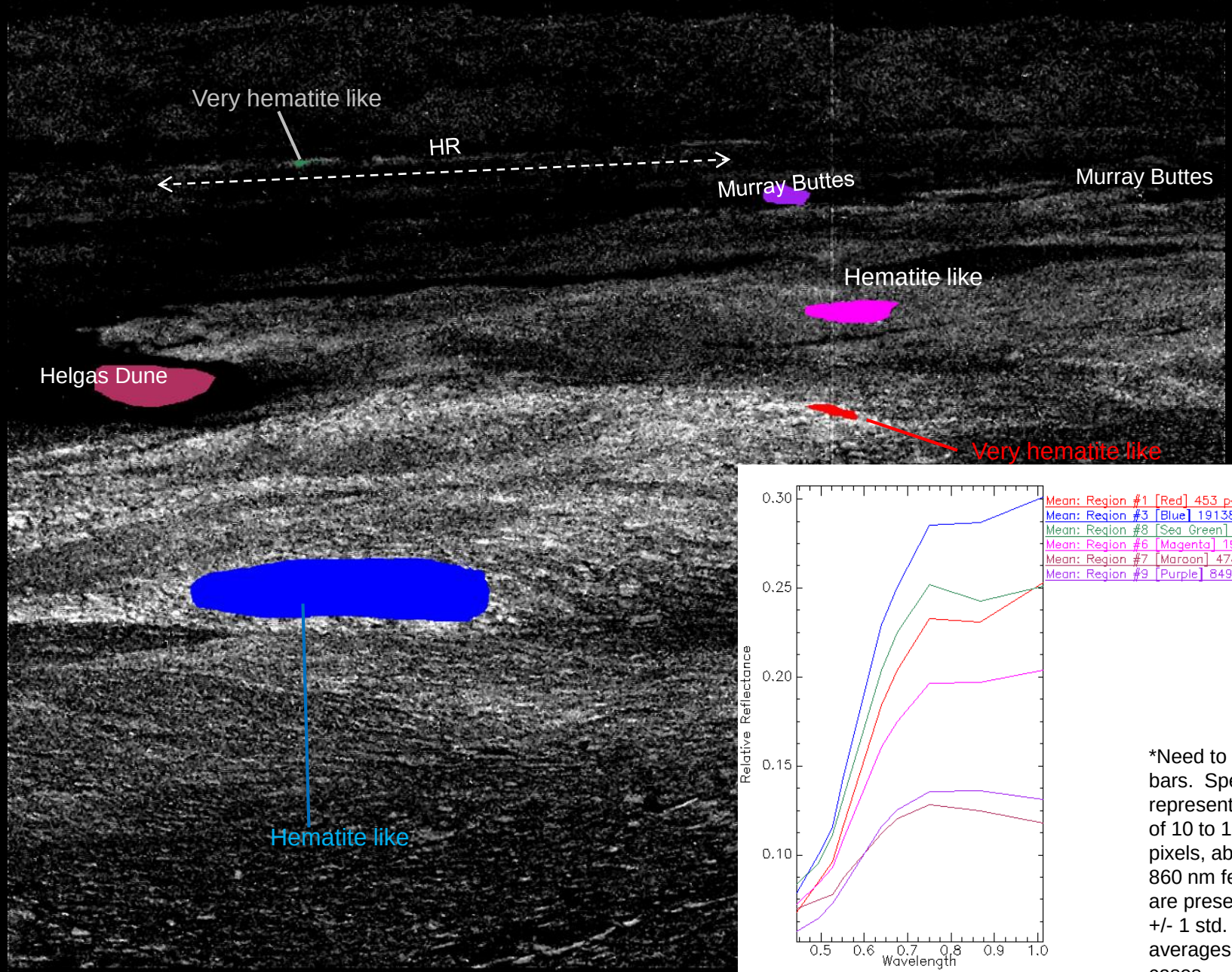

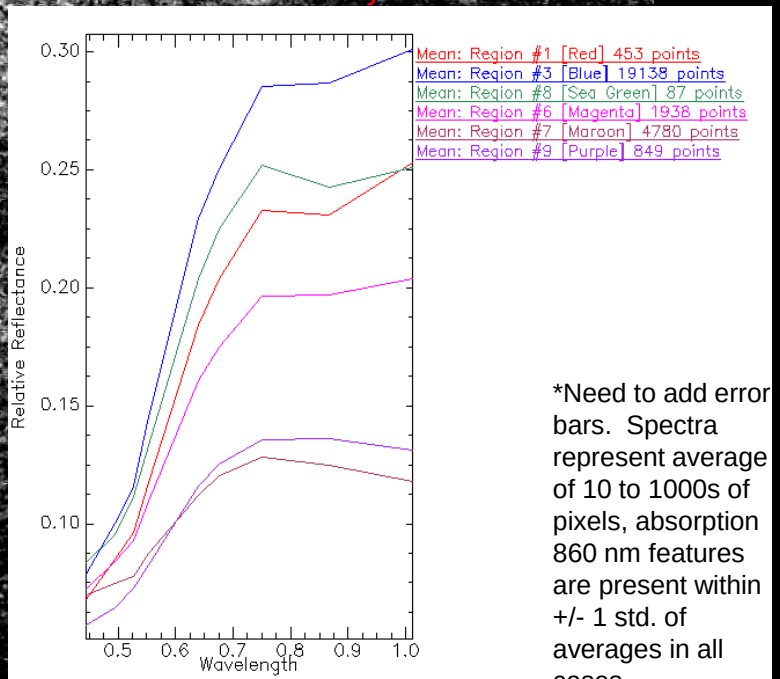

*Need to add error bars. Spectra represent average of 10 to 1000s of pixels, absorption 860 nm features are present within +/- 1 std. of averages in all cases.

Conclusions

- Hematite deposits stratigraphically controlled suggesting they are (1) primary depositional products or (2) formed through secondary diagenetic fluids controlled by stratigraphically residual matrix porosity or fracture porosity
- Hematite detection at multiple stratigraphic positions show redox interfaces were widespread through time and/or space during Mt. Sharp's formation
- No hematite seen from orbit or ground in Stimson formation; shows formation likely occurred before this unit emplaced
- Ongoing Curiosity investigations will continue to help us understand more