Mawrth Vallis

ExoMars 2018 First Landing Site Selection Workshop (LSS WS#1)
26–28 March 2014, ESAC (E)

General Site Presentation: Team

E X O M A R S

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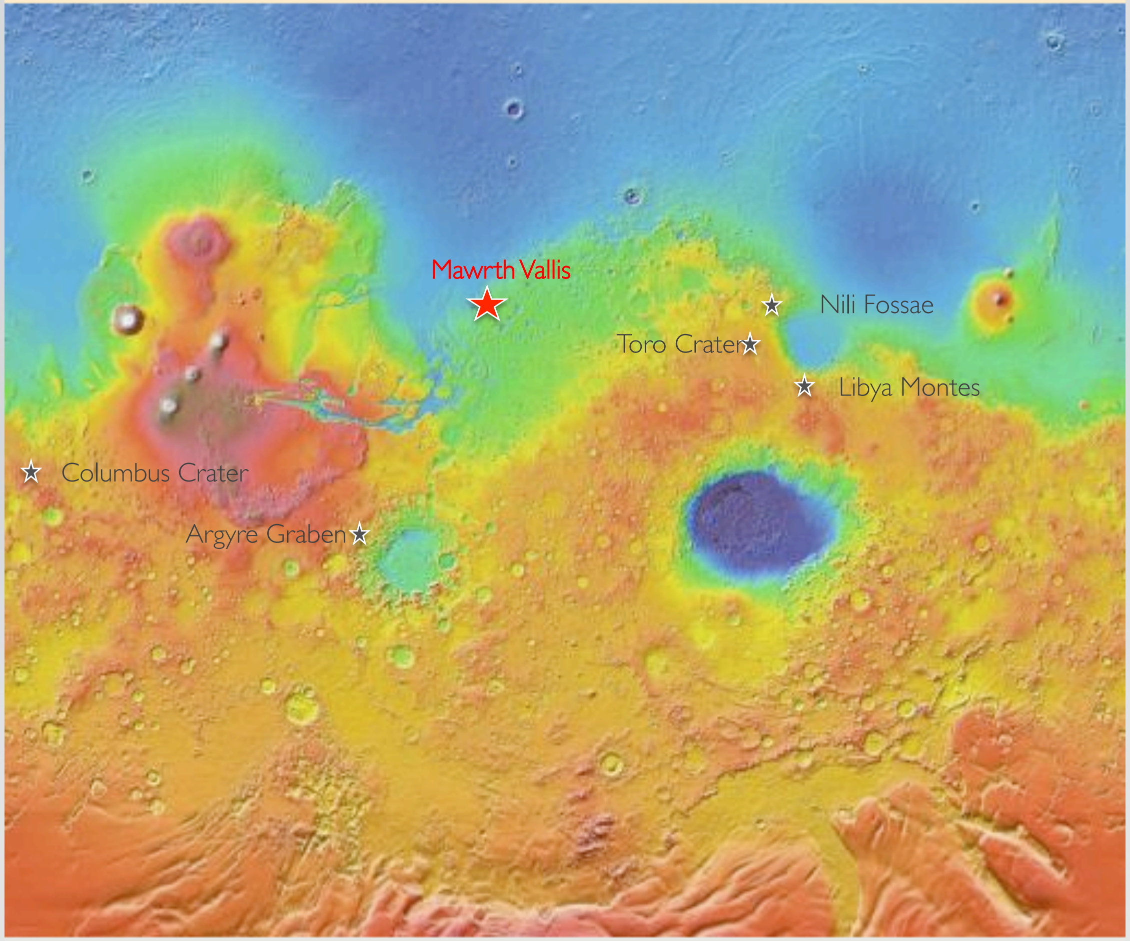
+ Inputs from A. Ody (Lyon University) and J. Audouard (IAS)

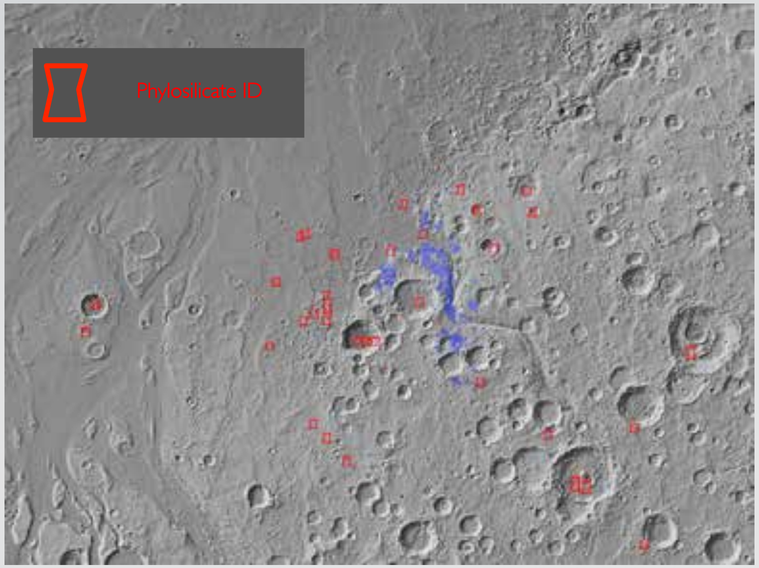
General Site Presentation: Site location

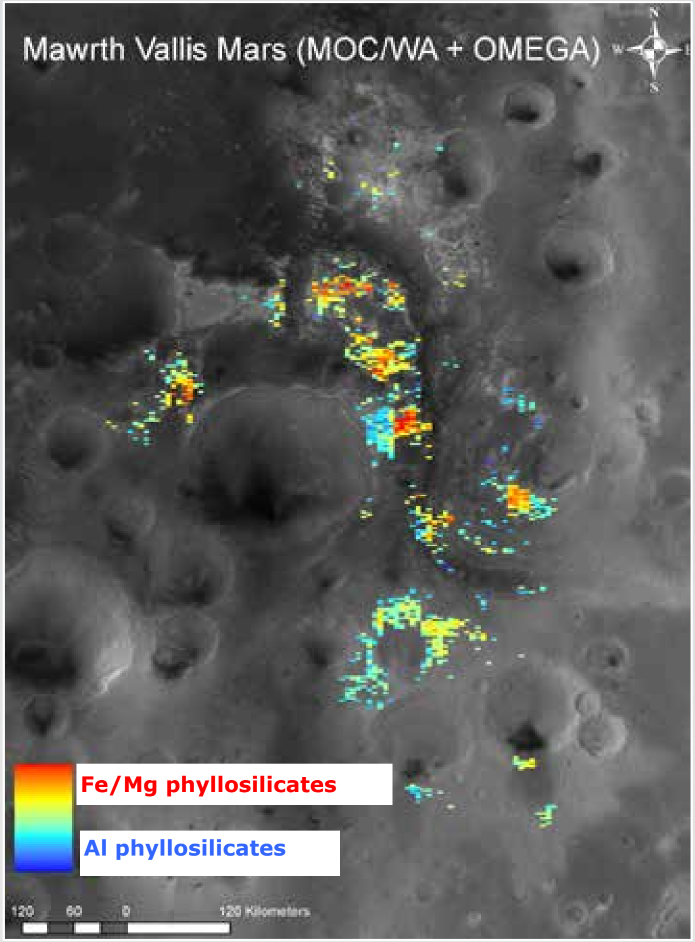


- Situated at boundary of cratered Noachian terrain and northern lowlands, ~25°N, 20° W
- OMEGA discovered abundant Fe- and Al-bearing phyllosilicates associated to layered terrains
- Numerous studies (32 peer-reviewed papers)
- One of final four MSL landing sites

General Site Presentation: Discovery

- **Phyllosilicates observed across Noachian-aged wide area:**
  - **Abundant outcrops across 300X300 km region**
  - **Sporadic outcrops across 1000X1000 km region**
- **Similar stratigraphy observed throughout Mawrth Vallis**

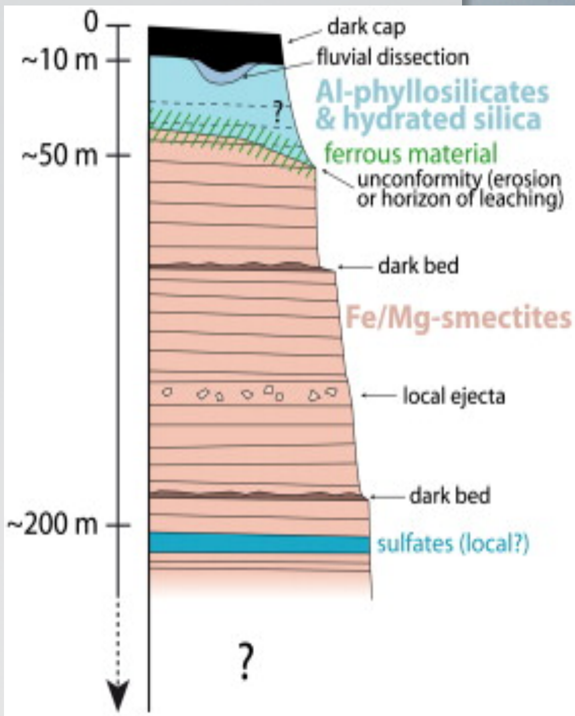




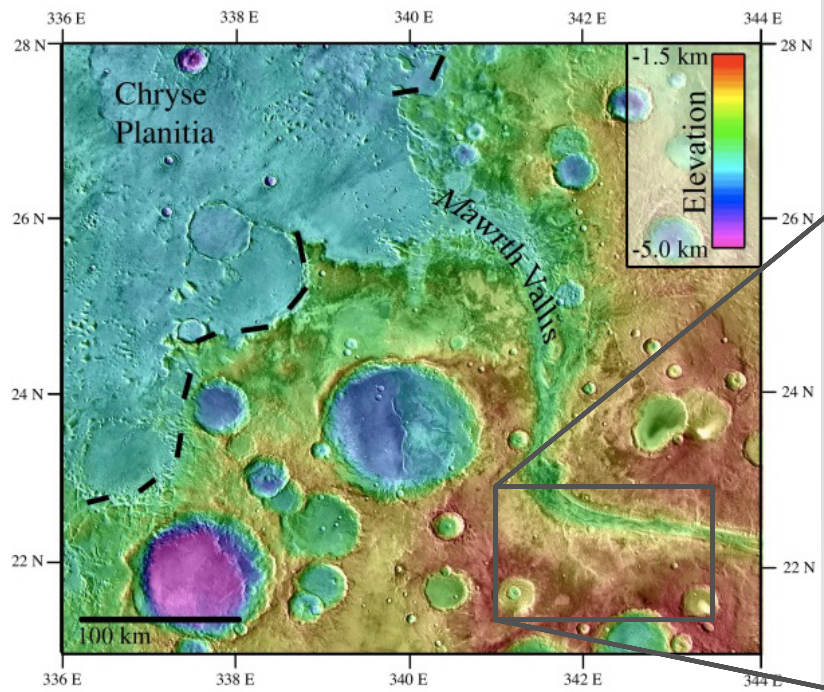
General Site Presentation: Main characteristics

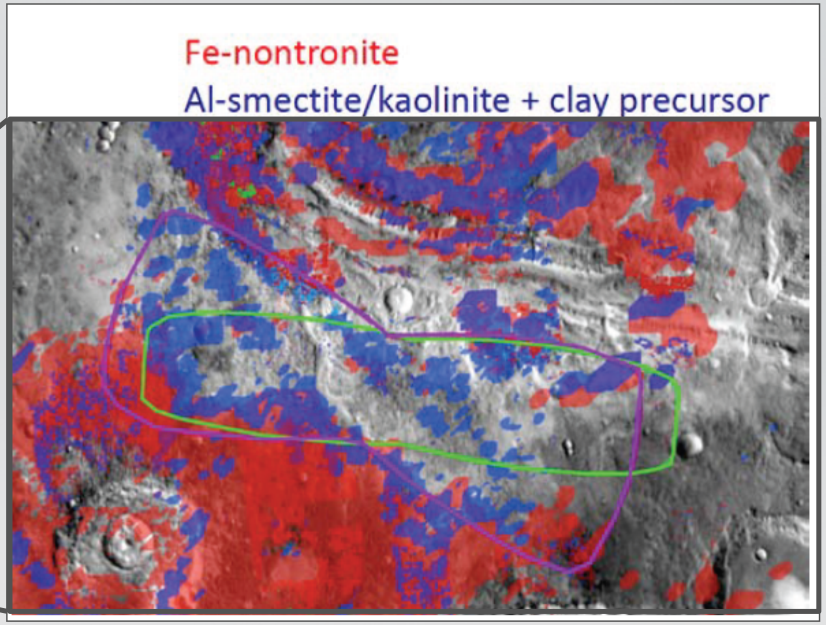
E X O M A R S

- ❖ Global signatures includes clays, sulfates, pyroxene, plagioclase, silica
- ❖ Layers everywhere
- ❖ Erosion and redeposition by fluvial and eolian activities
- ❖ Present elevation likely not the Noachian elevation
- ❖ Thinner (10-40 m thick) Al-phyllosilicate/silica unit on top
  - Bulk appears to be Al-smectite (montmorillonite/ beidelite)
  - Some hydrated silica/opal are mixed with much of the unit
  - Small outcrops of kaolin-family minerals
- ❖ Large >100 m thick Fe/Mg-smectite unit on bottom
- ❖ Fe^{2+} slope at boundary of Fe/Mg-smectite unit and Al-phyllosilicate unit
  - Most likely due to ferrous clay such as mica or chlorite, although no unique OH fingerprints detected
- ❖ Small sulfate outcrops



General Site Presentation: Ellipse

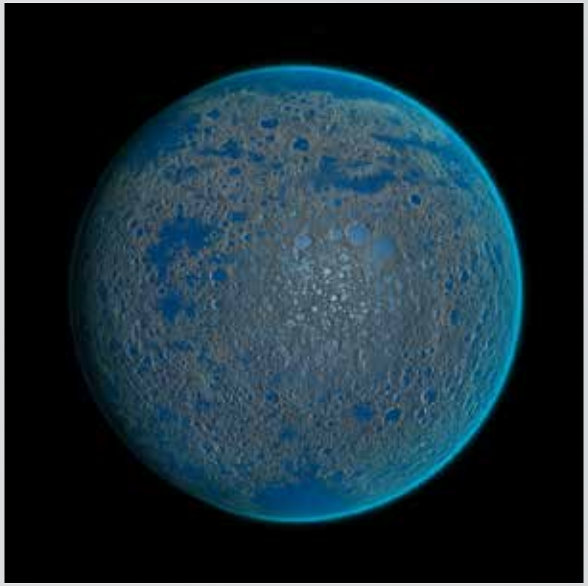


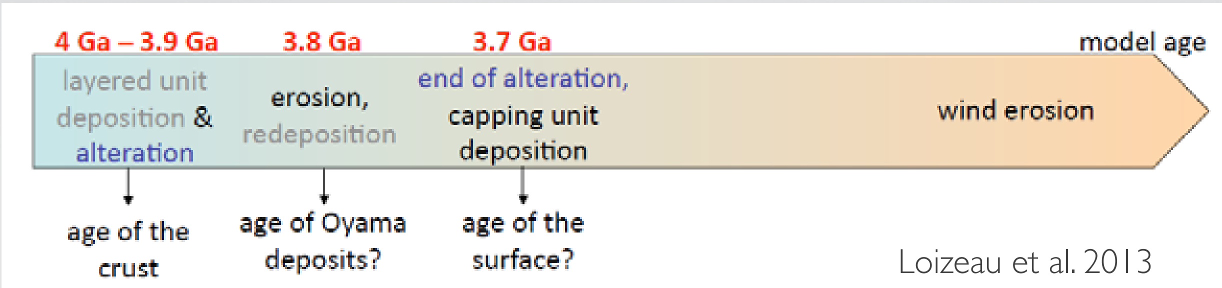


General Site Presentation: Attractive points

E X O M A R S

1. Mineralogically diverse site
2. Lithologically diverse site that captures multiple environments
3. Both in-situ, ancient crustal bedrock and remobilized sediments
4. Several types of science (astrobiological) targets
5. Extremely ancient section of rocks probing an enigmatic and important epoch in Solar System history
6. Opportunity to sample rocks from the deep Noachian up through the global transition into the Hesperian





1. Complex aqueous diversity on Mars

Mineralogical diversity provides window into times in past when water was present:

- Evidence for 100s of km expanse of phyllosilicate stratigraphy indicating large-scale aqueous events.
  - Observed mineral diversity and stratigraphy suggests multiple forms of aqueous systems.
- Evidence for intense alteration and possibly acidic leaching through presence of hydrated silica and kaolinite.
  - Consistent with period of warm and wet climate.
- Evidence for sulfate formation and acidic leaching through presence of sulfates, salts, and acid-treated clays.
  - Consistent with low pH.
- Evidence for active chemistry and changing redox potential due to presence of ferrous phase (Fe^{2+}) on top of nontronite (Fe^{3+}).
  - Implies unique aqueous environment, probably for a short period of time.
  - Consistent with microbial activity, hydrothermal activity, forced precipitation due to loss of water.

2. Largest abundance of phyllosilicates on Mars at km-scale

	Minerals	Eberswalde crater	Gale crater	Holden Crater	MV (Fe-bearing phyllosilicate unit)	MV (Al/Si-OH bearing phases unit)
Phases abundances (% Vol)	Hydrated phases	10-25 (Mg-smectite hectorite)	20:30 (Notronite)	25-45 (Mg-smectite saponite + Mg-mica celadonite/ Clinochlore)	Nontronite: 50+/-20 Celadonite: 10+/-10	Kaolinite: 10-30 Al/Si-OH phase: 10-30 Opal: 5-15
	Primary anhydrous minerals	>70 (HCP and LCP required)	>70 (HCP required)	>50 (HCP required)	15+/-15 (no pyroxene)	5-25 (no pyroxene)
Grain size	Hydrated phases	5-10 µm	5-10 µm	10-100 µm	5-20 µm	5-50 µm
	Primary anhydrous minerals	50-200 µm	50-200 µm	50-100 µm	100-200 µm	100-200 µm
Formation scenario		Detrital clays and authigenic process to explain the presence of opaline	In situ aqueous activity localized in space and time	Transport and deposition of altered basalts of the Noachian crust without major chemical transformation (detrital clays)	Low temperature (hydrothermal) alteration in marine environments and/or pedogenesis	Pedogenesis

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3. Pre-biotic Chemistry

- Phyllosilicate synthesis and reactions:
  - Phyllosilicates provide convenient reaction surface (silicate sheets with charged surface); industrial catalyst for chemical reactions (Pinnavaia, 1983).
  - Metal ions (especially Fe) in clay matrix attract nucleotides and may have played a crucial role in the origin and early evolution of life (Odom et al. 1979; Lawless et al., 1985).
- Clays and silica are good preservers of organic material:
  - If organics were present on early Mars, clay-rich sediments would be likely to trap these and then preserve them over time.

4. Preservation of Biosignatures

- Long-term preservation most successful in phyllosilicate- and silica-bearing host rocks that are resistant to weathering; these provide impermeable barrier for biosignatures (e.g. Farmer and Des Marais, 1999)
- No evidence for illitization or mixed layer clays at Mawrth Vallis that indicate biosignatures could be degraded through thermal processing such as diagenesis
- If microbes did inhabit the early environment at Mawrth Vallis, biosignatures could be retained in the phyllosilicate and hydrated silica deposits
- The material of interest was buried below the dark cap unit for a while and only recently exhumed

Site's Geological Context

EXOMARS

- **Geology – the big picture**
  - Strata: Large area with widespread layered deposits
    - 100s-1000s of layers, down to limit of resolution
  - Structure: low dips, only minor deformation (aside from impact)
    - Evidence for draping relationships (top-down processes?)
  - Geomorphology: response to erosion is diverse
    - Inverted craters, inverted channels
    - Inverted dikes or veins
    - Not 'boulder forming' units = fine grained
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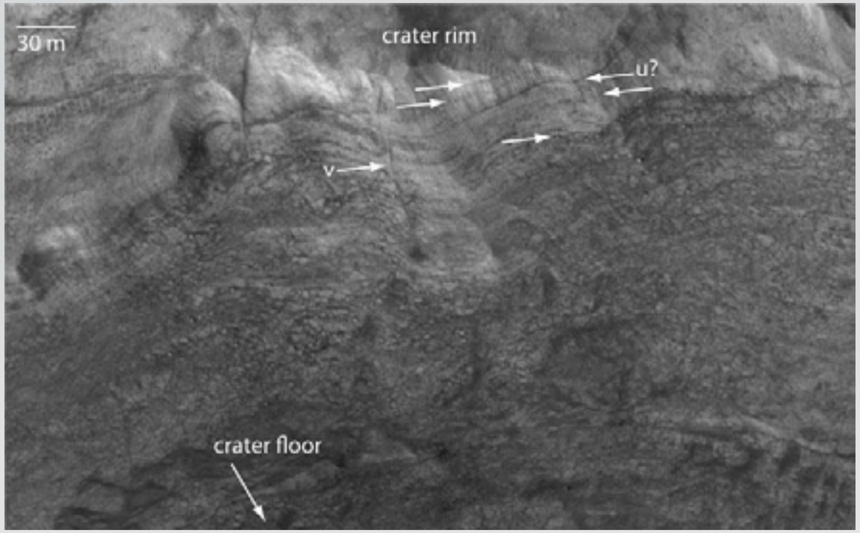

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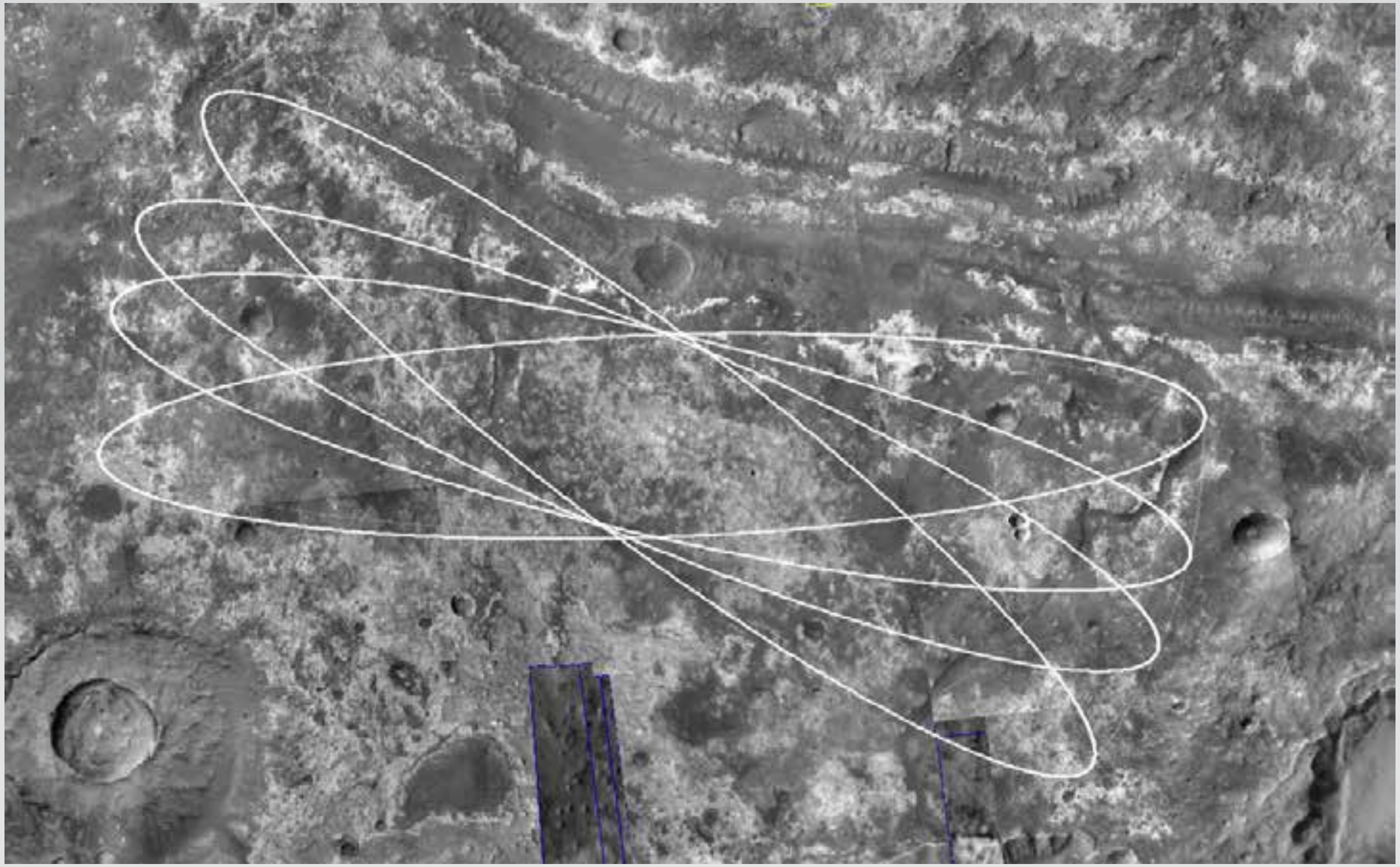

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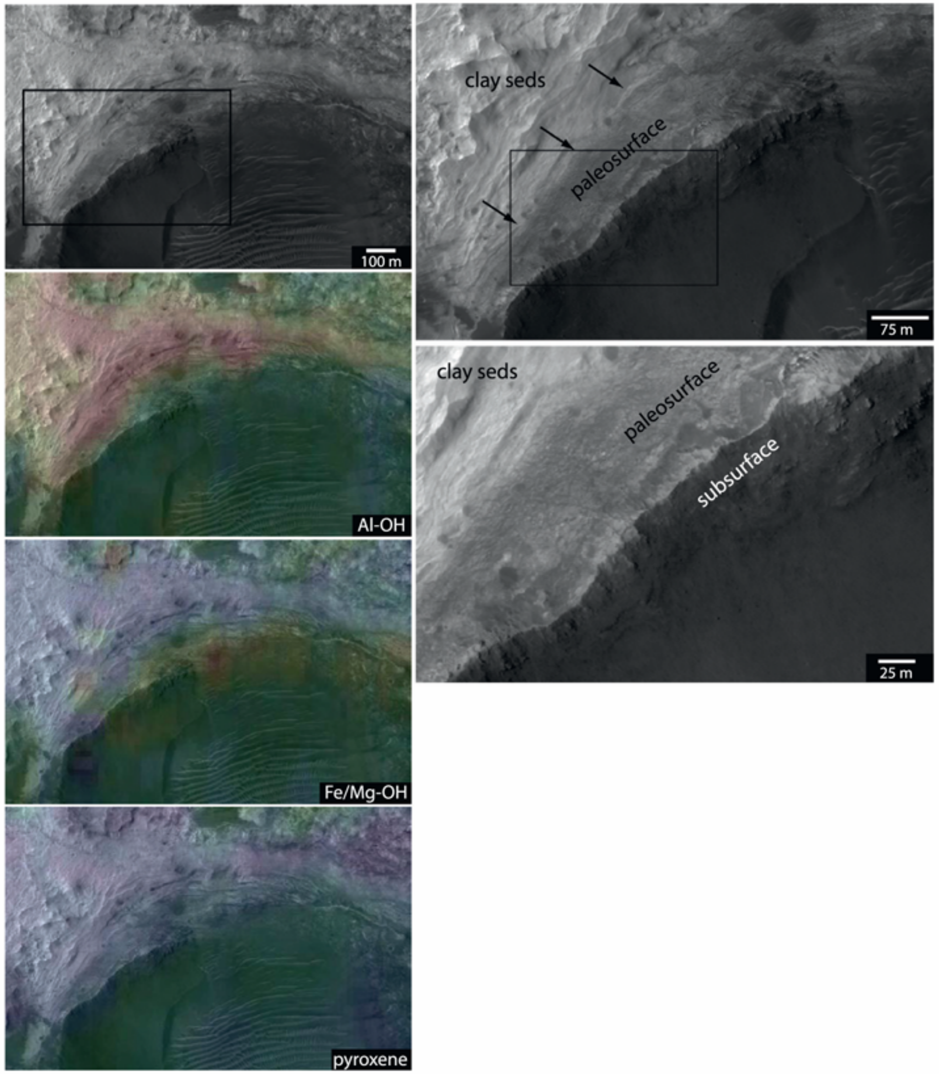

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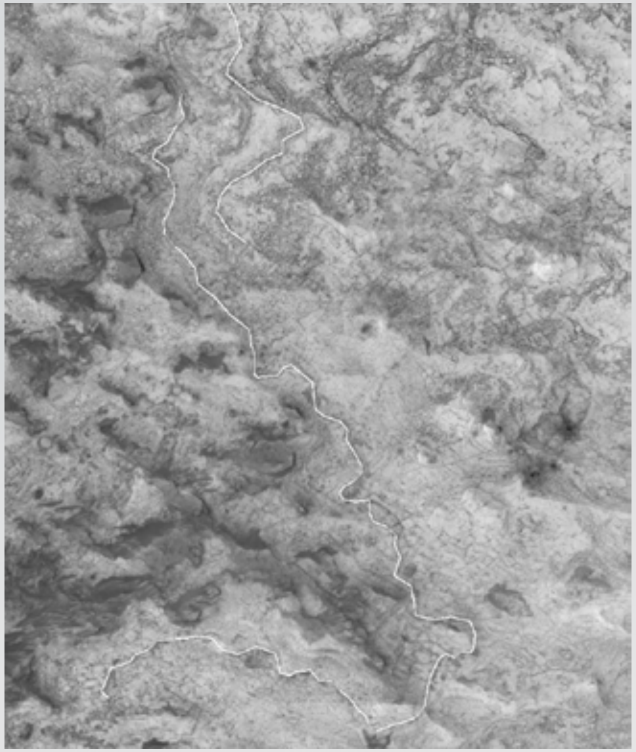

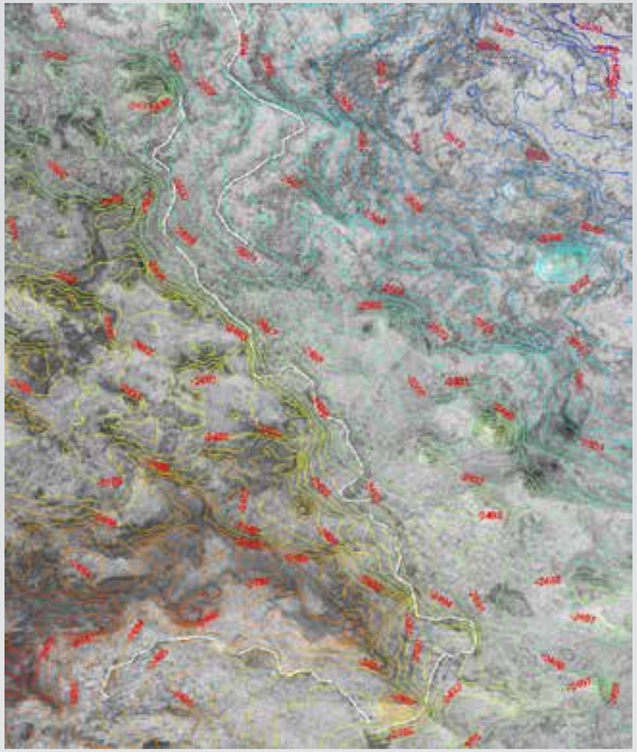

Loizeau et al., 2007; 2010

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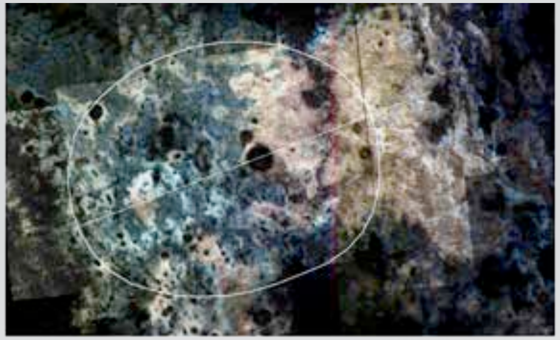

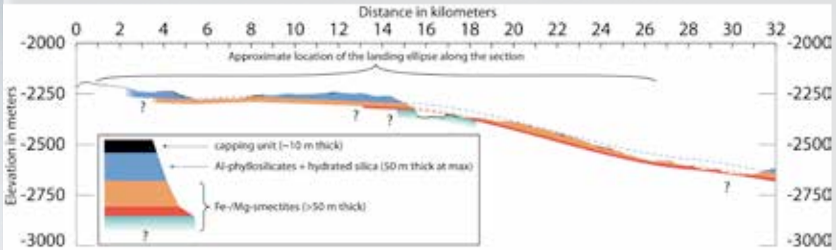

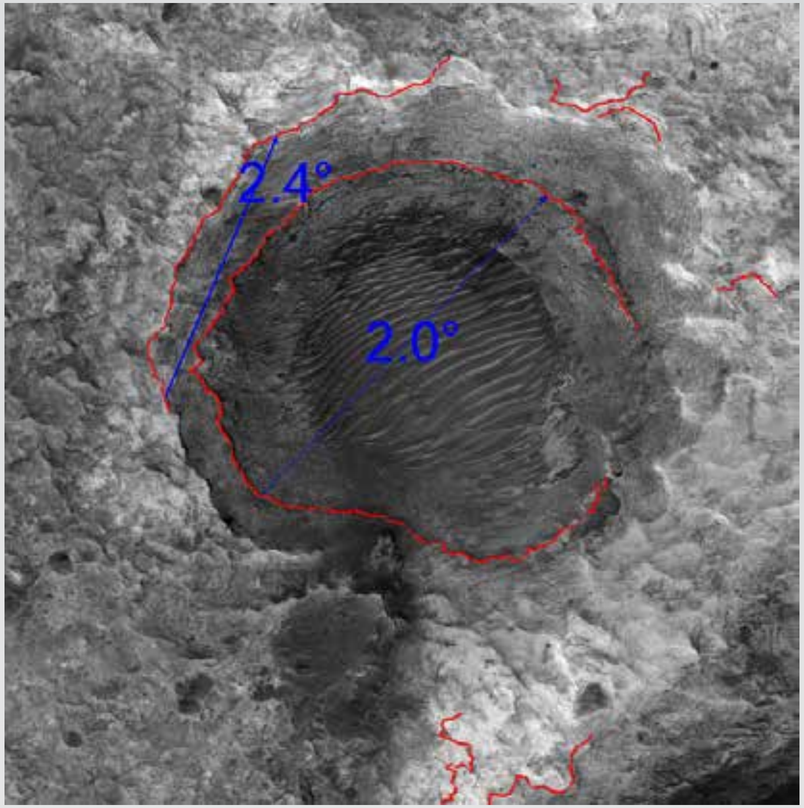

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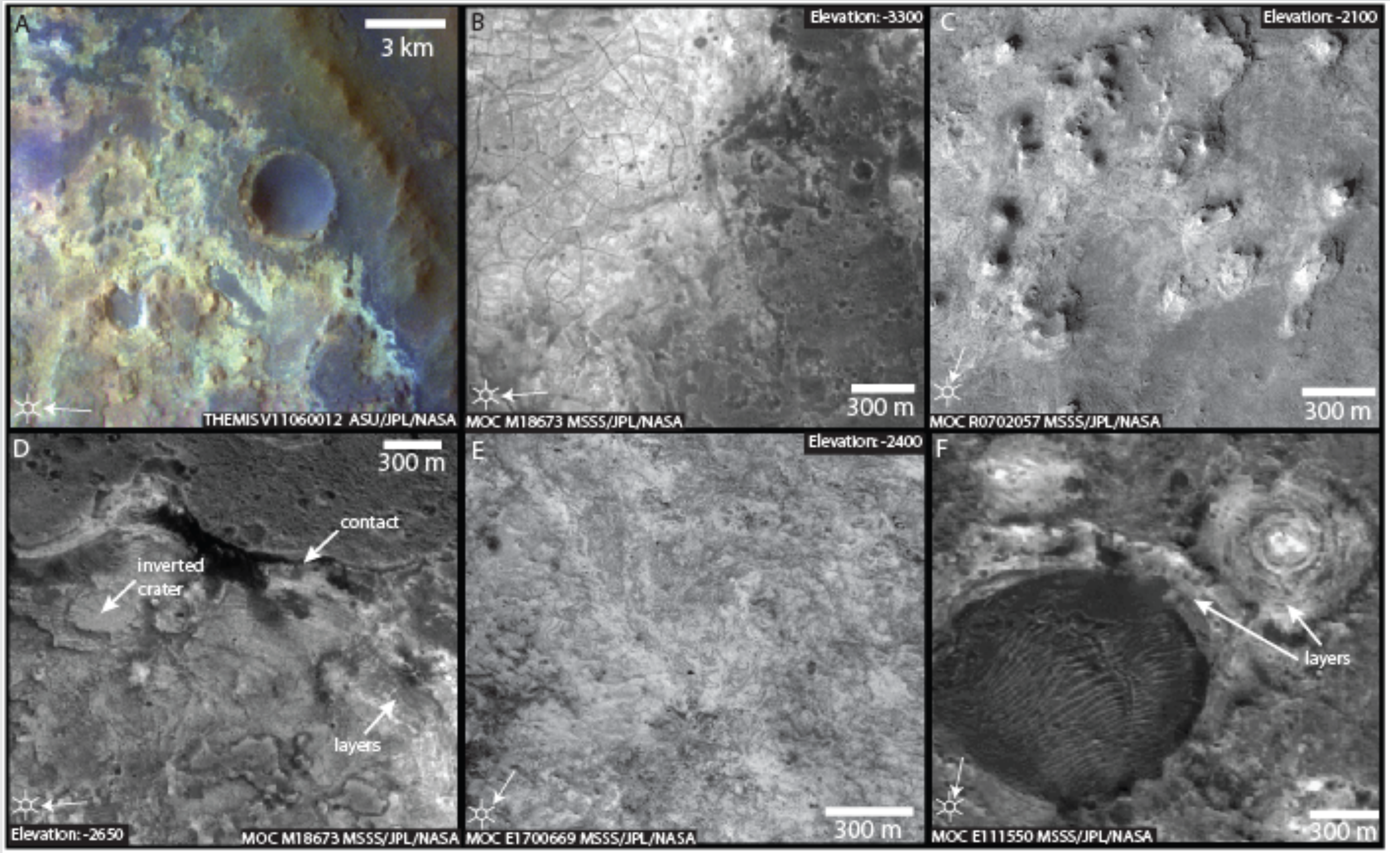

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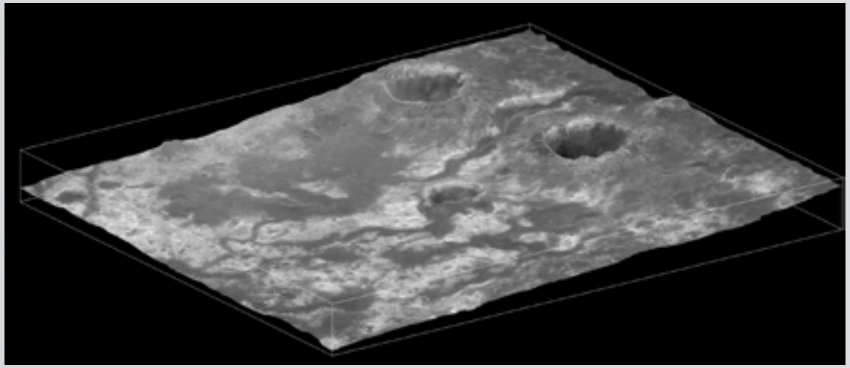
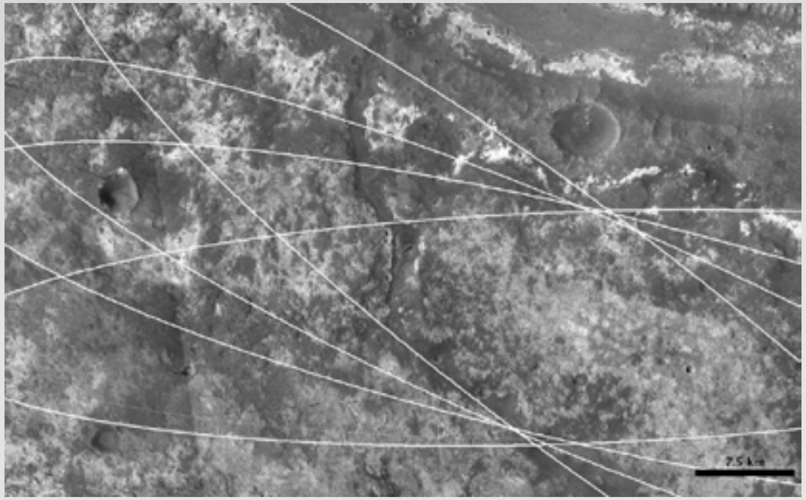
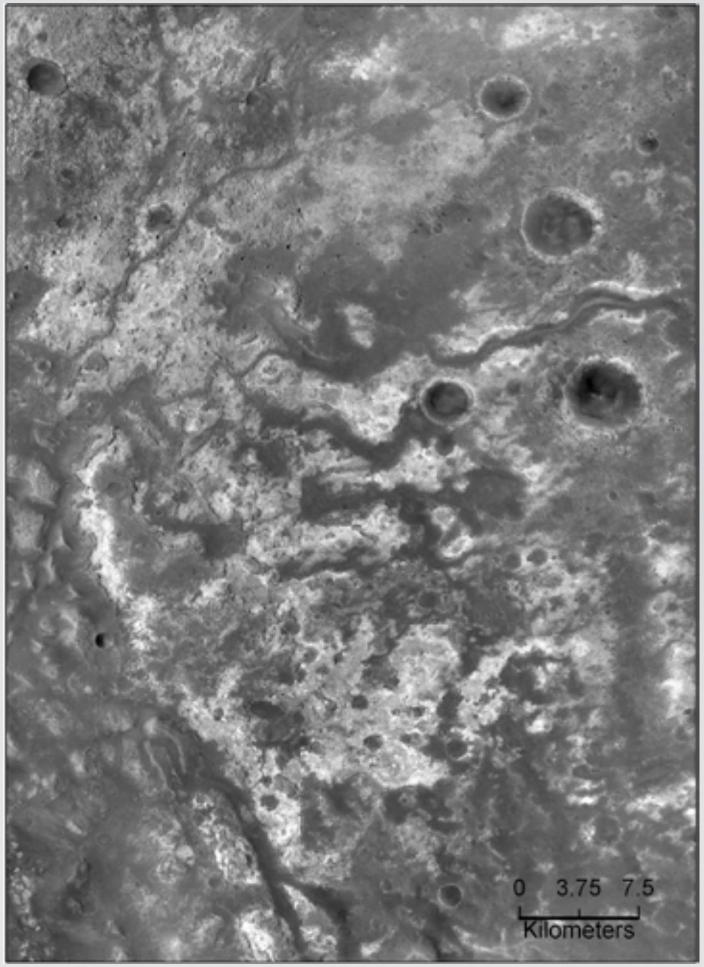


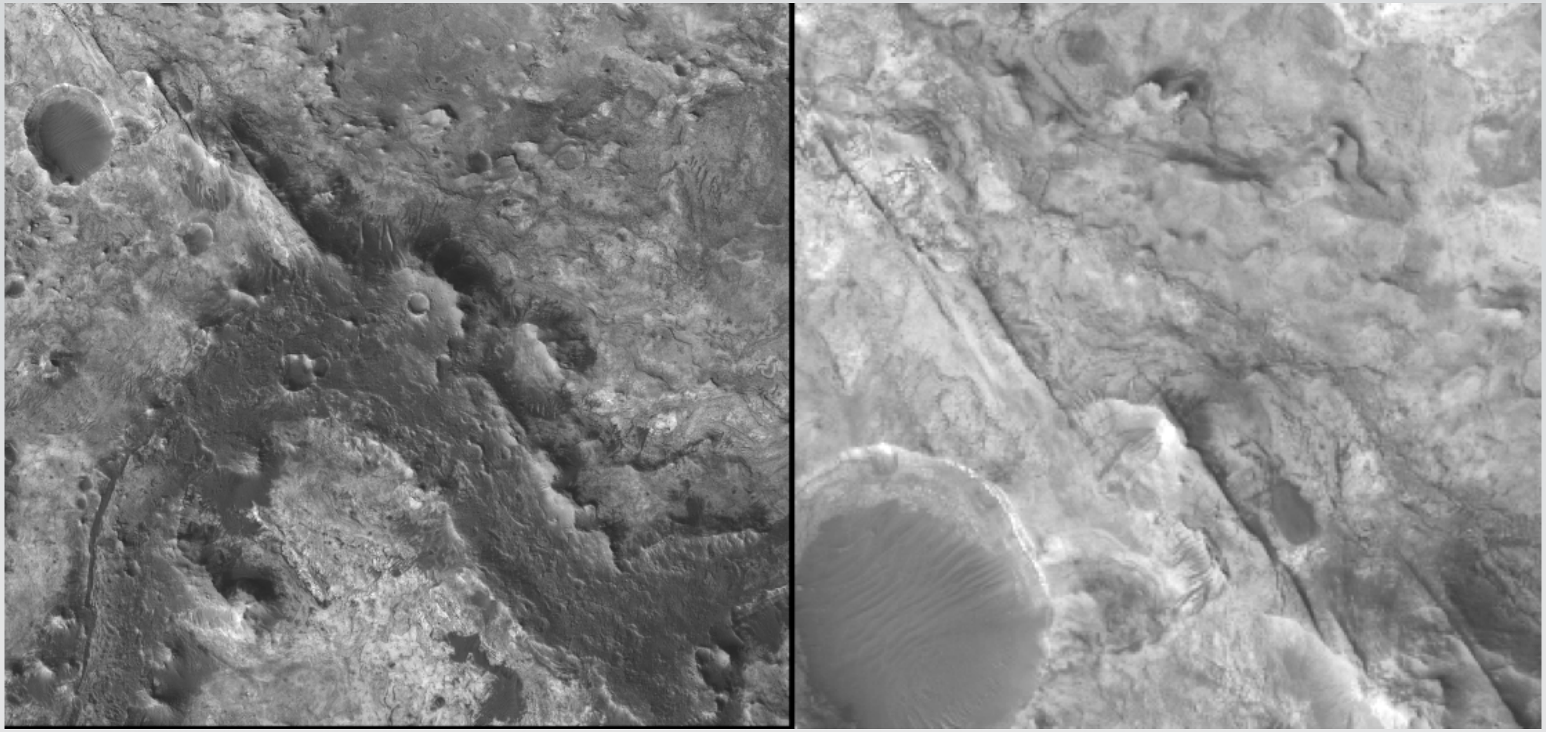




Site's Geological Context

EXOMARS

- **Geology – the big picture**
  - Geomorphology: response to erosion is diverse
    - Inverted dikes or veins (segments are 100-300 m-long)
      - Emplaced in the subsurface and eroded to become exposed



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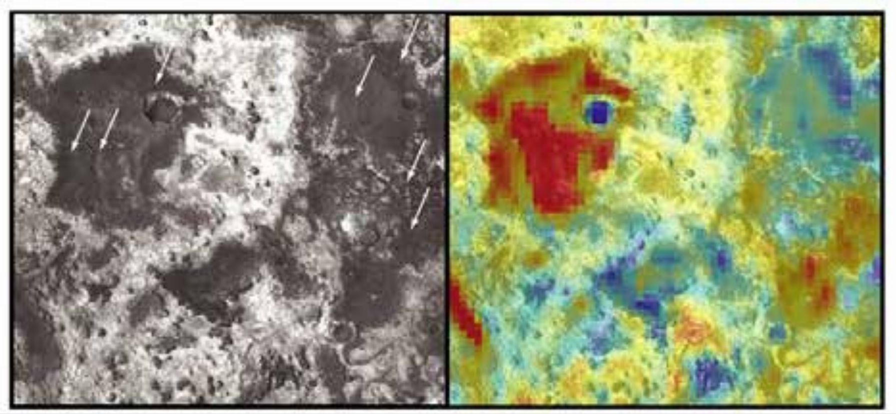
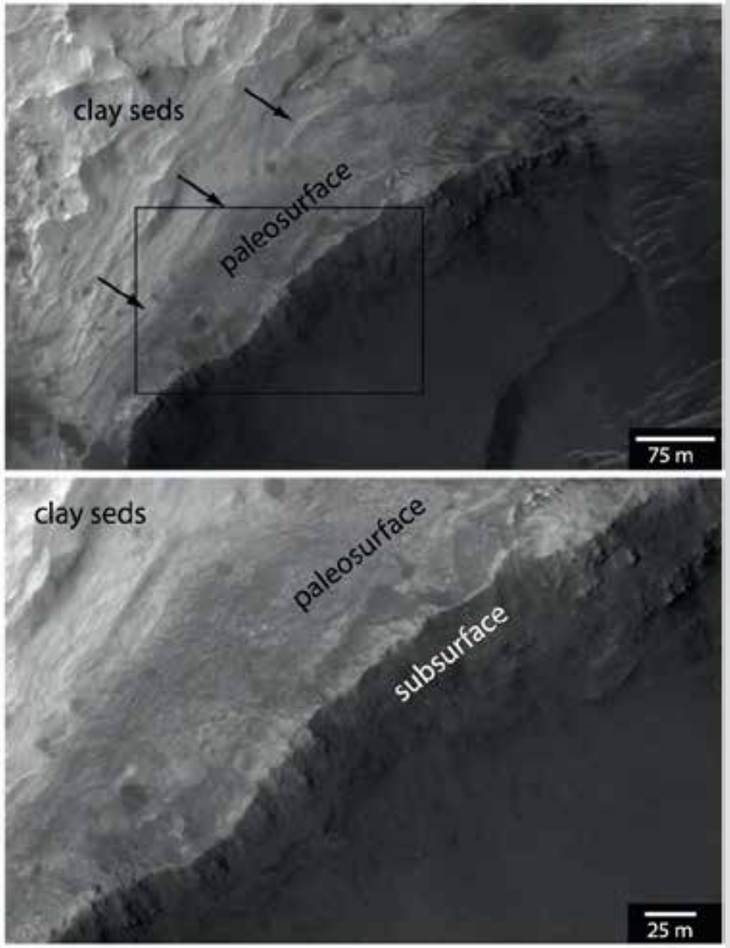
    - Not 'boulder forming' units + low TI = likely fine grained





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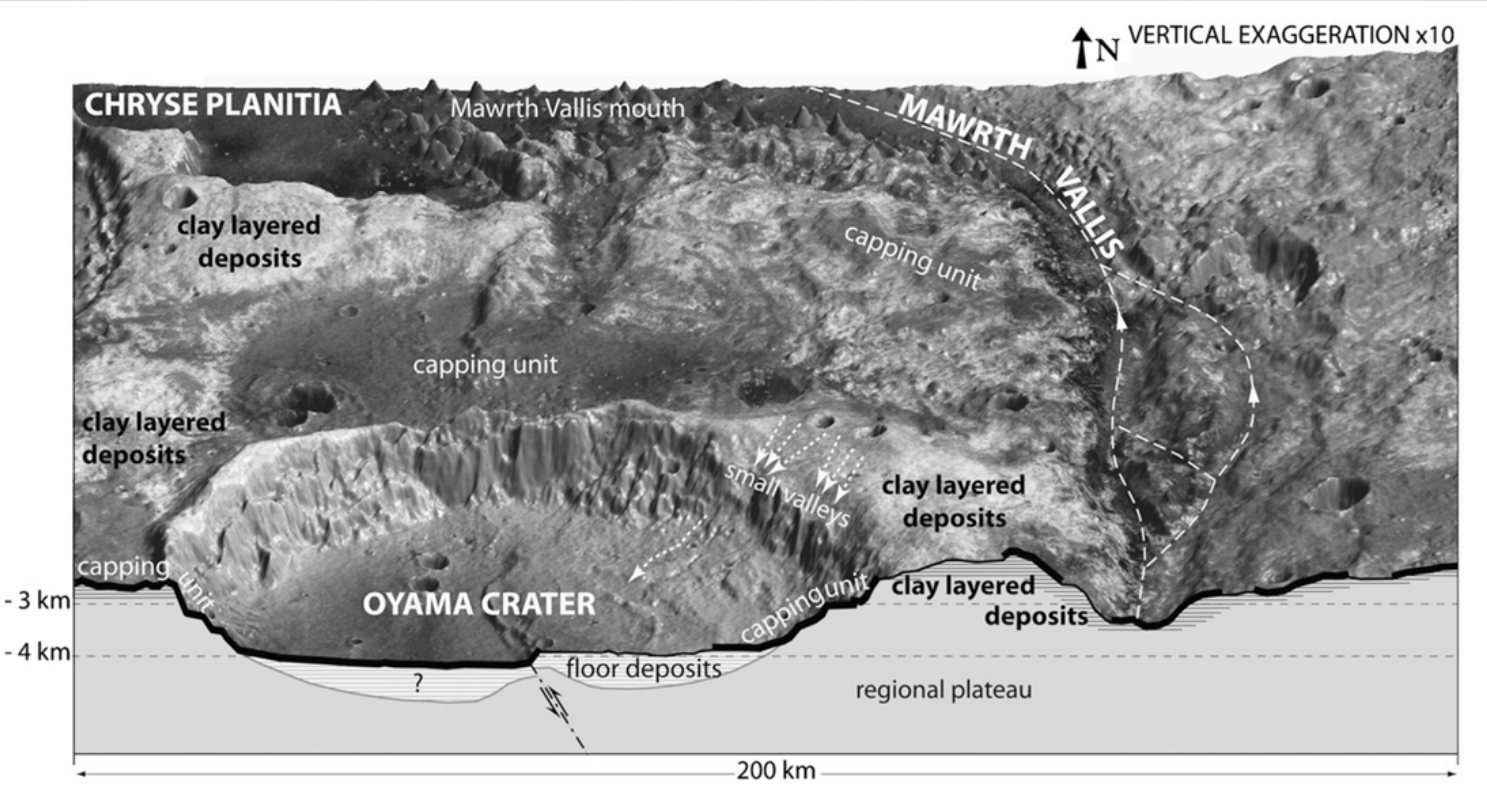

Site’s Geological Context

E X O M A R S

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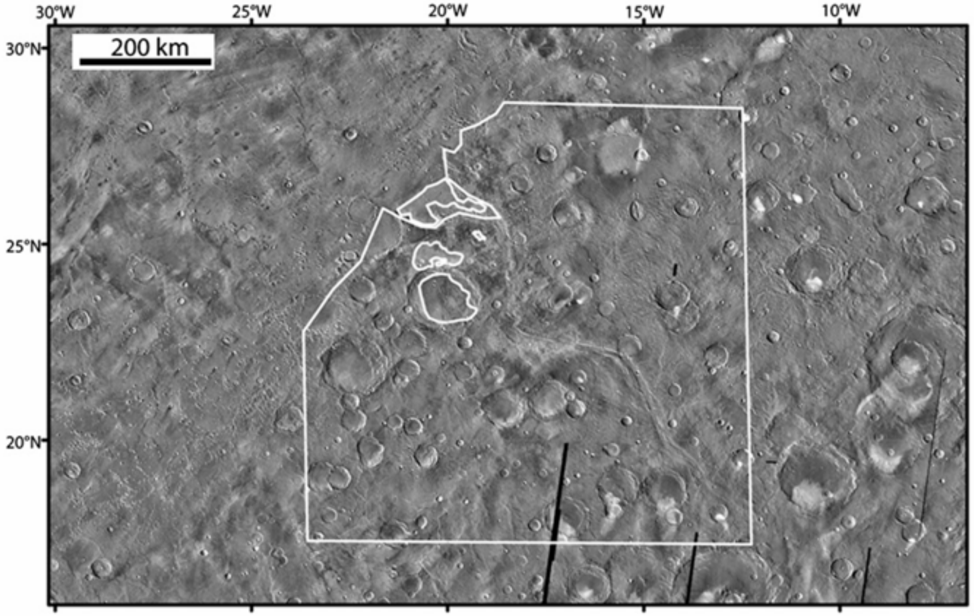

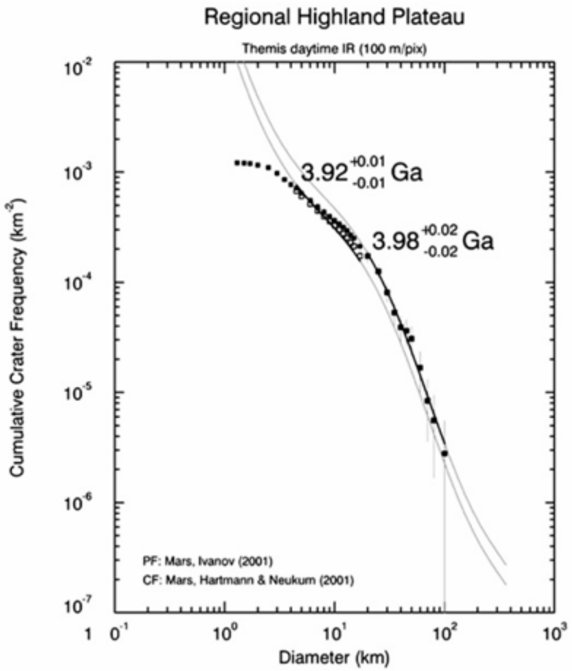

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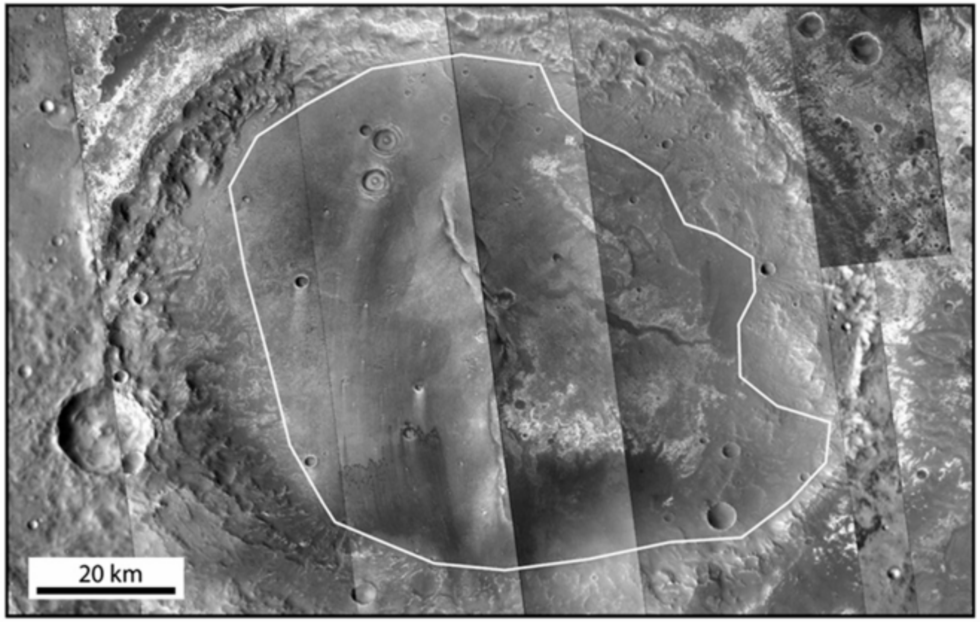

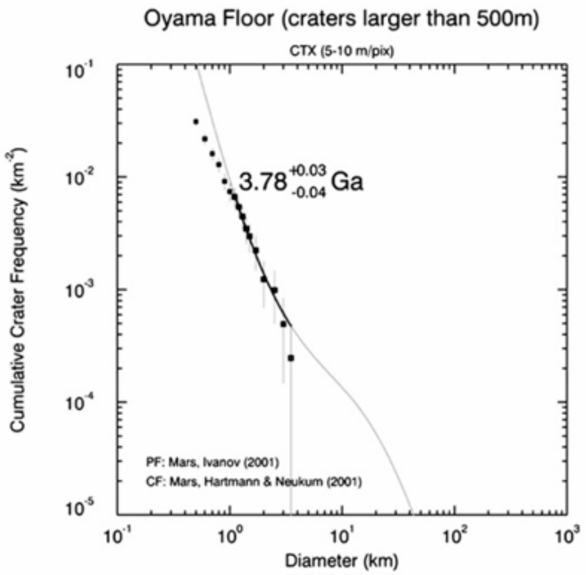

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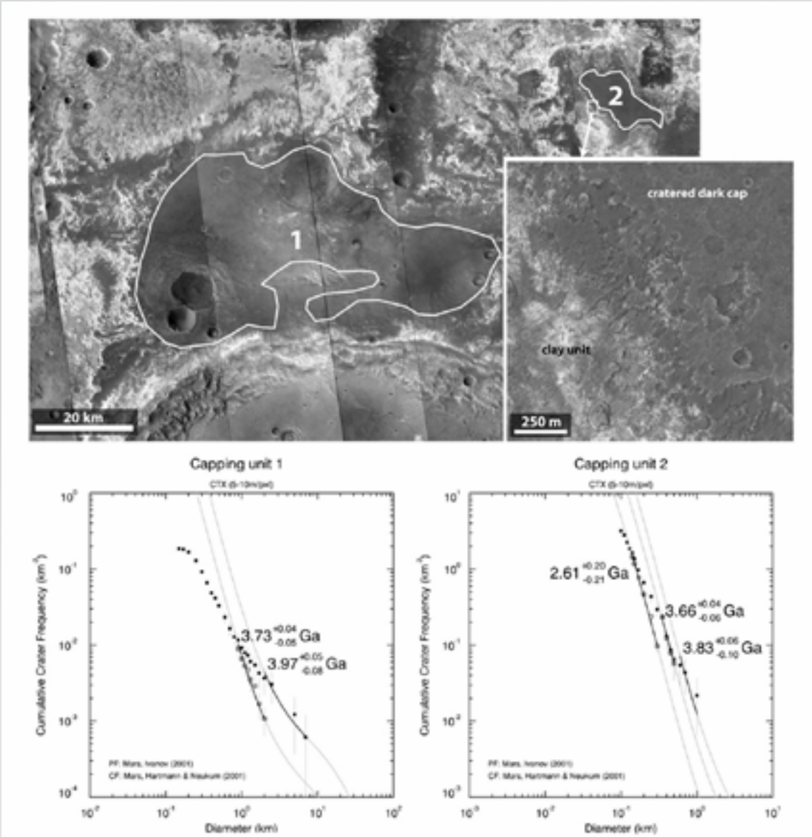

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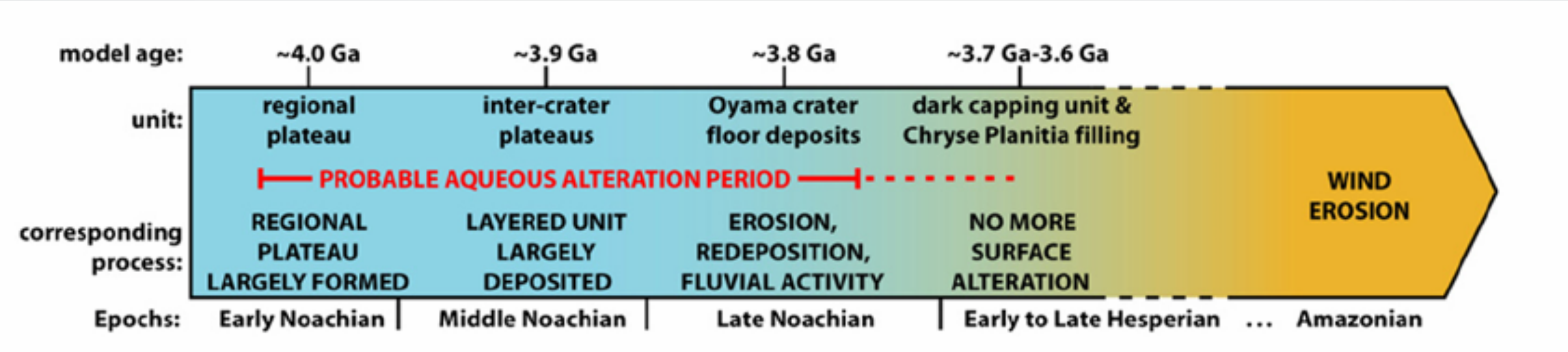

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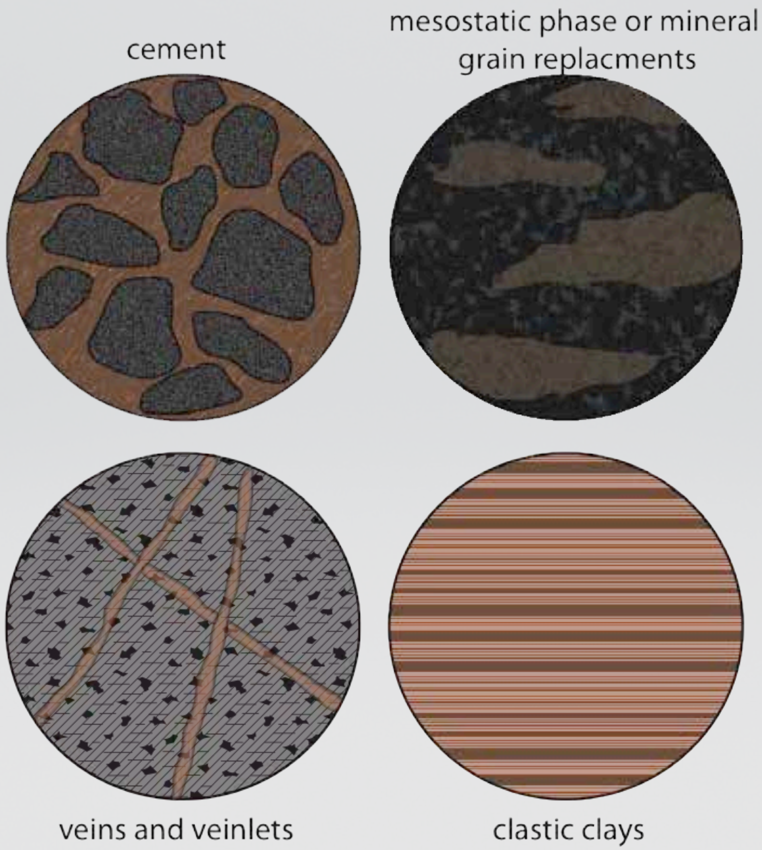
- **Geology – the big picture**
  - **Petrology**
    - **Textures are not well understood (this is true of every site)**



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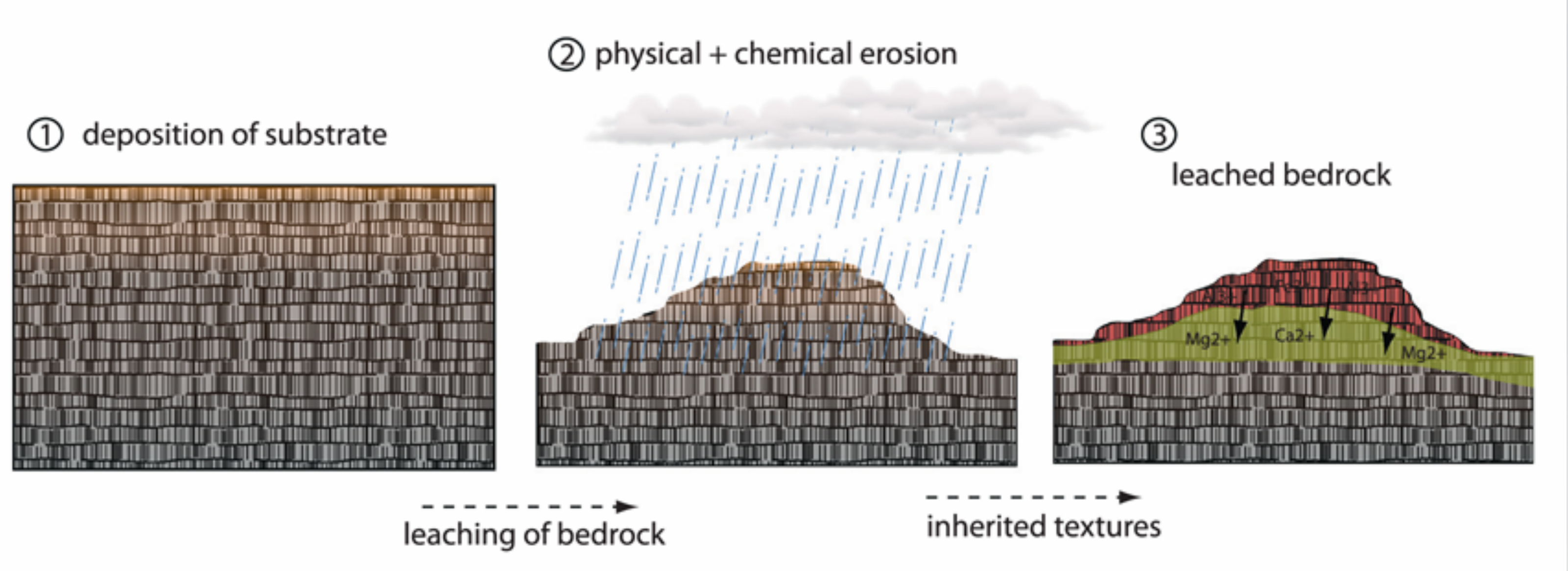

Site's Geological Context

EXOMARS

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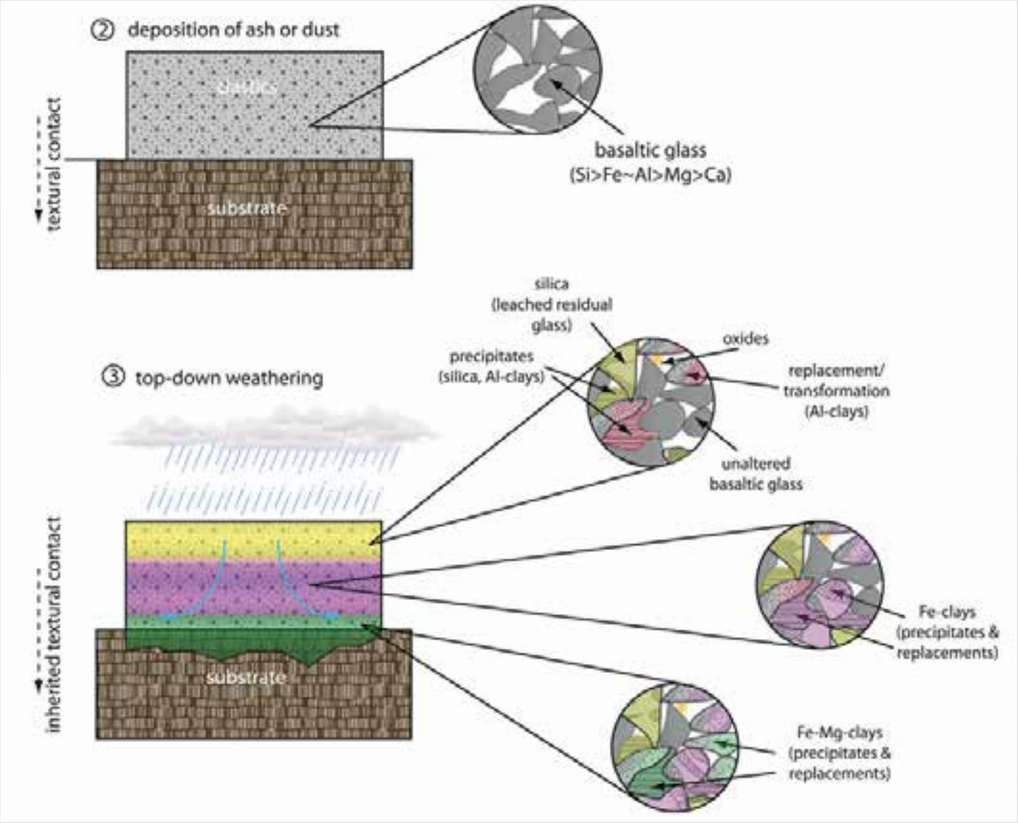
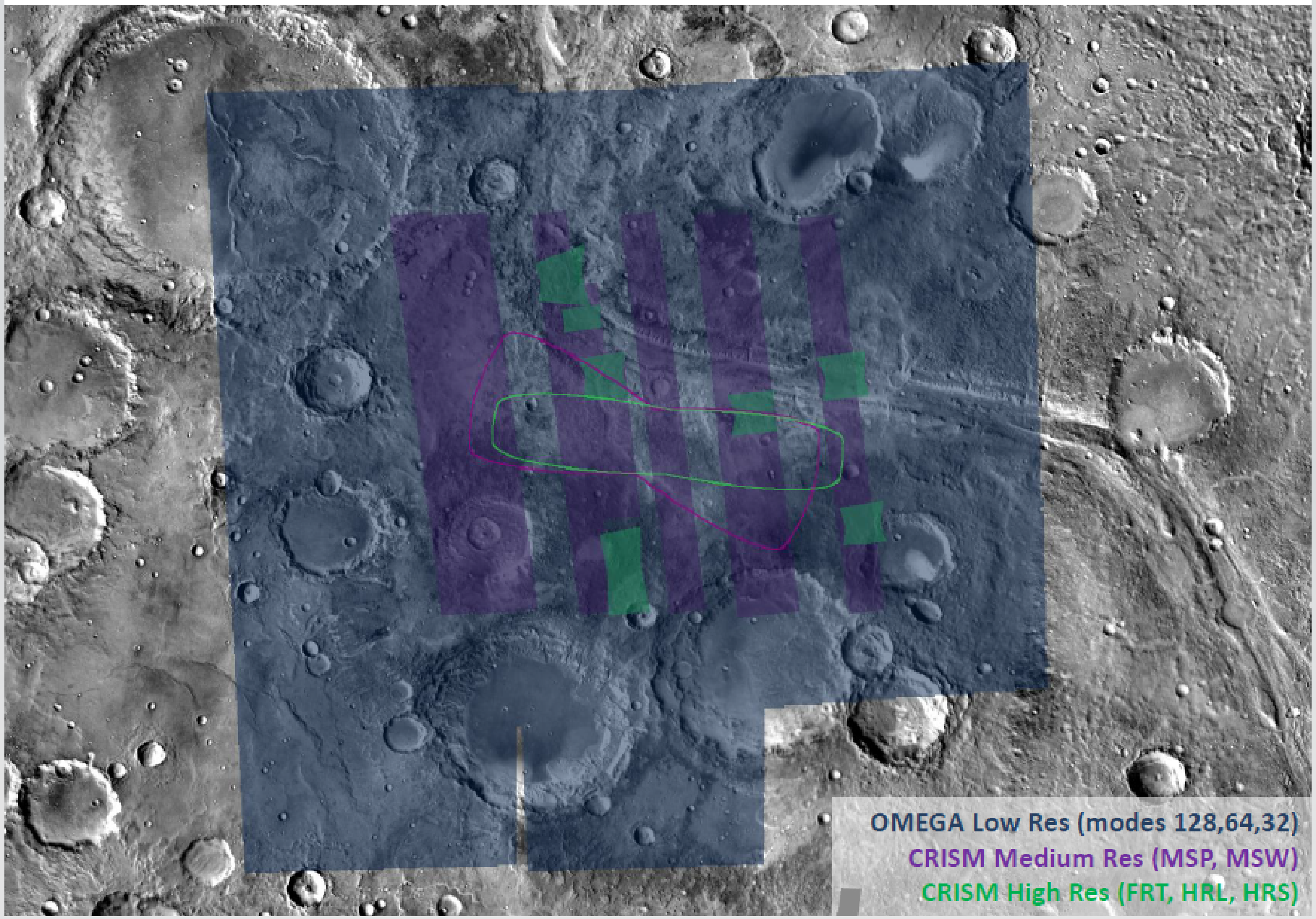
  - **Geology & Petrology**
    - **Clastics altered in top-down setting….**



OMEGA and CRISM observations



Mineralogical Description

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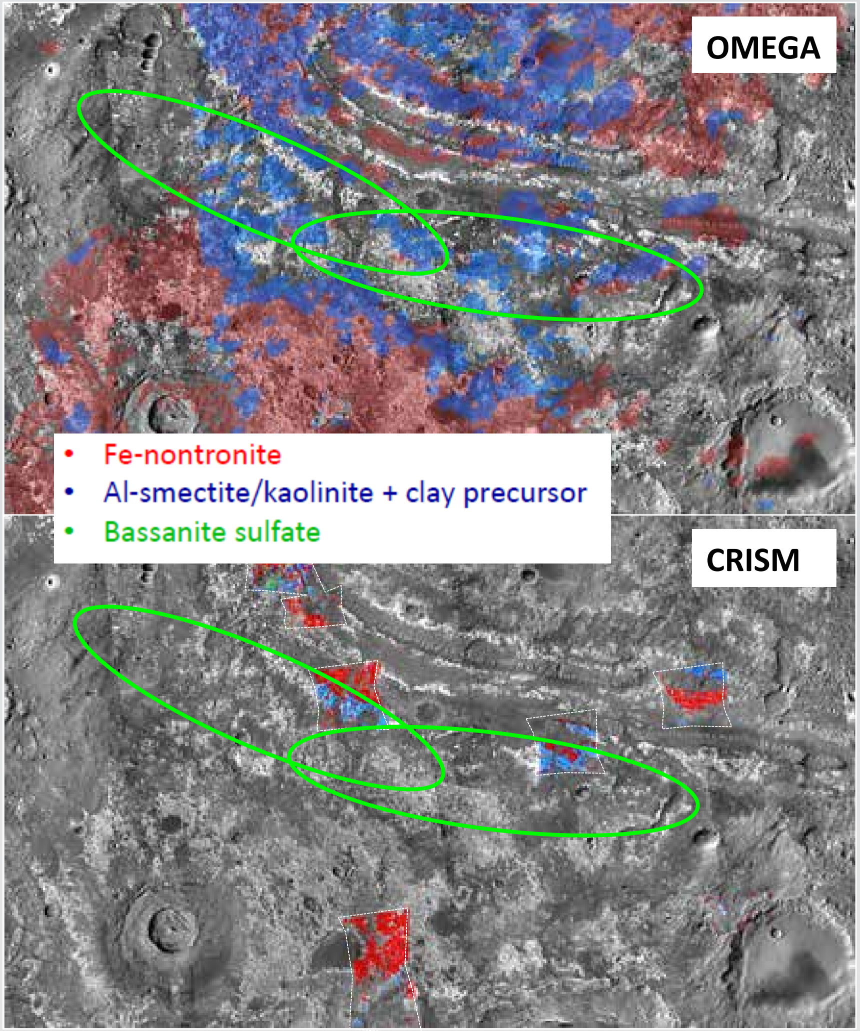
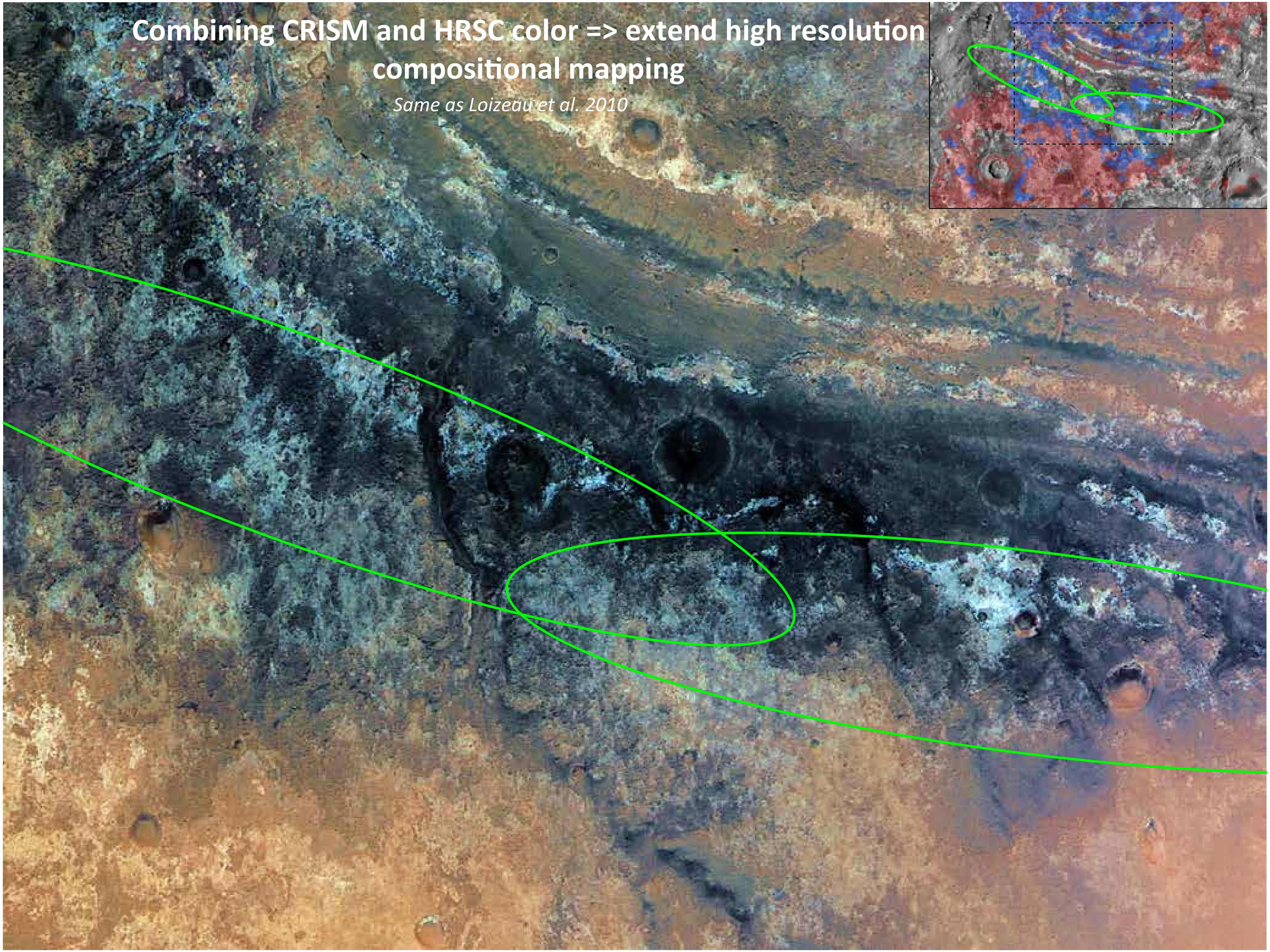
Alteration mineralogy at km-scale

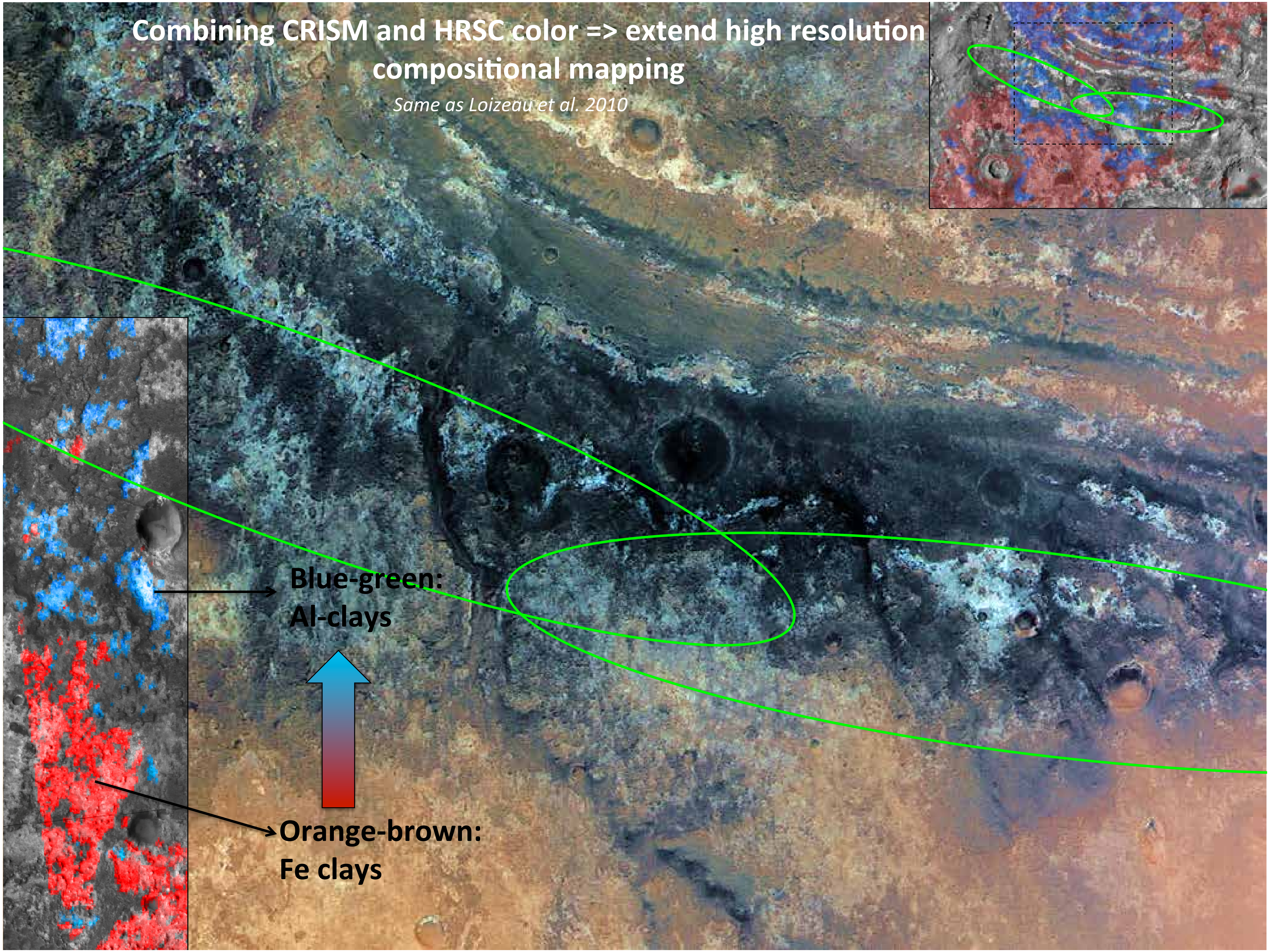
- Plateau ellipses show weak, scattered Al-rich clays (kaolinite and smectite) signatures. Signatures are stronger at the MV-walls and at southern areas where Fe-smectites become well visible. Both correspond to the edges of the ellipses

- Al-smectite unit: spectral variability between Al-smectite, kaolins and a clay precursor (Al/Fe allophane)

- Localized deposits of sulfates (K-jarosite and Ca-bassanite) in the walls and floor of Mawrth Channel




Combining CRISM and HRSC color => extend high resolution compositional mapping
Same as Loizeau et al. 2010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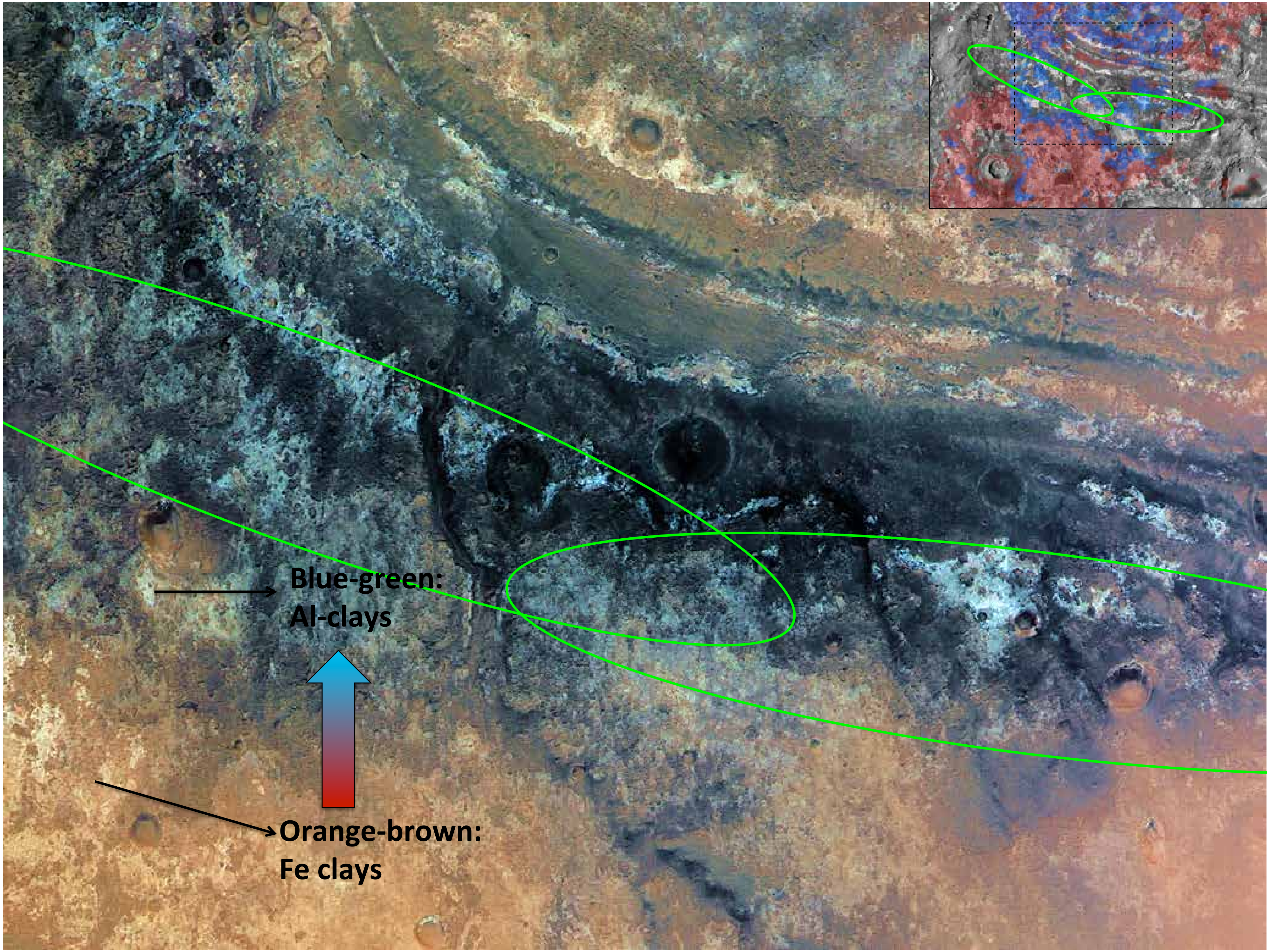
Blue-green: Al-clays
Orange-brown: Fe clays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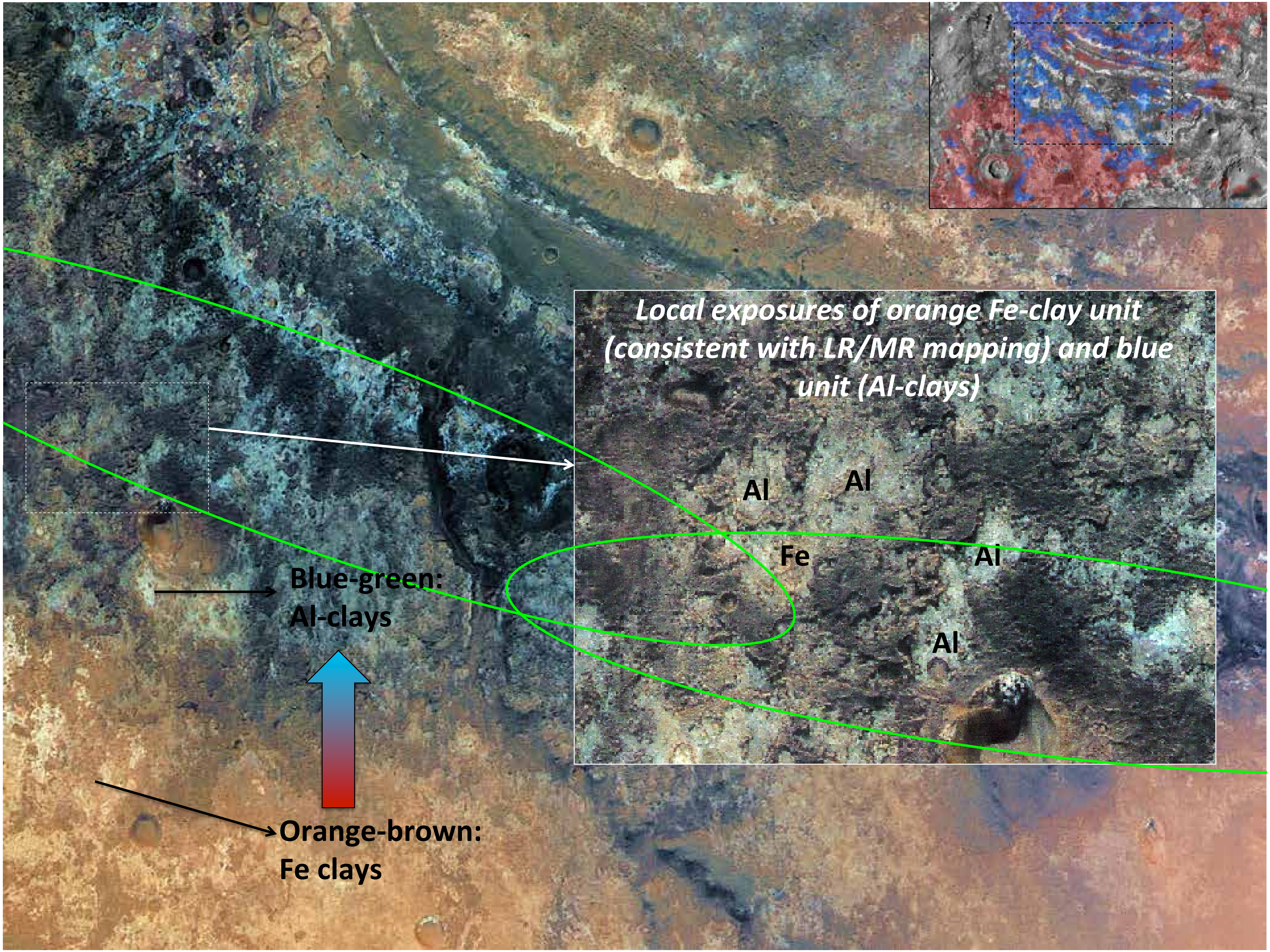
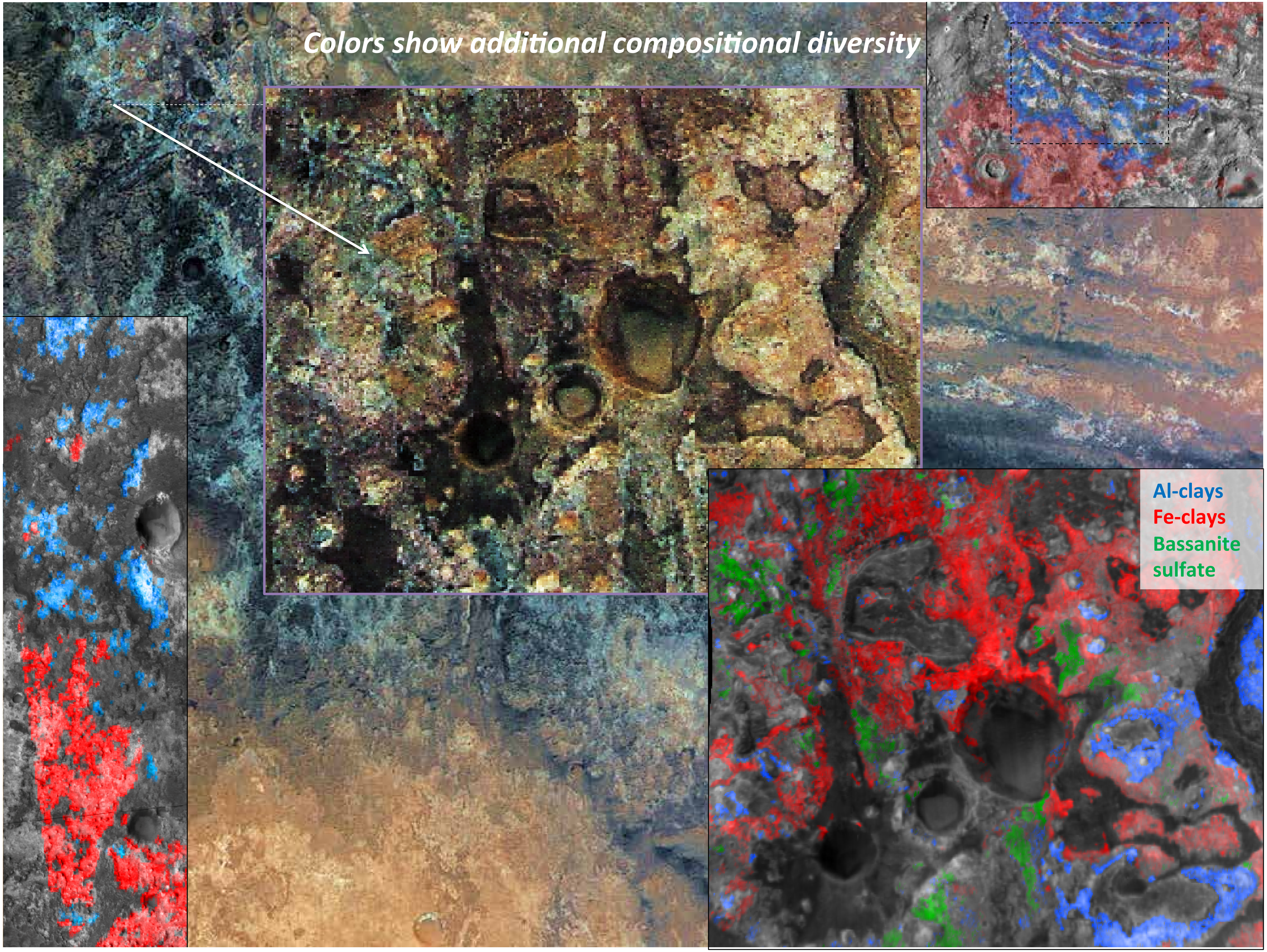
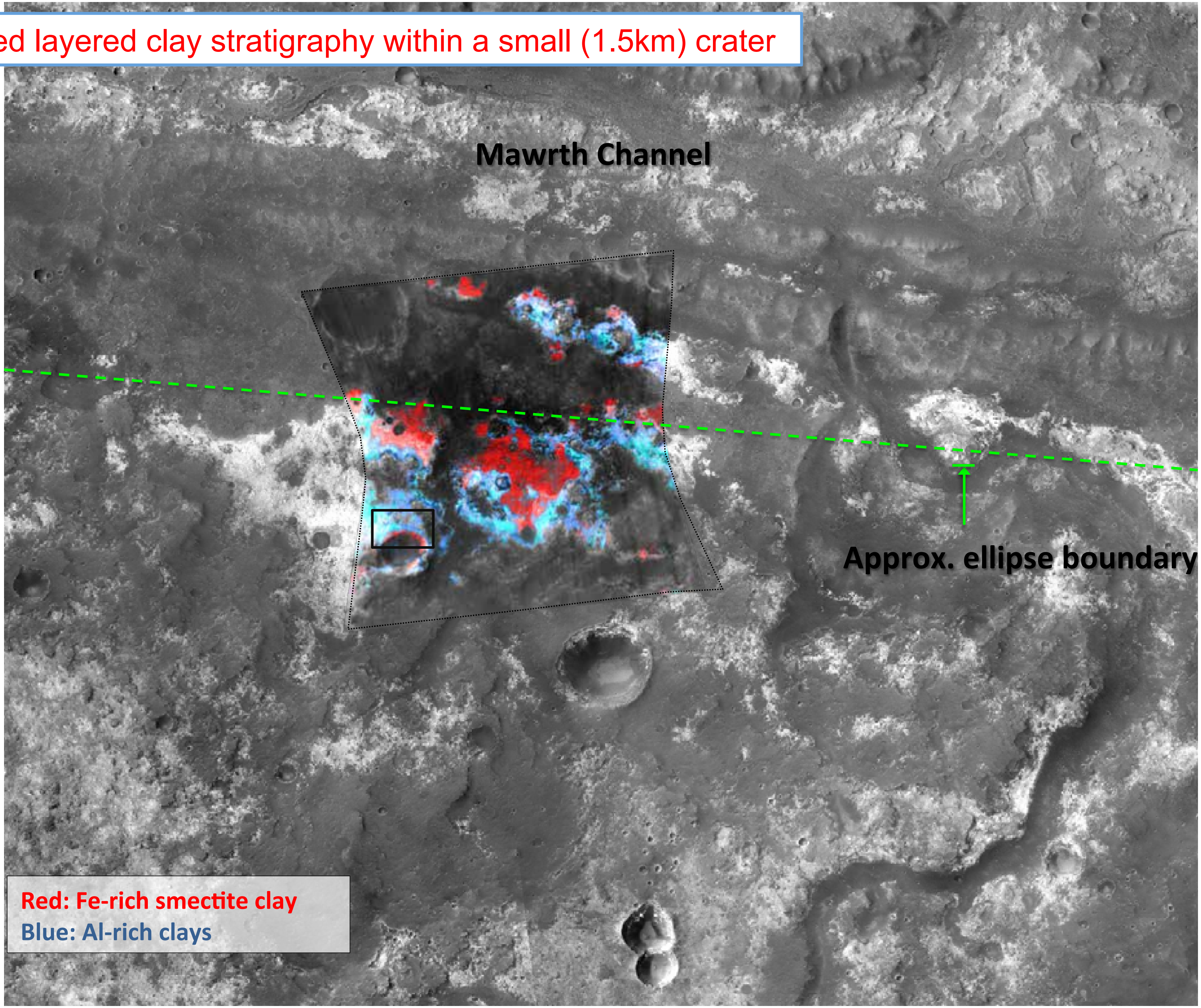
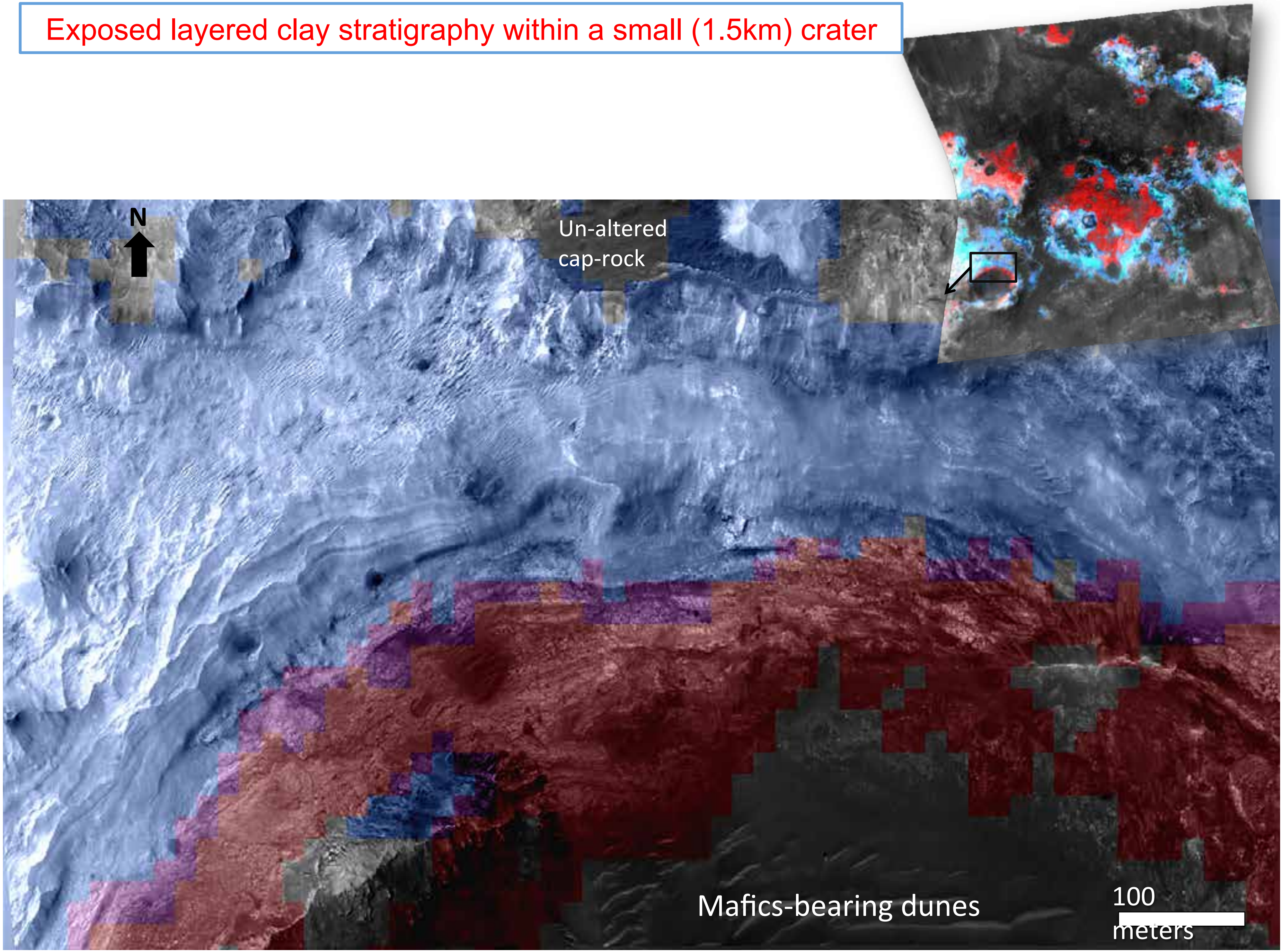

Local exposures of orange Fe-clay unit (consistent with LR/MR mapping) and blue unit (Al-clays)
Al
Al
Fe
Al
Al
Blue-green: Al-clays
Orange-brown: Fe clays


Colors show additional compositional diversity
Al-clays
Fe-clays
Bassanite
sulfate

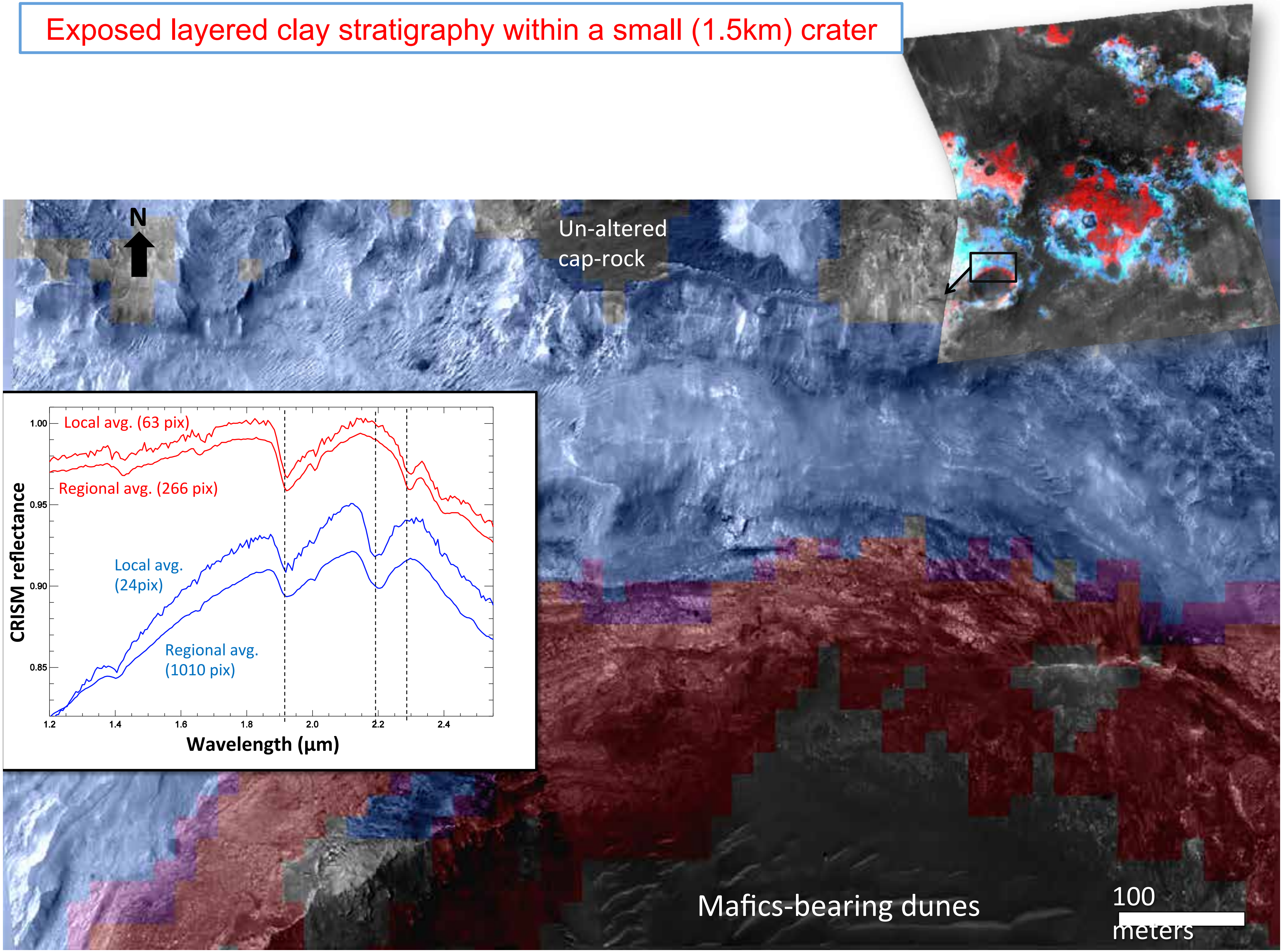
Exposed layered clay stratigraphy within a small (1.5km) crater



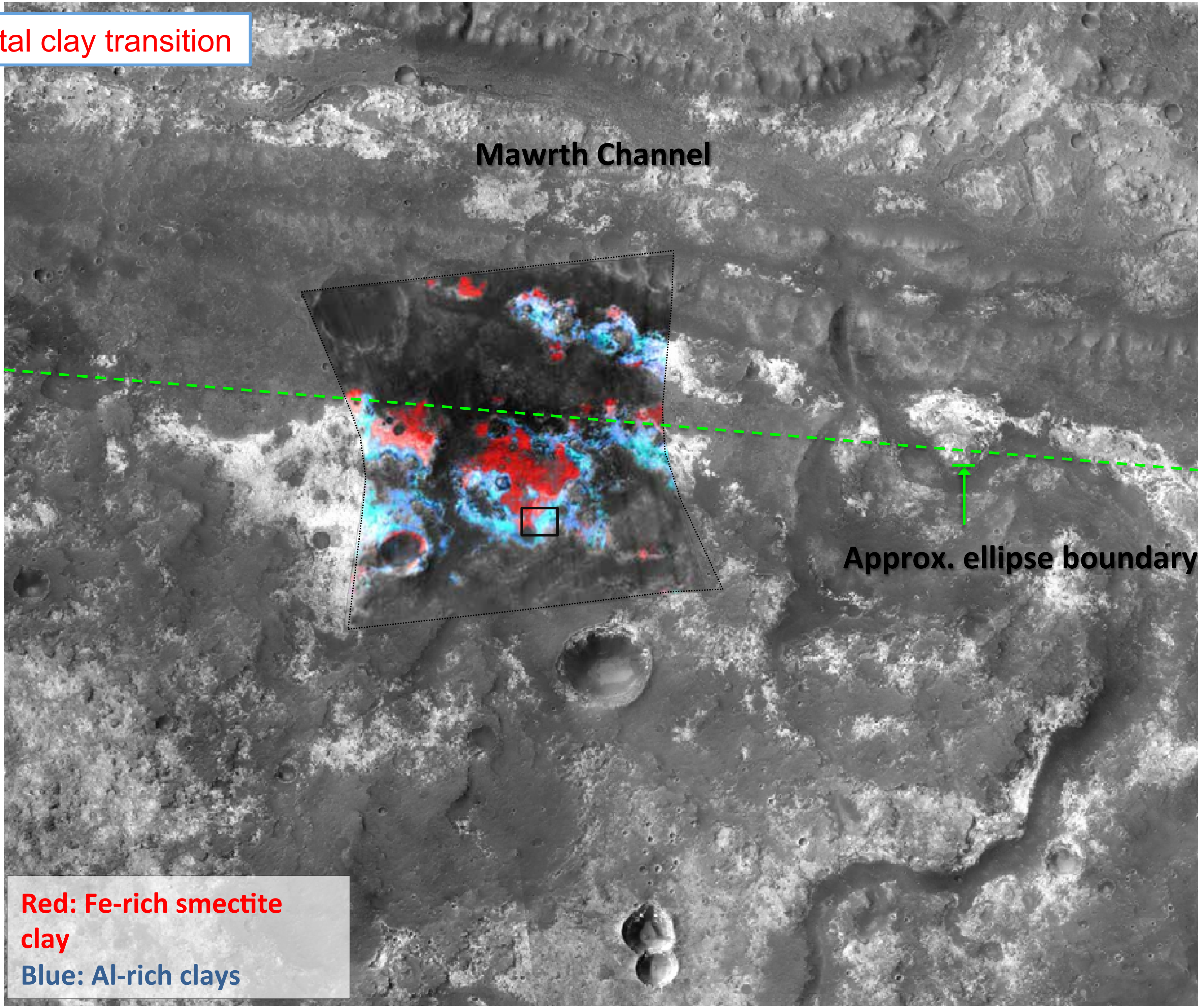
Exposed layered clay stratigraphy within a small (1.5km) crater



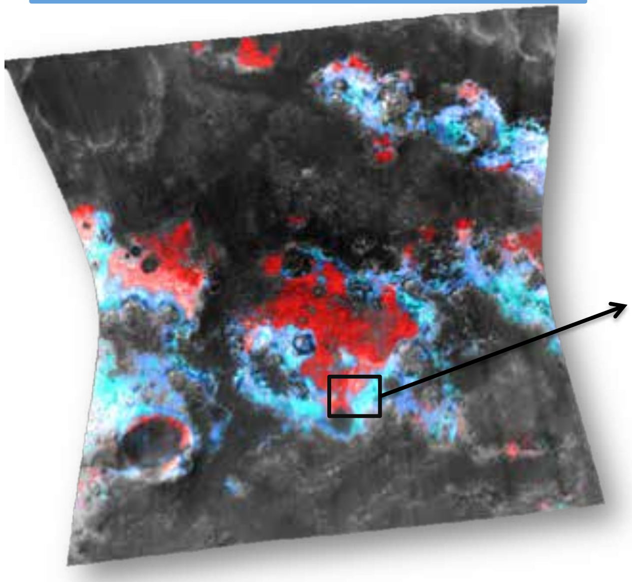
Exposed layered clay stratigraphy within a small (1.5km) crater

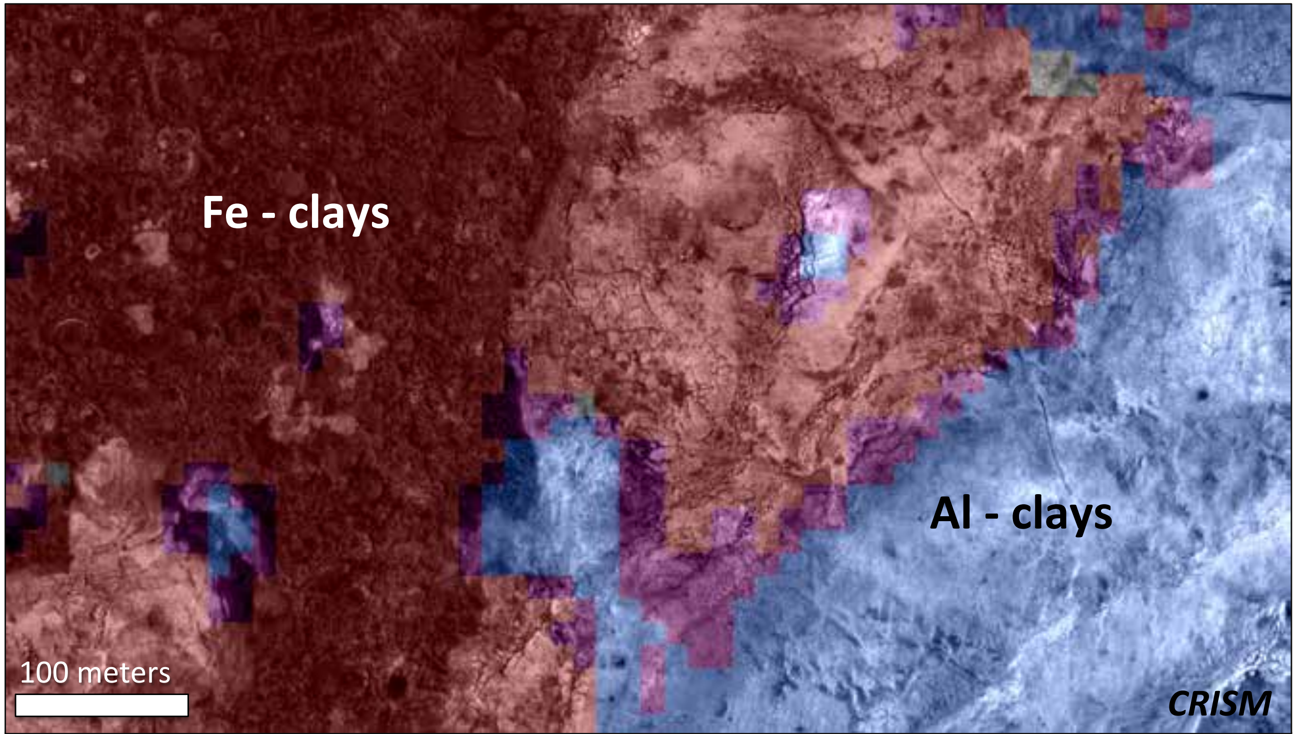


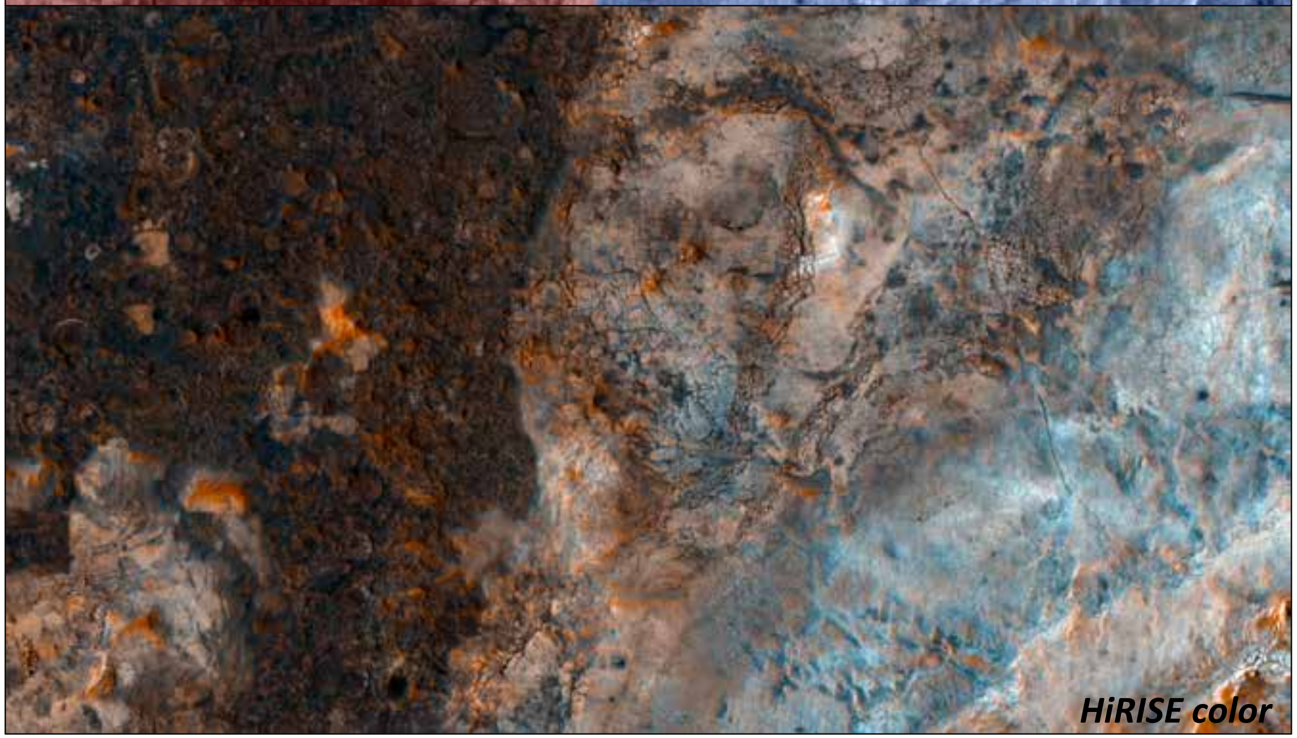
Horizontal clay transition

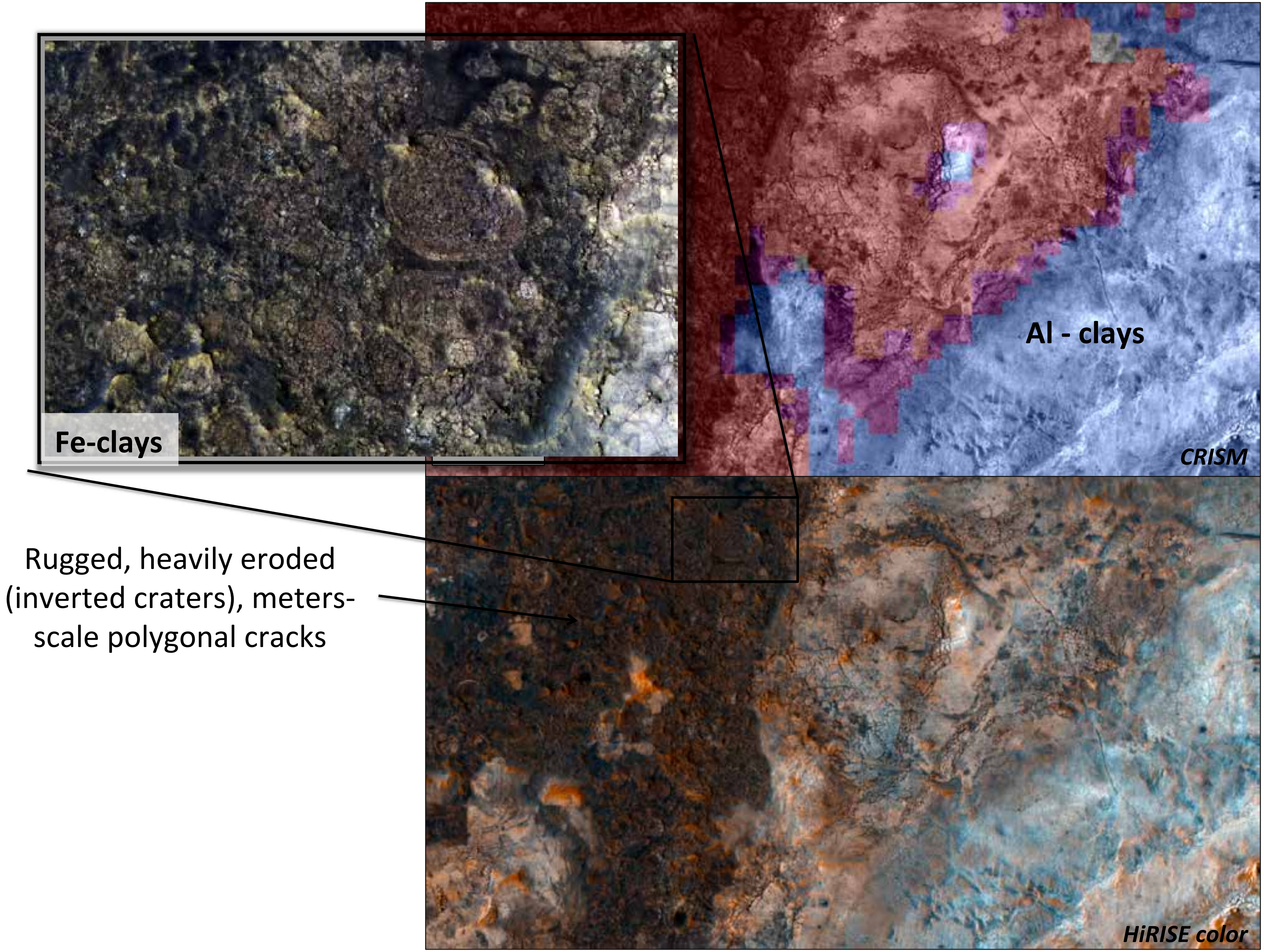


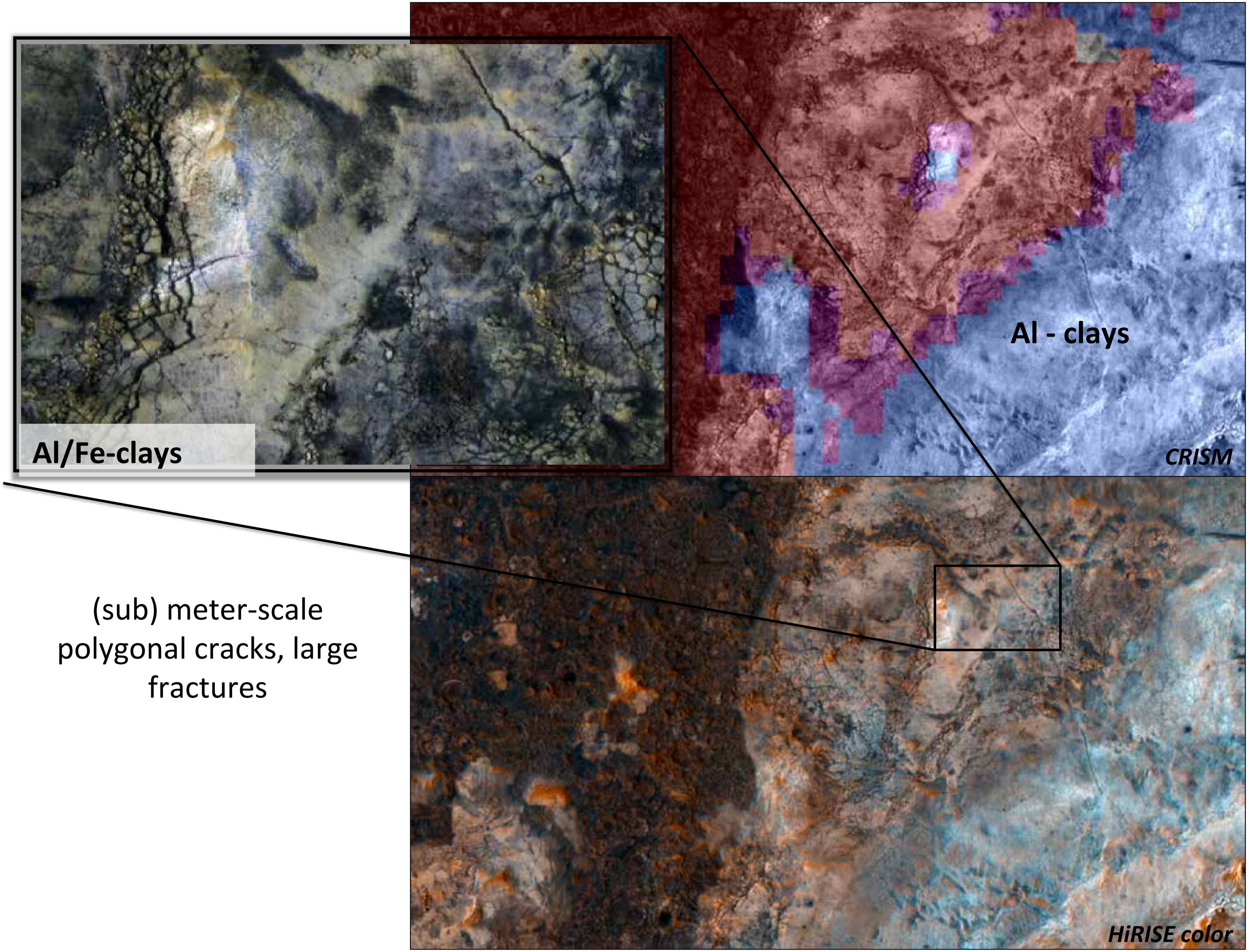
Horizontal clay transition



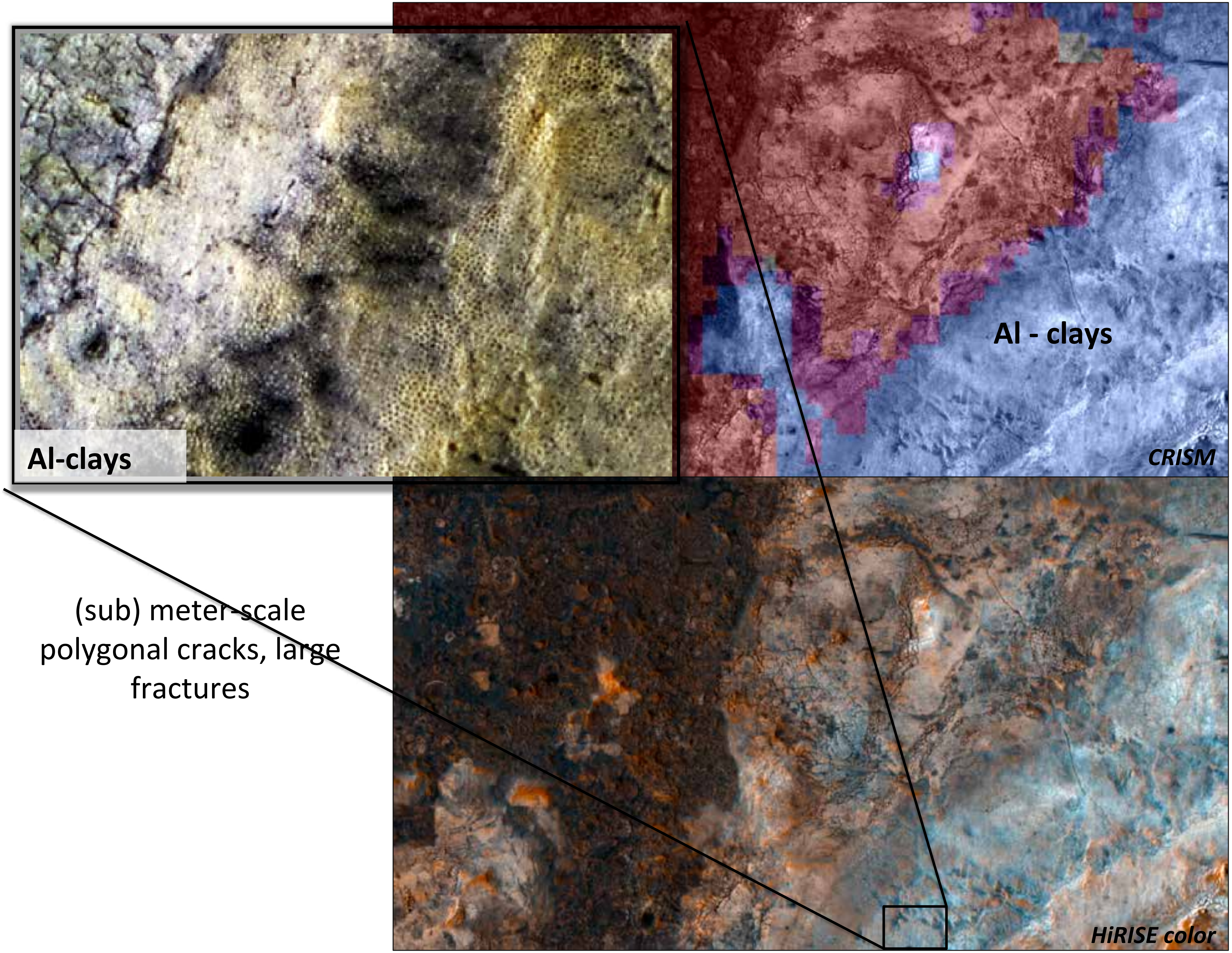




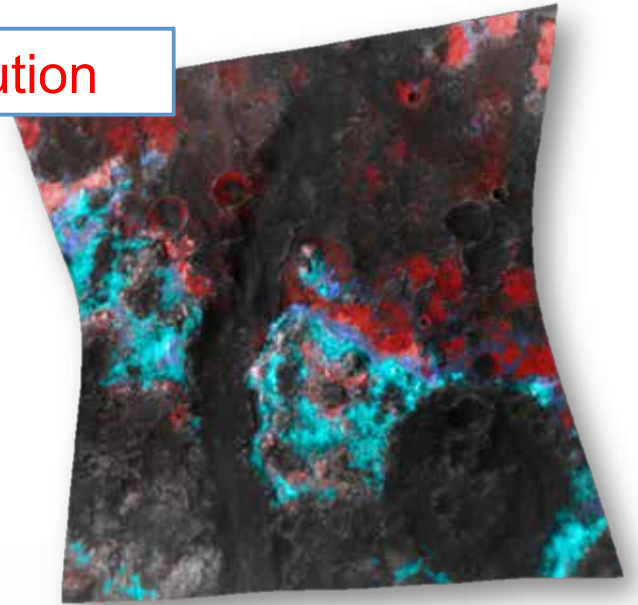

Fe-clays
Al - clays
CRISM
Rugged, heavily eroded (inverted craters), meters-scale polygonal cracks
HiRISE color



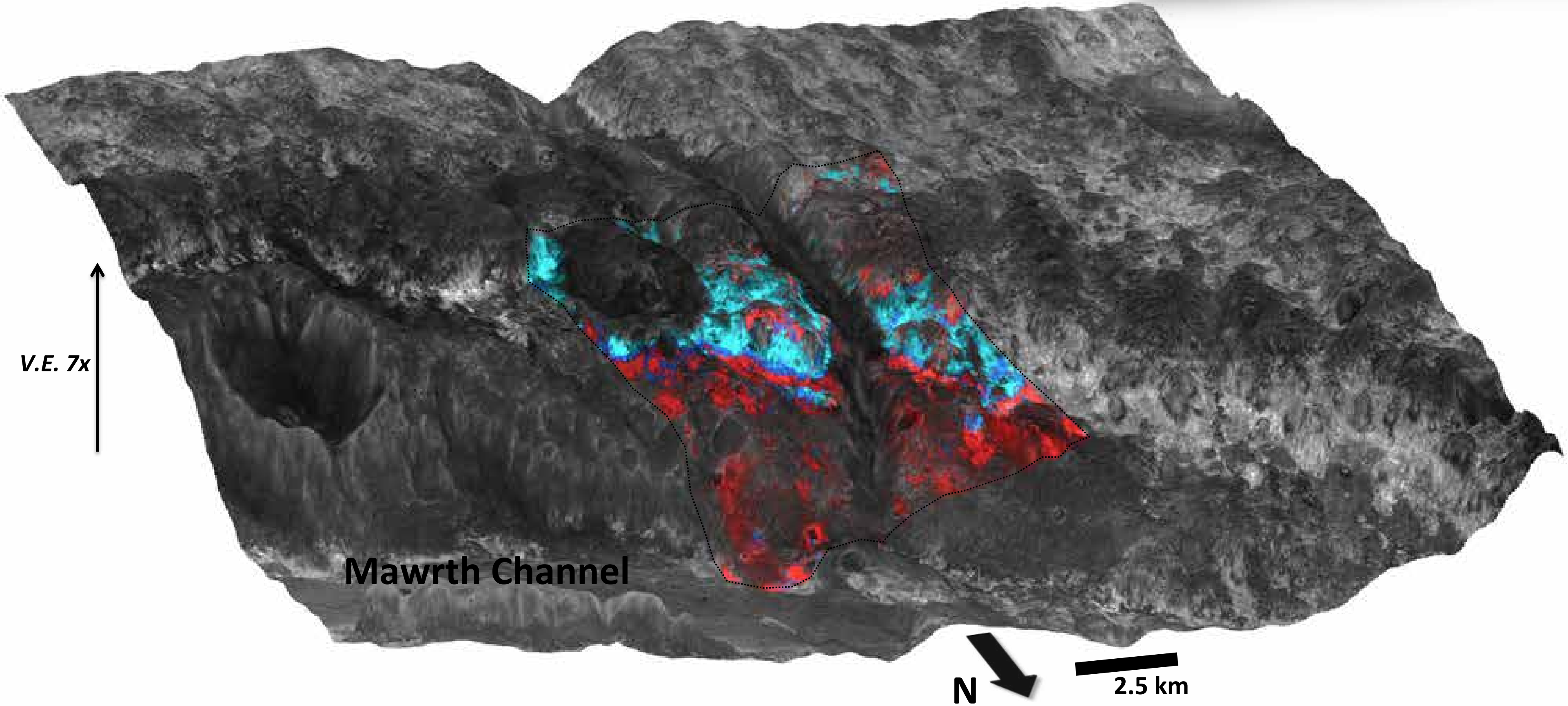
(sub) meter-scale polygonal cracks, large fractures


Al-clays
Al - clays
CRISM
(sub) meter-scale
polygonal cracks, large
fractures
HiRISE color

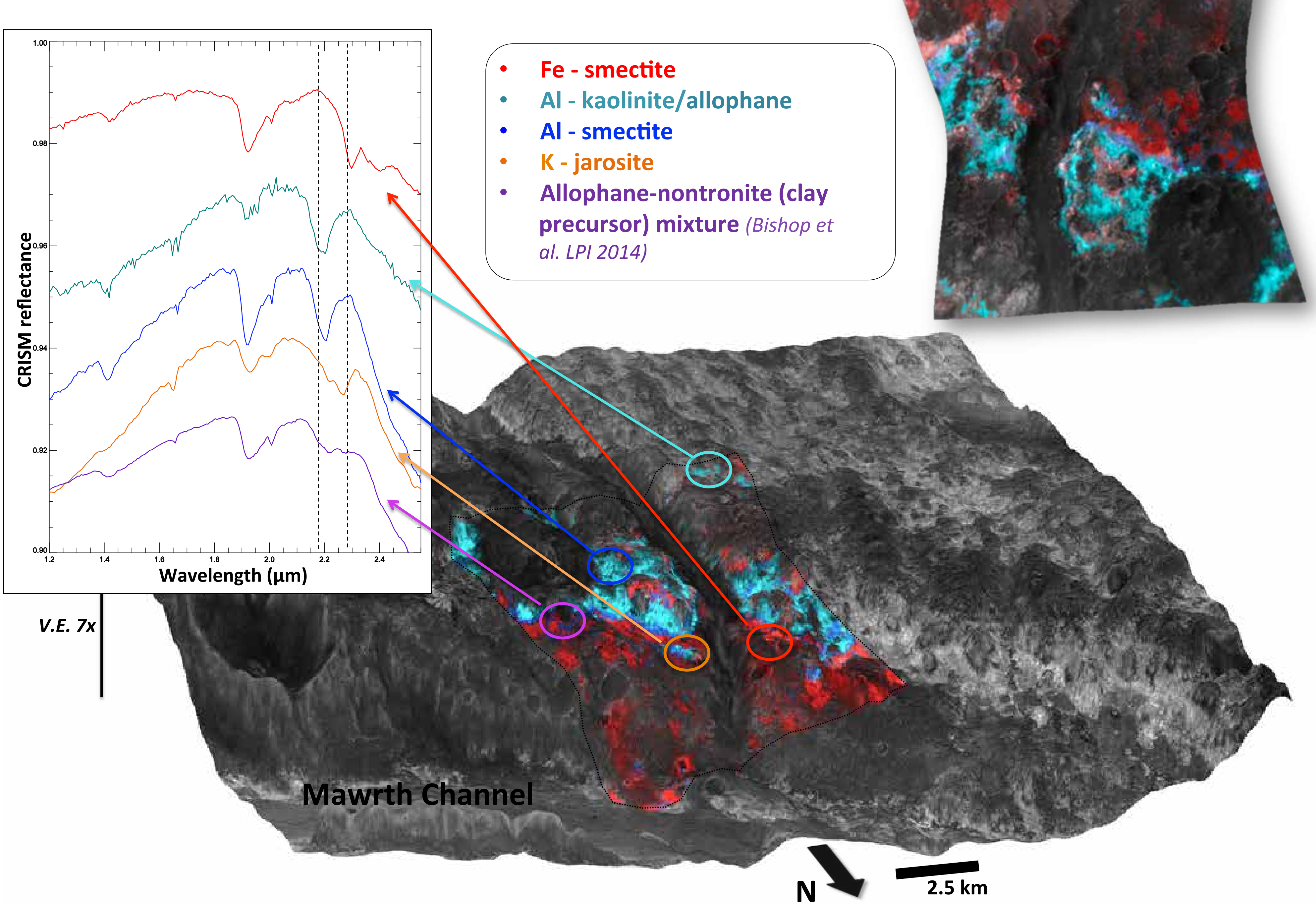
Local scale mineral diversity at the CRISM full resolution



Exposed stratigraphy within Mawrth Channel walls



Local scale mineral diversity at the CRISM full resolution



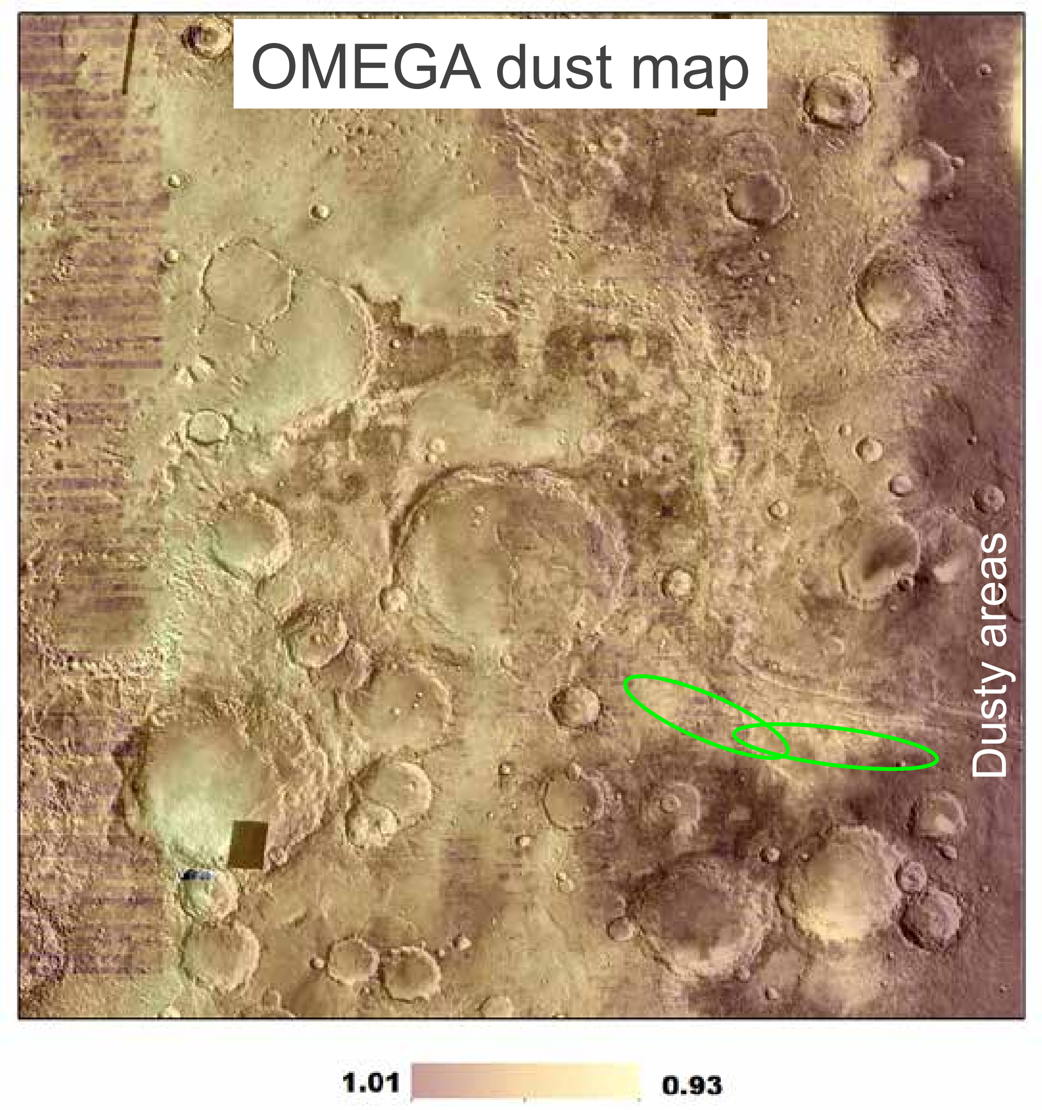
Target Accessibility

E X O M A R S

Table 1: Details for candidate landing site in the Mawrth Vallis region.

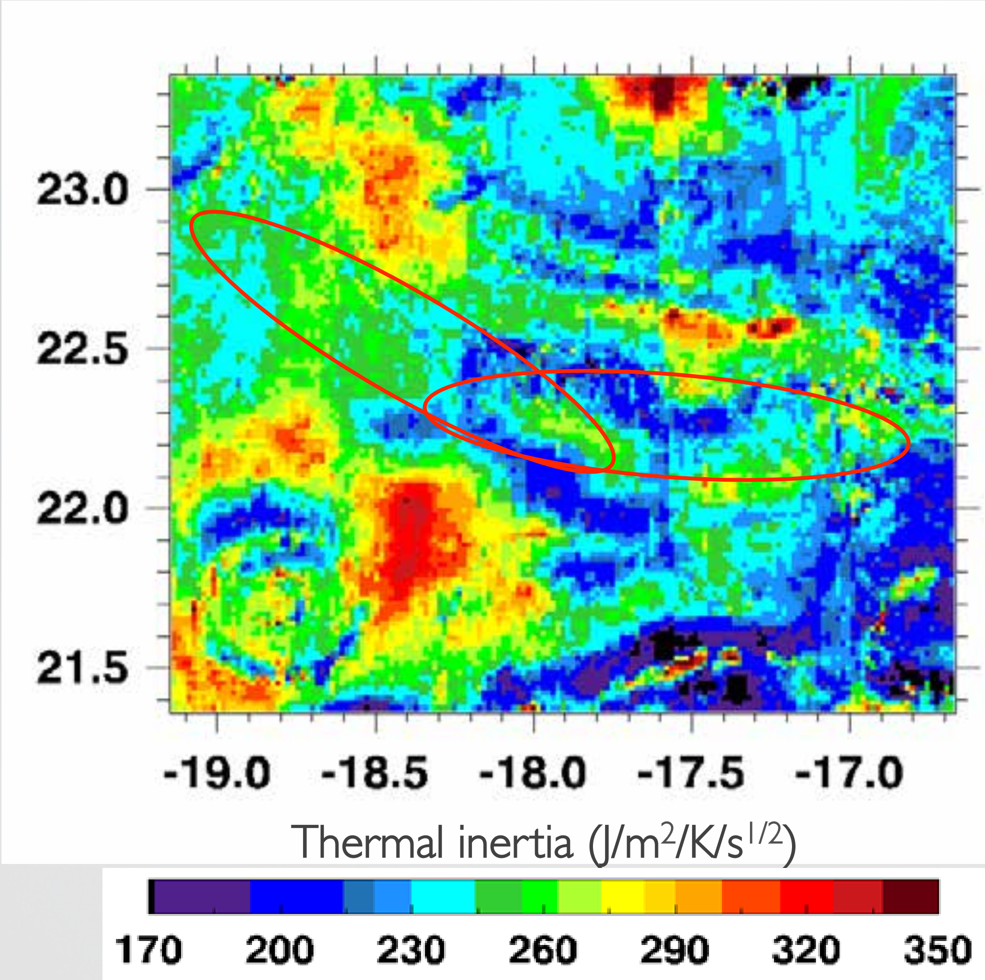
Site Name	**Mawrth Vallis**
Ellipse pattern centre's latitude, longitude, and size	22.16N, 342.05 E 104 km x 19 km
Elevation (for centre, max, min)	Centre: -2214 m Max: -1799 m Min: -2214 m
Prime science targets	Layered sedimentary rocks Phyllosilicates within layered rocks Stratigraphy contact between Al-OH clays overlying Fe-OH clays Dissected channels
Distance of prime science targets from ellipse centre	- Phyllosilicates deposits and stratigraphic section: from 300 m to 1 km for all ellipses - Channels: 7 to 11 km (depending on the ellipse) - Layered sedimentary stratigraphy (everywhere)
Distance of other science targets from ellipse centre	- Confirmed sulfate deposit < 19 km Dark-toned caprock, regional stratigraphic marker (everywhere)
Overall distribution of science targets in ellipse	Al-rich clay coverage: ~30% Fe/Mg-rich clay coeverage: ~21%
Occurrences of dark streaks	No
Occurrences of RSL	No

Dust



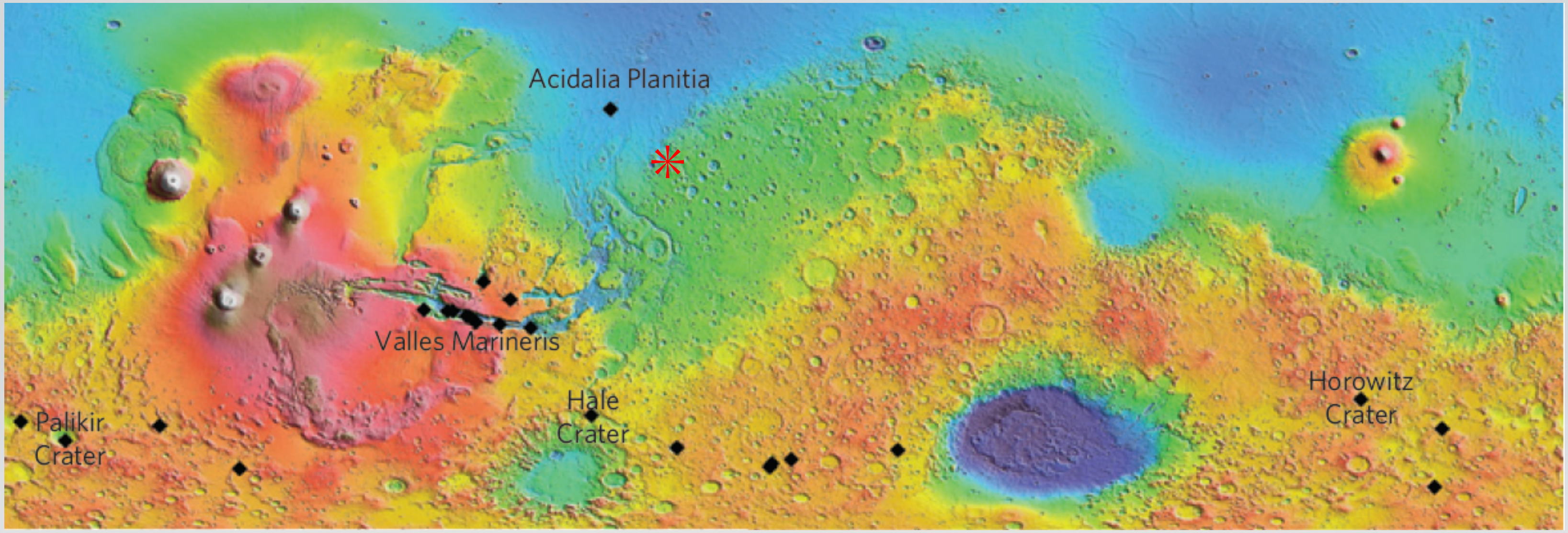
Dust index ~ 0.95
=> Low dust coverage

OMEGA Thermal Inertia map

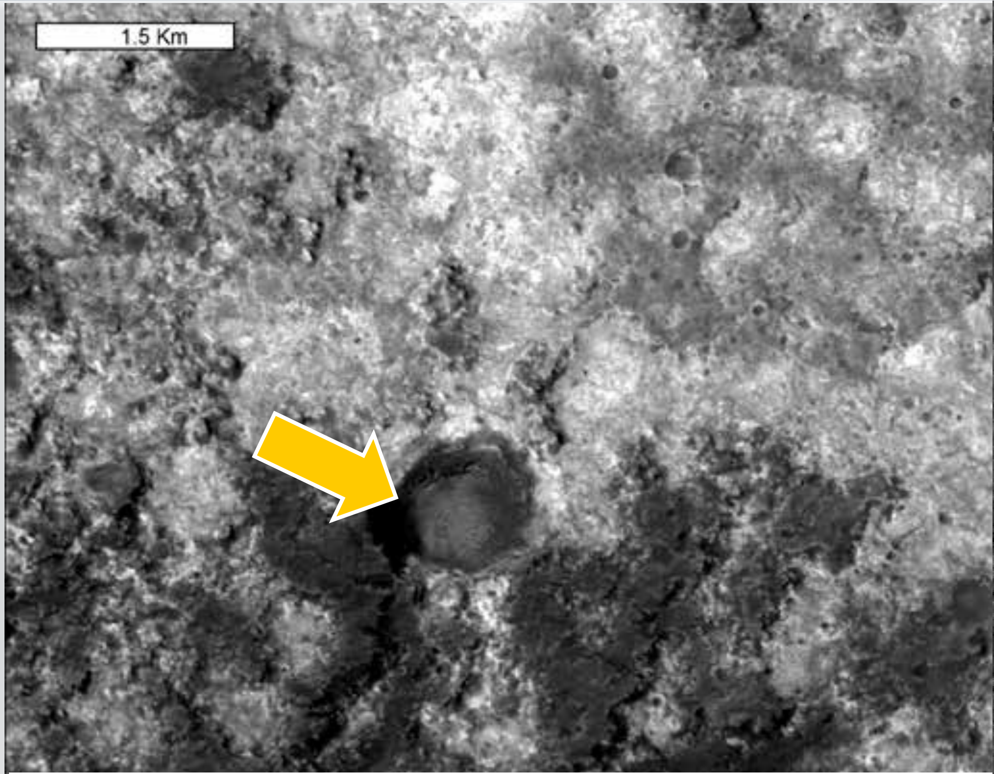


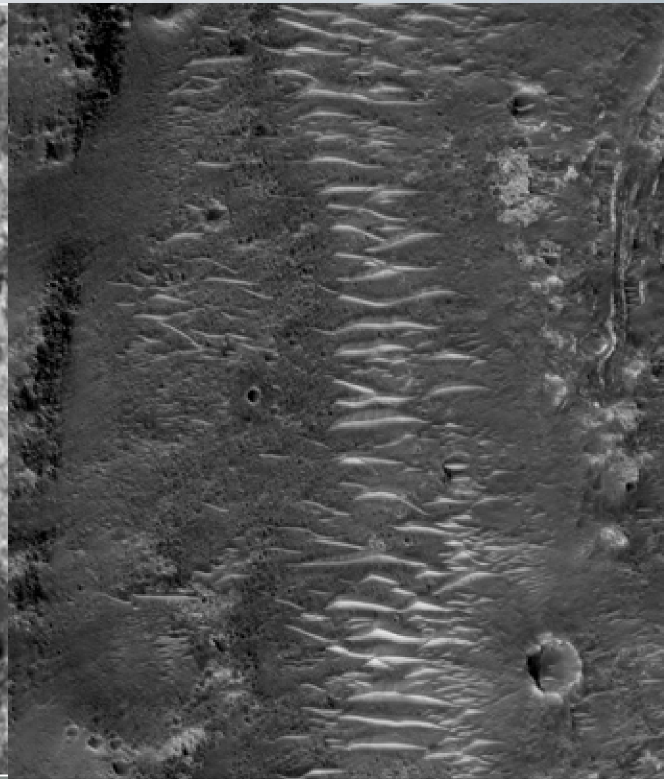
180 < TI < 280
=> Low dust coverage

RSL map


Acidalia Planitia
Valles Marineris
Hale Crater
Palikir Crater
Horowitz Crater

Dust, ripples and TAR

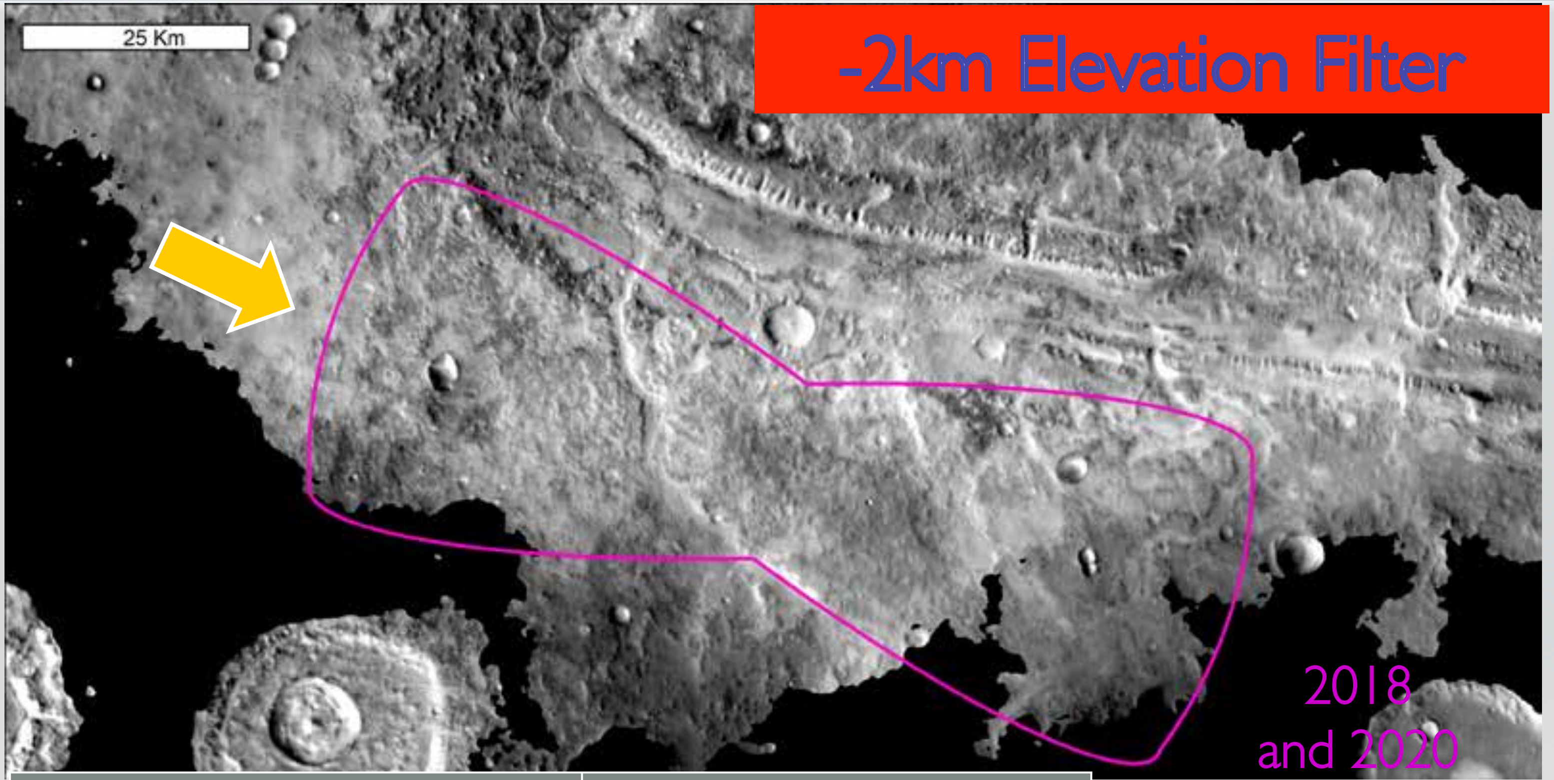




Ellipse Year/Azim.)	%	Location
Dust coverage	<1 %	
Ripples	<1 %	In craters and channels
TAR coverage	0 observed	

Very few Ripples and no TARs

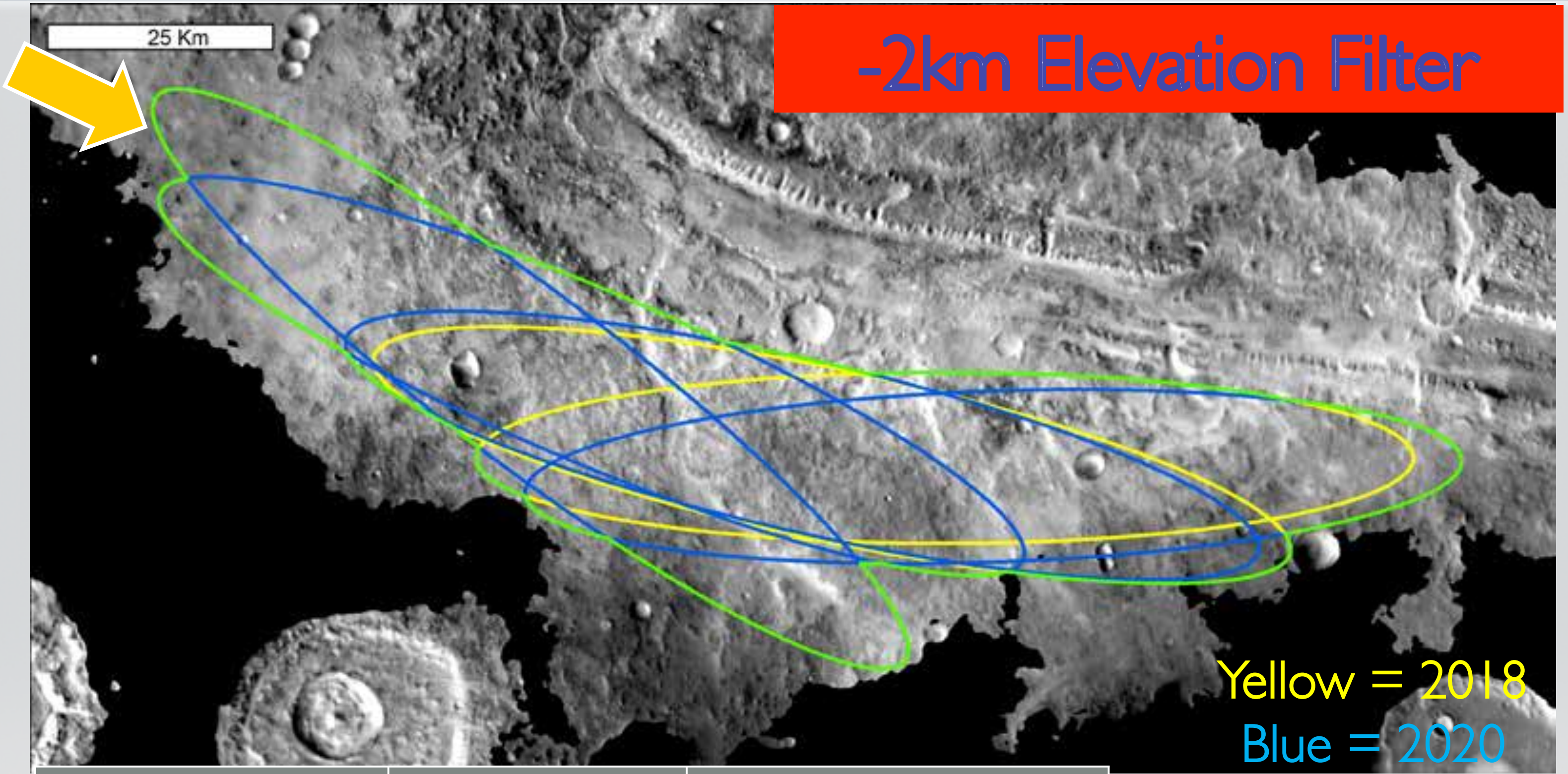
Landing Ellipse Properties - ELEVATION



Ellipse Year/Azim.)	% above -2000m
2018 / 2020	7.9 %

Common centre ellipse pattern

Landing Ellipse Properties - ELEVATION

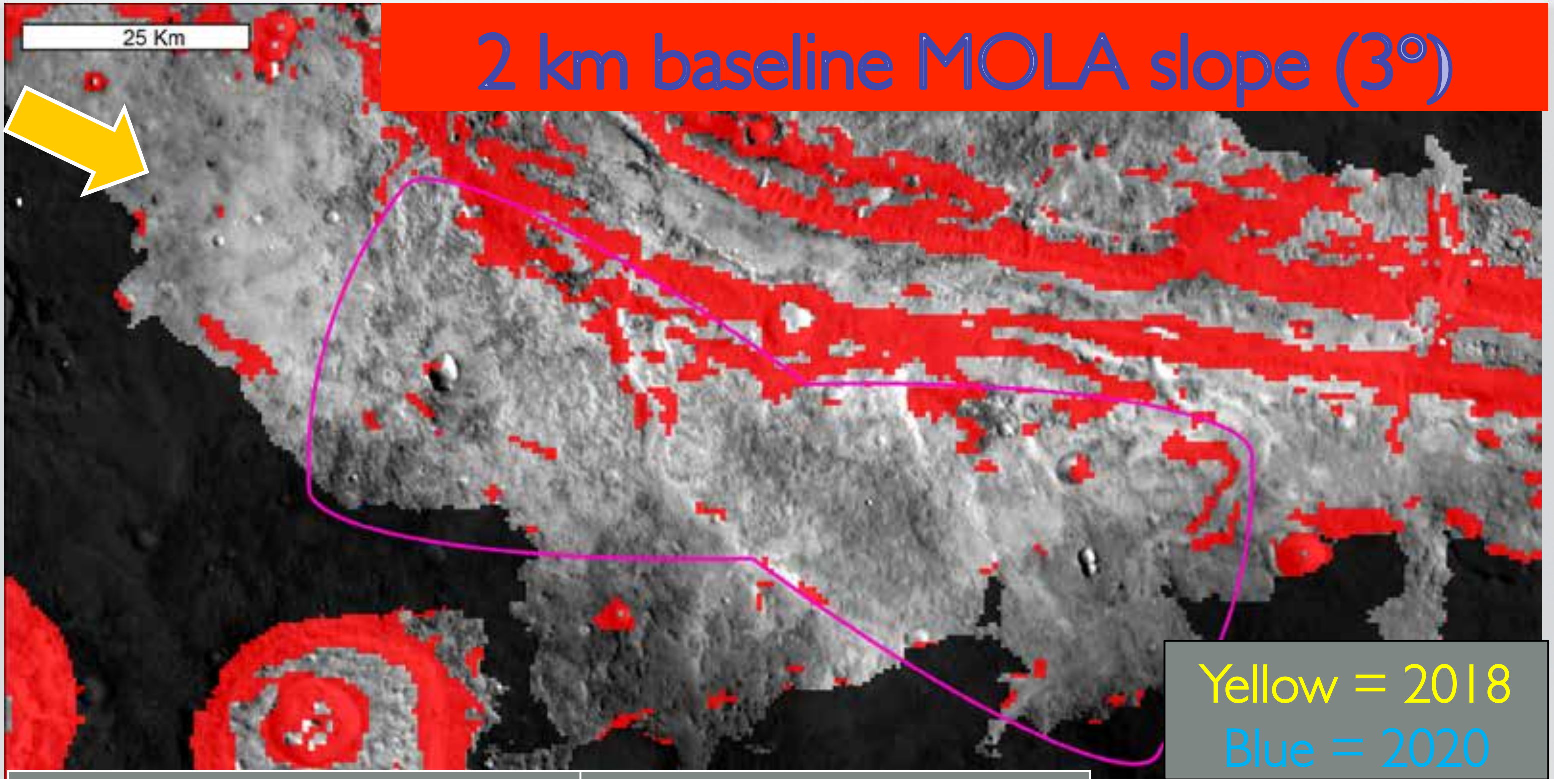


Ellipse Year/Azim.)	% above -2000m	Mean Elevation
2018 (90°)	0.0	-2273.18
2018 (102°)	0.0	-2251.72
2020 (88°)	0.0	-2246.13
2020 (103°)	0.0	-2265.67
2020 (113°)	0.0	-2327.28
2020 (127°)	0.0	-2333.99

Multi centred ellipse pattern

No violation

Landing Ellipse Properties - SLOPE

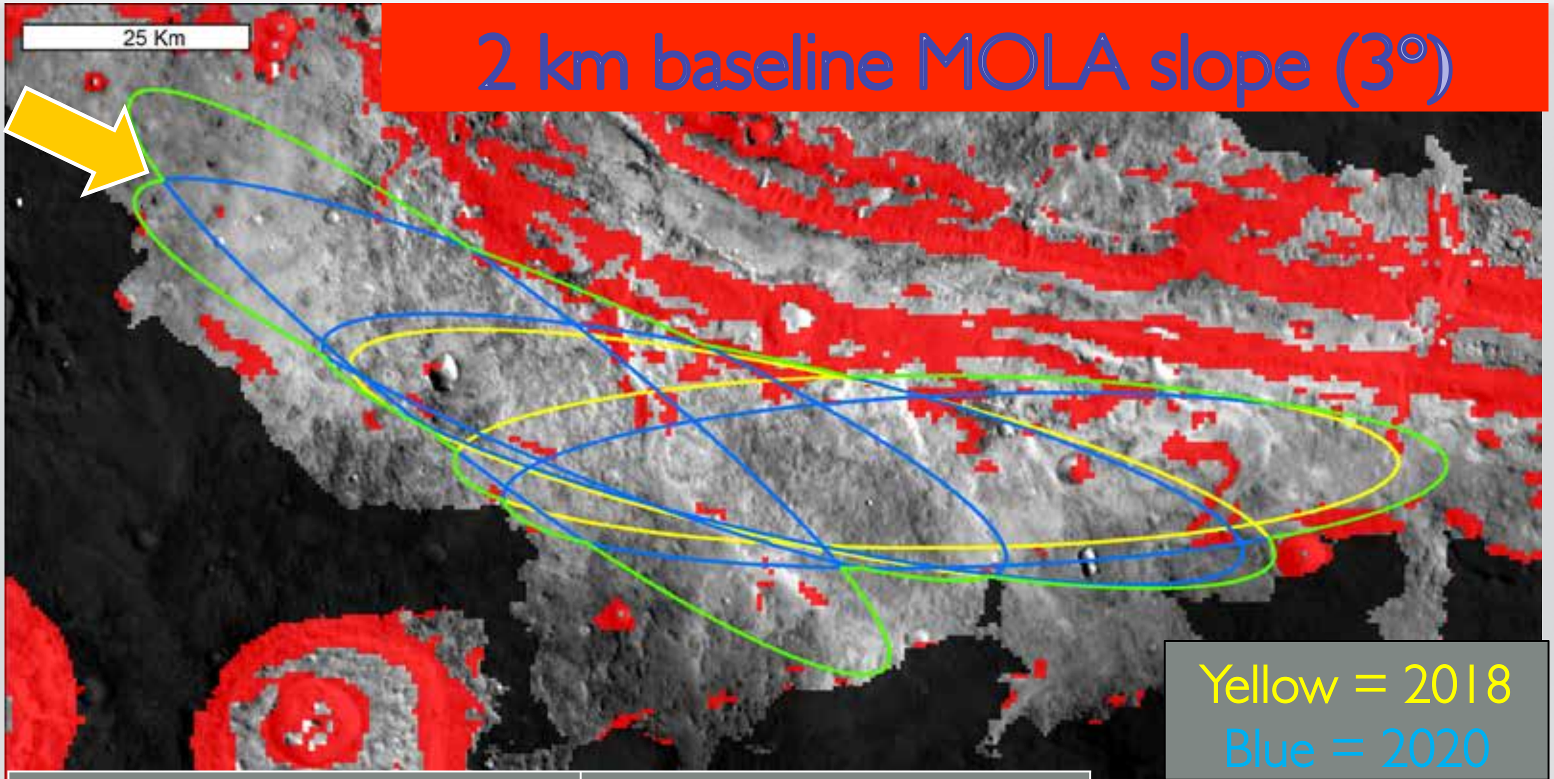


Ellipse (Year/Azim.)	% above 3°
2018 / 2020	9.7

Slopes on the banks of Mawrth Vallis

Landing Ellipse Properties - SLOPE

EXOMARS



Ellipse (Year/Azim.)	% above 3°
2018 - 90°	0
2018 - 102°	2.4
2020 – 88°	0.9
2020 – 103°	2.3
2020 – 113°	3.9
2020 – 127°	3.6

Most slopes are avoidable

Landing Ellipse Properties - SLOPE

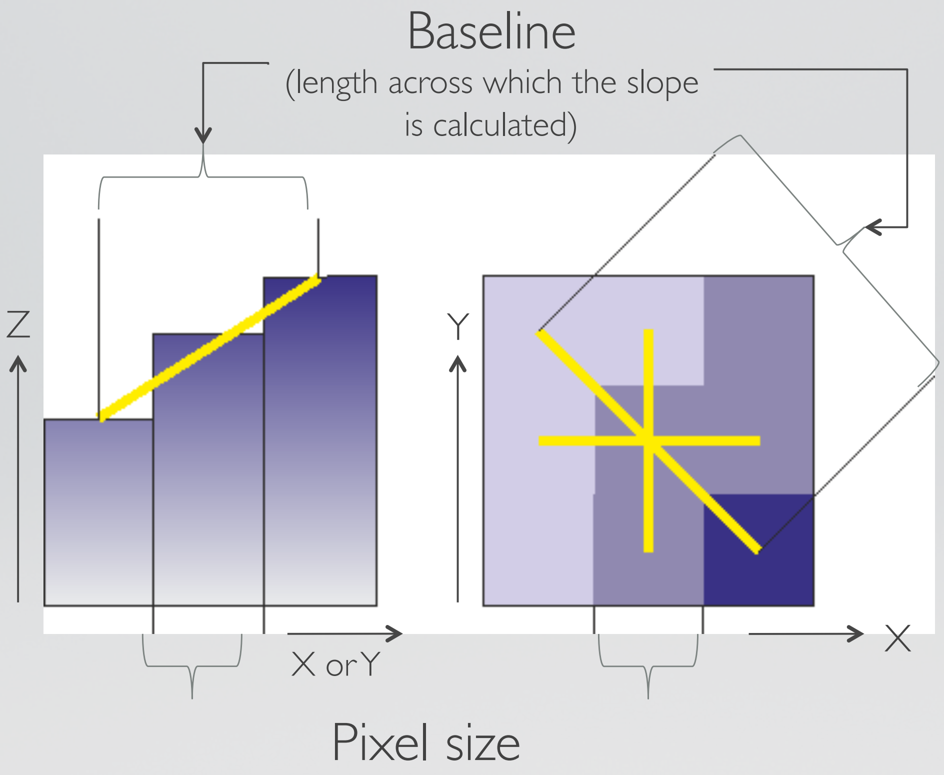
EXOMARS

Slope map creation method

- Raw data: MOLA point data, or CTX/HiRISE stereo DEMs created in BAE SocetSet software
- Data sampled at 1/3 of baseline length (e.g. 666m/pixel for a 2km baseline) to produce a gridded, interpolated DEM
  - MOLA DEM interpolated from raw Global point data
  - CTX/HiRISE DEMs created at 20m/1m gridding originally, then down-sampled to 110m for CTX (for 330m baseline) or to 2.33m for HiRISE (for 7m baseline)
- Slope maps then created in ArcGIS using 3D analyst tools
- Compliance maps then created by applying a ‘greater than’ mask to the slope maps

EXOMARS

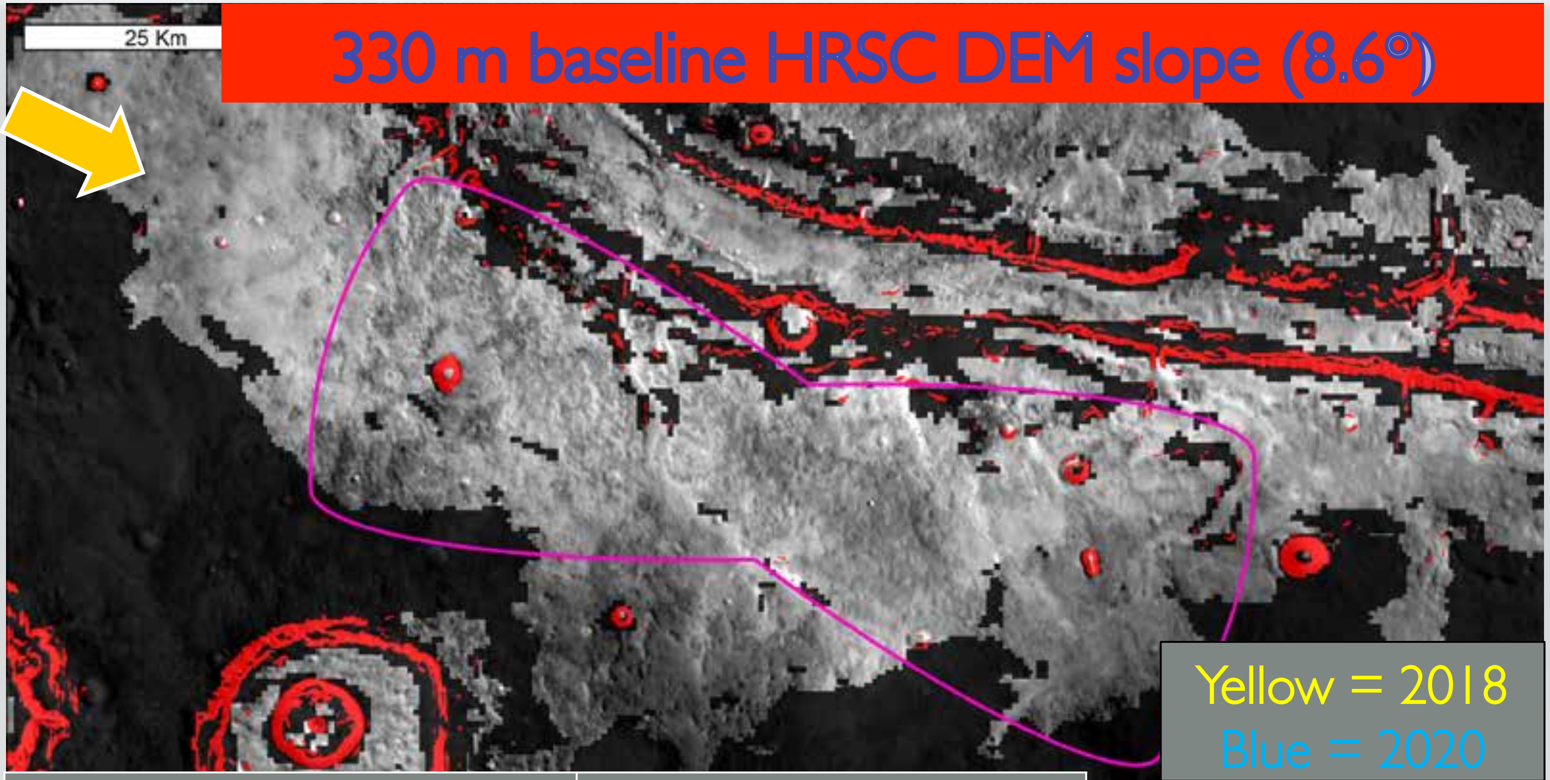
Slope Methodology



Maximum baseline ≈ 3 x pixel size

=> Pixel size ≈ 1/3 x baseline

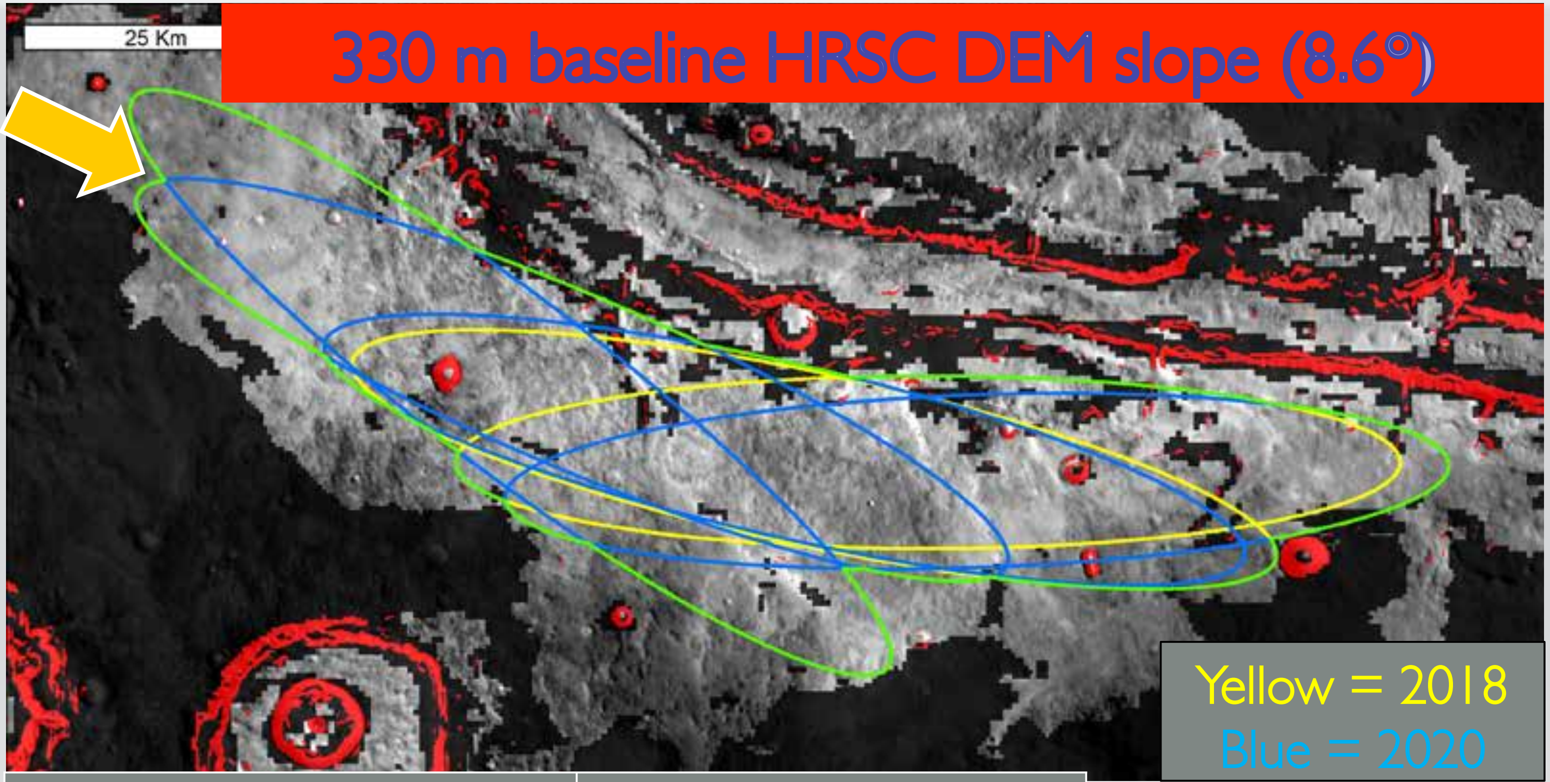
Landing Ellipse Properties - SLOPE



Ellipse (Year/Azim.)	% above 8.6°
2018 - 90°	0.5

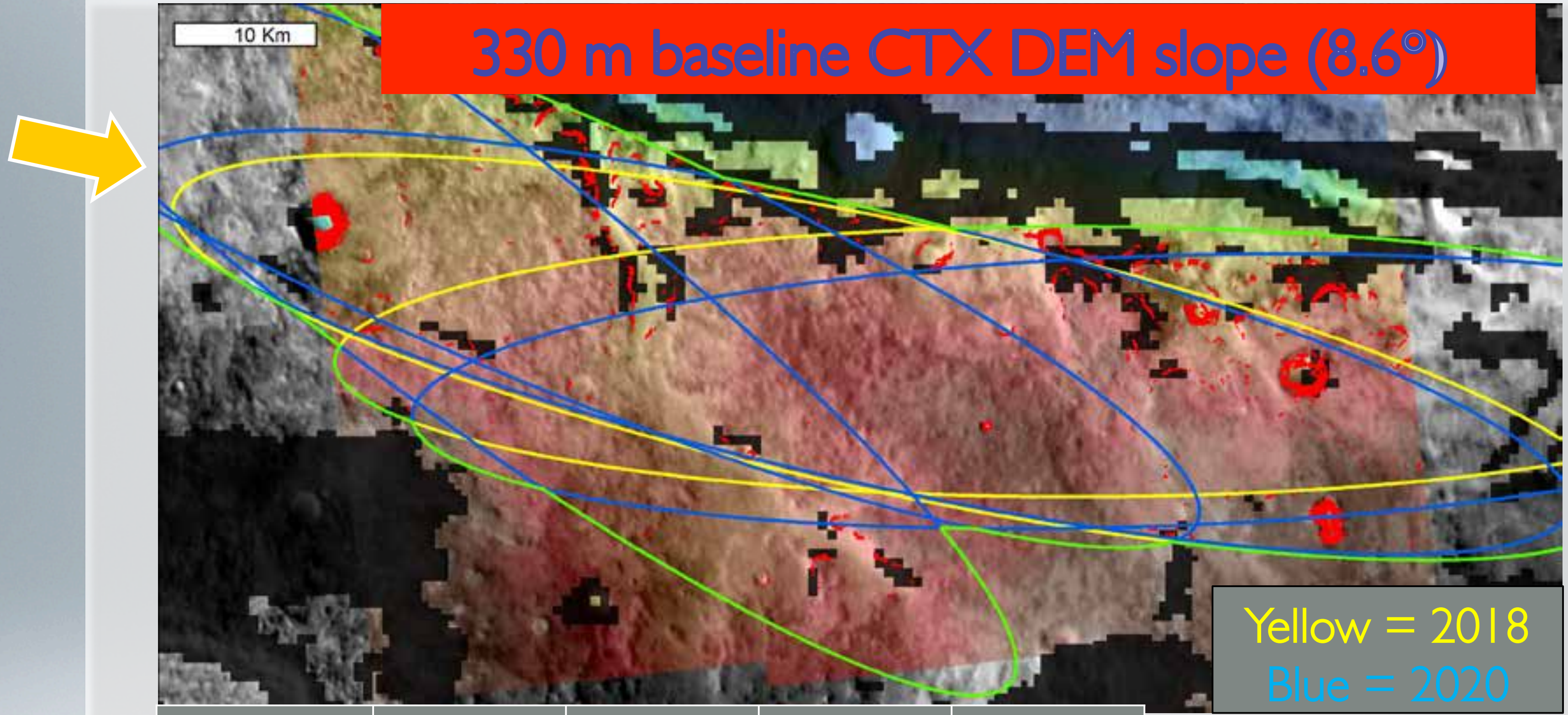
Landing Ellipse Properties - SLOPE

EXOMARS



Ellipse (Year/Azim.)	% above 8.6°
2018 - 90°	1.2
2018 - 102°	1.6
2020 – 88°	1.0
2020 – 103°	1.8
2020 – 113°	1.0
2020 – 127°	0.7

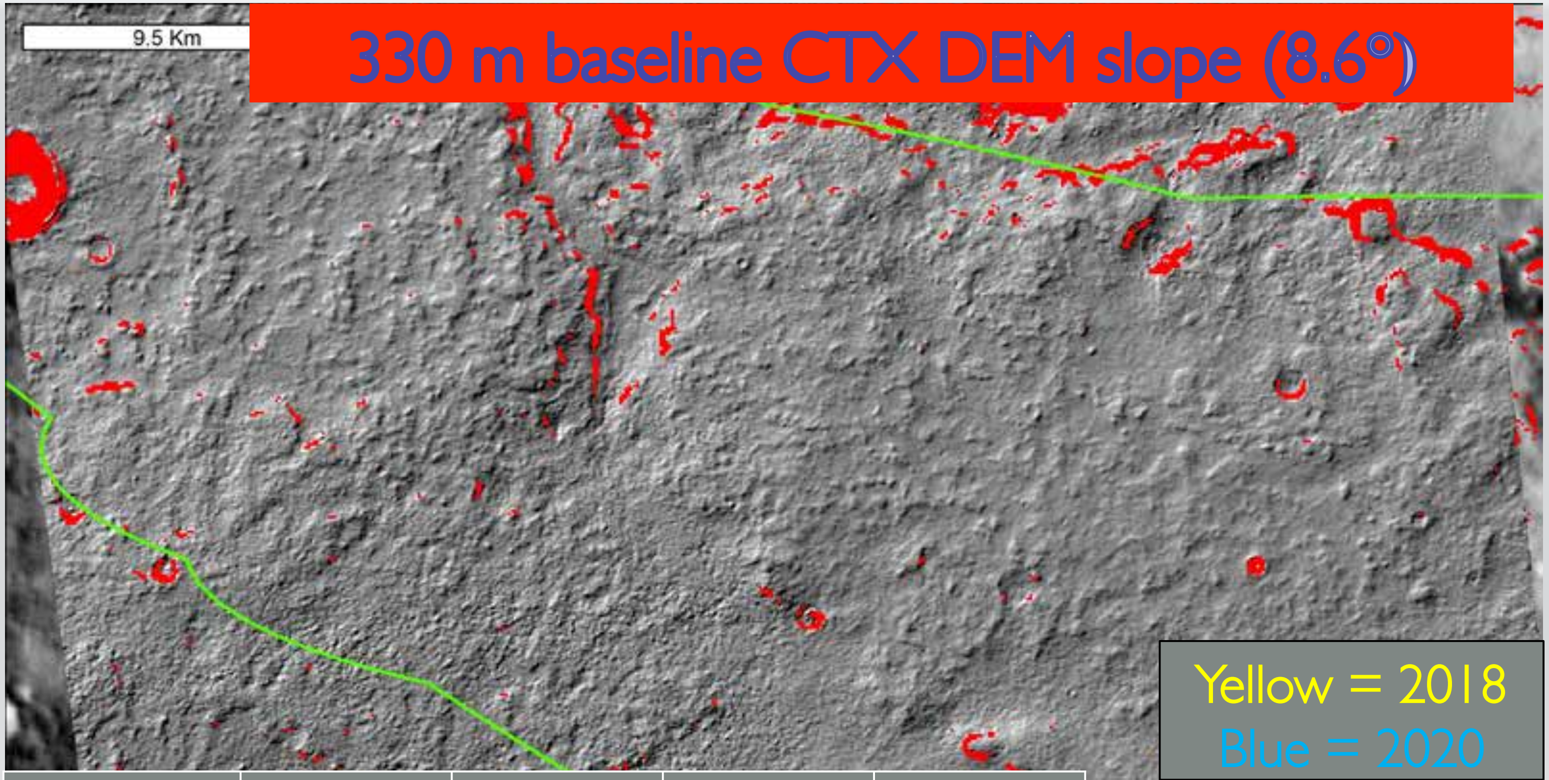
Landing Ellipse Properties - SLOPE



Ellipse (Year/ Azim.)	% above 8.6°	Starting Pixel size	Slope map pixel size	Baseline
2018/2020 (CTX area)	3.0	20	110 m	330 m
2018/2020 HRSC in CTX area)	1.4	50	110 m	330 m

Surface is rougher than seen by HRSC

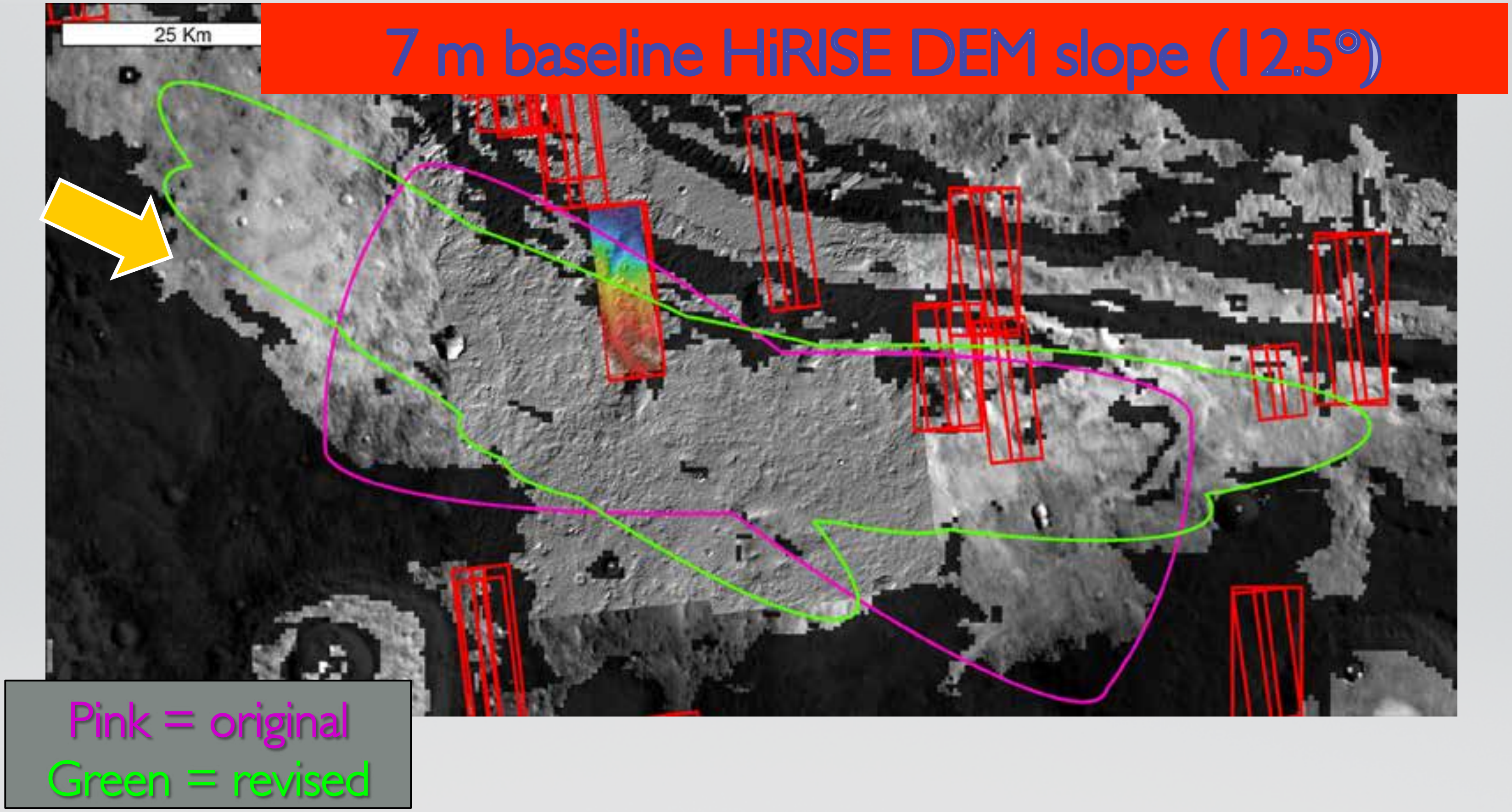
Landing Ellipse Properties - SLOPE



Ellipse (Year/ Azim.)	% above 8.6°	Starting Pixel size	Slope map pixel size	Baseline
2018/2020 (CTX area)	3.0	20	110 m	330 m
2018/2020 HRSC in CTX area)	1.4	50	110 m	330 m

Surface is rougher than seen by HRSC

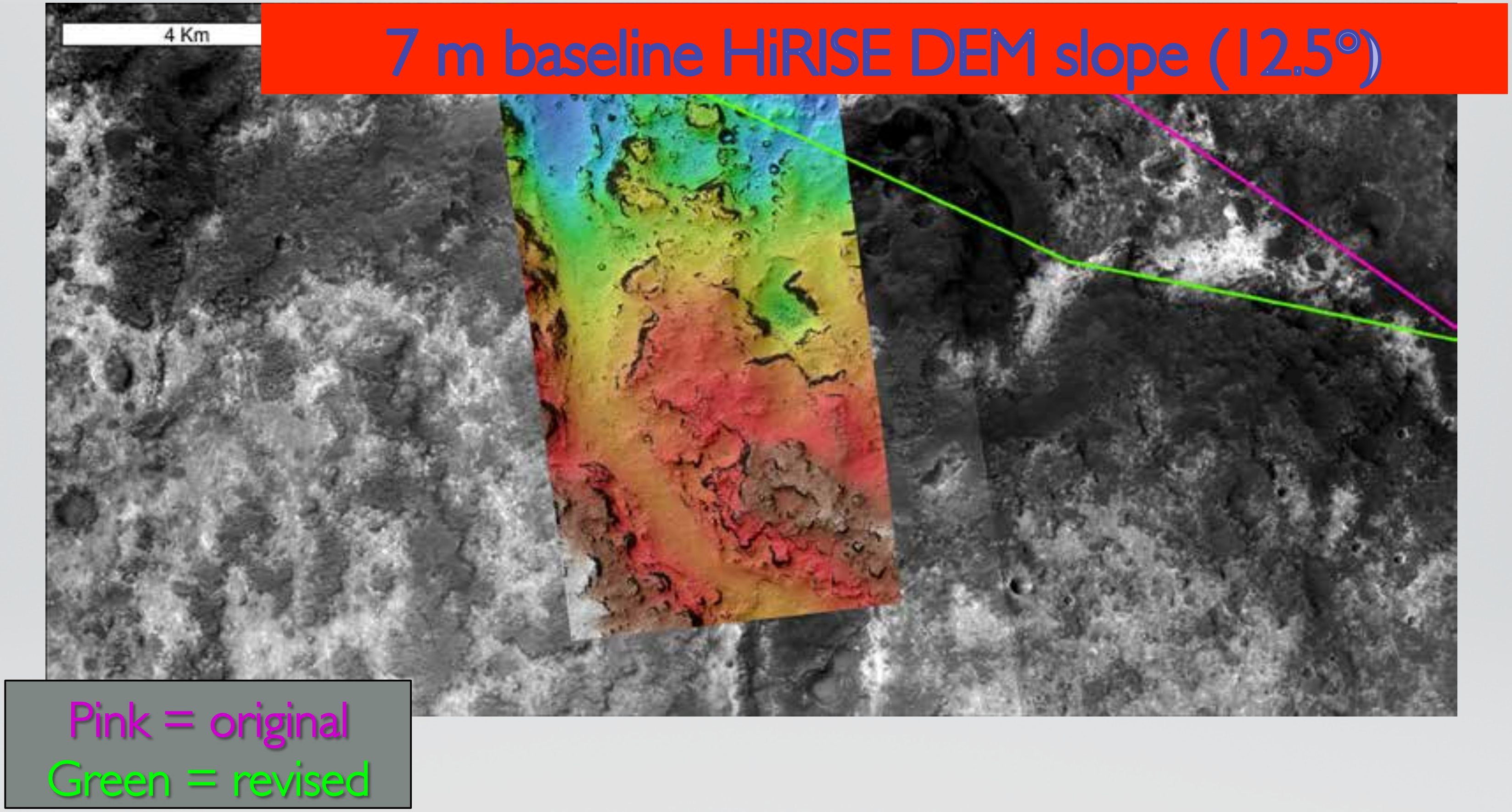
Landing Ellipse Properties - SLOPE



Only 1 stereo pair. Only partially within the landing area.

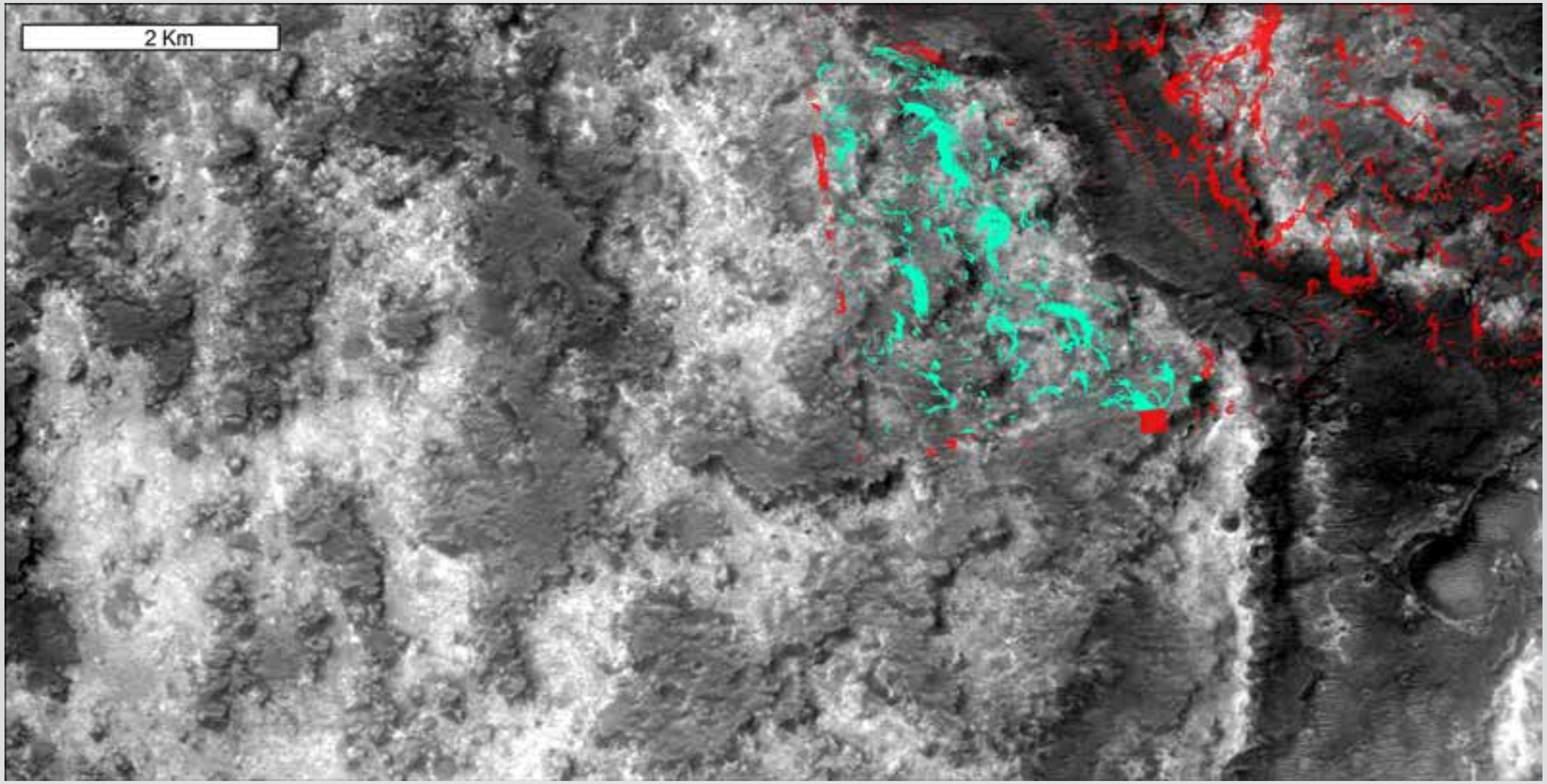
Landing Ellipse Properties - SLOPE

EXOMARS



~11.2 % of DEM within the ellipse patterns > 12.5° slope.

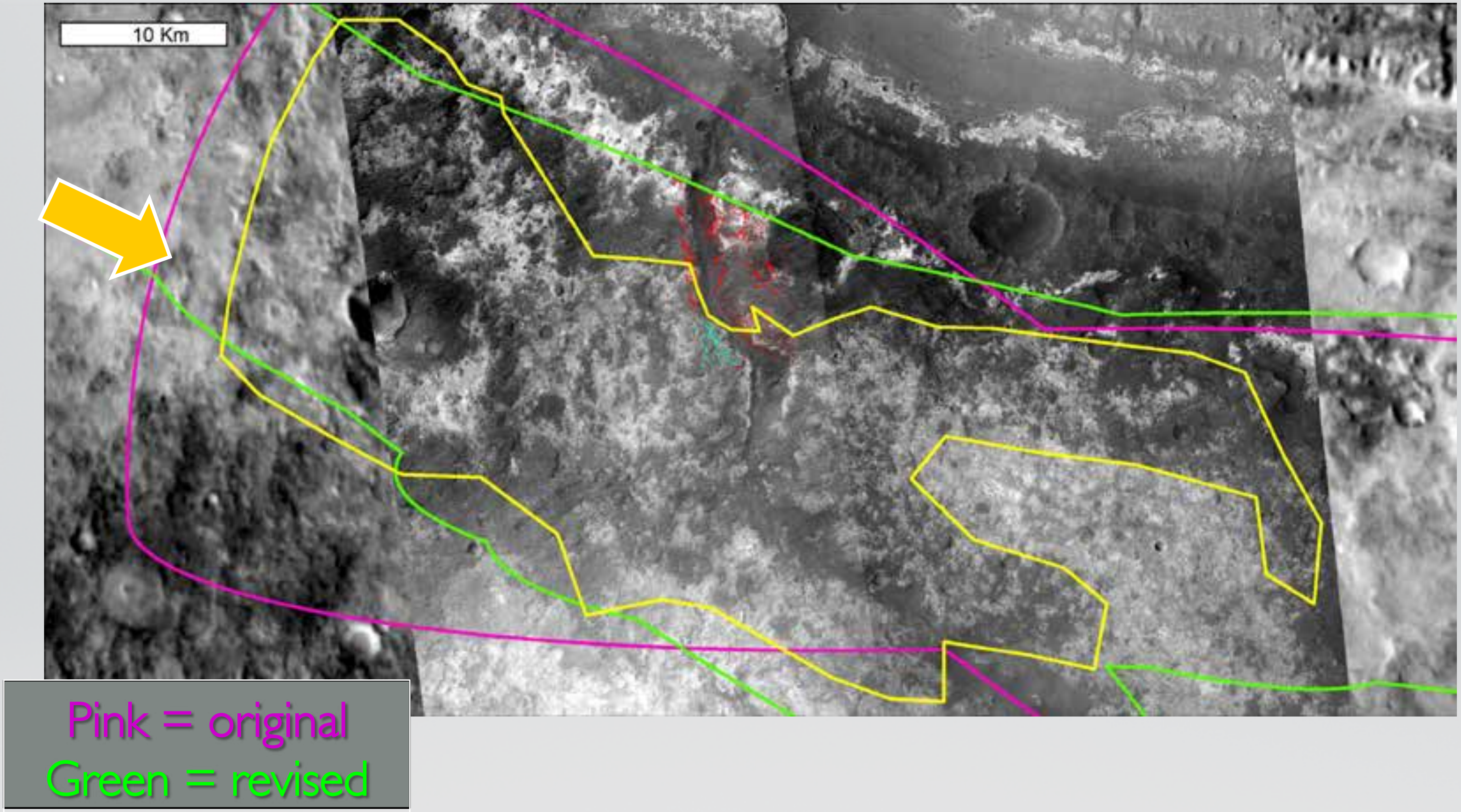
Landing Ellipse Properties - SLOPE



~14.5 % of DEM > 12.5° slope. In the area sampling the dark capping mesas

Landing Ellipse Properties - SLOPE

E X O M A R S

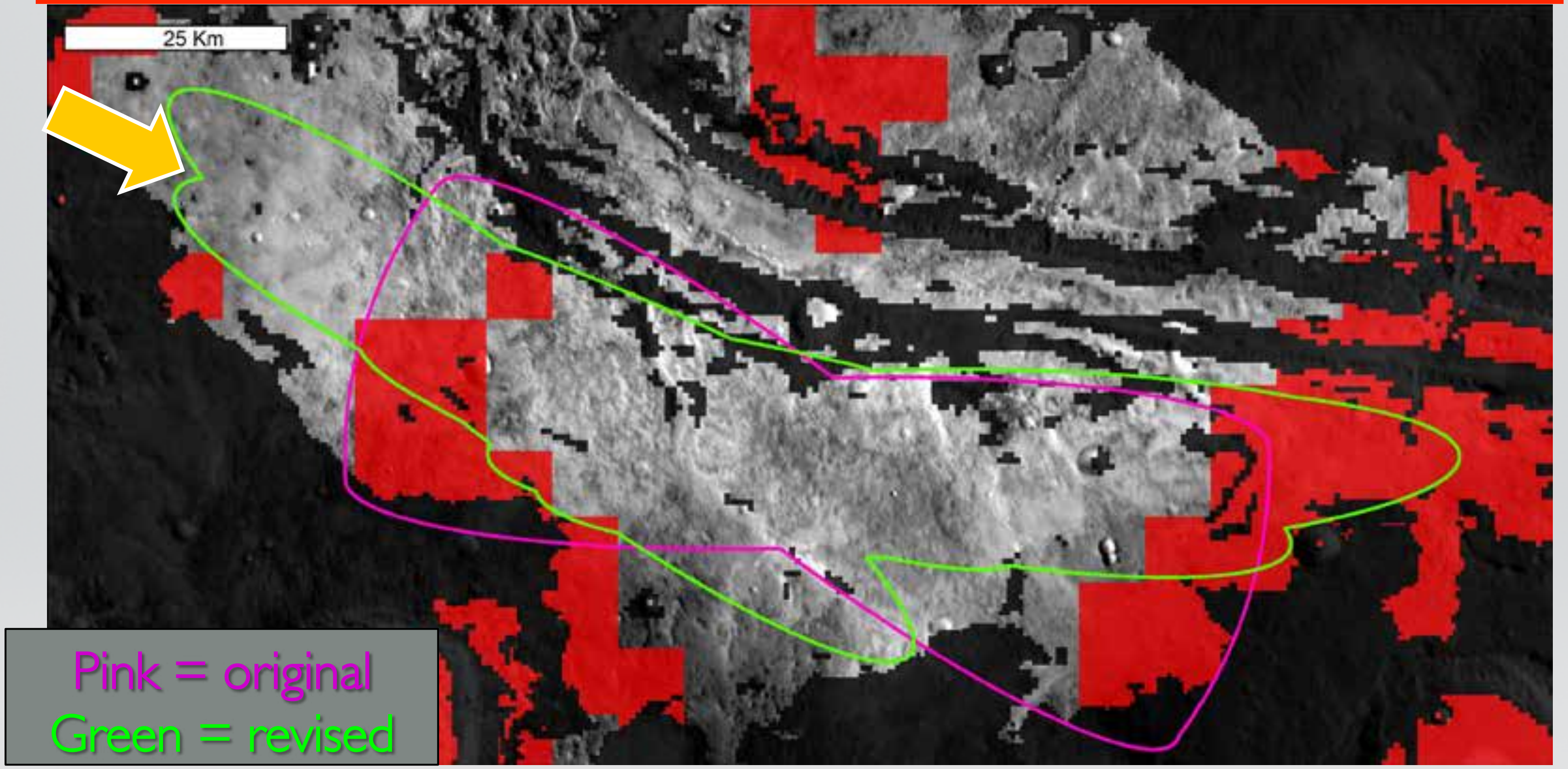


Dark capping mesas cover a large area of the landing ellipses

Landing Ellipse Properties - OTHER

EXOMARS

Rock abundance

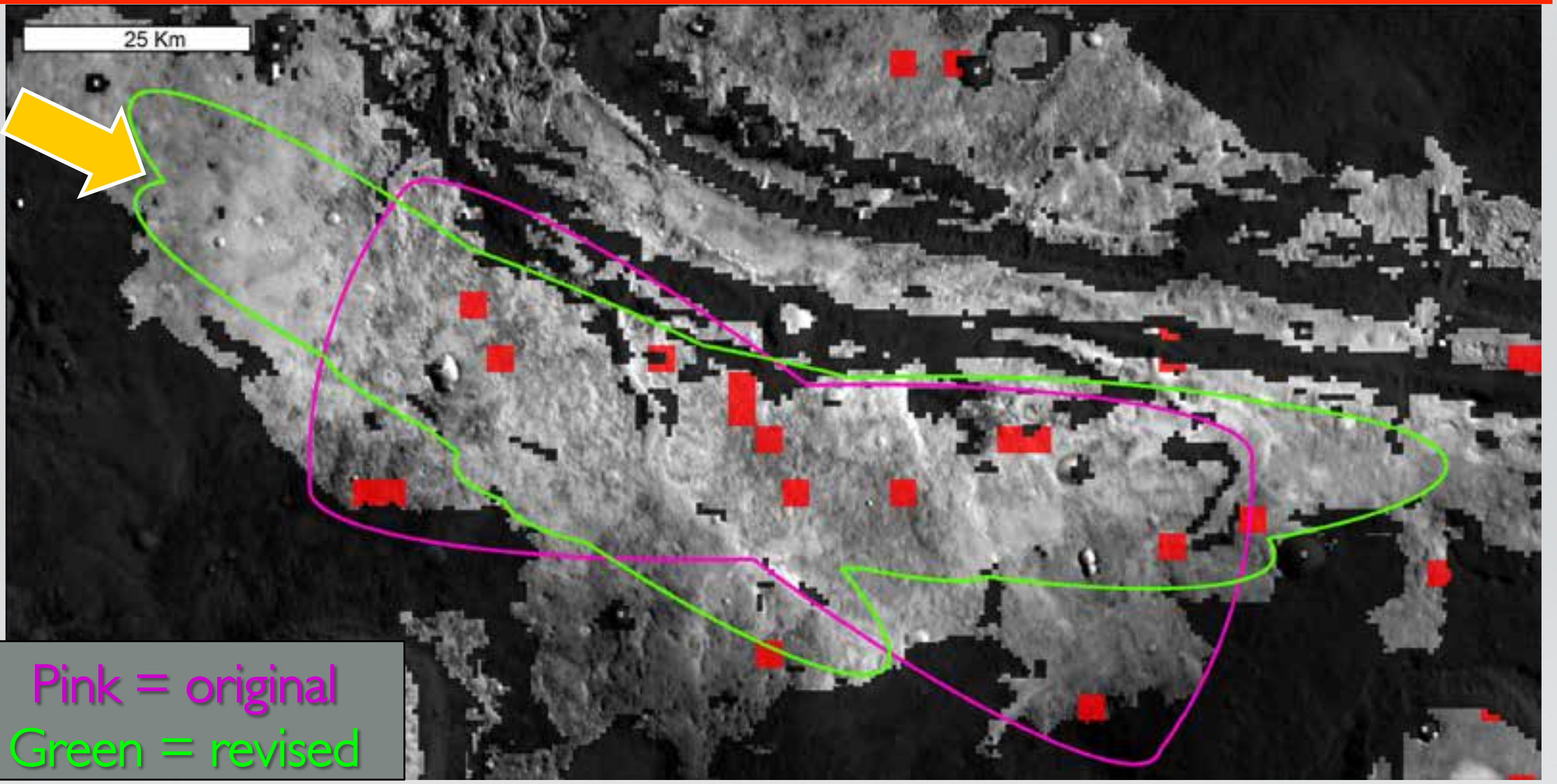


Red = TES rock abundance > 7% (Nowicki et al. JGR 2007)

Landing Ellipse Properties - OTHER

EXOMARS

Thermal inertia



Pink = original

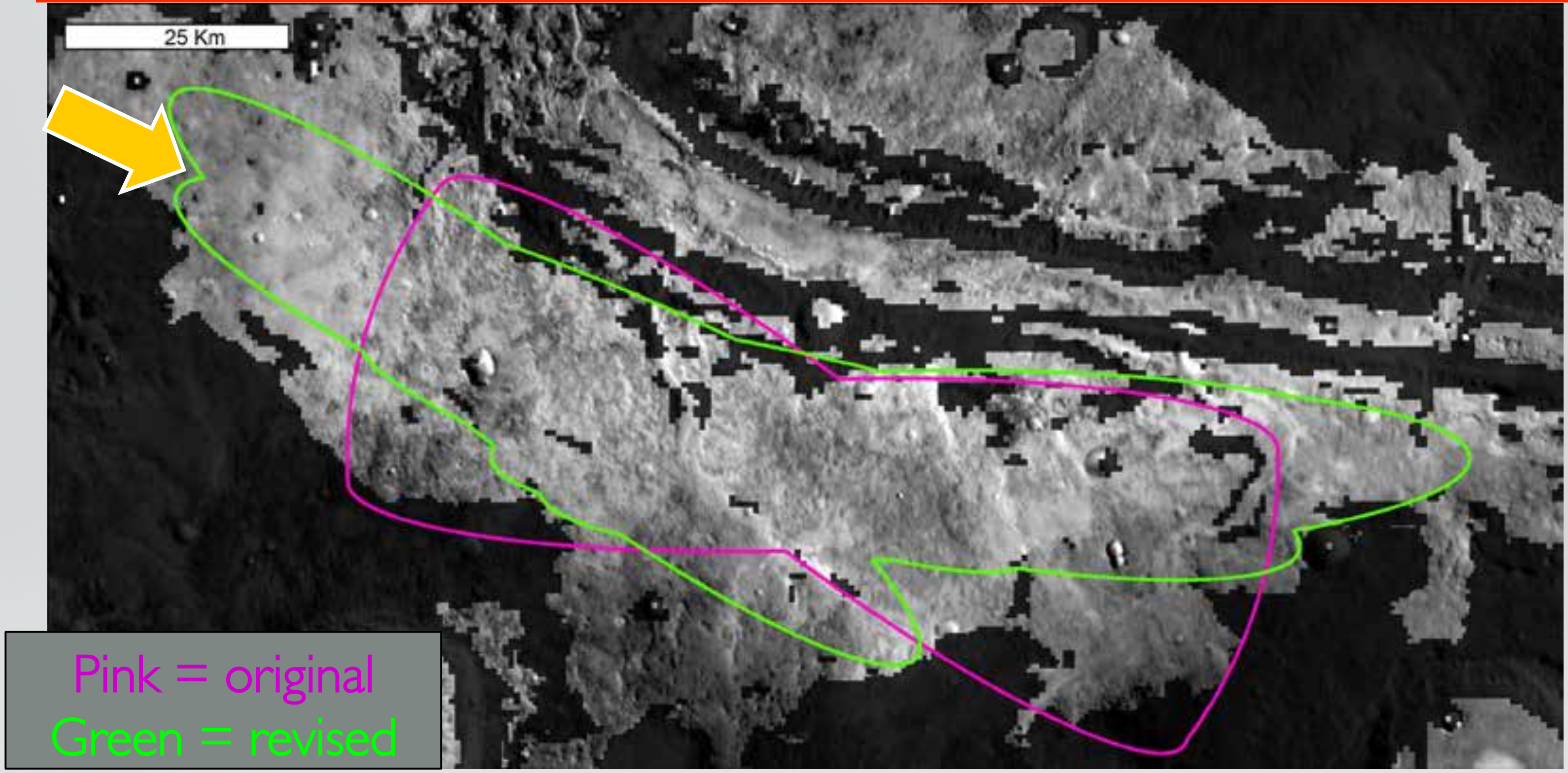
Green = revised

Red = TES Thermal inertia ≥ **150 J m^{-2} $s^{-0.5}$ K^{-1}**

Landing Ellipse Properties - OTHER

EXOMARS

Albedo



The whole region meets the albedo criterion: 0.1 ≤ albedo ≤ 0.26

Summary 1

EXOMARS

Why Mawrth is exciting landing site?

- Mawrth Vallis is unique *across all of Mars* in having high phyllosilicate abundances
- Mawrth Vallis is unique among the sites in having the most diverse altered phases
- Lack of evidence for illitization / thermal diagenesis that may have occurred elsewhere on Mars and reduced biosignature preservation potential
- Multiple distinct mineralogies shall be accessible throughout the landing site
- ExoMars would help resolve some questions about mineralogy and formation processes
- Mawrth Vallis offers the potential to link discoveries made by ExoMars to alteration processes acting across a broad region

Summary 2

EXOMARS

Revised ellipses

Criterion	Specification	Data Used	This Landing Site
Latitude	5 S to 25 N	MOLA	Variable (roughly -17.49 W, 22.16N)
Elevation	Below –2 km	MOLA	100 % of ellipse is below, 0 % is above
Slopes (2–10 km)	≤ 3.0˚	MOLA	At 10 km, 9 % of ellipse is below, 1.5 % is above
Slopes (2–10 km)	≤ 3.0˚	MOLA	At 2 km, 98 % of ellipse is below, 7.4 % is above
Slopes (330 m)	≤ 8.6˚	HRSC	98.7 % of ellipse is below, 1.3 % is above
Slopes (330 m)	≤ 8.6˚	CTX	99.1 % of ellipse is below, 3.9 % is above
Slopes (7 m)	≤ 12.5˚	HiRISE	90.2 % of ellipse is below, 9.8 % is above
Slopes (2 m)(3m)	≤ 15.0˚	No Data	93.1 % of ellipse is below, 6.9 % is above
Rock abundance	≤ 7%	IRTM	Poor coverage: 8–12 % is bedrock (flat + rocks)
Rock abundance	≤ 7%	HiRISE	No Data
Thermal Inertia	≥ 150 J m^{-2} $s^{-0.5}$ K^{-1}	TES	99.2 % of ellipse is above (night time data)
Albedo	0.1 ≤ albedo ≤ 0.26	TES	100 % of ellipse is in spec
Radar Reflectivity	–15 dB ≤ Ka band backscatter cross section at nadir ≤ 27.5 dB	No Data	No Data
Horizontal Wind (1 m–10 km agl)	≤ 0.25 m/s	GCM	Max speed: 35–45 m/s at 1–9 km agl (arrival season, arrival time)
Horizontal Wind (1 m above ground)	≤ 0.30 m/s	GCM	No Data