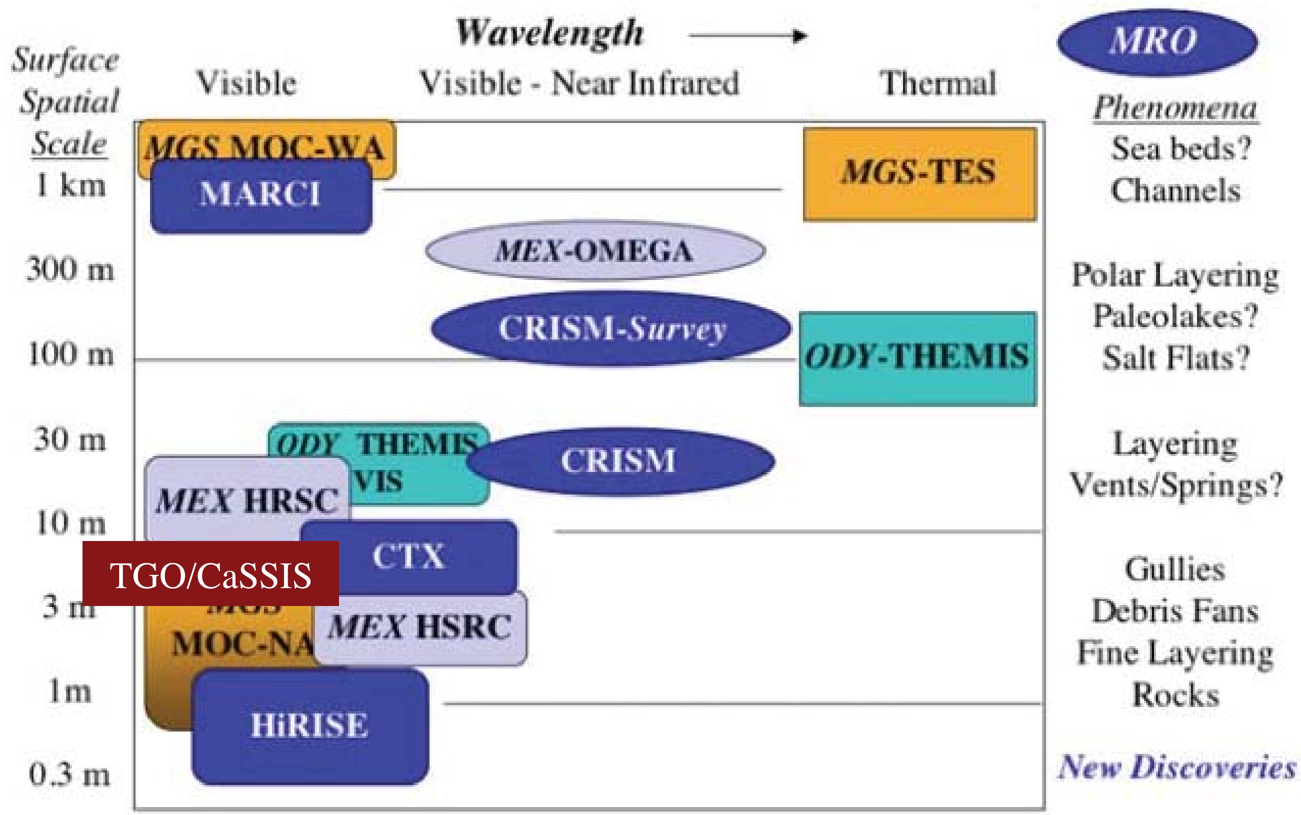
ESP_045747_2030: Mawrth Vallis region

Martian Geologic Settings of Interest to the Search for Biosignatures, as Seen from Orbit

Alfred S. McEwen
University of Arizona

The highest spatial resolution at each wavelength region are generally of greatest interest to landing sites and the search for biosignatures



Radar
SHARAD

Figure 1. Spatial resolutions for imaging instruments now flying on Mars Global Surveyor (MGS), Mars Odyssey (ODY), and Mars Express (MEX) are compared schematically with MRO capabilities (dark blue). Resolution increases in the chart from top to bottom, with instruments separated by column into visible, near-IR, and thermal IR wavelength regions.

Orbits

- MRO and Mars Odyssey are in sun-synchronous orbits
  - MRO ~3 AM/PM, inclination 92.65 deg.
  - Mars Odyssey has varied from 3-6 AM/PM
- TGO orbits will be inclined 74° and rotate through all times of day

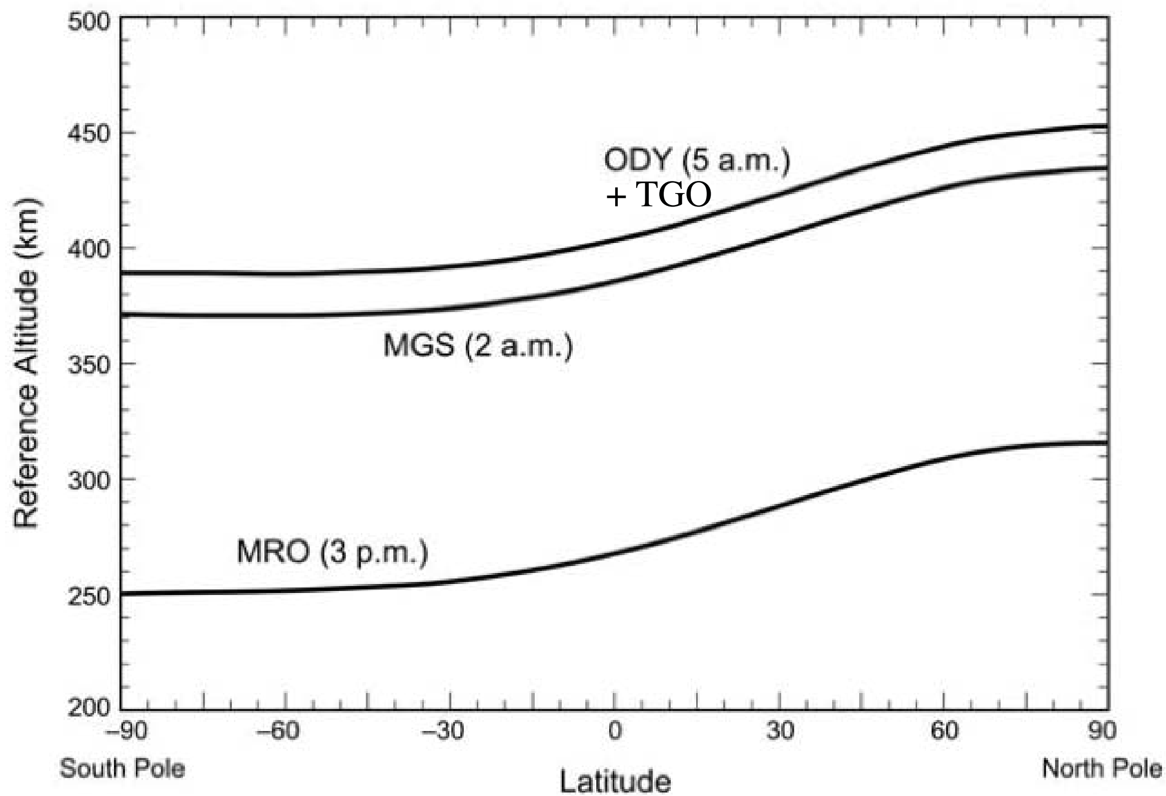


Figure 2. Orbital altitude as a function of latitude for MRO, MGS, and ODY. The variation from south to north is due to asymmetries in the Martian gravity field. The periapsis altitude of the highly elliptical Mars Express orbit traces a path similar to the MRO orbit at varying local times.

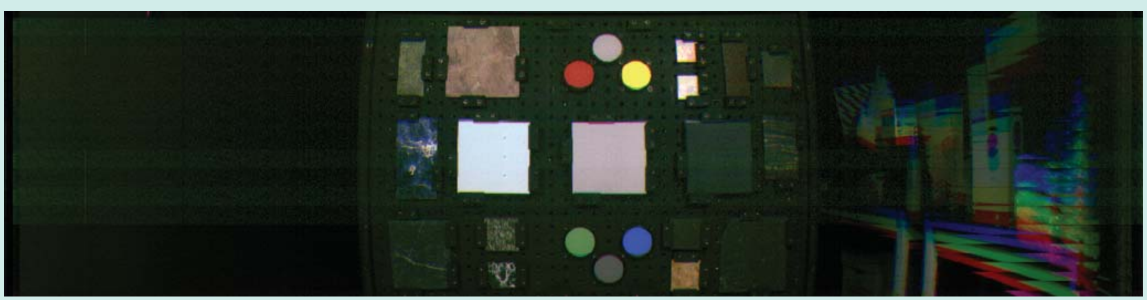
Data Return Comparison (MRO now over 250 Tb)

Table 4. MRO Data Volume Allocations

Instrument	Allocation	% × 26 Tbits
CRISM	30%	7.8
CTX	13%	3.5
HiRISE	35%	9.1
MARCI	7%	1.6
SHARAD	15%	4.0

How to take images from an orbiter

- Framing (like your cell phones, and Viking Orbiter cameras)
- Pushbroom
  - MOC, CTX – single line moves across surface with s/c motion
  - HiRISE – multiple lines (TDI) and multiple detectors
  - CRISM – uses gimbals to increase exposure time
- Push-frame--MARCI (see animation) and TGO/CaSSIS
- Radar sounding -- SHARAD



Context Imager (CTX)

- Simple B&W line array, 5-6 m/pixel
- Has now covered most of Mars!

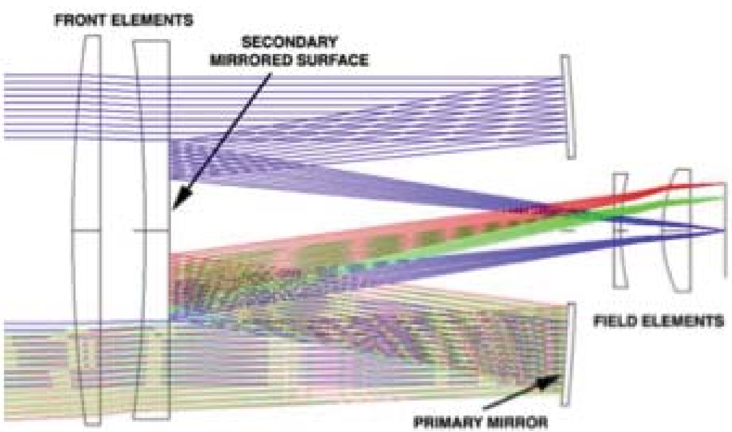
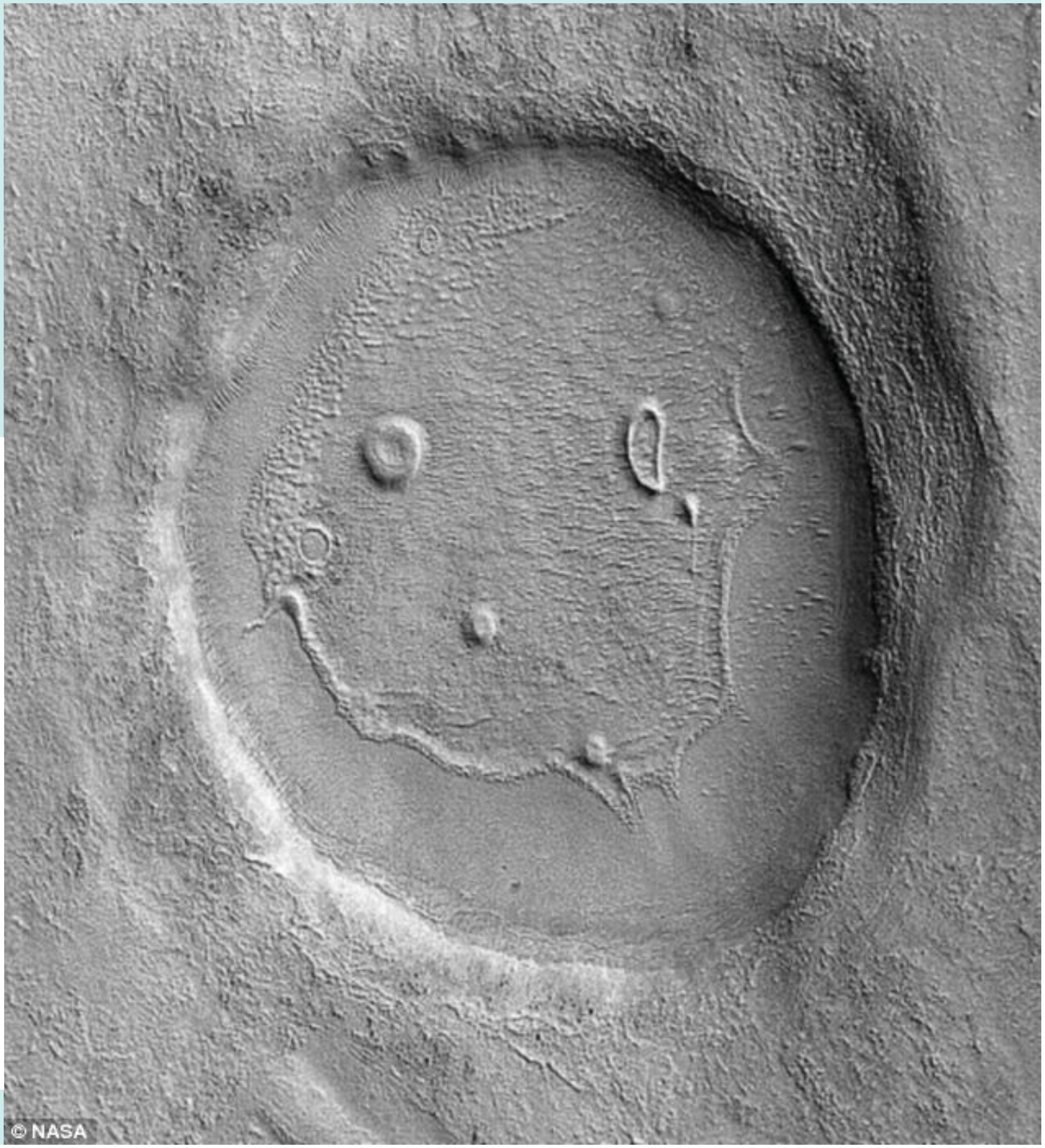


Figure 13. Ray traces, representing the optical path within the CTX telescope. The top portion of the diagram shows paths of on-axis rays (blue); the bottom portion shows paths of rays from the edge of the field of view (red) and midfield (green).



CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) on MRO

Instrument and Investigation overview

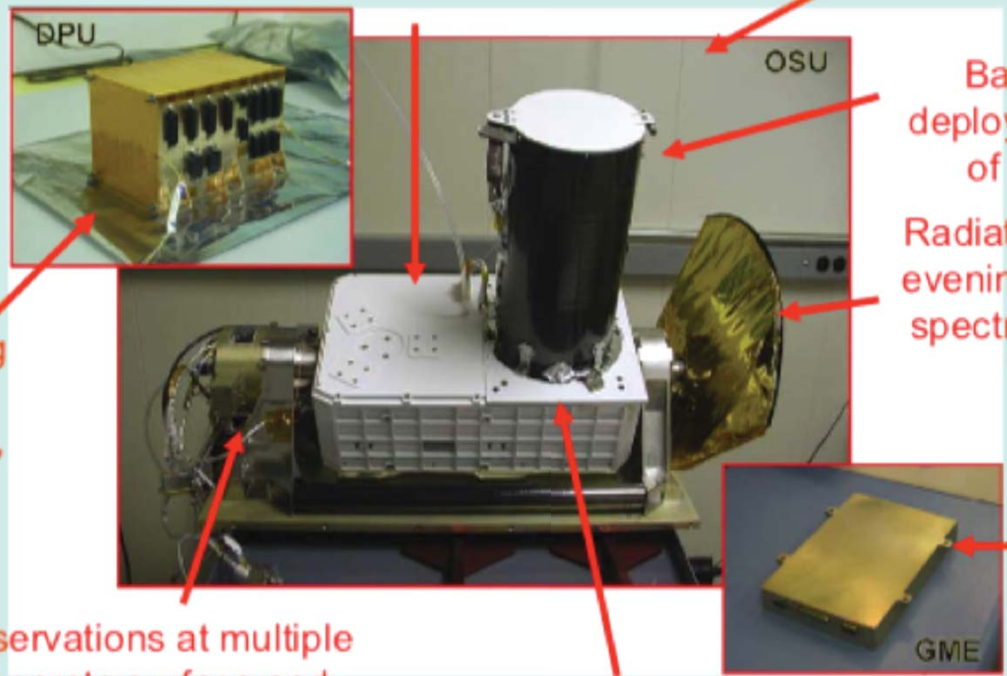
Scott Murchie
Applied Physics Laboratory, Laurel, MD 20723

18 March 2012

CRISM Hardware Overview

3 cryocoolers keep IR detector at 110-125K to control noise

Optical Sensor Unit



Baffle with 1-time deployed cover cuts out of field stray light

Radiator pointing toward evening terminator cools spectrometer optics to - 70C to -80C

Data Processing Unit controls data acquisition, pixel binning, data editing

Gimbal Motor Electronics controls gimbal

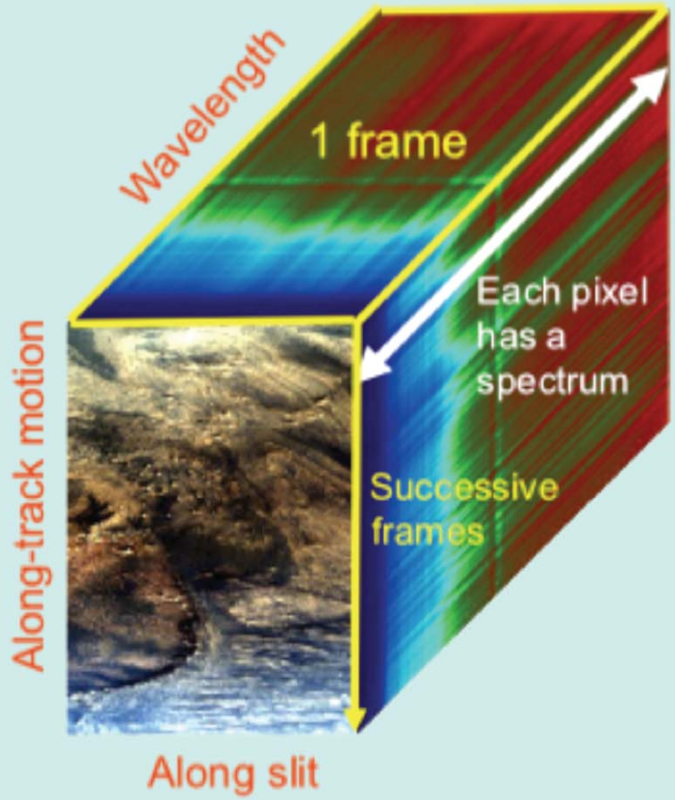
Gimbal allows observations at multiple geometries to separate surface and atmosphere (±60° along-track)

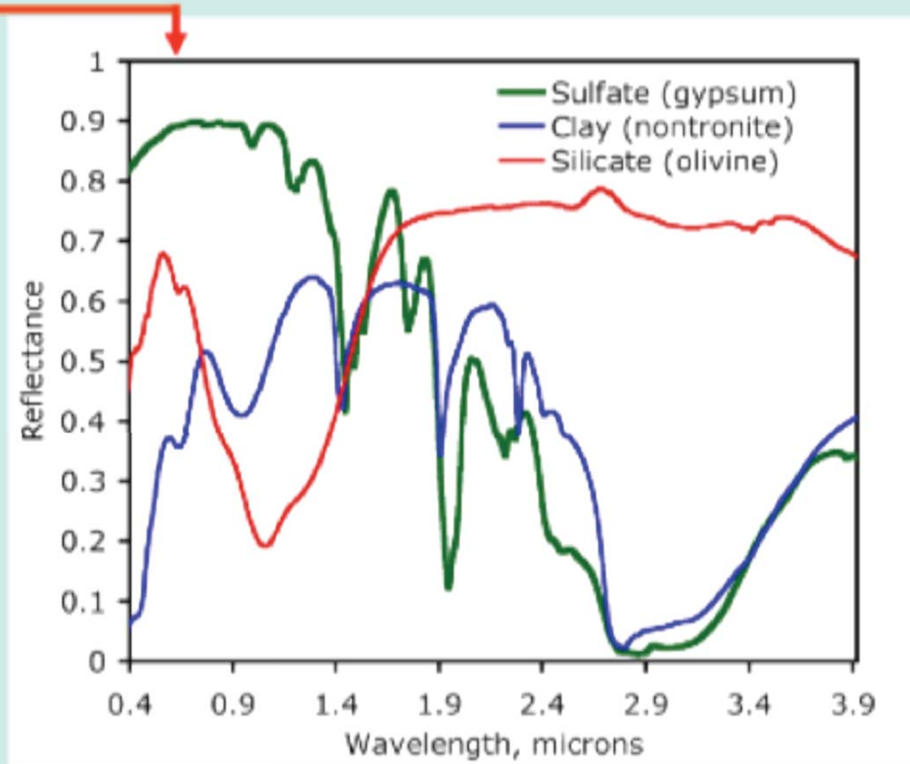
Internal calibration: shutter for dark measurements, integrating sphere for radiometric calibration

Wavelength range	0.4-3.9 μm
Spectral sampling	6.55 nm/channel
Spatial sampling	18 m/pixel from 300 km

5

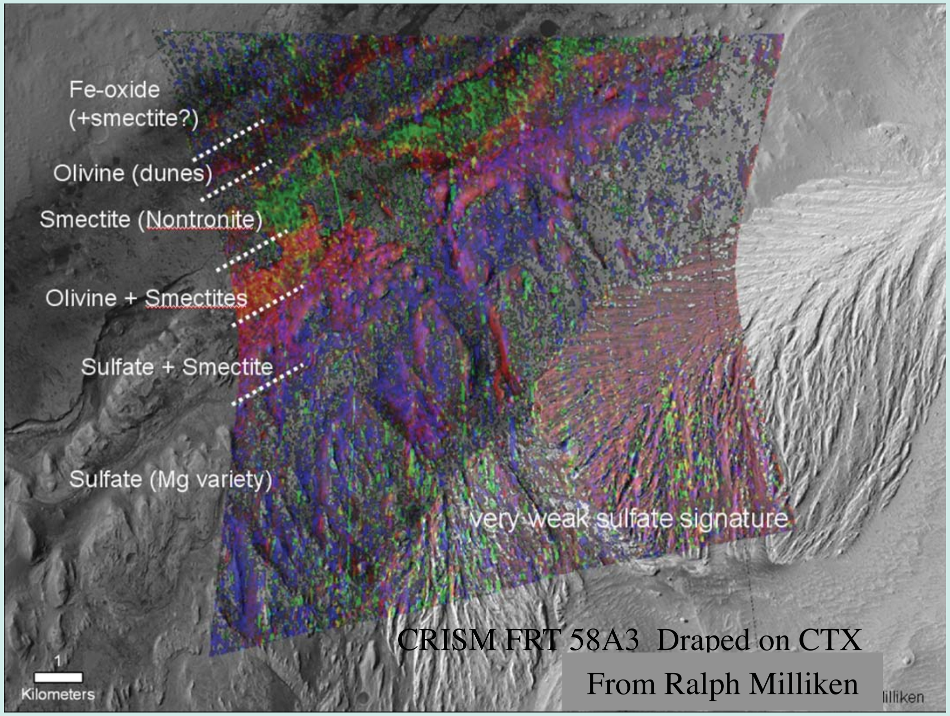
Basic Structure of the Data: Successive Frames Acquired Along Track

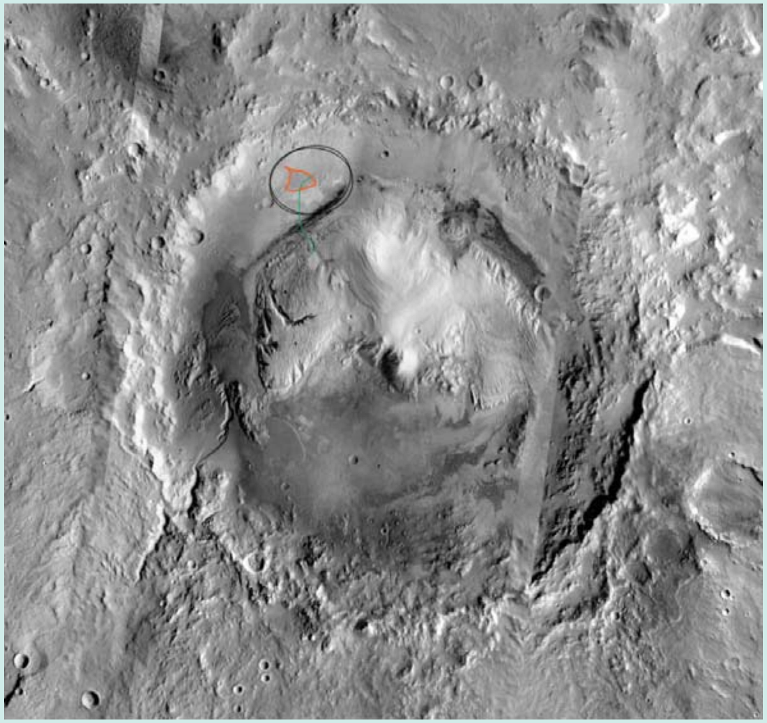




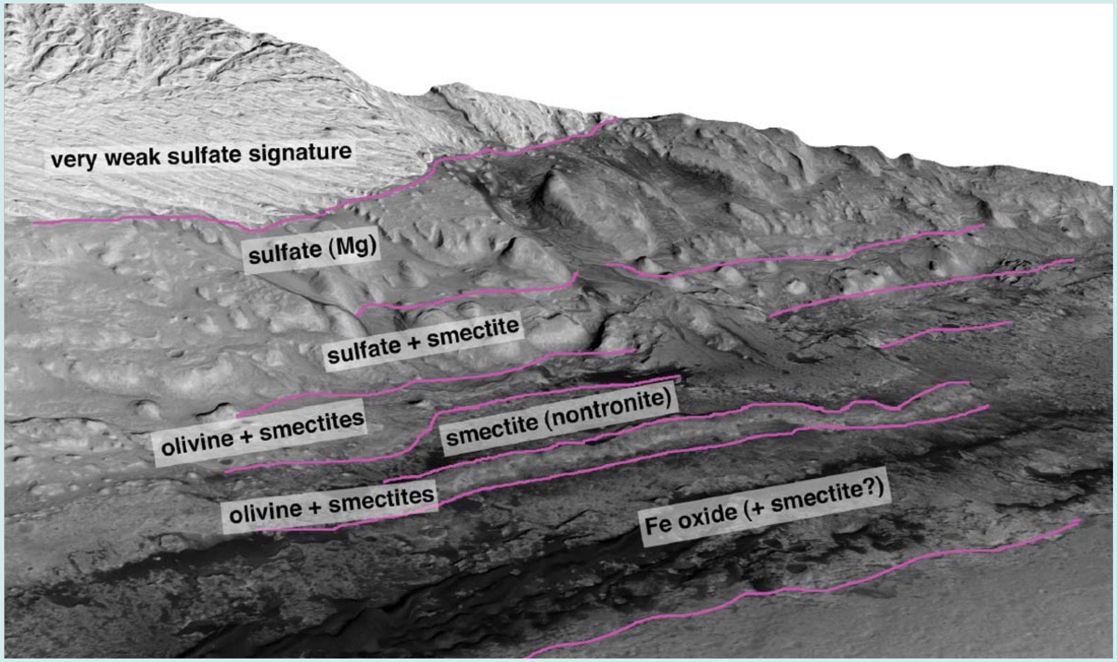
Each readout of the detector is 1 line of a spatial image. The whole image is built as MRO moves along its ground track.

Each pixel has a spectrum whose absorptions can be compared with minerals



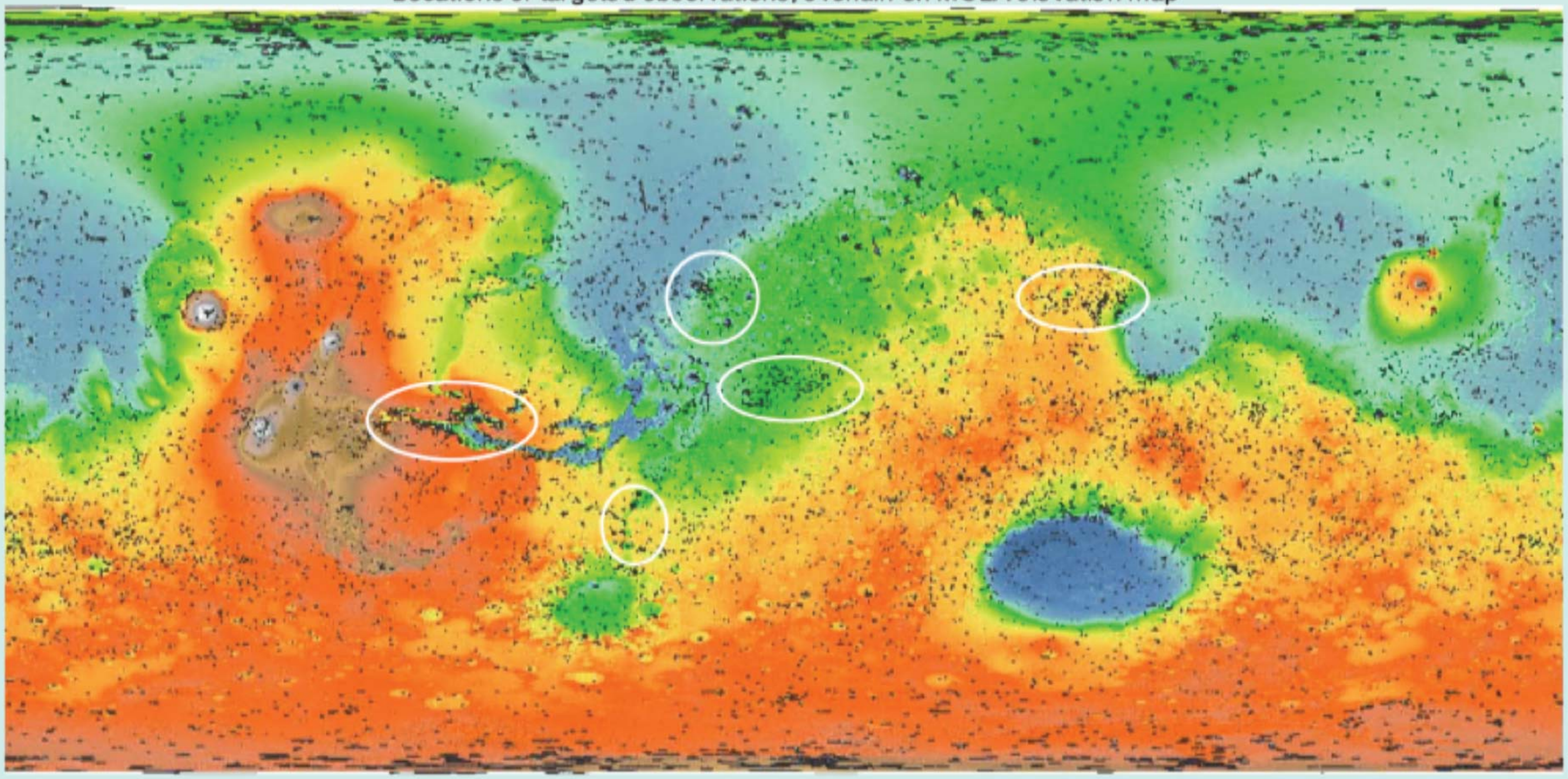


CRISM: Minerals in Gale Crater



Campaign 3: Targeted Observations Directed at High-Priority Sites

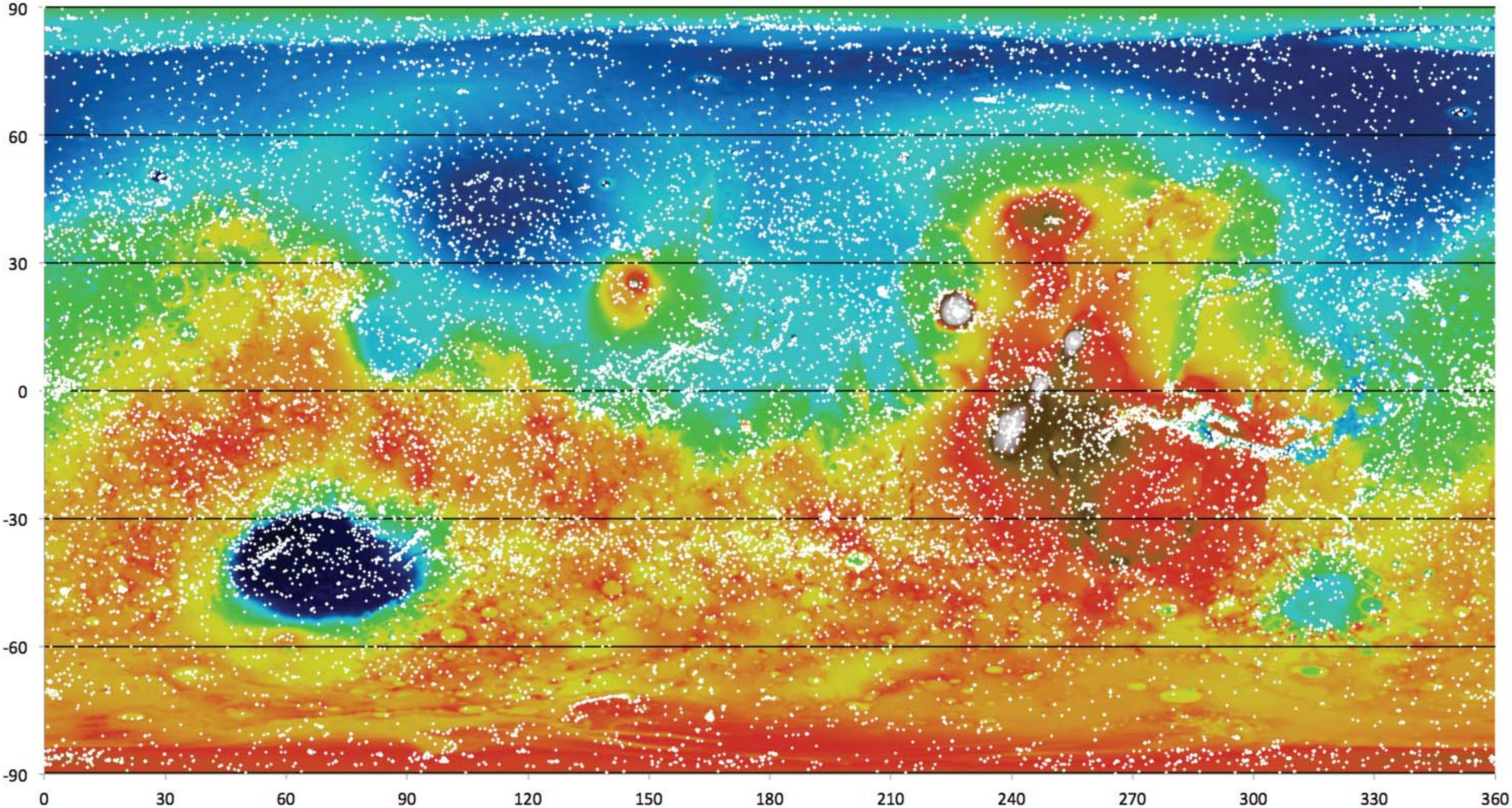
Locations of targeted observations, overlain on MOLA elevation map



21,340 targeted observations have been taken. 15,057 are at full resolution (18 m/pixel) and 6,282 are at half resolution (36 m/pixel). The highest concentrations are at major outcrops of phyllosilicate- and sulfate-bearing deposits formed in wet environments.

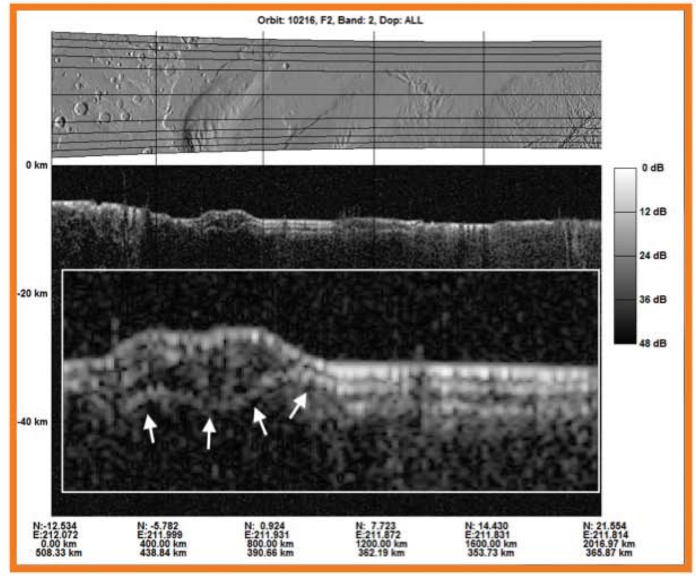
23

HiRISE Coverage as of 10/7/2013



Sounding Radars 101

Roger Phillips
Isaac Smith

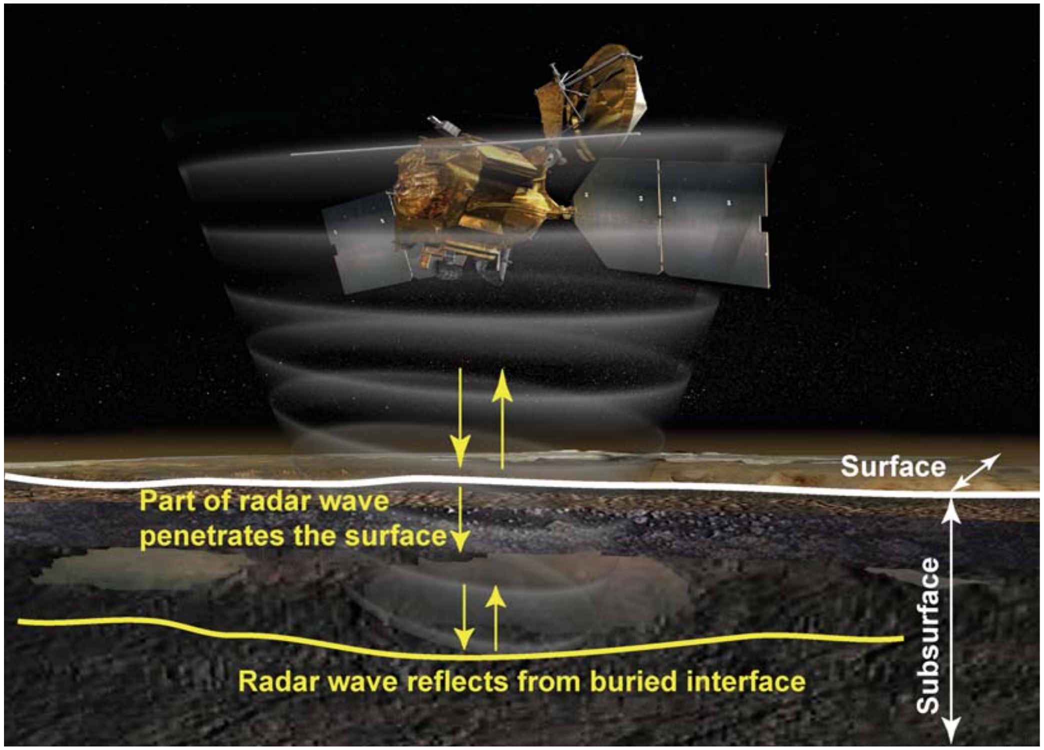


If you already know that

distance = velocity×time

you're in great shape, though really

2×distance = velocity×time



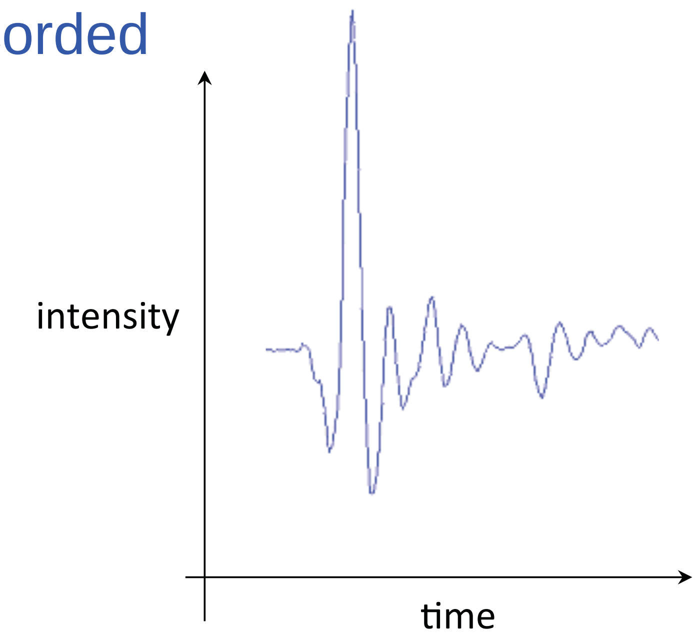
2

What is radar doing?

Pulse of energy sent

Some energy is reflected

Intensity and time are recorded



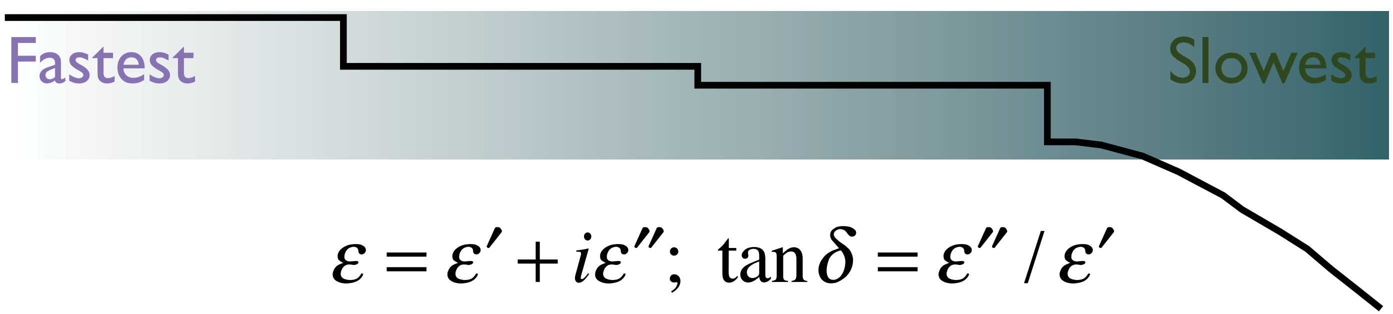
Velocities in Media

Signal Velocity depends on real part of permittivity, ε'

$$V \approx V_0 / \sqrt{\varepsilon'}$$

Space	CO_2	H_2O ice	Rock
$V_0 = \frac{3 \times 10^8}{\sqrt{1}}$	$V = \frac{3 \times 10^8}{\sqrt{2.1}}$	$V = \frac{3 \times 10^8}{\sqrt{3.15}}$	$V = \frac{3 \times 10^8}{\sqrt{\sim 4 \text{ to } 12}}$

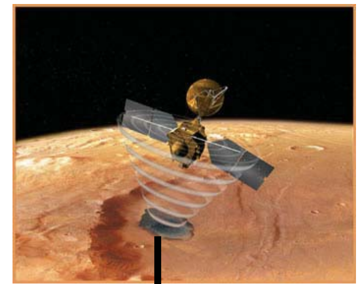
Water
ε’ ~80!

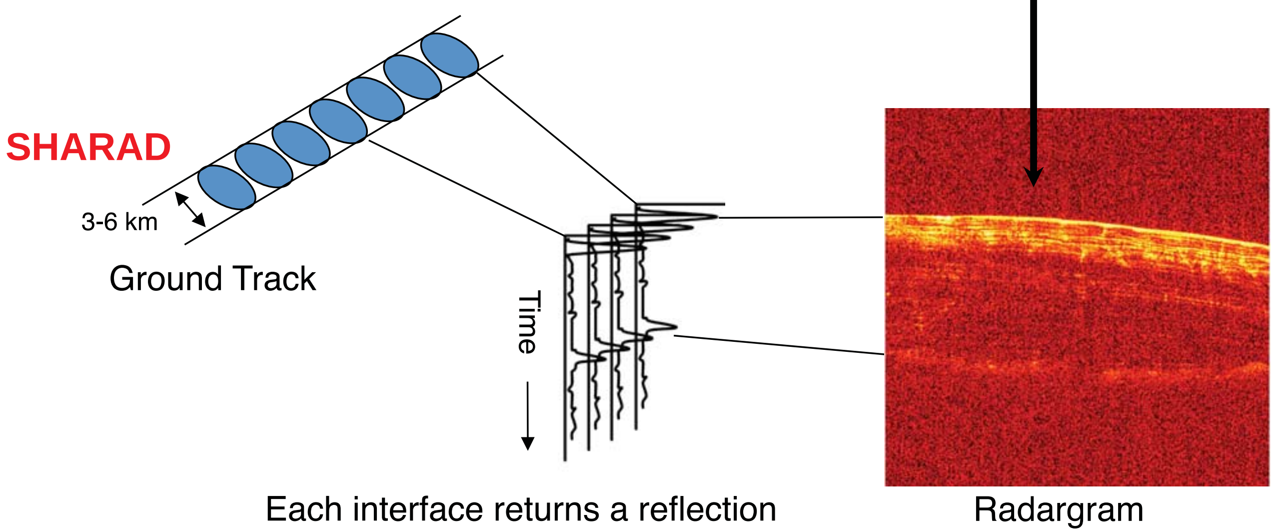


$$\varepsilon = \varepsilon' + i\varepsilon''; \ \tan\delta = \varepsilon'' / \varepsilon'$$

Basic quest is for depth, but estimates of ε' & $\tan\delta$ constrain composition and porosity

Build a radargram





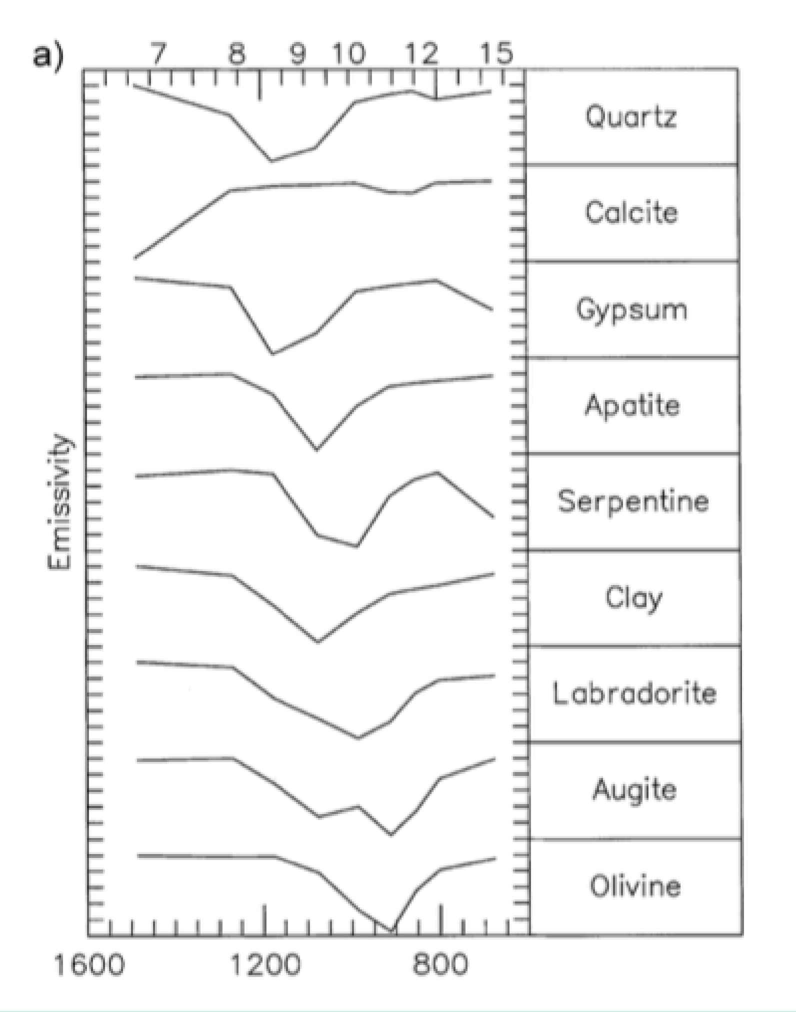
Stack individual echo traces along track to build up a **radargram**

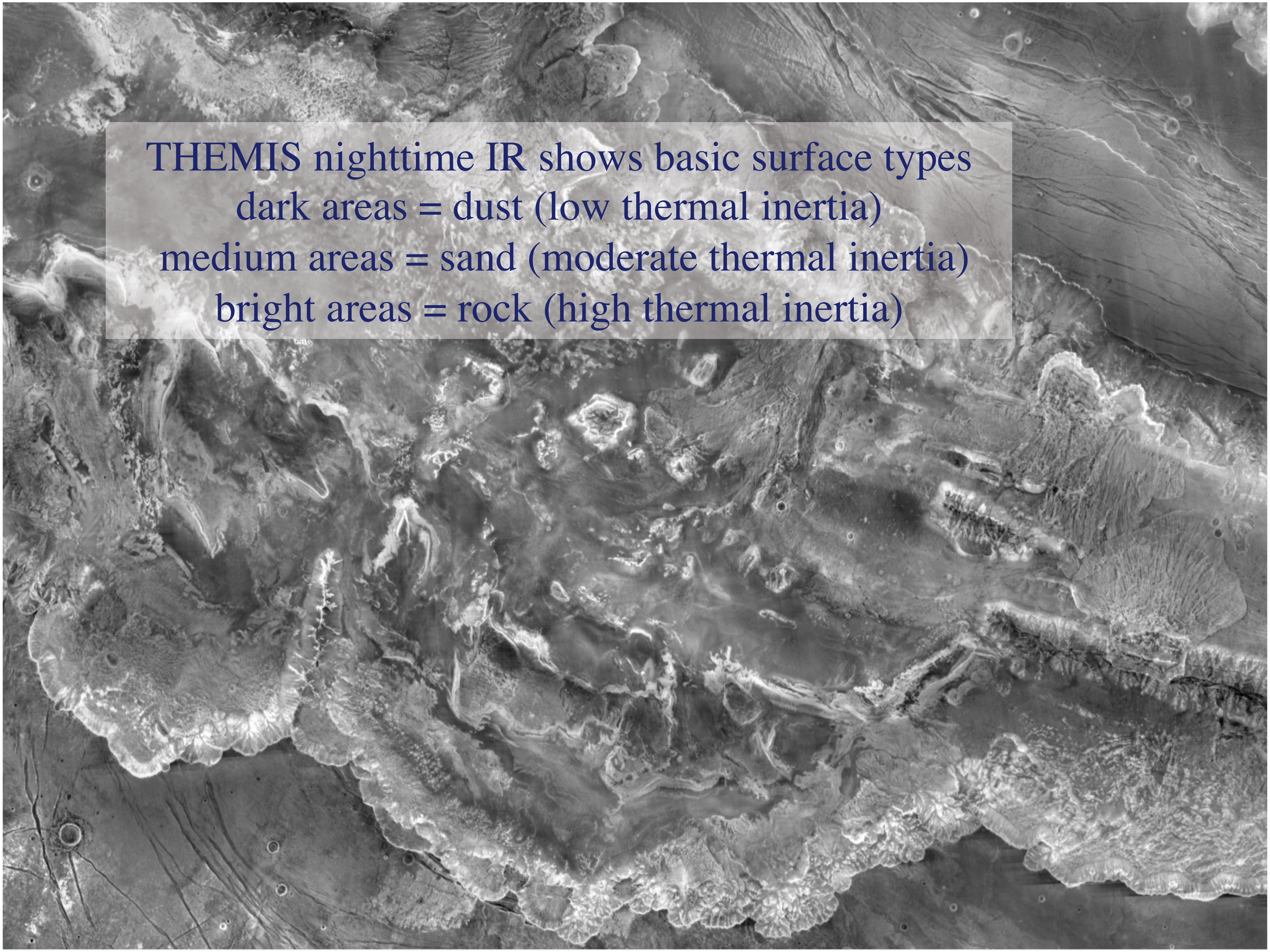
~10-20 m vertical resolution

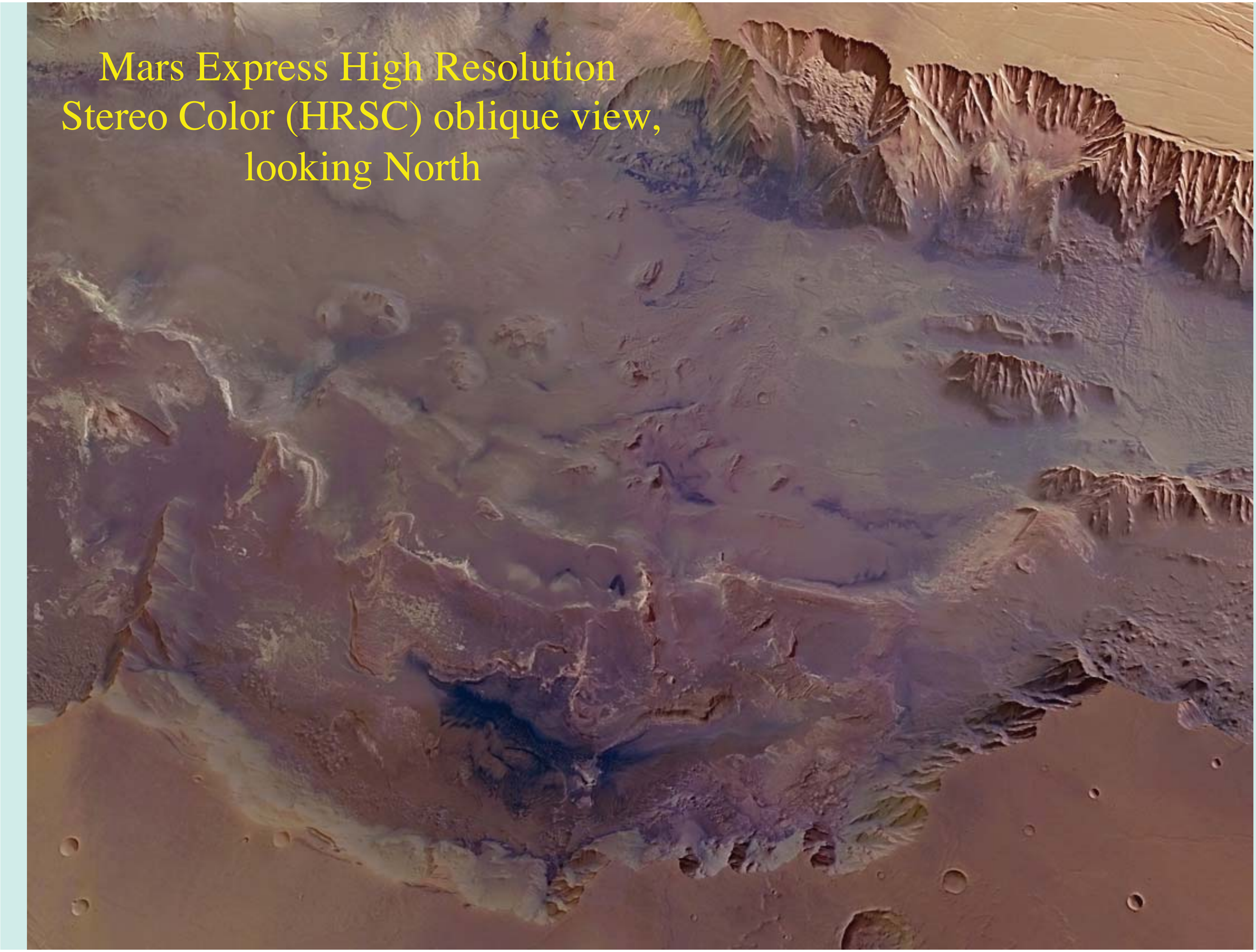
Mars Odyssey Thermal Emission Imaging System (THEMIS) (from THEMIS web site)

Mars Odyssey launched on April 7, 2001, arrived at Mars on October 24,2001, and aerobraking concluded in early February 2002. It has been circling Mars 12.8 times per day for over 14 years.

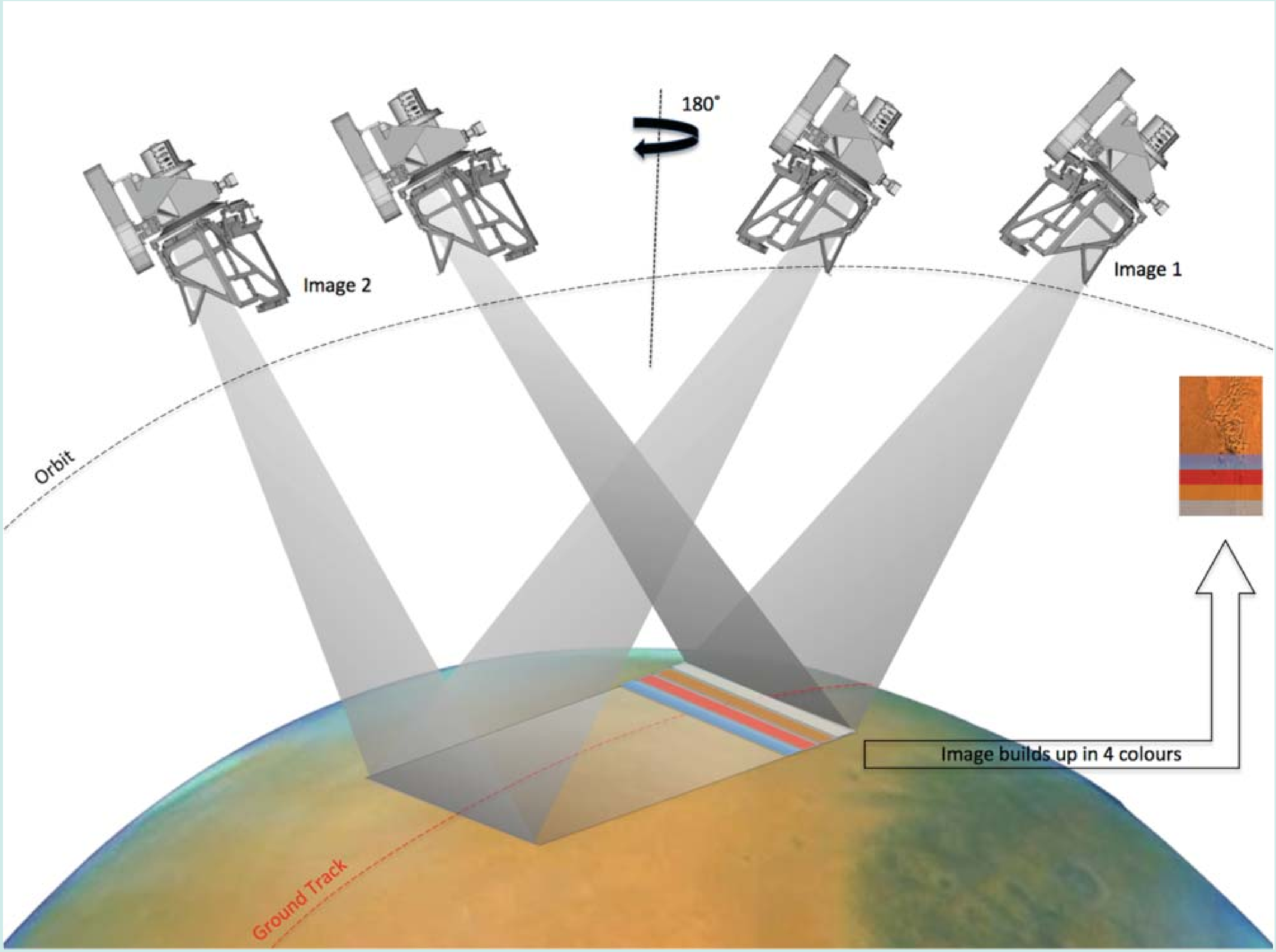
- **5 visual bands:**
  0.425 microns, 0.540 microns, 0.654 microns, 0.749 microns, 0.860 microns
- **10 infrared bands:**
  6.78 microns (used twice), 7.93 microns, 8.56 microns, 9.35 microns,10.21 microns, 11.04 microns, 11.79 microns, 12.57 microns, 14.88 microns
- **Image Scale:**
  visual images, 59 feet (18 meters) per pixel
  infrared images, 328 feet (100 meters) per pixel
- **Chief Science Goals**
  Look for rocks altered by water
  Study geologic details on Mars
  Hunt for "hot spots" indicating underground hydrothermal systems



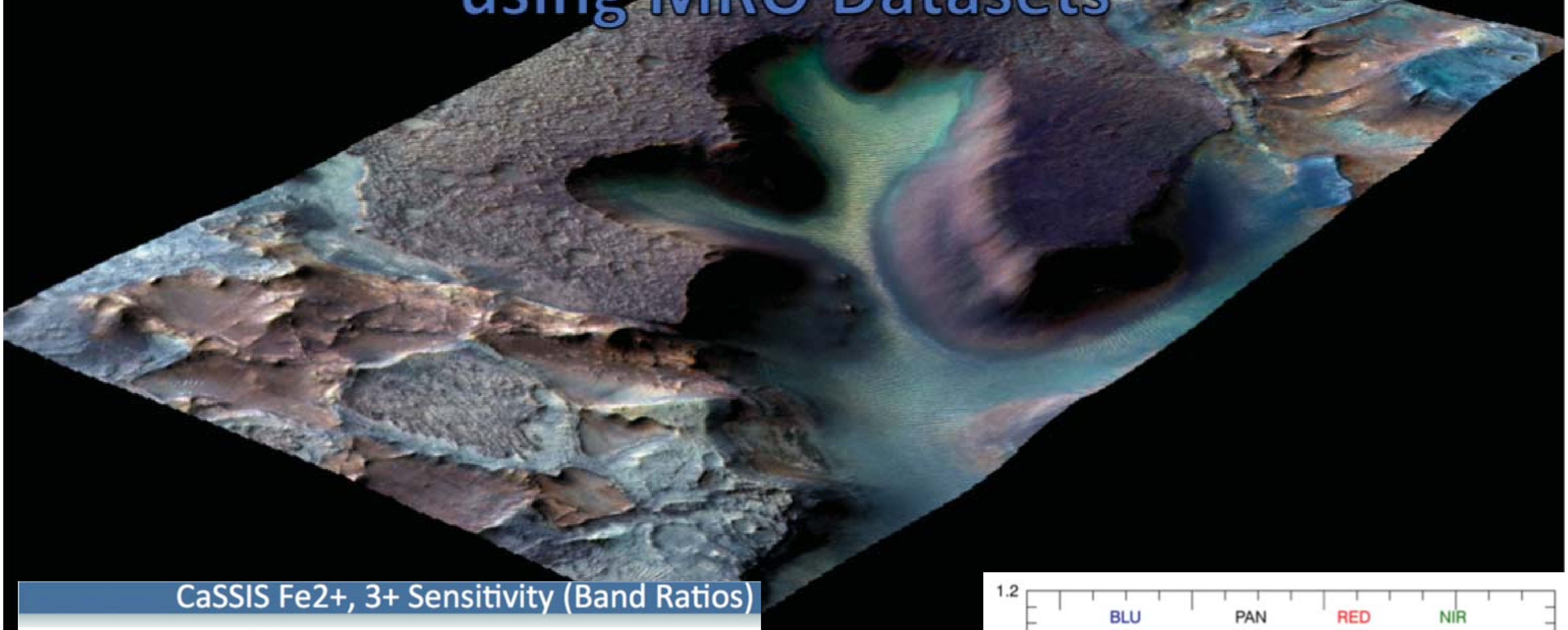

THEMIS nighttime IR shows basic surface types
dark areas = dust (low thermal inertia)
medium areas = sand (moderate thermal inertia)
bright areas = rock (high thermal inertia)

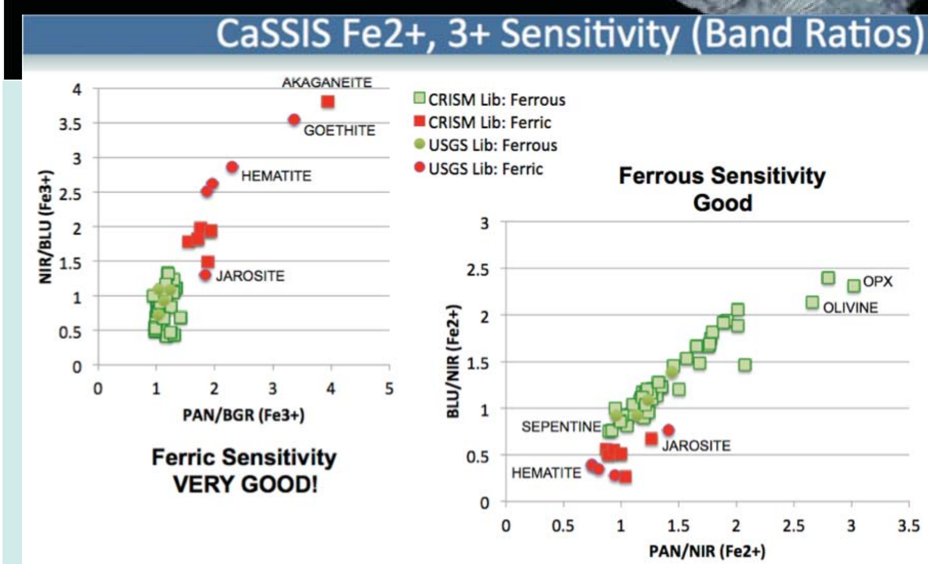

Mars Express High Resolution
Stereo Color (HRSC) oblique view,
looking North

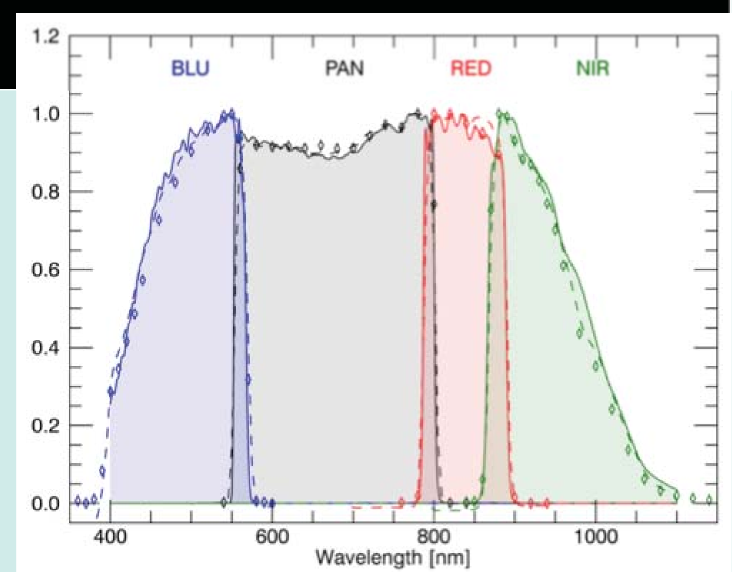
Colour and Stereo Surface Imaging System (CaSSIS)



CaSSIS Fe-Sensitivity and Image Simulations using MRO Datasets

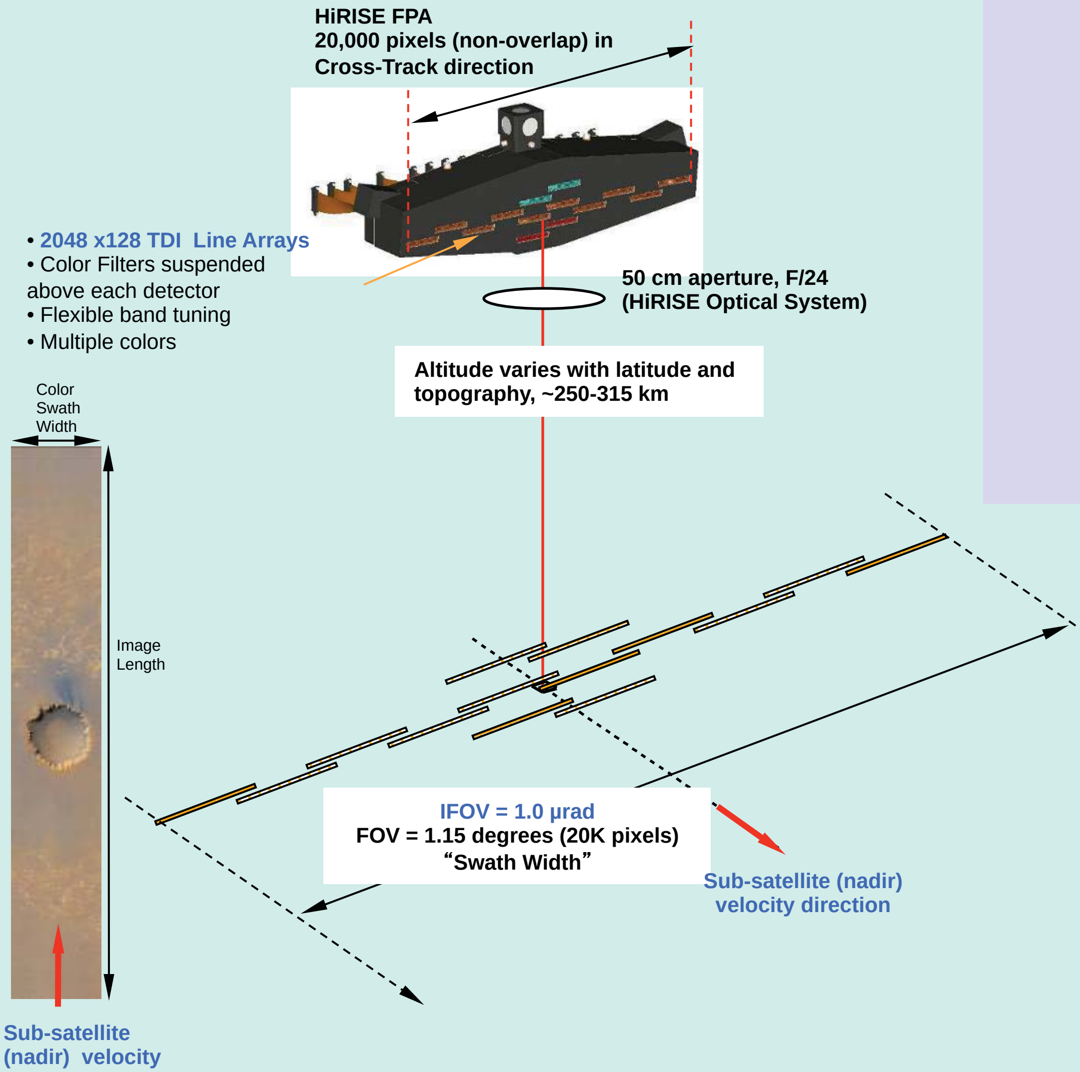




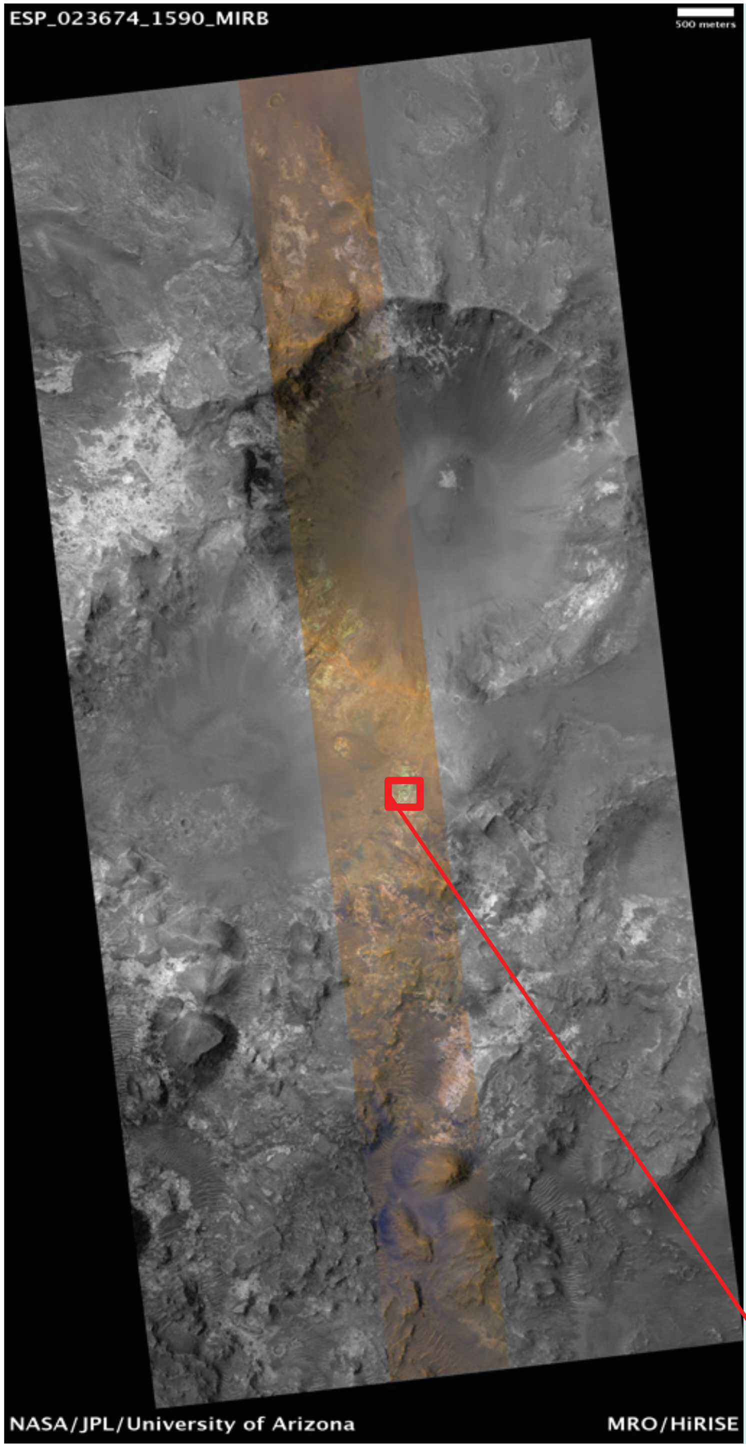


HiRISE “Pushbroom” Imaging

High resolution Imaging Science Experiment



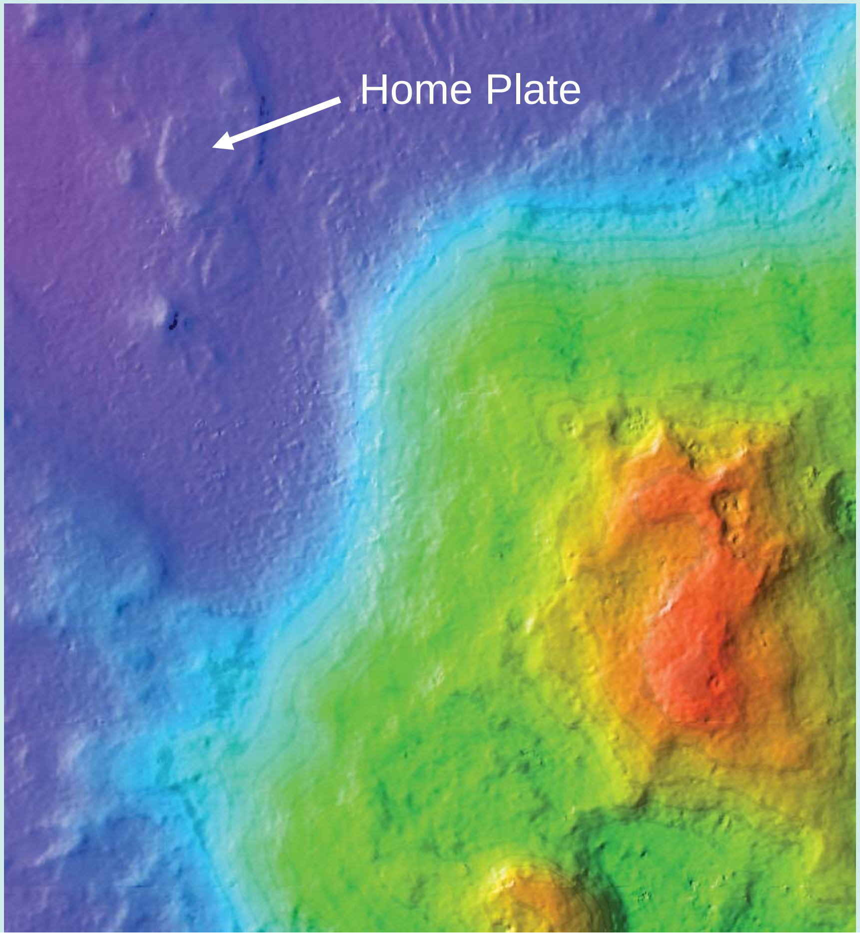
- S/C orbital motion (Nadir) “pushes” sensor projection across ground
- Line integration timing is identically matched to orbital ground speed (~3.2 km/s or 6,912 mph!)
- 25-32 cm/pixel
- Sensor (linear array of pixels) integrates during motion of single pixel: ~0.0001 second!

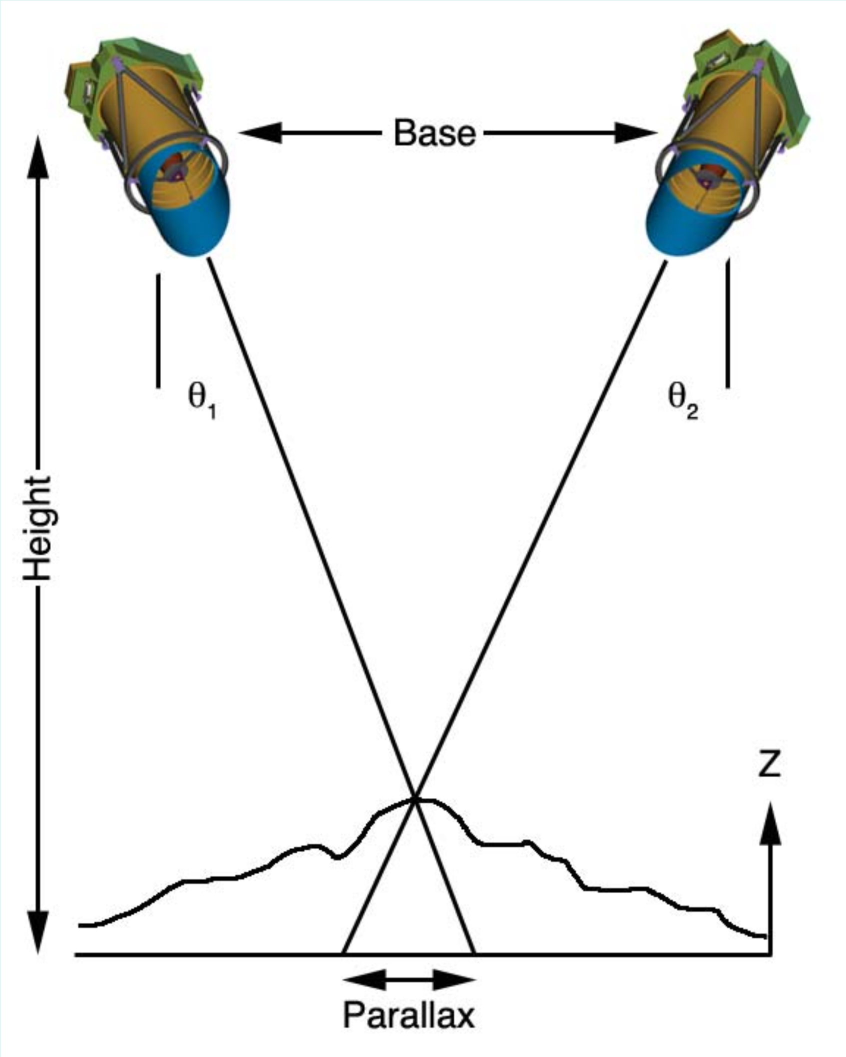


HiRISE Images with color stripe and full-res sample

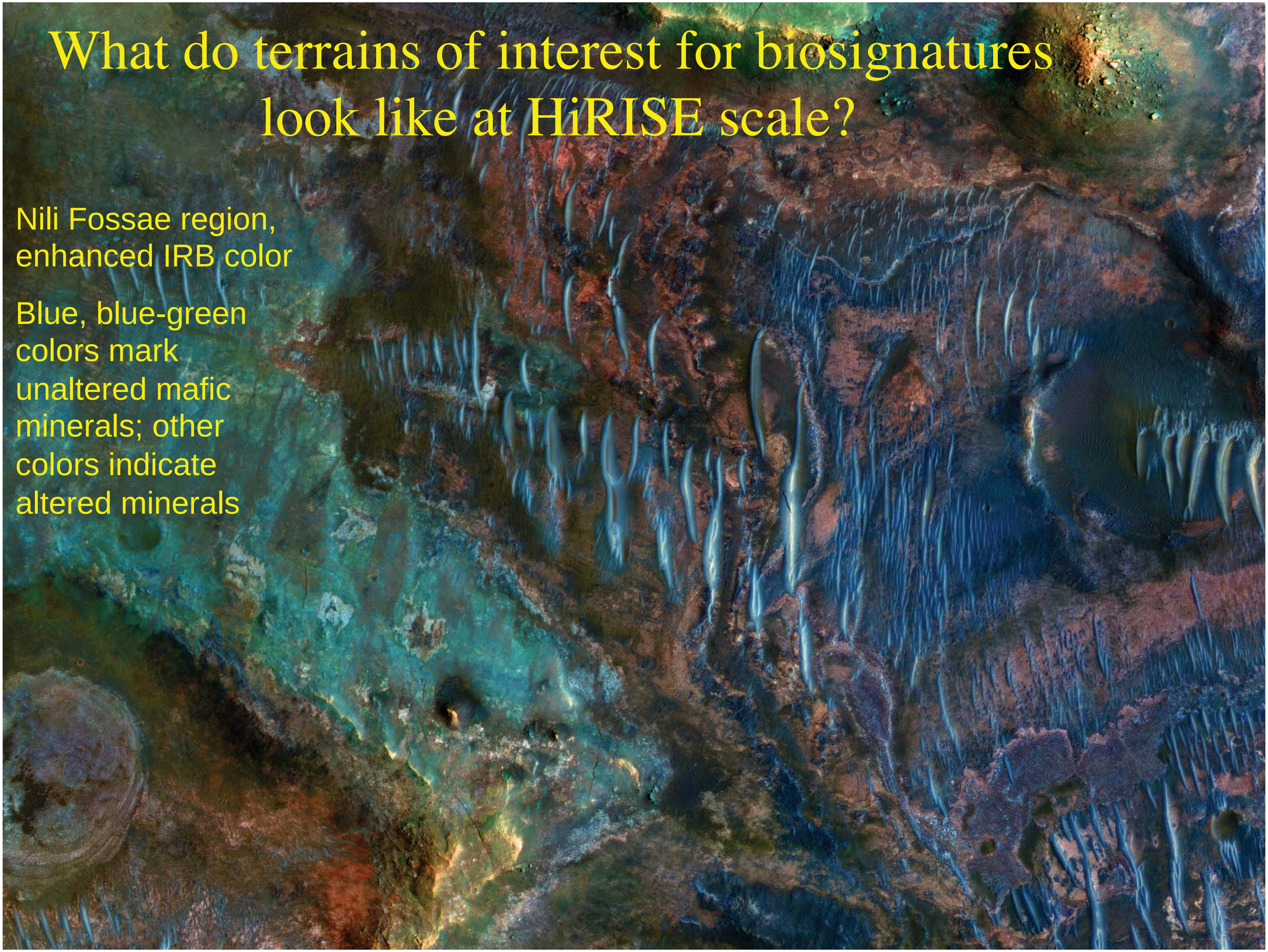
Stereo Data Acquisition on different orbits

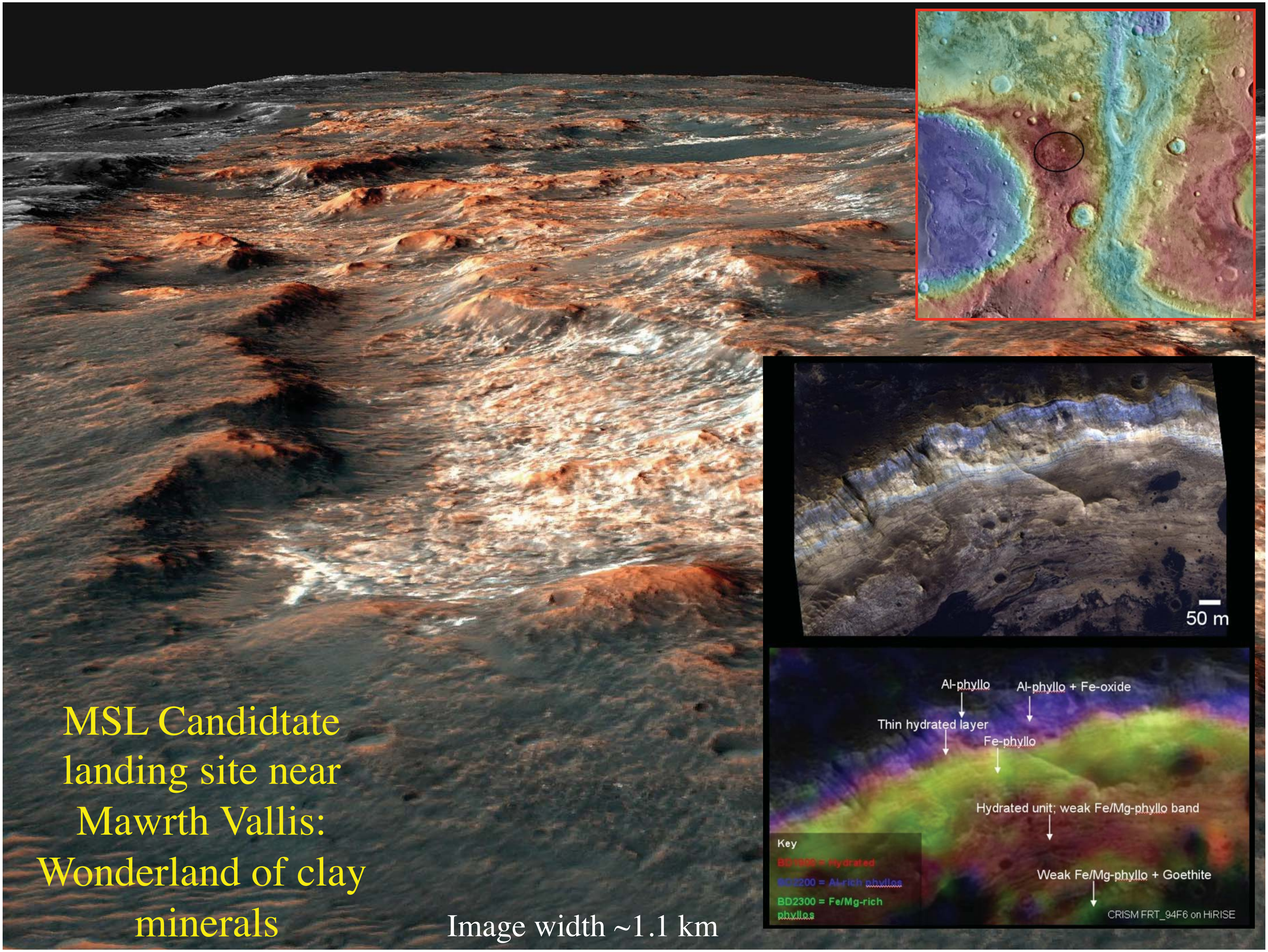
- **Acquire ~1000 stereo pairs in 2 years**
- **Digital Elevation Model (DEM) resolution ~1 m**
- **Require $\theta_1+\theta_2$ >15° for 0.2 m vertical precision**





Left: Digital Terrain Model (DTM) of part of Columbia Hills (Kirk et al., 2008)


What do terrains of interest for biosignatures look like at HiRISE scale?
Nili Fossae region, enhanced IRB color
Blue, blue-green colors mark unaltered mafic minerals; other colors indicate altered minerals

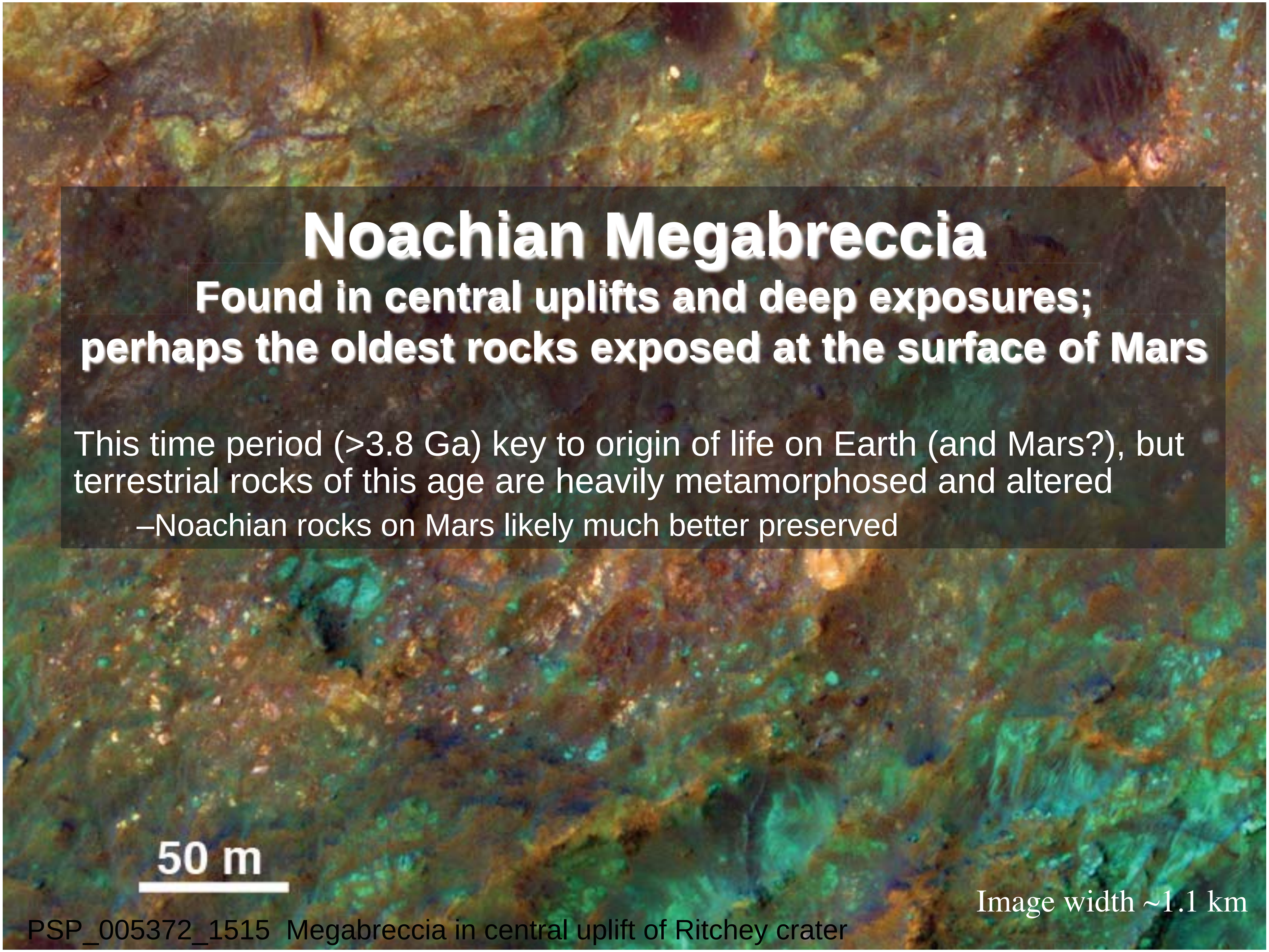

MSL Candidtate landing site near Mawrth Vallis: Wonderland of clay minerals
Image width ~1.1 km
50 m
Al-phyllo
Al-phyllo + Fe-oxide
Thin hydrated layer
Fe-phyllo
Hydrated unit; weak Fe/Mg-phyllo band
Weak Fe/Mg-phyllo + Goethite
Key
BD2200 = Al-rich phyllos
BD2300 = Fe/Mg-rich phyllos
CRISM FRT_94F6 on HiRISE

Noachian Megabreccia

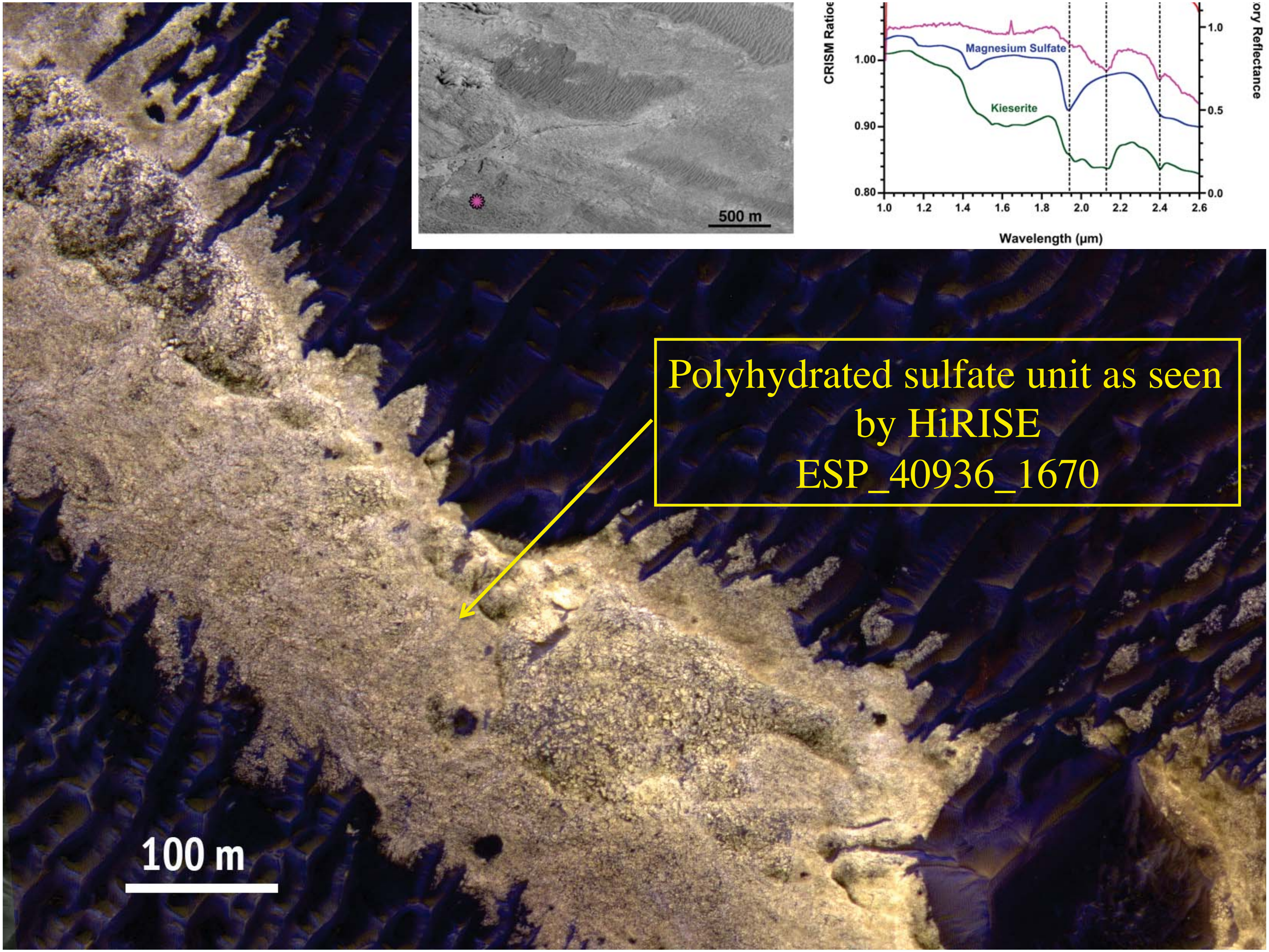
Found in central uplifts and deep exposures; perhaps the oldest rocks exposed at the surface of Mars

This time period (>3.8 Ga) key to origin of life on Earth (and Mars?), but terrestrial rocks of this age are heavily metamorphosed and altered

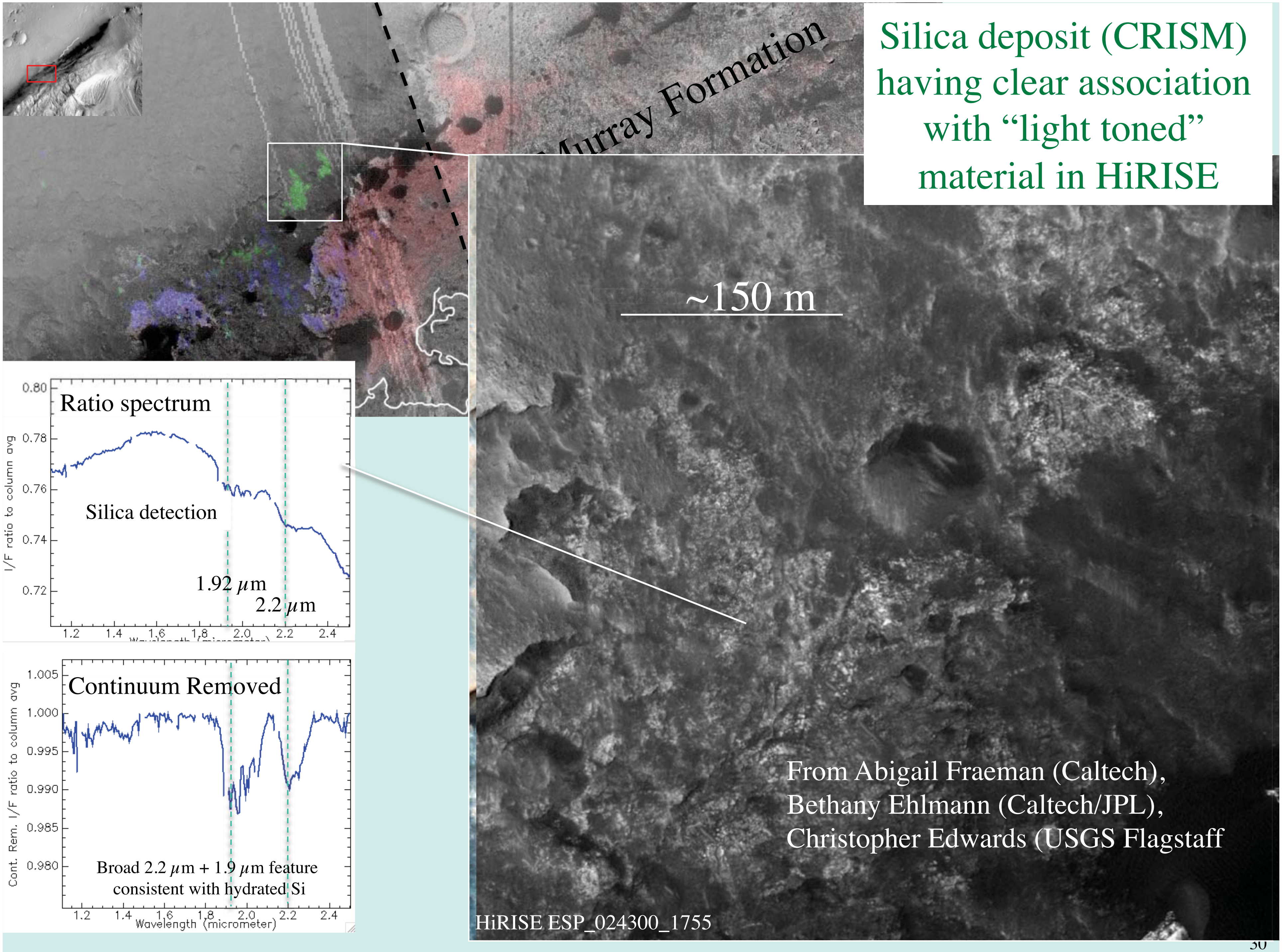
- –Noachian rocks on Mars likely much better preserved



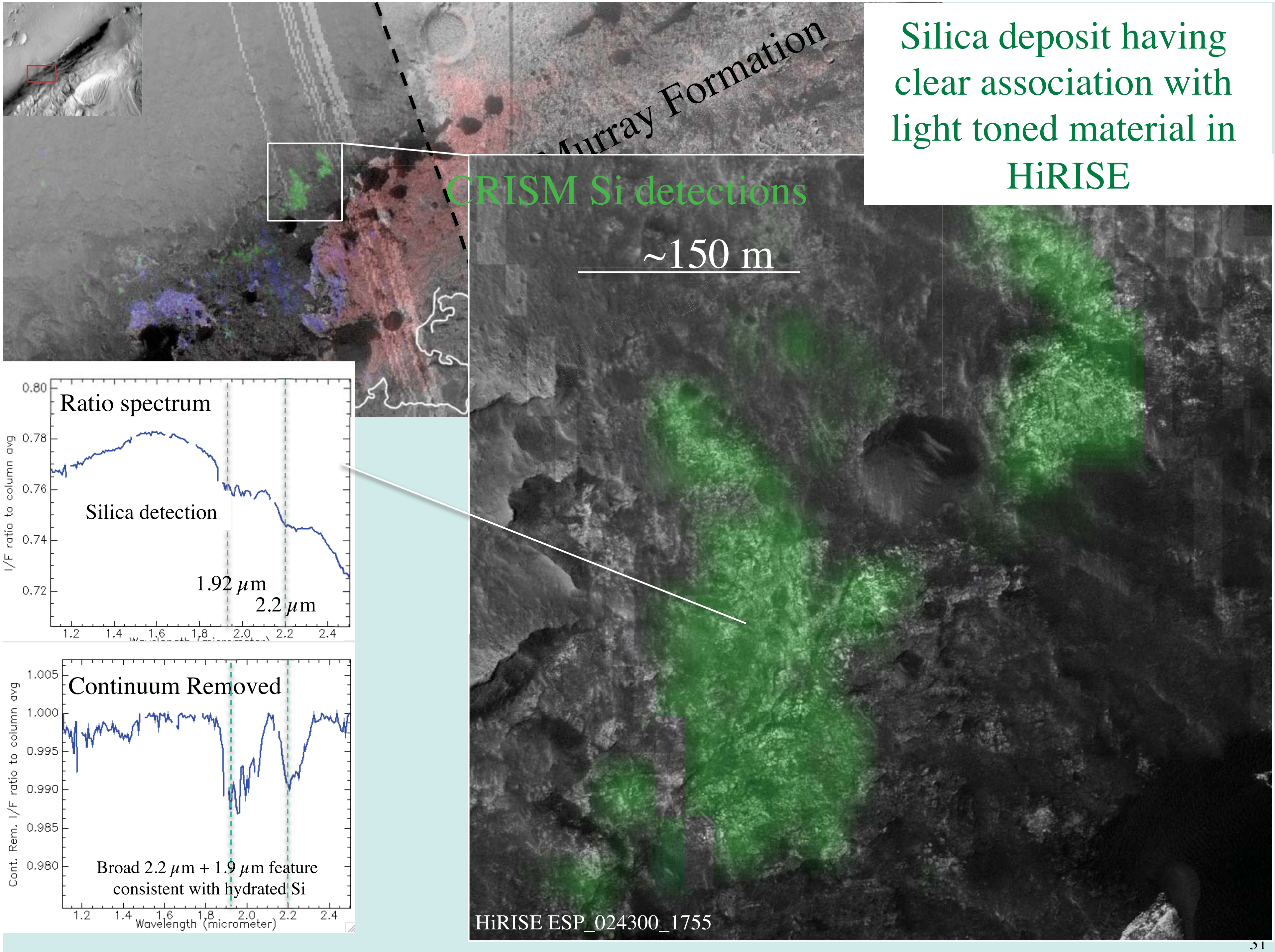
PSP_005372_1515 Megabreccia in central uplift of Ritchey crater



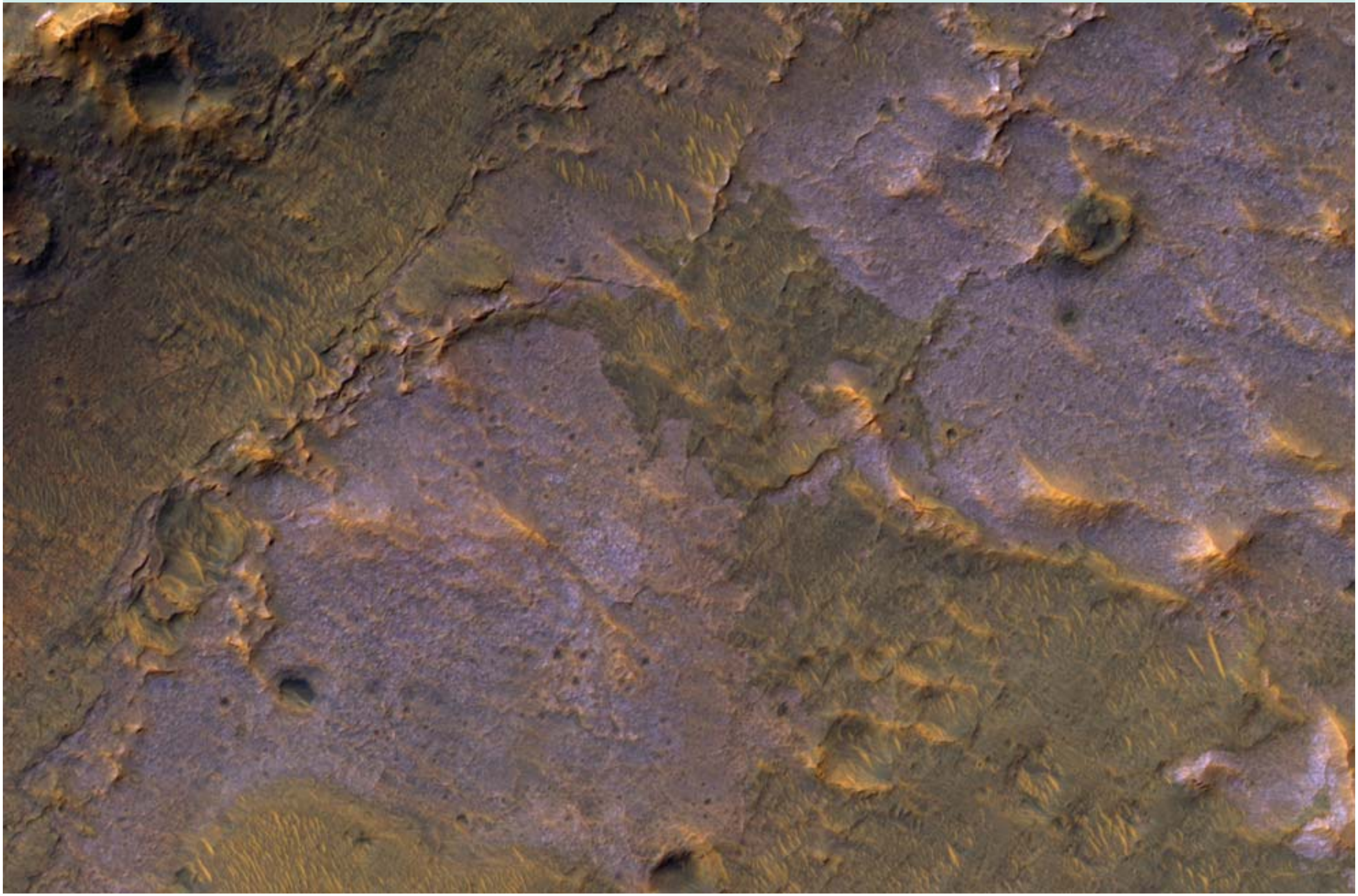
500 m
CRISM Ratios
Magnesium Sulfate
Kieserite
Wavelength (µm)
1.00
0.90
0.80
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
1.0
0.5
0.0
Polyhydrated sulfate unit as seen by HiRISE ESP_40936_1670
100 m

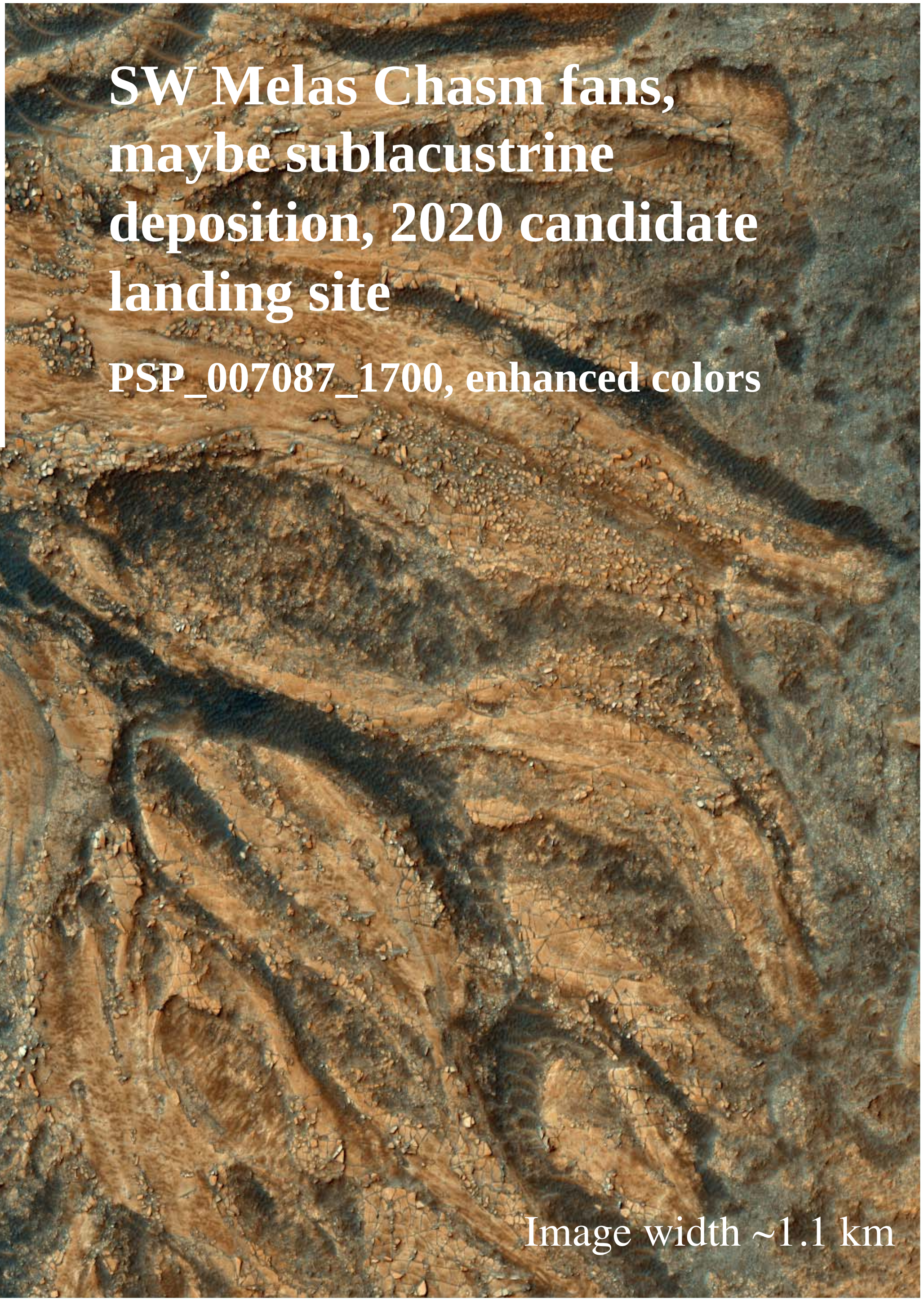


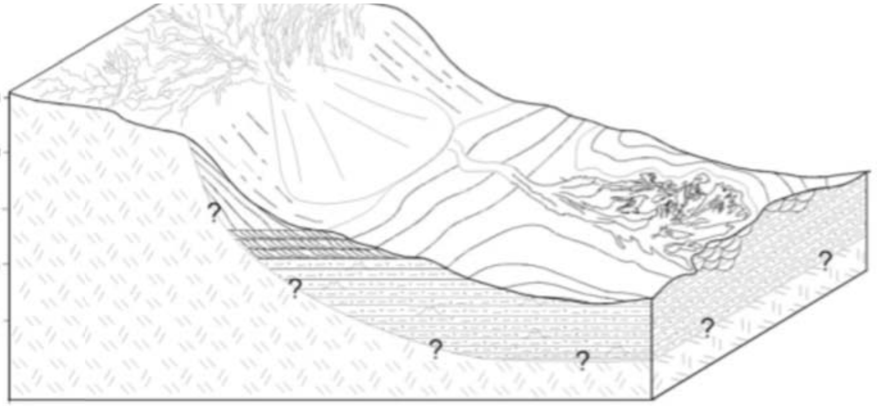
Silica deposit (CRISM) having clear association with "light toned" material in HiRISE
Murray Formation
~150 m
Ratio spectrum
Silica detection
1.92 μm
2.2 μm
I/F ratio to column avg
Continuum Removed
Broad 2.2 μm + 1.9 μm feature consistent with hydrated Si
Cont. Rem. I/F ratio to column avg
Wavelength (micrometer)
From Abigail Fraeman (Caltech), Bethany Ehlmann (Caltech/JPL), Christopher Edwards (USGS Flagstaff
HiRISE ESP_024300_1755


Silica deposit having clear association with light toned material in HiRISE
Murray Formation
CRISM Si detections
~150 m
Ratio spectrum
Silica detection
1.92 μm
2.2 μm
I/F ratio to column avg
Continuum Removed
Broad 2.2 μm + 1.9 μm feature consistent with hydrated Si
Cont. Rem. I/F ratio to column avg
Wavelength (micrometer)
HiRISE ESP_024300_1755

Chloride deposits in playas



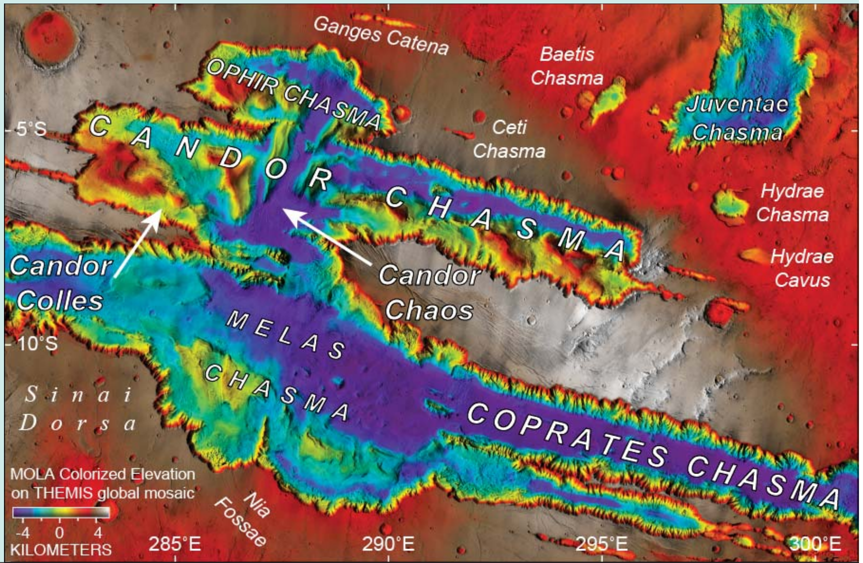




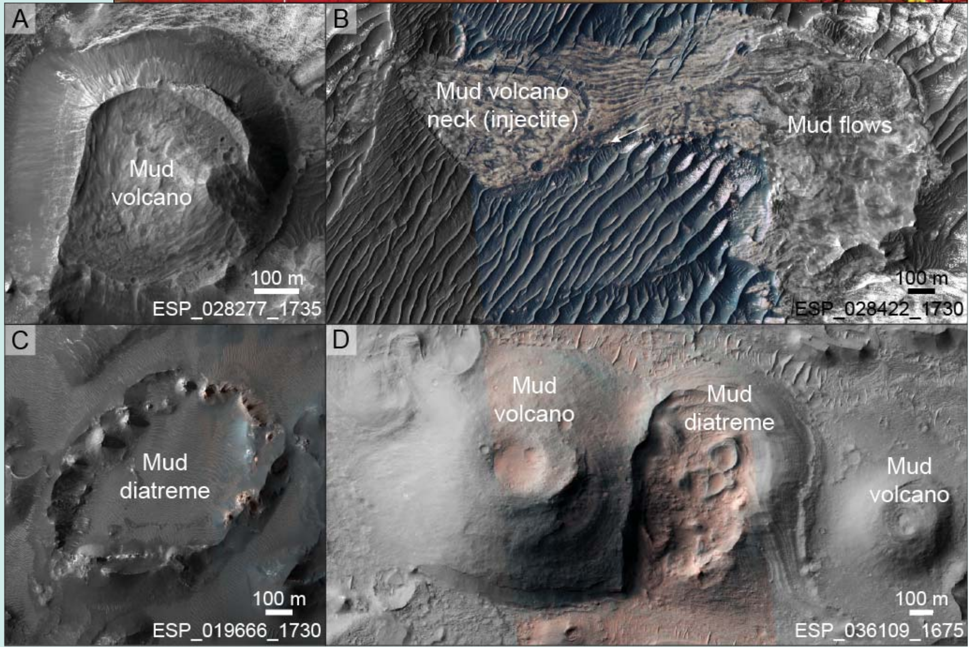
12. Ideal schematic arrangement of environments including sublacustrine fans, clinoforms, fan, and incised channels; actual topography represented by white line in Figure 2b. The inferred strine fans occur in the topographically lowest part of the basin.

MRO images show subsurface sediment mobilization and mud volcanism in Candor and Coprates Chasmata

- Populations of knobs, rings and lobate structures in the Candor Colles (A & B), the Candor Chaos (C), and Coprates Chasma (D), regions of Valles Marineris are interpreted as mud volcanoes, exhumed injectites and mud flows based on their facies, morphologies, superposition and cross-cutting relationships.
- Mud volcanoes and mud flows occur when water-saturated sediments in the subsurface are mobilized, injected upward, and erupted onto the ground surface. Processes such as earthquakes, impact cratering, and rapid sedimentation can trigger subsurface sediment mobilization.



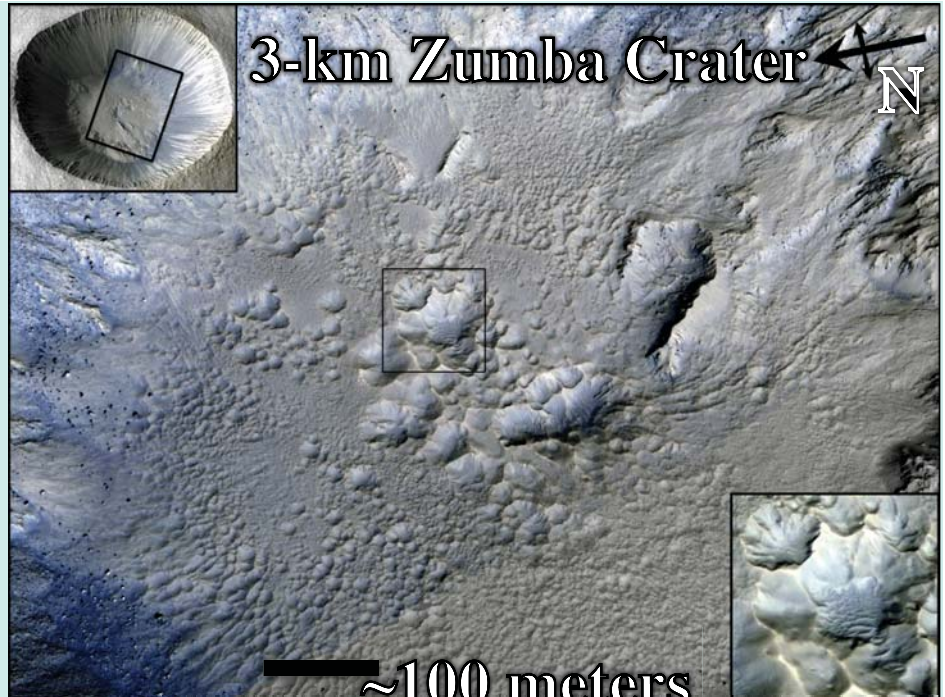
- Subsurface sediment mobilization is also interpreted as the primary mechanism for the formation of Candor Chaos, providing impetus for future investigations of mud volcanism in other chaotic terrains in the Valles Marineris region.
- Mud volcanoes and mud flows on Earth are key sites for the migration of volatiles and biosignatures from subsurface reservoirs to the surface environment. Thus mud volcanoes and flows on Mars are key sites for investigations of past habitability and future surface exploration.

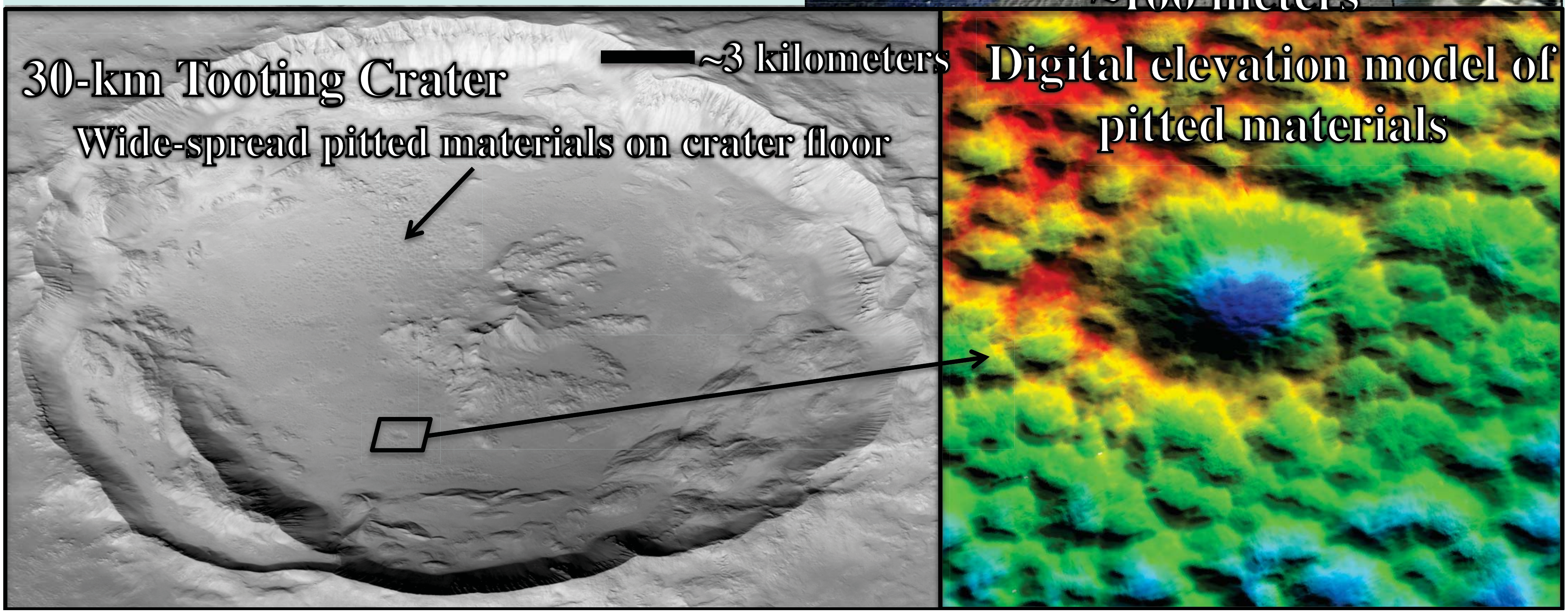


Okubo, C.H. (2016) *Icarus*, http://dx.doi.org/10.1016/j.icarus.2015.12.051.

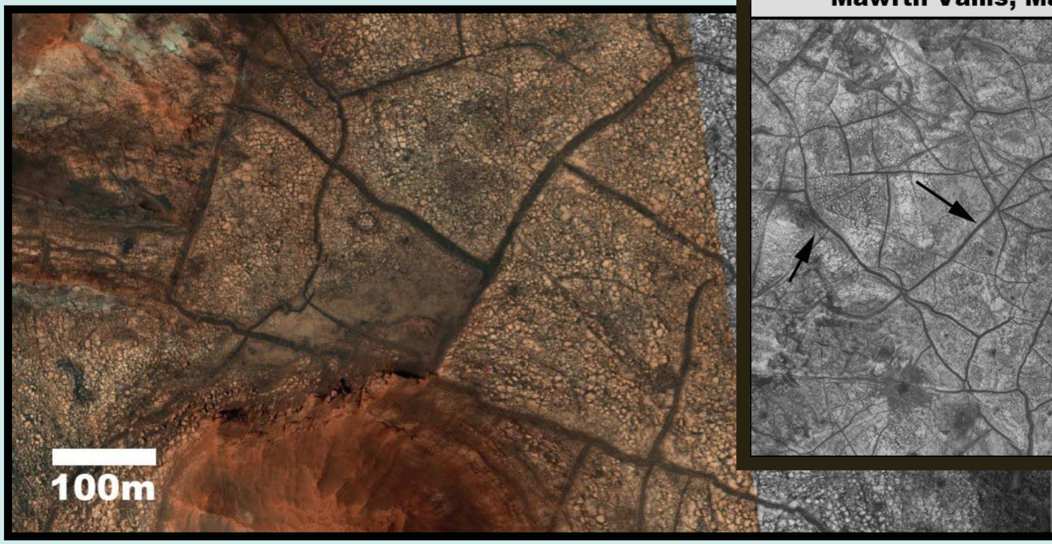
Crater-Related Pitted Materials on Mars

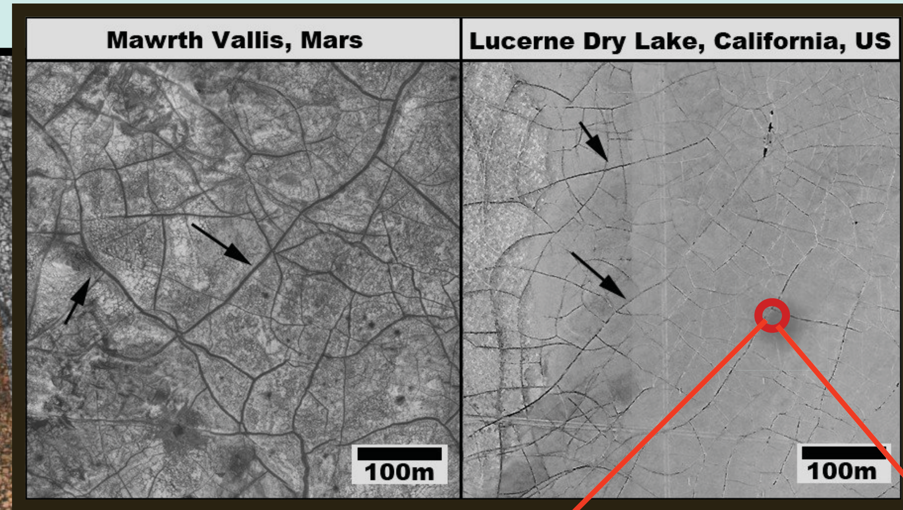
- Previously recognized, but thought to be rare.
- HiRISE determined that they are wide-spread in over 200 fresh and well-preserved craters ranging from ~1 to 150 km in size.
- Pits are likely to form through the interaction of hot deposits generated by the impact and preexisting water-ice contained in the Martian subsurface.
- See **Tornabene L. L.**, & 5 others (2012), Widespread crater-related pitted materials on Mars: further evidence for the role of target volatiles during the impact process, *Icarus*, doi:10.1016/j.icarus.2012.05.022.





"Mud Cracks" on Mars





Mawrth Vallis, Mars (HiRISE image PSP_006755_2030)

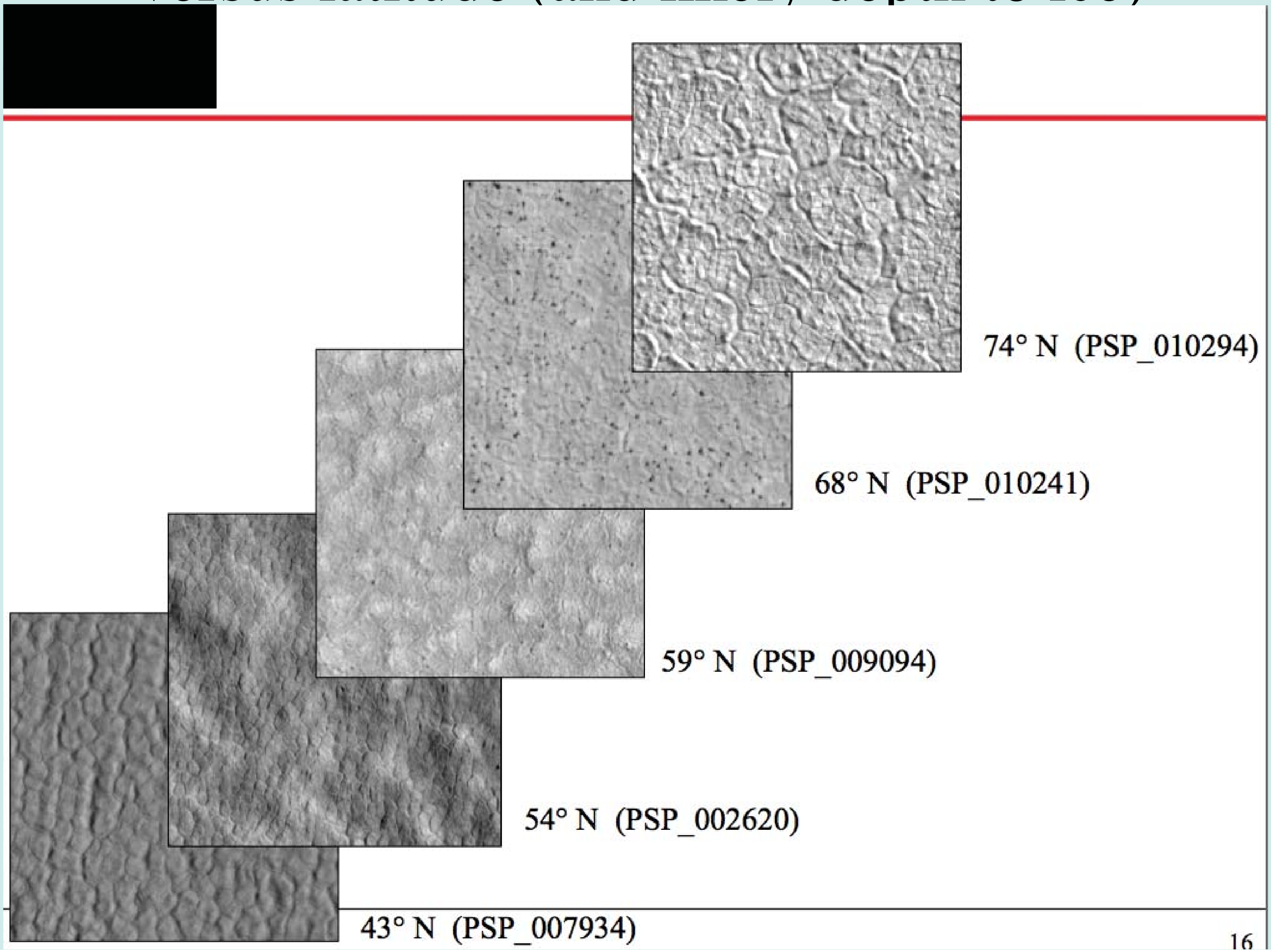
- They are located in areas that display minerals that may have formed in ancient lakes and rivers.
- When these ancient lakes dried out, they may have produced these beautiful features.
- Similar features are also visible in Gale Crater where the Curiosity Rover discovered minerals that may have formed in the presence of liquid water.
- Large polygonal surface features resembling giant mud-cracks are observed by HiRISE in many locations on Mars.

El-Maarry et al., 2014, (Icarus)

Significance

The presence of giant mud cracks can be used as an identifying tool of areas that may have harboured lakes **<u>and possibly life</u>** on ancient Mars.

Periglacial polygon sizes and morphology versus latitude (and likely depth to ice)



What Remote Sensing Cannot Do: Date Rocks and Minerals

- Crater counting dates *landscapes*
  - Rocks near the surface may be much older or younger than the landscape
- *Interpretations* of rock ages are still possible
  - Interpretations are not facts
- Alteration minerals have the same or younger age than the host rock
  - Again, interpretations can be made
  - Now we have two levels of interpretations
- Remote-sensing interpretations say that most altered minerals on Mars are ancient
- From Mars meteorites we know that alteration has occurred throughout geologic time
  - But may be a biased sample

Thanks for Listening!