DISCOVERY OF DIVERSE MARTIAN AQUEOUS DEPOSITS FROM ORBITAL REMOTE SENSING

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A Presentation to

GROUND TRUTH FROM MARS:
SCIENCE PAYOFF FROM A SAMPLE RETURN MISSION

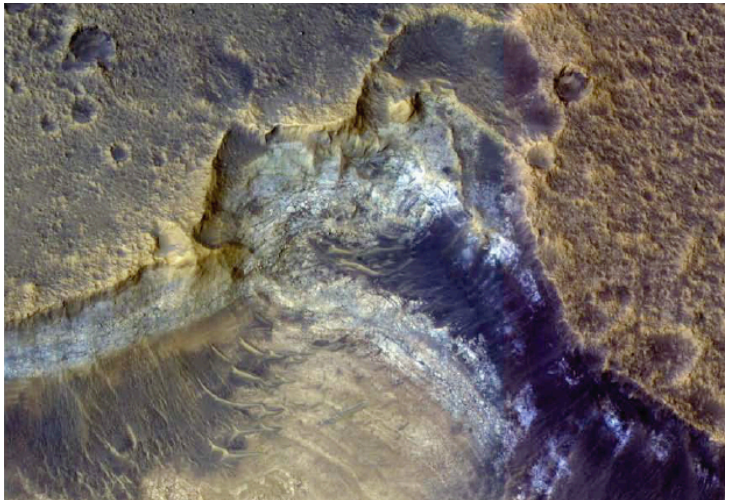
Background

- Three major types of evidence for aqueous environments have the potential to record past habitats:
  - Macro-scale structures and stratigraphy (beds, large bedforms, superposition relations)
  - Chemical precipitates or alteration products
  - Micro-scale bedforms, texture, composition

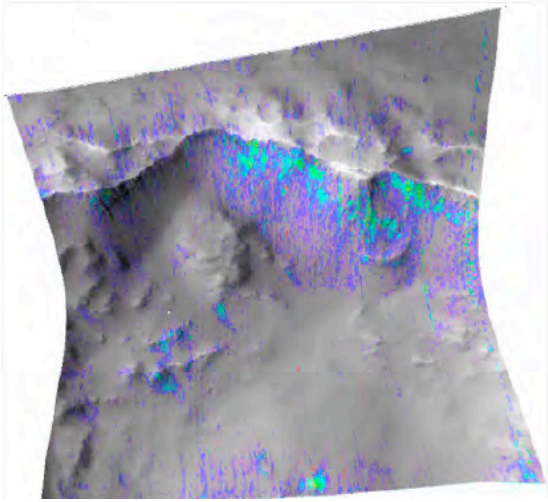
  May be detectable from orbit

  Detectable in situ
- Deposits with aqueous minerals (phyllosilicate, precipitates) are of special interest:
  - Clays and precipitates preserve a chemical record of past biology or pre-biotic compounds better than coarser clastics alone
  - Aqueous mineralogy in addition to structures preserves a more detailed record of the past environment
- With observations by MER, THEMIS, OMEGA and MRO, the recognized diversity and spatial extent of deposits with aqueous minerals has grown dramatically
- At least 8 classes of deposits with distinctive mineralogy, structures, and stratigraphy are recognizable in current data
- They may represent multiple environments that record different parts of the history of water on Mars

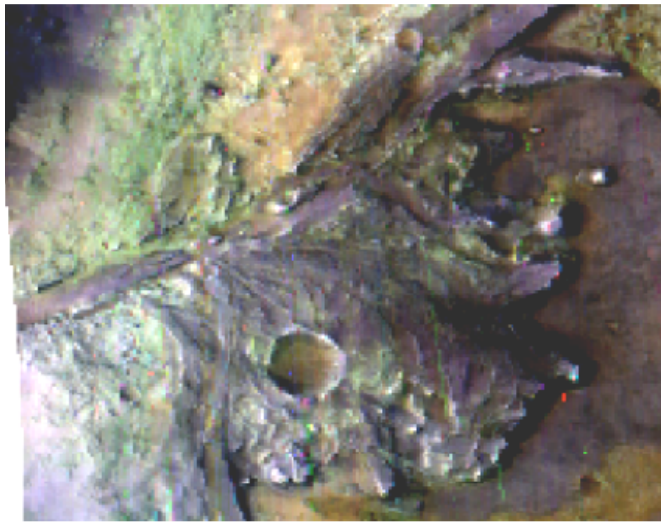
Summary of Deposit Types (1-4)



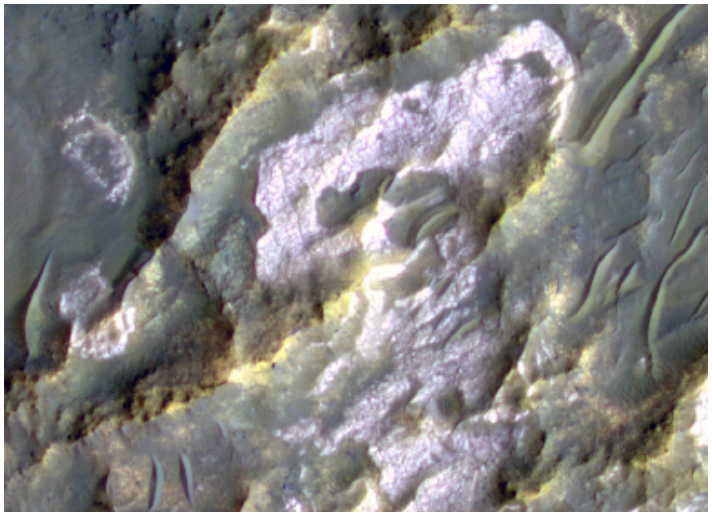
Noachian layered phyllosilicates



Noachian deep phyllosilicates exposed in highland craters, chasma walls

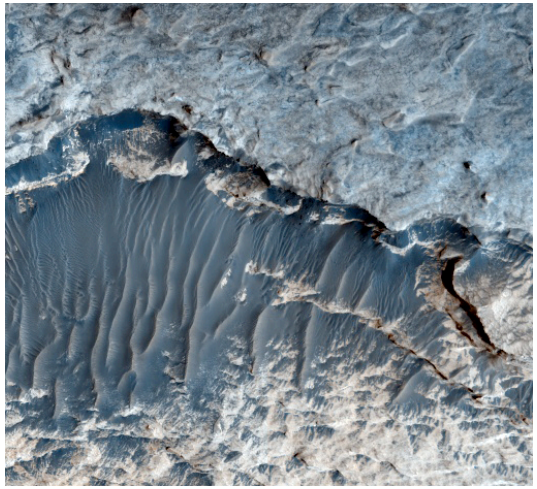


Noachian intra-crater fans with phyllosilicate-rich layers

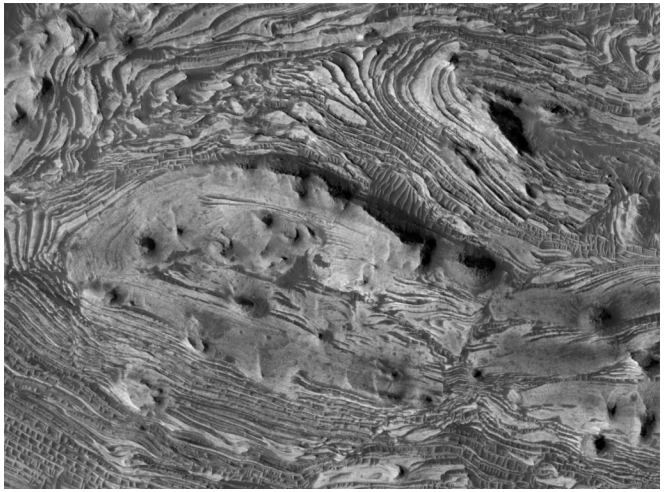


Noachian "glowing terrain" thought to be rich in chlorides

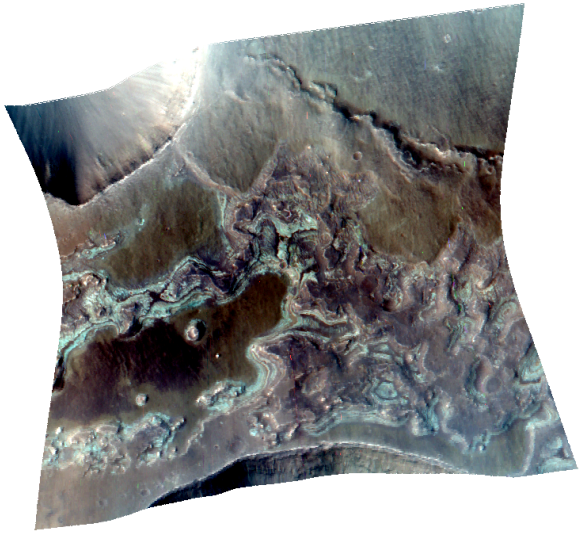
Summary of Deposit Types (5-8)



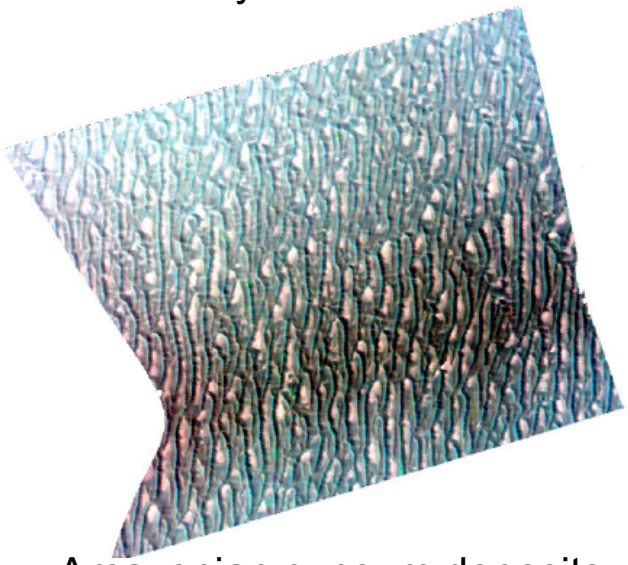
Noachian Meridiani-type layered deposits with sulfates + hematite (MER/Opportunity)



Hesperian Valles-type layered deposits with diverse layered sulfates + Fe oxide



Thin Hesperian layered deposits with hydrated silica



Amazonian gypsum deposits surrounding north polar layered deposits

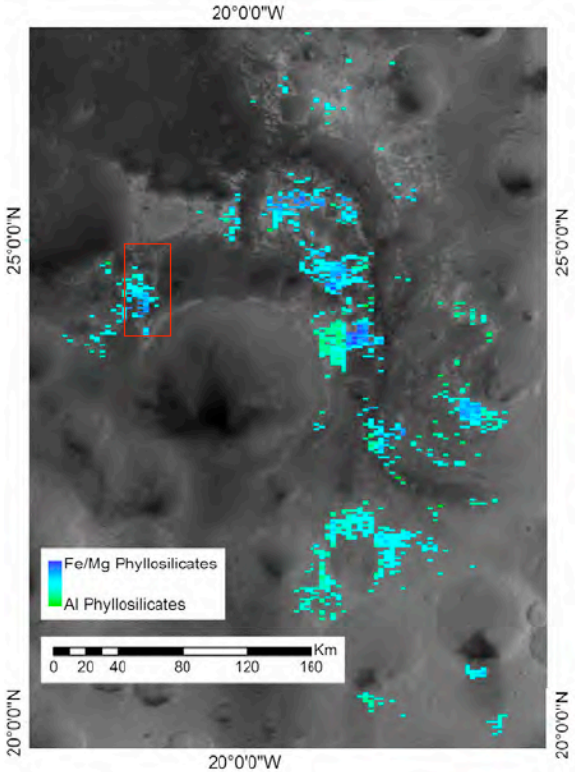
Timeline of Discovery

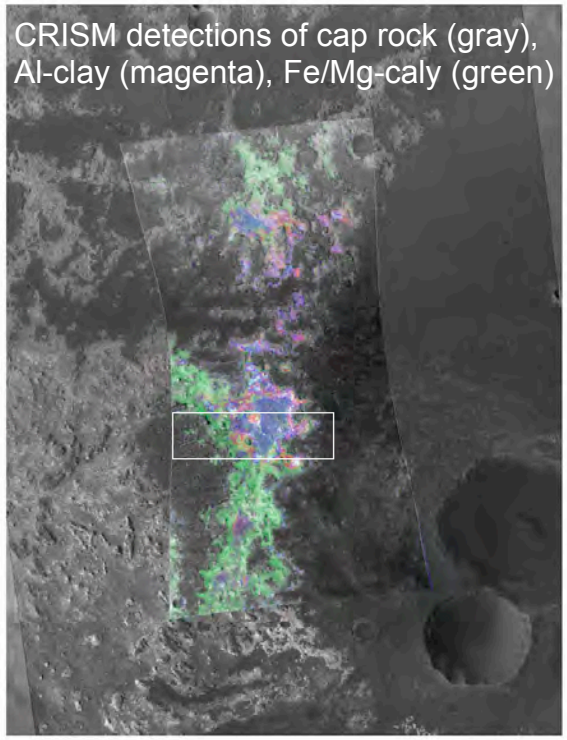
Short nam e	MGS/TES	Mex/OMEGA	Odyssey/ THEMIS	MER	MRO/CRISM MRO/HiRISE
Meridiani-type layered de-posits	Deposits of gray hema-tite	Adjacent occurrences of mono- and polyhydrated sulfates	-	In situ measurements reveal geologic history	Improved resolution of ver-tical stratification
Valles-type layered de-posits	Patches of gray hema-tite	Adjacent occurrences of mono- and polyhydrated sulfates, gypsum, Fe ox-ides	-	-	Intricate vertical layering of sulfate types; folding; al-teration zones
Gypsum plains	-	Gypsum-rich optical sur-face	-	-	Role of eolian reworking; relationship to basal unit
Layered phyl-losilicates	-	Al- and Fe/Mg-clays at Nili and Mawrth	-	-	Thin interbedding of clay units; detailed stratigraphy
Massive phyl-losilicates	-	Unknown hydrated min-eral associated with doz-ens highland craters	-	-	~10K highland outcrops in craters, chasmata; chlorite + other phyllosilicates
Phyllosilicates in fans	-	-	-	-	Highland crater fans/deltas contain phyllosilicate-rich layers
Glowing ter-rain	-	-	Detection of chloride	-	Polygonal fracturing, lack of sulfates
Siliceous lay-ered deposits	-	-	-	High-Si deposits at Home Plate	Widespread hydrated silica in layered deposits on Hes-perian plains

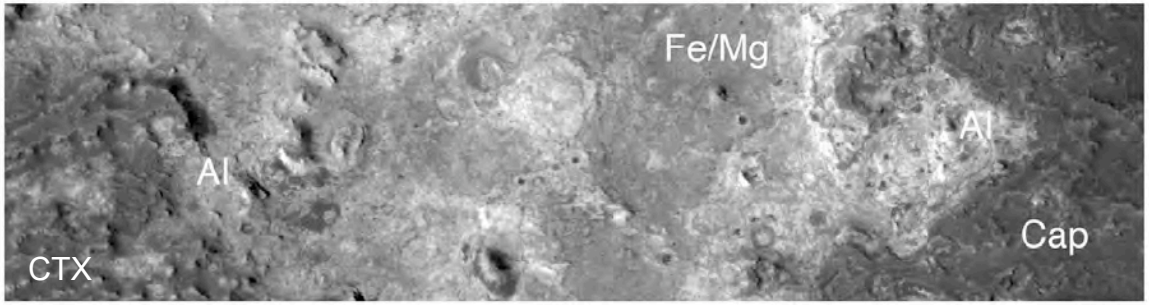
2004

The recognized diversity and extent of deposits possibly preserving fossil evidence for life has grown dramatically since 2004

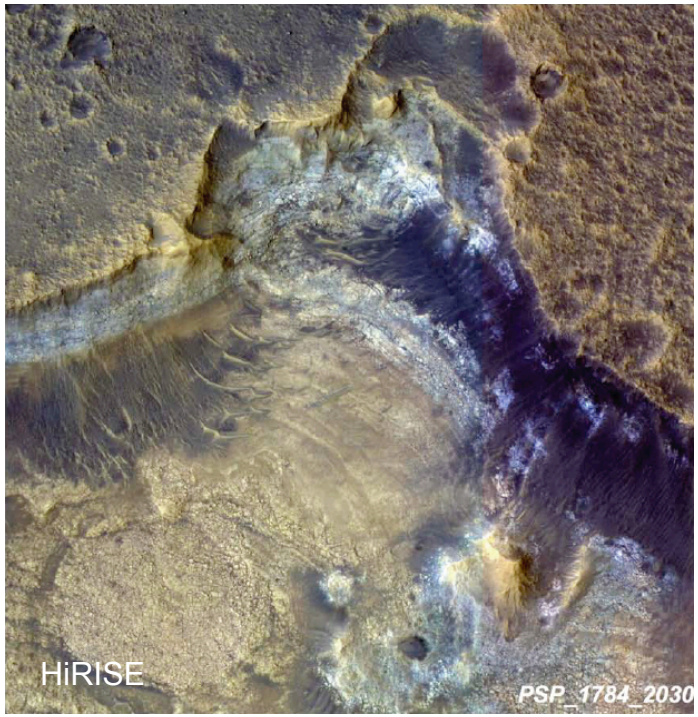
1. Layered Phyllosilicates





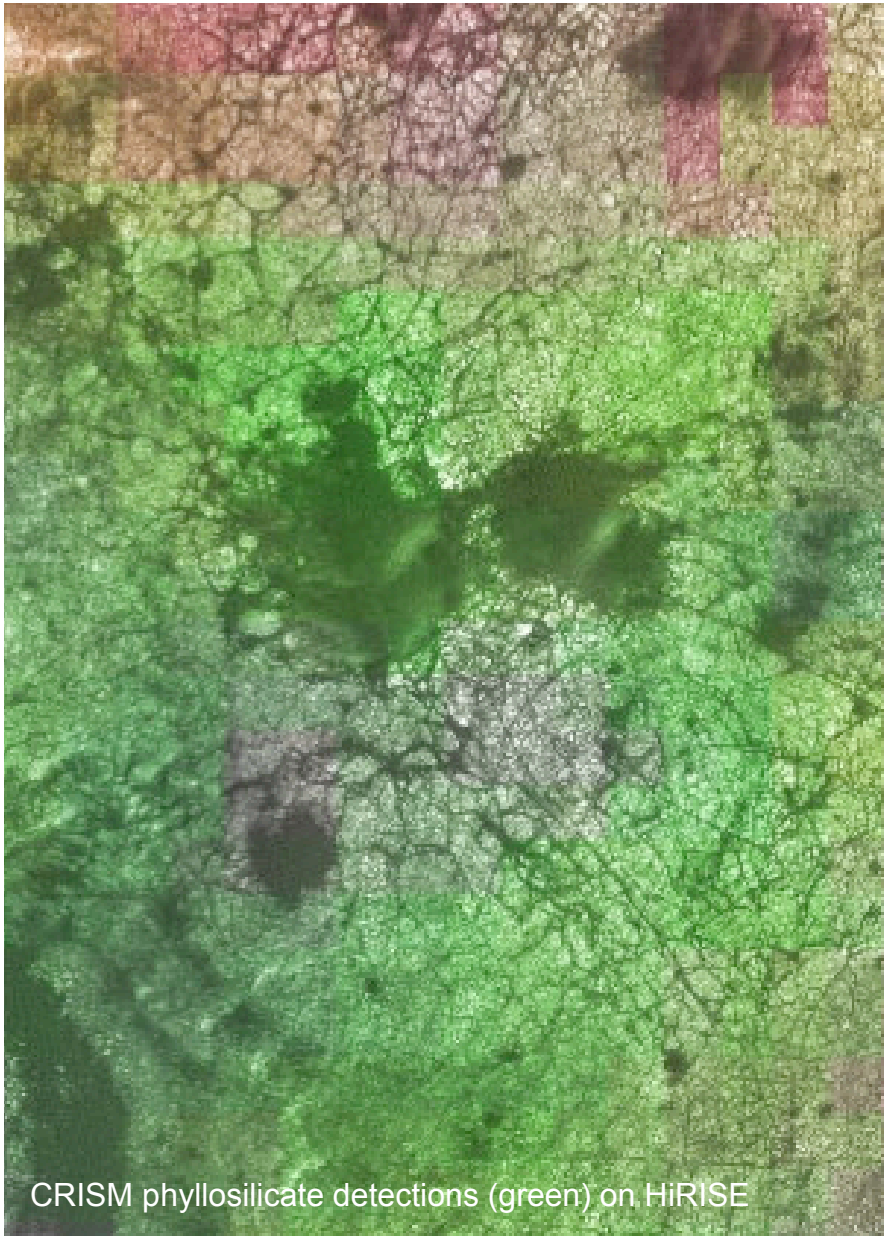


- Occurrence
  - Early Noachian plains, Mawrth Vallis / Nili Fossae
- Composition
  - Fe/Mg-, Al-rich phyllosilicates in layers
- Morphology
  - Exhumed where protective cap rock has been eroded



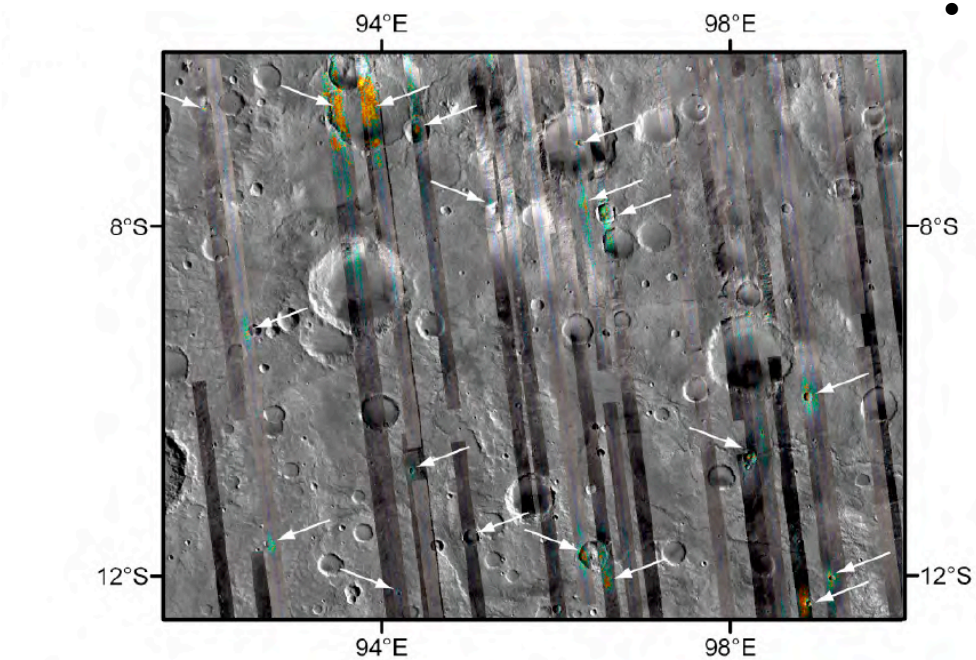
1. Layered Phyllosilicates

- Morphology (cont'd)
  - Light- and darker-toned layered deposits
  - Extensive polygonal fracturing exposed in some locations
  - In Mawrth, remnants over 700x900 km area indicate former widespread extent
- Possible origins
  - Alteration of volcanic ash
  - Subaerial weathering of basaltic regolith during wet period
  - Shallow marine sedimentation of sorted, transported clays
- Significance to Mars exploration
  - **The most widely distributed record of a possible near-surface Noachian wet environment, with mineral types capable of preserving fossil evidence of early life.**

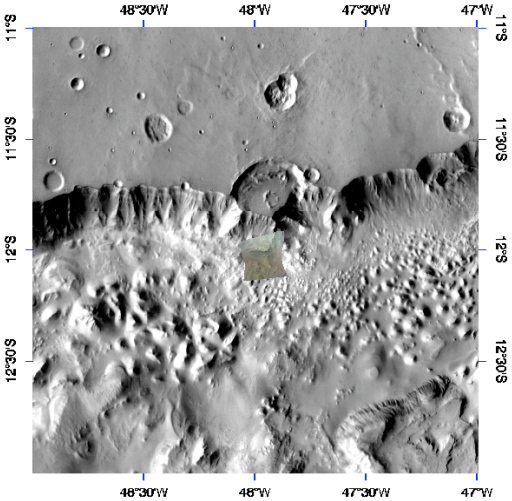


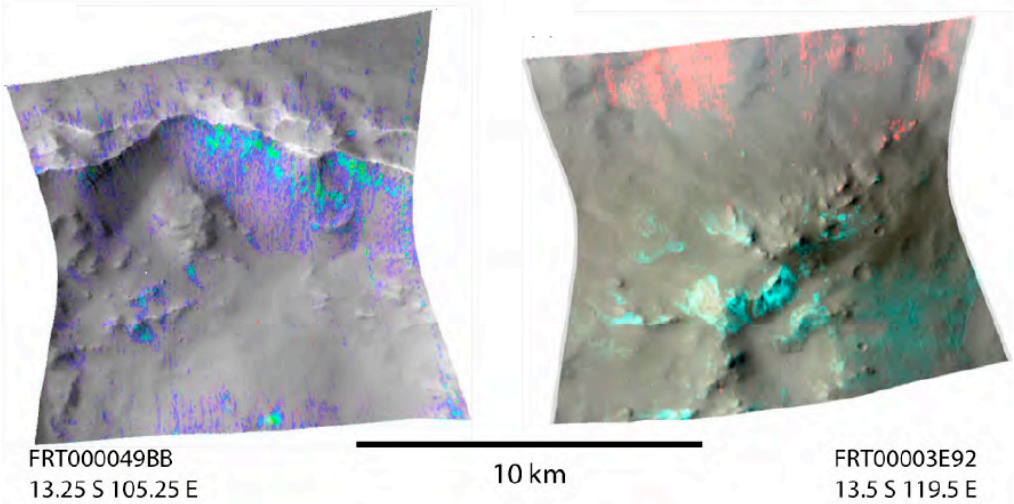
CRISM phyllosilicate detections (green) on HiRISE

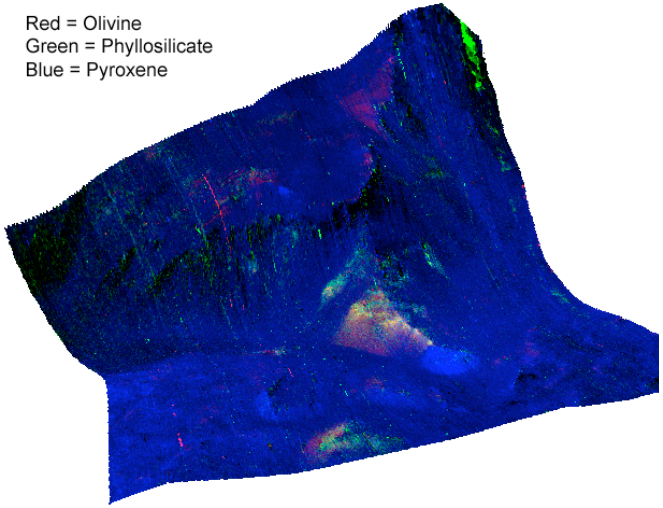
2. Deeply Excavated Phyllosilicates



- Occurrence
  - ~10,000 exposures in Noachian craters
  - Layers in chasmata walls
  - Massifs



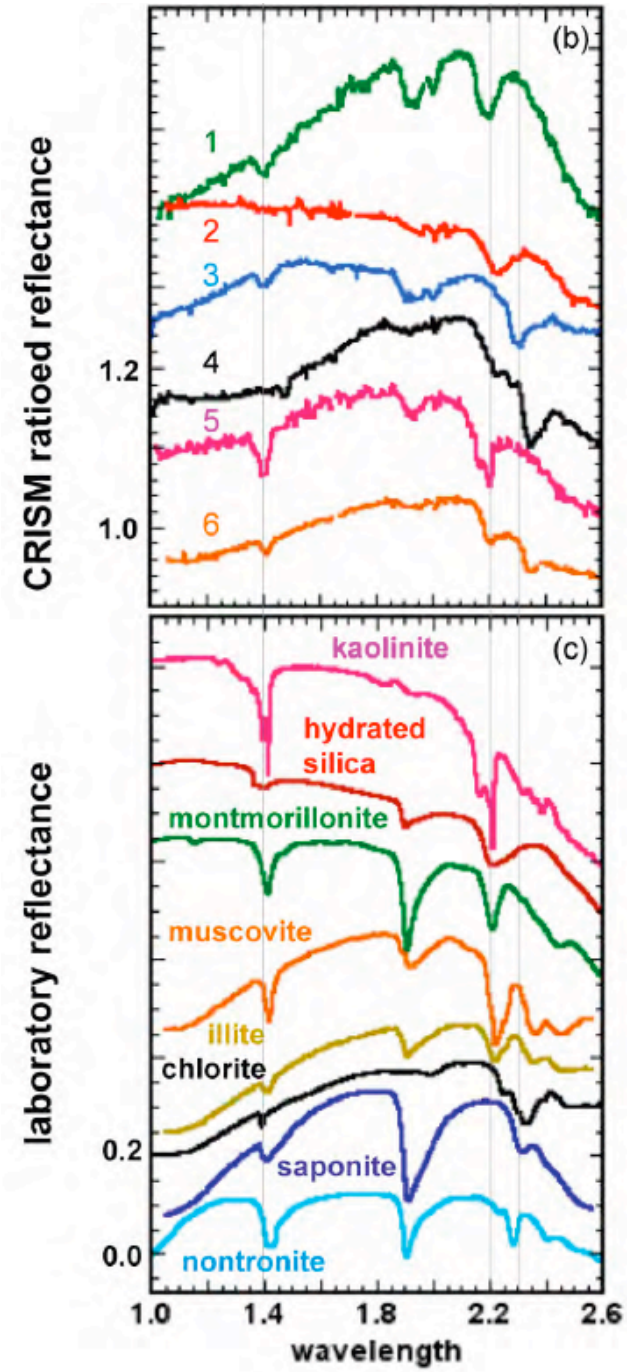




CRISM phyllosilicate detections

2. Deep Phyllosilicates

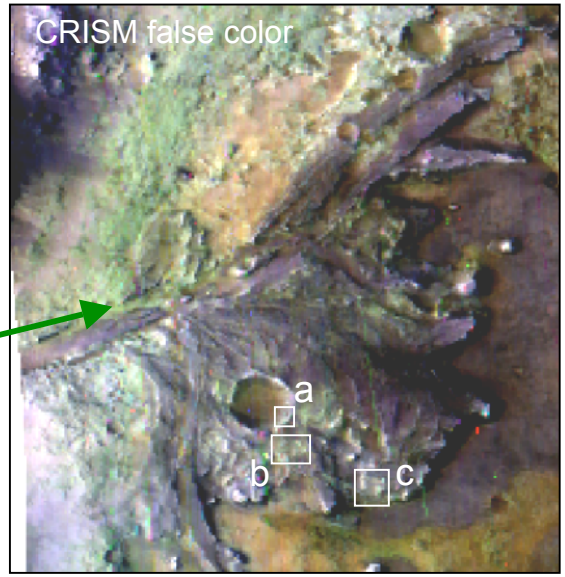
- Compositions
  - Wide variety of phyllosilicate spectral signatures
  - Chlorite/saponite particularly common in highland craters
- Morphology
  - Some occurrences massive, some layered
  - Associated with megabreccia in some highland crater central peaks
- Possible origins
  - Burial of layered phyllosilicates
  - Impact-generated hydrothermal processes
  - Hydrothermal alteration of crust
- Significance to Mars exploration
  - **This type of deposit occurs widely in the Noachian crust. Depending on its origin, it may record a history of buried wet surface environments, or a sub-surface environment with long-lived chemical energy sources.**

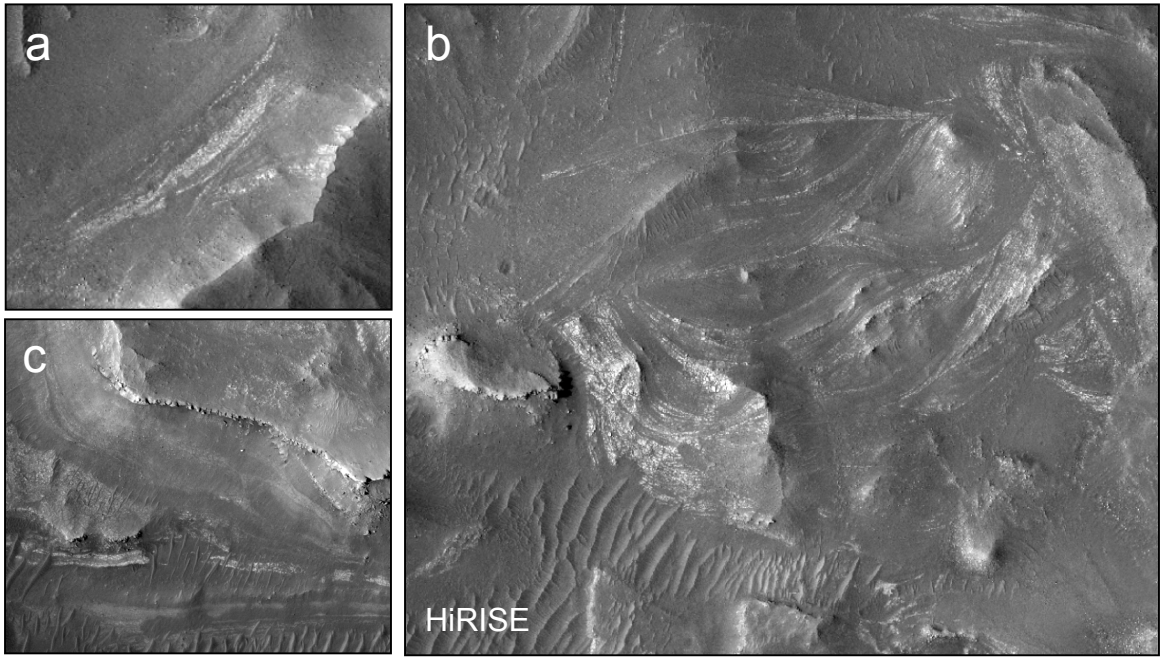


3. Phyllosilicates in Fans

- Occurrence
  - Several Noachian highland crater fans exhibit evidence of phyllosilicates that could entomb biomarkers
  - Include Holden, Eberswalde, Terby, Jezero
  - There are probably others
- Morphology
  - Typically lower beds are layered and show strongest evidence of phyllosilicate (c)
  - Typically overlain by alluvial deposits with evidence for bars (b)
  - Internally stratified (a)

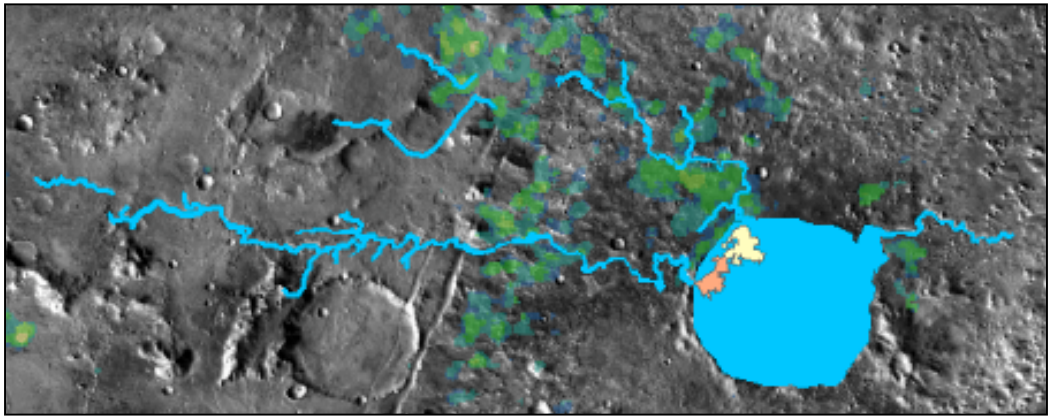
Green = phyllosilicate

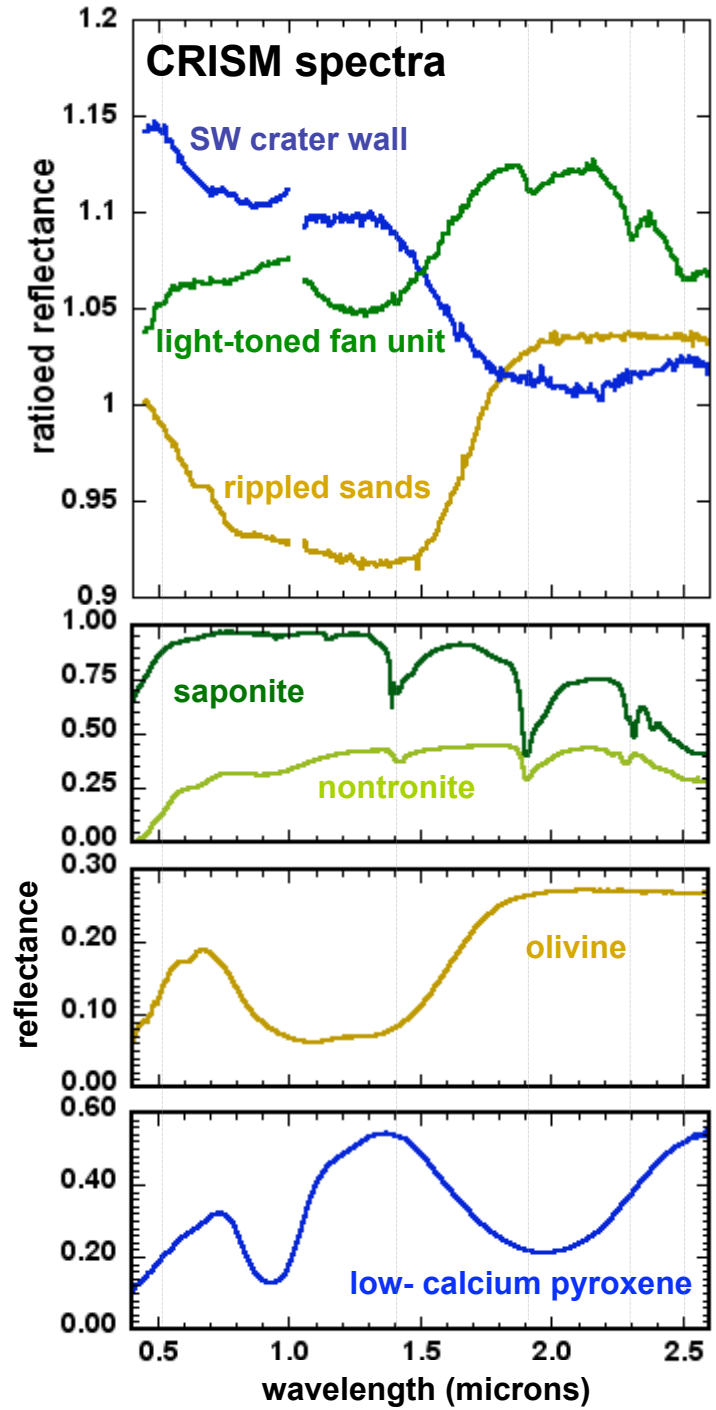




3. Phyllosilicates in Fans

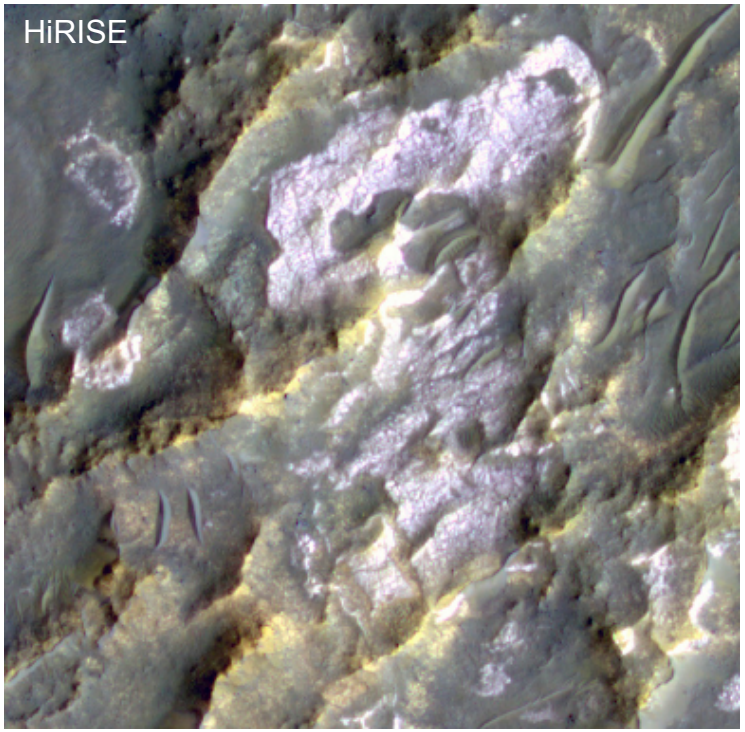
- Compositions
  - Representative of mineralogy of drainage basin
- Possible origins
  - Fluvial origin is clear
  - Uncertain to what extent diagenesis has contributed to phyllosilicate formation
- Significance to Mars exploration
  - **This type of deposit has the clearest evidence for Noachian standing bodies of water, and could have sequestered organic materials.**

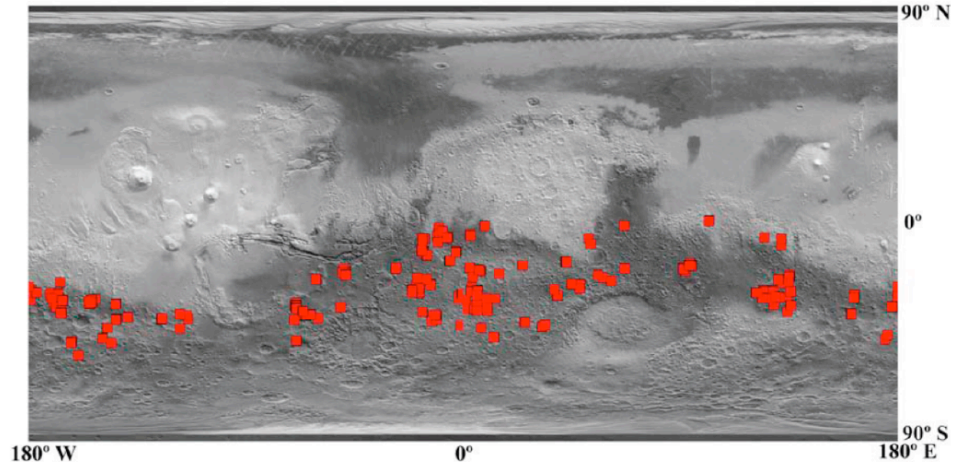


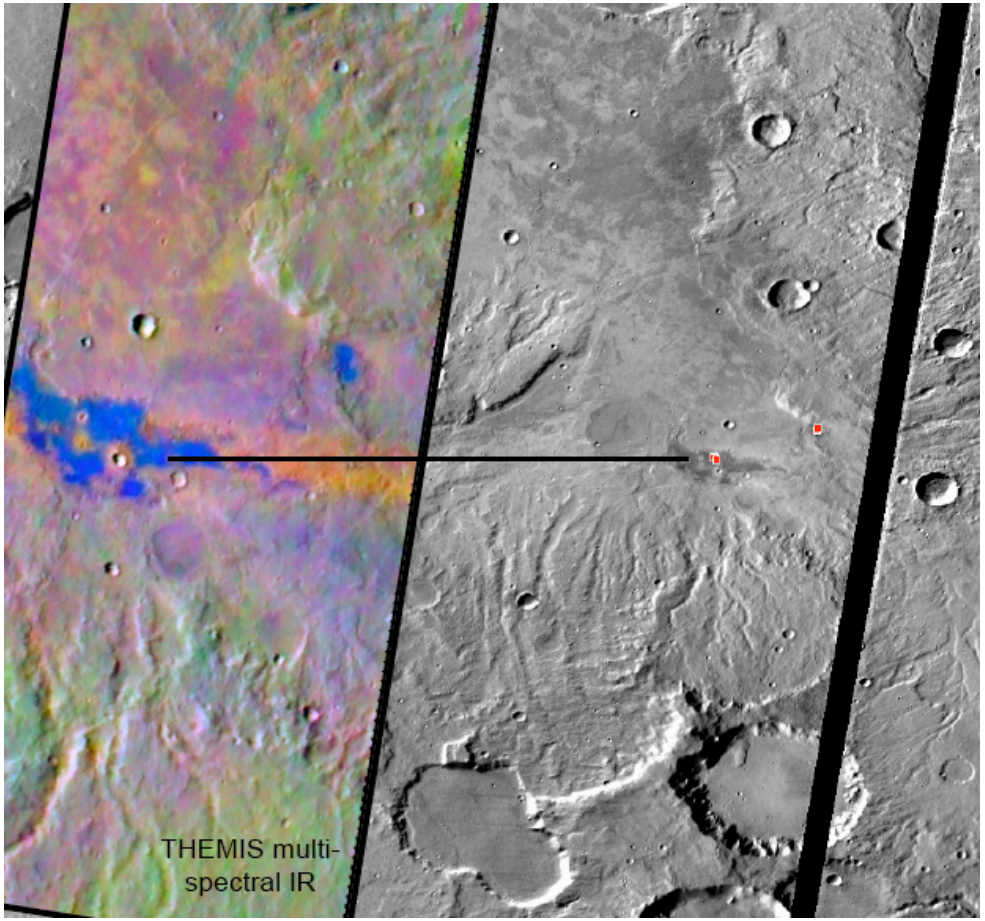


4. Glowing Terrain

- Occurrence
  - ~250 exposures in Noachian highlands
- Composition
  - "Blue" spectrum of apparent thermal IR emissivity consisent with few geologic materials
  - Chloride is the best candidate

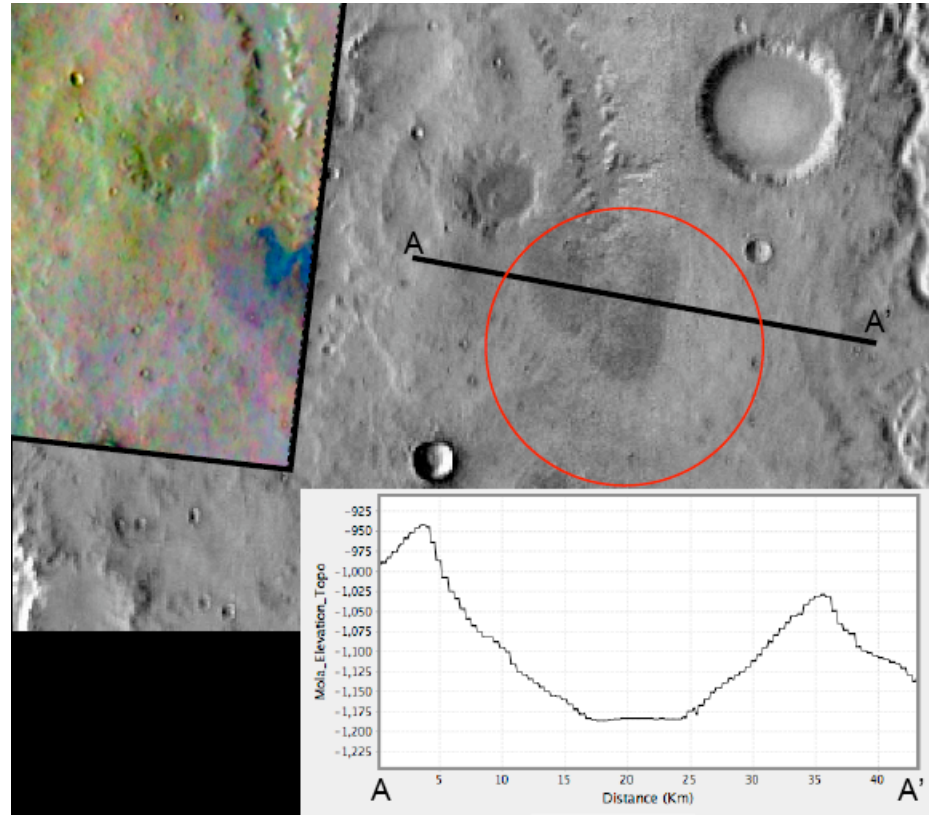


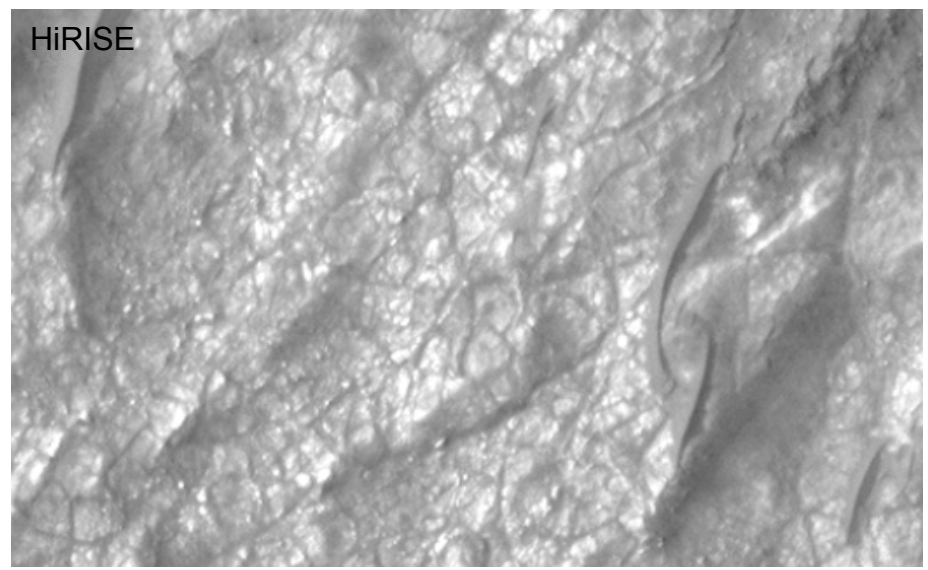




4. Glowing Terrain

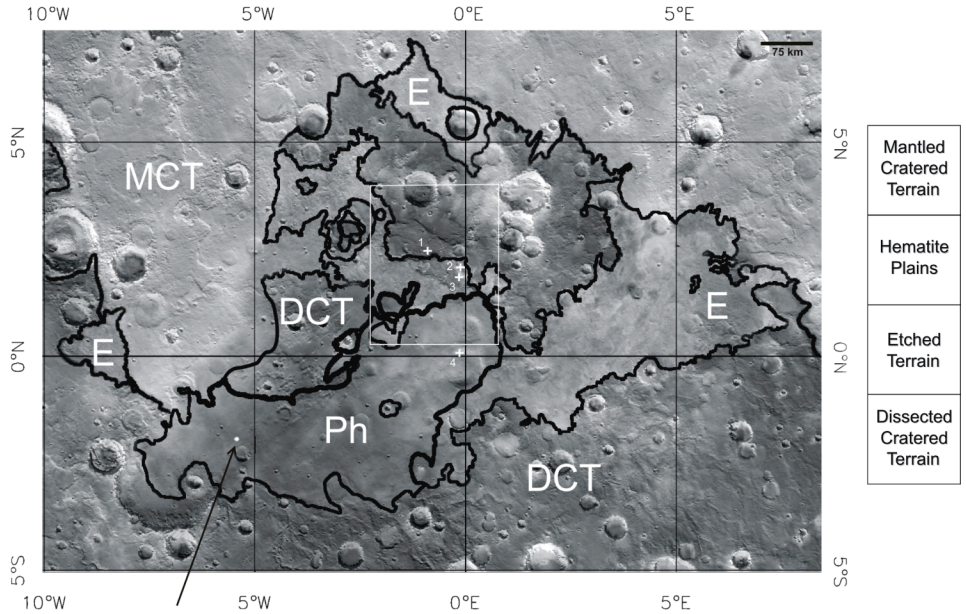
- Morphology
  - Closed basins or topographic lows
  - Light-toned and polygonally fractured
  - Often occurs as exhumed layers
- Possible origins
  - Playas
  - Saline lakes
- Significance to Mars exploration
  - **These meters-thick sequences may be a record of Noachian or later standing water. If confirmed, chlorides have excellent potential to preserve any record of biological activity.**



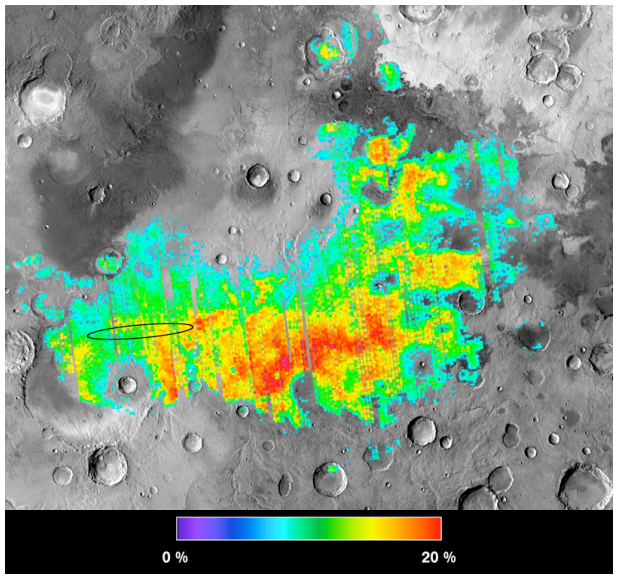


5. Meridiani Layered Deposits

- Occurrence
  - Late Noachian etched terrain and related hematite-bearing plains in Terra Meridiani
- Morphology
  - Layered materials superposed unconformably on older cratered terrain
  - Extensive eolian erosion but little large-scale internal deformation (folds, faults, etc.)

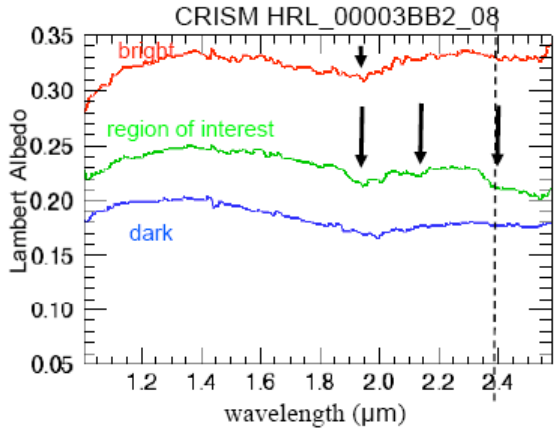


Gray hematite distribution map

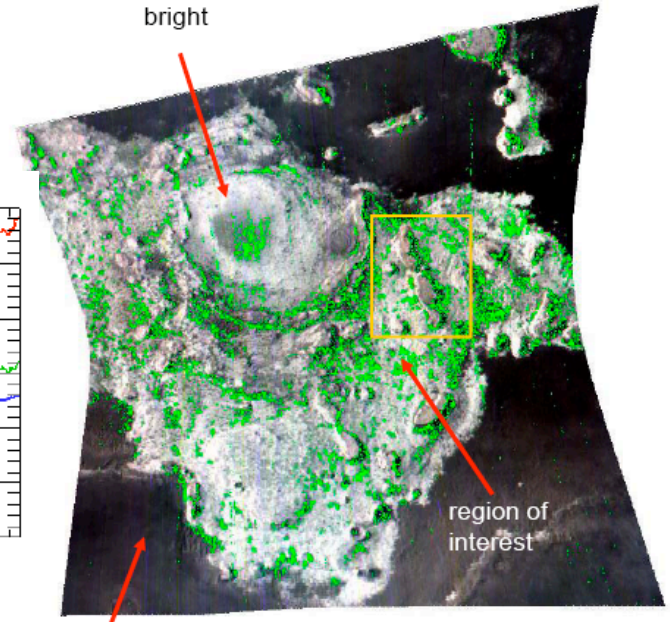


5. Meridiani Layered Deposits

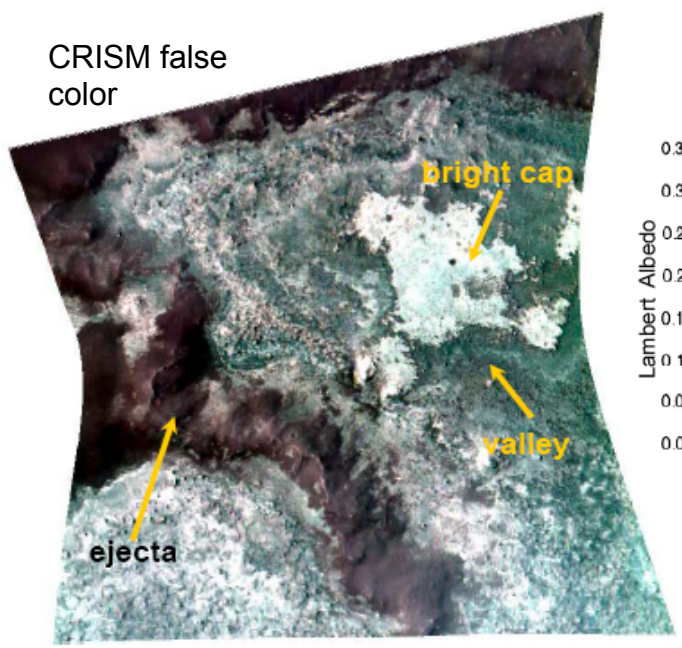
- Composition
  - TES found gray hematite-bearing layer, suggesting aqueous activity
  - OMEGA, CRISM later found layers of poly- and monohydrated sulfates
  - Vertically stratified composition or differences in exposure at optical surface
- Genetic mechanisms
  - Deposition in shallow acidic, saline surface water
  - Fluvial and eolian modification
  - Diagenesis by rising groundwater

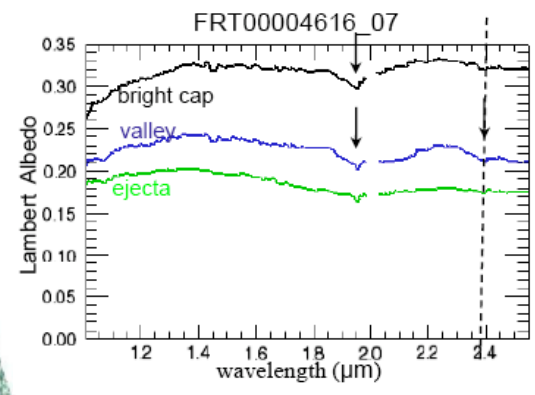


Layers with polyhydrated sulfate



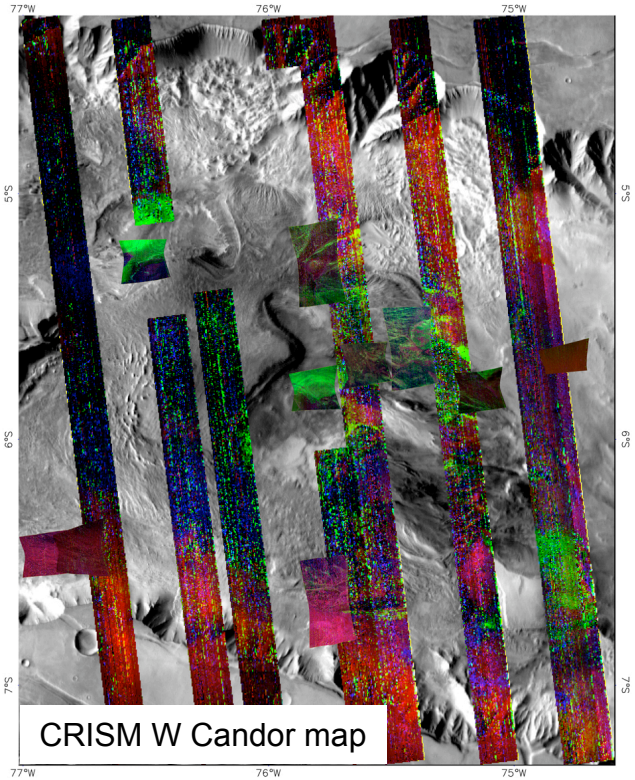
CRISM false color





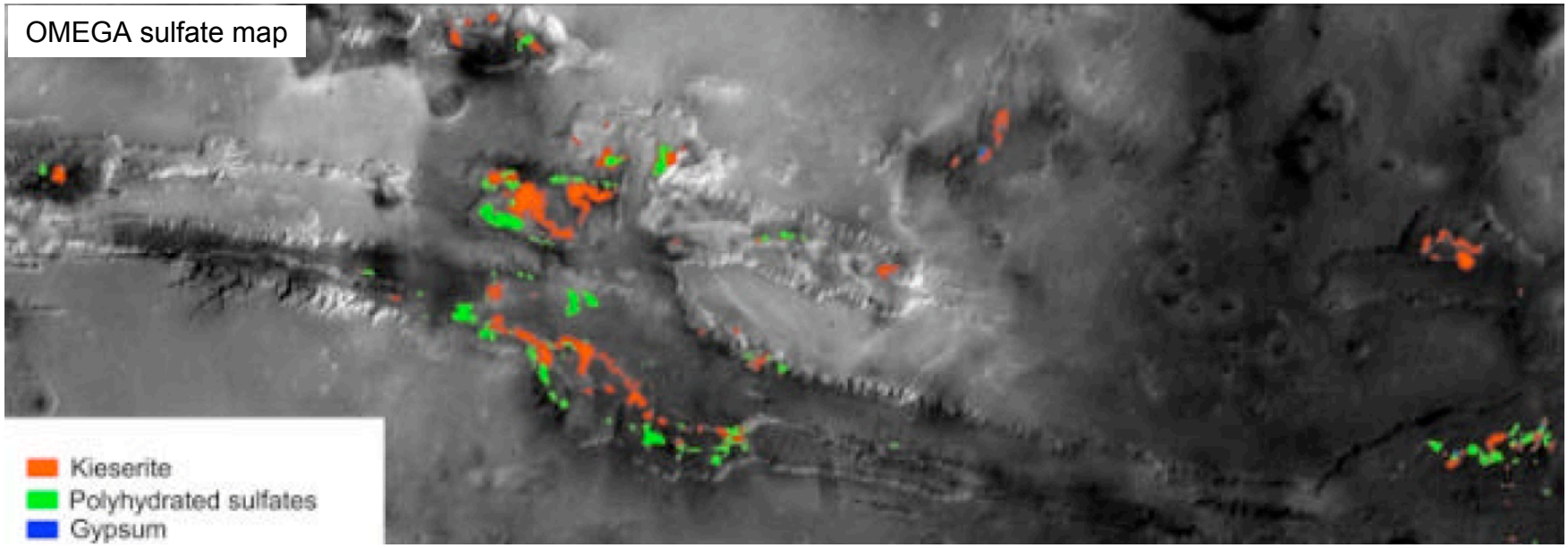
Layers with monohydrated sulfate

6. Valles Layered Deposits



CRISM W Candor map

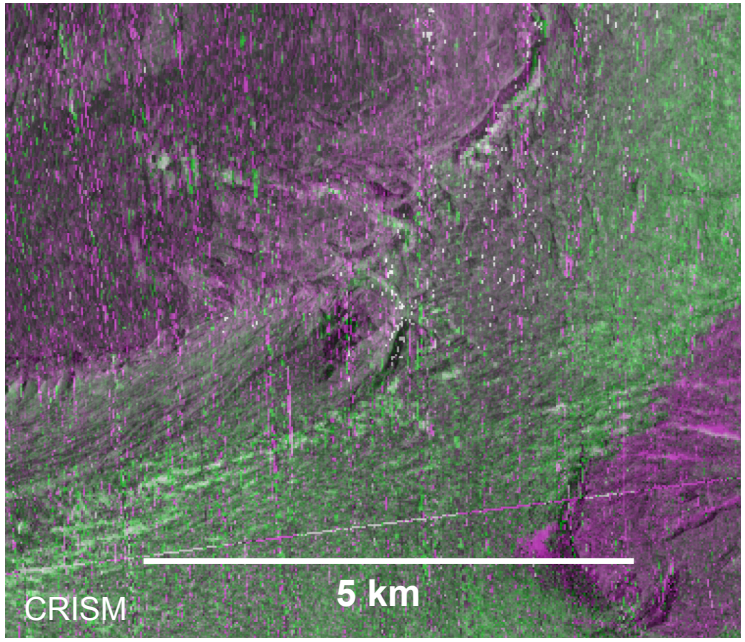
- Occurrence
  - Interior layered deposits of Valles Marineris
- Composition
  - Mono- and polyhydrated sulfates, gypsum
  - Different sulfates occur in discrete layers
  - Associated with gray hematite
  - Red Fe oxide (probably hematite) in erosional debris



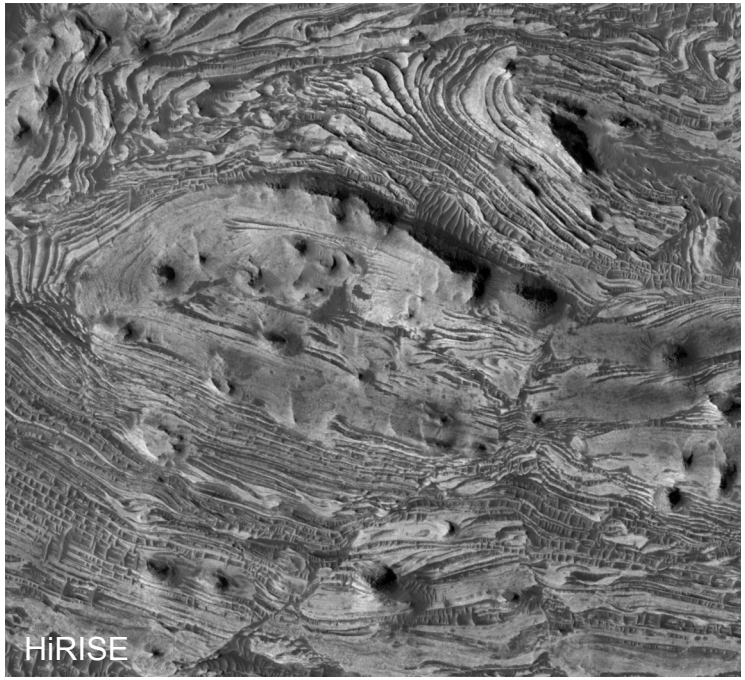
OMEGA sulfate map

6. Valles Layered Deposits

- Morphology
  - Interbedded differentially erodible layers
  - Different sulfates appear segregated into layers with different erosion resistance
  - Folding suggests ductile deformation
  - Alteration along fracture zones suggests fluid flow through fractures
- Possible genetic mechanisms (may be different in different chasmata)
  - Layered materials:
    - Airfall sedimentation into standing water
    - Alluvial deposits
    - Pyroclastic materials
    - Chemical precipitates
  - Diagenesis:
    - Groundwater alteration
    - Phase changes at eroded surfaces
- Significance to Mars exploration
  - **The best evidence for long-lived Hesperian surface water. Understanding interlayer variations will provide crucial insight into this environment**.



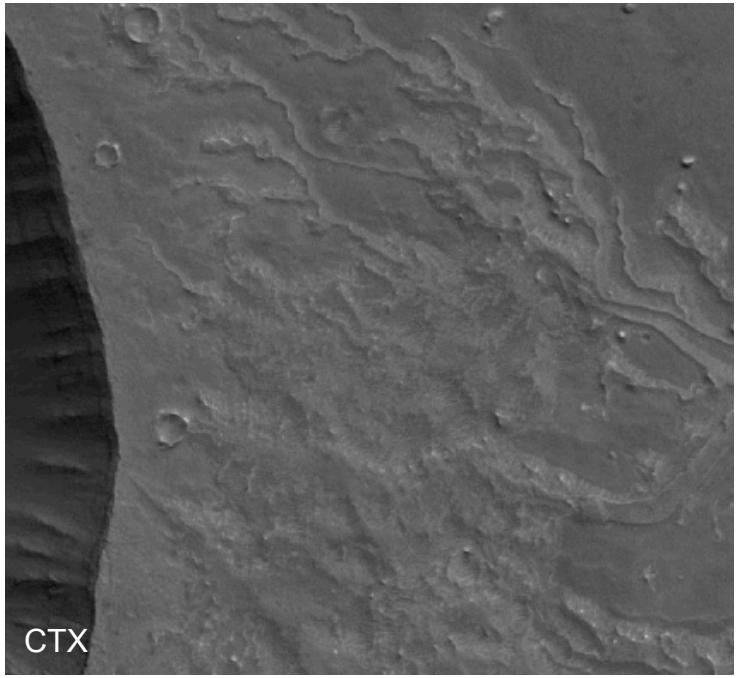
Magenta= polyhydrate, green= monohydrate

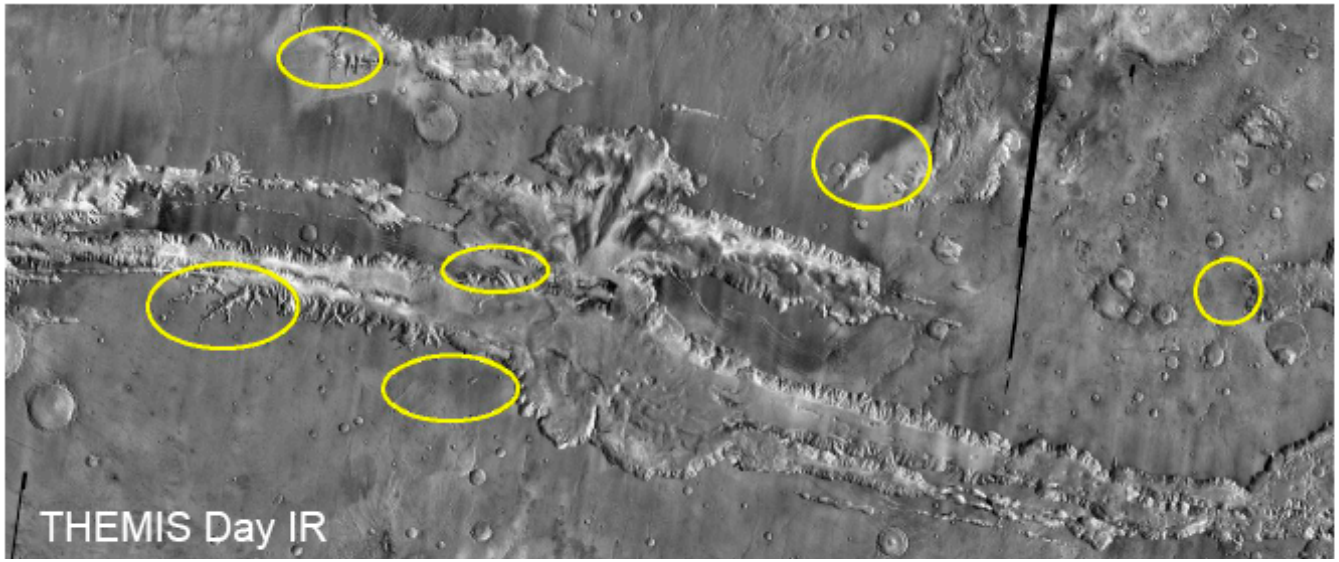


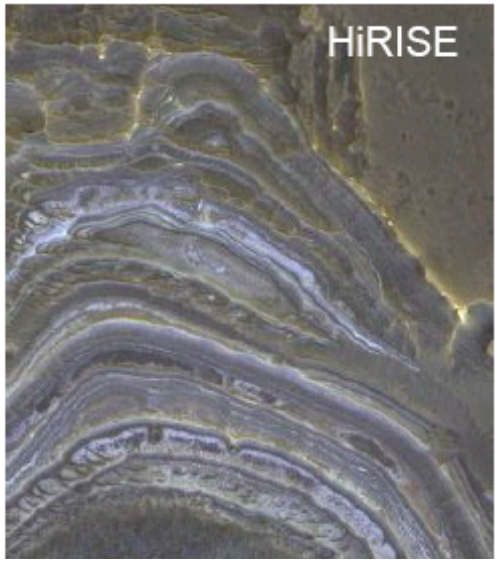
1.57 km

7. Siliceous Layered Deposits

- Occurrence
  - On Hesperian-aged plains around Valles Marineris
  - Distinct from interior layered deposits
- Morphology
  - Light-toned layered deposits on Hesperian plains
  - Unconformably overlain on older craters
  - Eroded into yardangs
  - Some occurrences exhibit inverted channels
  - Silica, jarosite in discrete layers

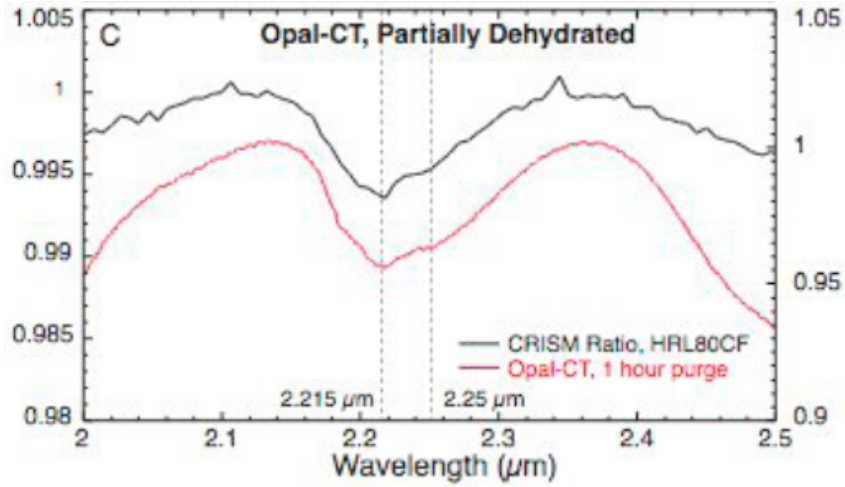


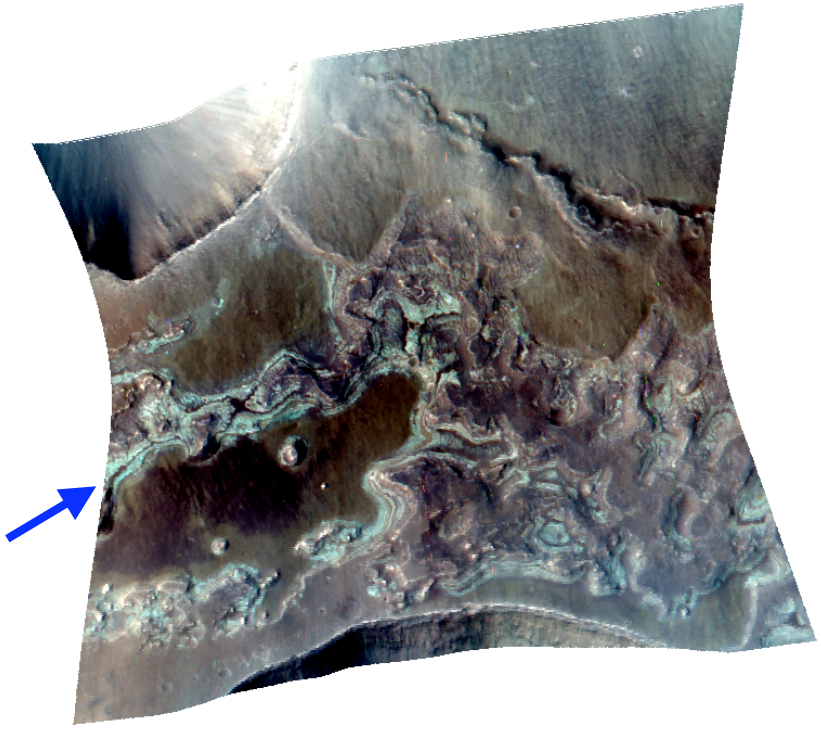




7. Siliceous Layered Deposits

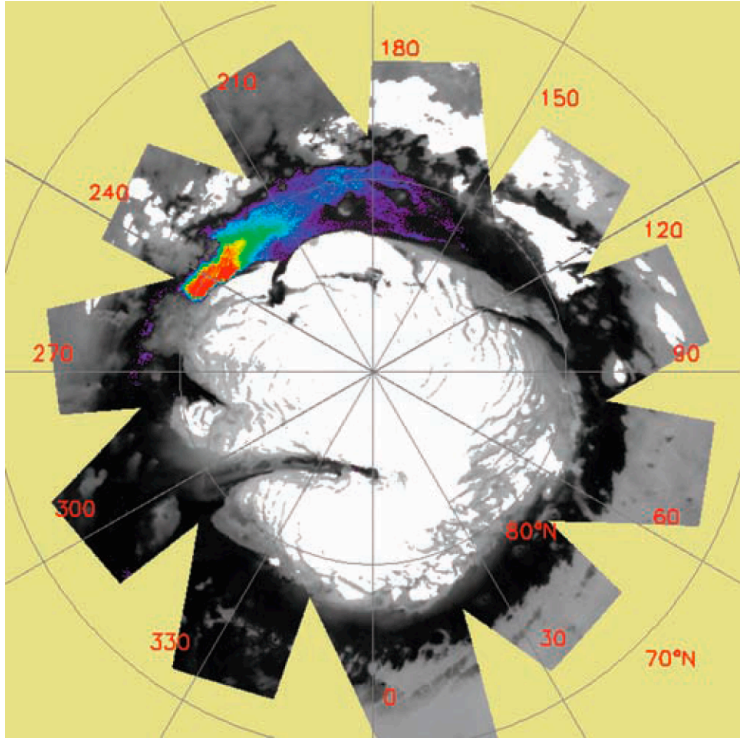
- Composition
  - IR spectral show bands due to hydrated and hydroylated silica (opal)
  - Close spatial association with jarosite (1st identification from orbit!)
- Possible origins
  - Alteration of volcanic ash
  - Acid weathering of ash or lava flows
  - Sedimentary precipates in fluvial, lacustrine, or alluvial environment
- Significance to Mars exploration
  - **This newly recognized class of aqueous deposits has high potential to entomb a fossil record (i.e. silica), and its age extends the temporal and spatial range of possible biological habitats**

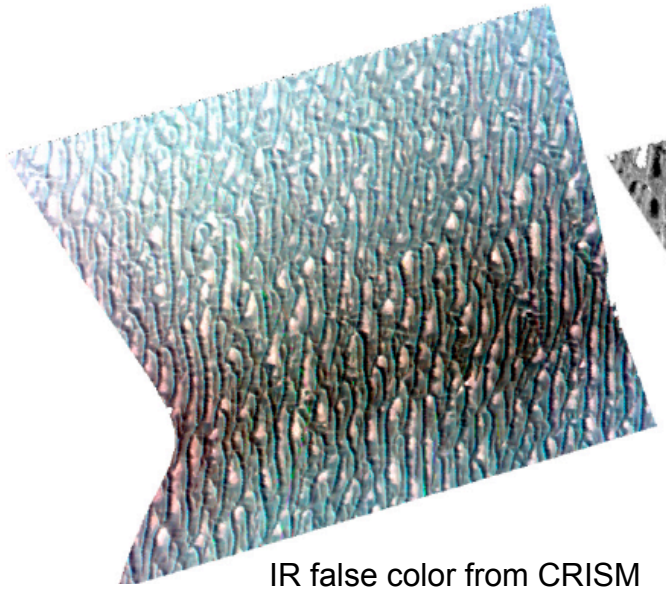




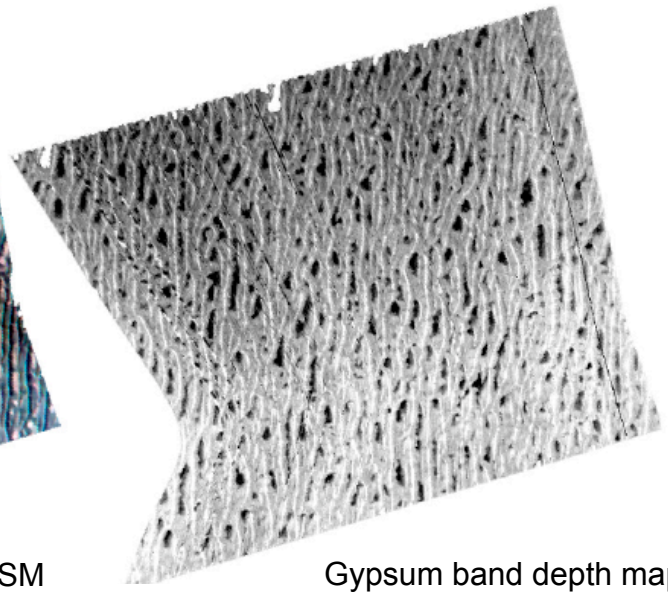
8. Gypsum Plains

- Occurrence
  - Amazonian-aged north polar dunes
- Composition
  - Strong NIR spectral signature of gypsum
  - Spectral modeling indicates abundances at optical surface sometimes >30%
- Morphology
  - High gypsum abundances in dunes, lesser in inter-dune bright materials
  - Highest abundance at dune crests suggests eolian redistribution / concentration



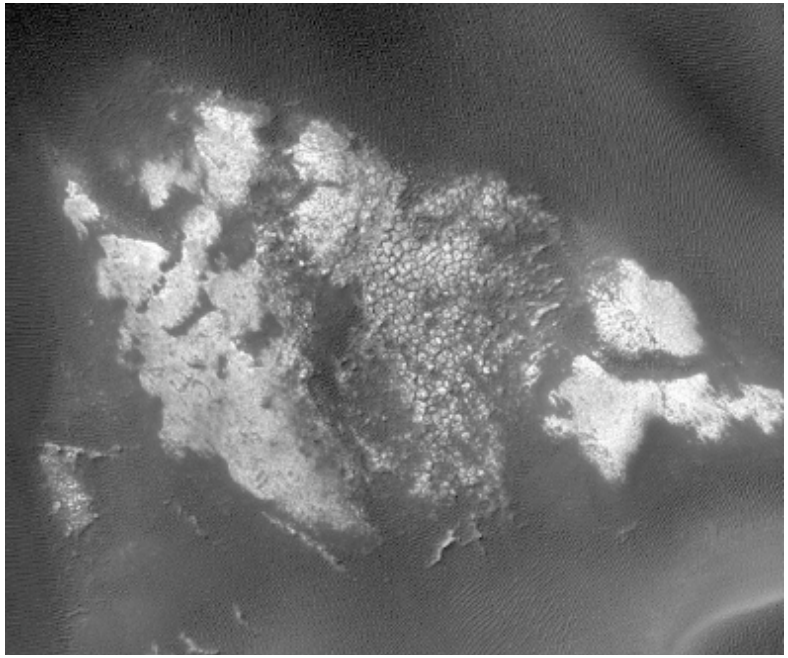


IR false color from CRISM

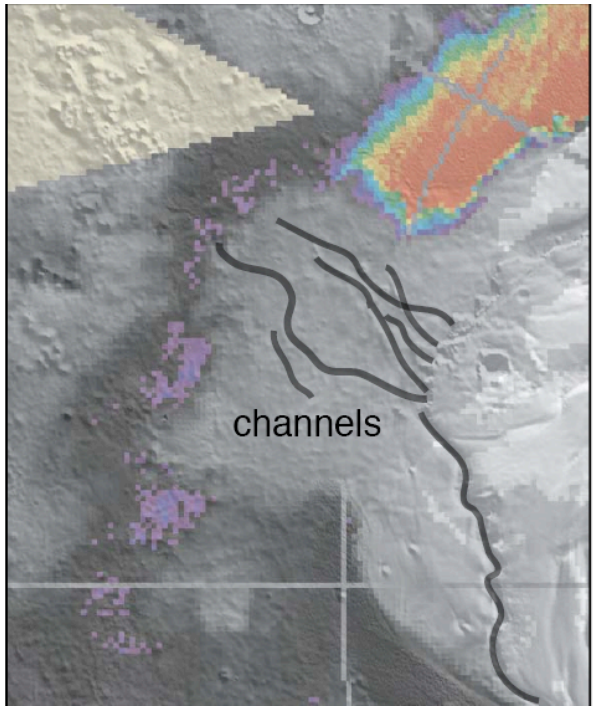


Gypsum band depth map

- Morphology (cont'd)
  - Polygonally fractured light materials and dark sands analogous to N polar basal unit; paleopolar deposit?
- Possible origins
  - Gypsum:
    - Precipitated from outflow of basal melting
    - In situ alteration of dune by outflow of basal melting
    - Precipitated during melting of paleopolar cap
    - In situ alteration during melting of paleopolar cap
  - High abundances
    - Representative of the dunes
    - An effect of eolian sorting
- Significance to Mars exploration
  - **This youngest aqueous mineral deposit provides information on possible habitats younger than 3 Ga.**



HiRISE image



Summary

- Orbital reconnaissance from MGS, Odyssey, MEx, and MRO has been spectacularly successful in finding deposits with evidence of past water

- Orbital missions have identified at least 8 different types of deposits having aqueous mineralogy that could preserve fossil evidence of past biology or pre-biotic compounds

- A Mars sample return mission can provide detailed information on at least one of these past environments