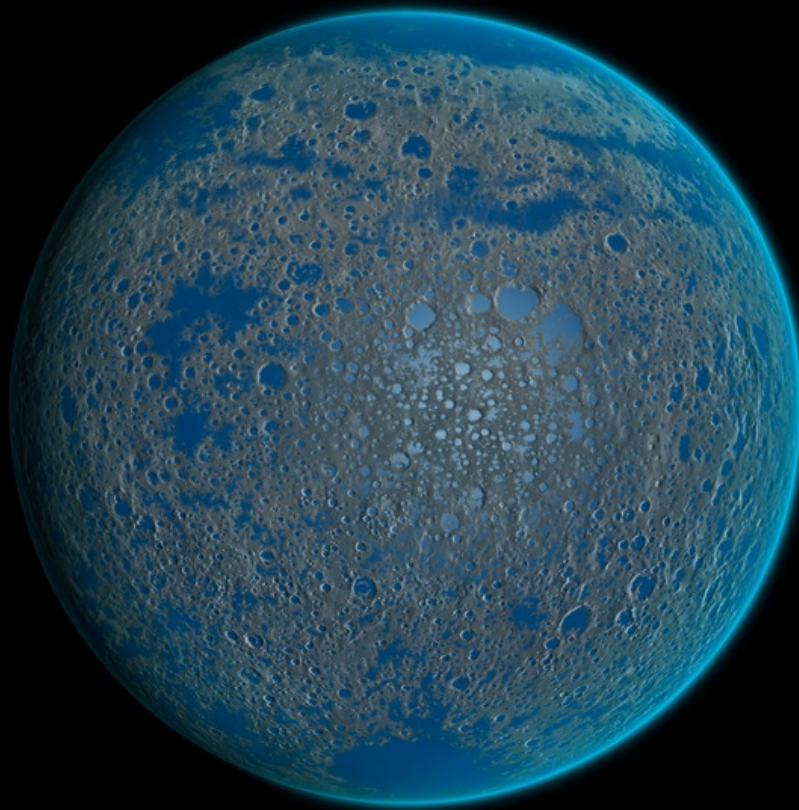


Mawrth Vallis

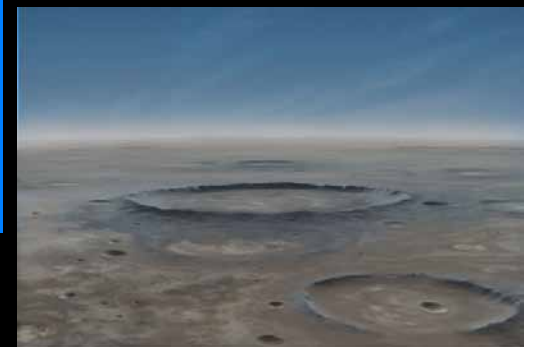
preserving the

Introduction: Overview of the MSL Landing Site
at Mawrth Vallis

origins



J. Michalski, J-P. Bibring, J. Bishop, J. Carter, B. Ehlmann,
D. Loizeau, N. Mangold, N. McKeown, J. Mustard,
E. Noe Dobrea, M. Parente, F. Poulet, J. Wray



and Past Aquatic
at Mawrth Vallis, Mars

Evidence for a sedimentary origin of clay minerals in the Mawrth Vallis region of Mars

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Abstract: The Mawrth Vallis region of Mars is a prominent feature of the northern plains. It is a large, low-lying area with a complex topography. The region is characterized by a variety of mineralogical features, including clay minerals. The clay minerals are found in a variety of forms, including as small grains, as larger aggregates, and as thin layers. The clay minerals are found in a variety of locations, including in the walls of the valley, in the floor of the valley, and in the surrounding plains. The clay minerals are found in a variety of colors, including red, brown, and white. The clay minerals are found in a variety of sizes, including small grains, larger aggregates, and thin layers. The clay minerals are found in a variety of shapes, including rounded grains, angular grains, and thin layers. The clay minerals are found in a variety of textures, including smooth, rough, and crystalline. The clay minerals are found in a variety of orientations, including horizontal, vertical, and diagonal. The clay minerals are found in a variety of depths, including near the surface, in the middle of the valley, and in the surrounding plains. The clay minerals are found in a variety of ages, including recent, intermediate, and ancient. The clay minerals are found in a variety of environments, including arid, semi-arid, and sub-arid. The clay minerals are found in a variety of climates, including hot, warm, and cool. The clay minerals are found in a variety of seasons, including spring, summer, autumn, and winter. The clay minerals are found in a variety of times of day, including morning, afternoon, and evening. The clay minerals are found in a variety of places, including the Mawrth Vallis region of Mars, the northern plains of Mars, and the surrounding areas. The clay minerals are found in a variety of ways, including by wind, by water, and by other means. The clay minerals are found in a variety of places, including the Mawrth Vallis region of Mars, the northern plains of Mars, and the surrounding areas. The clay minerals are found in a variety of ways, including by wind, by water, and by other means.

ABSTRACT
Clay minerals detected spectroscopically in the Mawrth Vallis region of Mars are complex, layered, thick (>600 m) stratigraphic sections of well-sorted, clay-bearing rocks are lithologically and mineralogically distinct from the significant internal layering and complexly diverse mineralogy of the host rocks to which they were deposited, or suggest that the host rocks were deposited in a different environment.

Keywords: Mars, clay minerals, alteration, weathering, sediments, astrobiology

LETTERS

Hydrated silicate minerals on Mars observed by the
Reconnaissance Orbiter CRISM instrument

Mars Reconnaissance Orbiter J. F. Mustard¹, S. L. Murchie², S. M. Pelkey³, B. L. Ehlmann⁴, R. S. Wiseman⁵, K. Ureskog⁶, A. Knudsen⁷, J. Bishop⁸, E. Noe Dobra⁹, L. Roach¹⁰, F. Seelos¹¹, R. E. Arvidson¹², S. Des Marais¹³, N. Tezberg¹⁴, A. Knudson¹⁵, E. Malaret¹⁶, J. A. McGovern¹⁷, K. Seelos¹⁸, T. Clancy¹⁹, R. Clark²⁰, D. Des Marais²¹, N. Tezberg²², T. Roush²³, M. Smith²⁴, G. Swayze²⁵, H. Taylor²⁶, Y. Langevin²⁷, T. Martin²⁸, P. McGuire²⁹, R. Morris³⁰, M. Robinson³¹, T. Roush³², M. Smith³³, G. Swayze³⁴, H. Taylor³⁵, T. Tilley³⁶ & M. Wolff³⁷

[illegible]

Hyperthermia. Images of the impact Reconnaissance Orbiter Mars (CRISM) (2, 3) exhibit a variety of minerals in the visible/near-infrared (VNIR: 0.4 – 4 μ m) that are attributed to phyllosilicates and are consistent with observations of this area made by the Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité (OMEGA) instrument on Mars Express (3–5). OMEGA detected the presence of montmorillonite and Fe-OH absorption bands at 1.9 and 2.1 μ m, respectively (4, 6). The presence of Fe-Mg phyllosilicates in a few of the samples was also detected by the Mars Exploration Rover (MER) instrument, the Alpha Particle X-ray Spectrometer (APXS), which revealed the presence of Fe and Mg in the samples (7).

**Vallis region, Mars
and implications**

Received 14 November 2008; revised 21 May 2009; accepted 22 July 2009.

[illegible]

... Characterization of phyllosilicates observed in the central Maestrazgo region, Man...

Mars Surface Diversity as Revealed by the OMEGA/Mars Express Observations

[illegible]

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[E-mail: td@gauss.u-psud.fr]
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www.sciencemag.org

Phyllosilicates on Mars and implications for early martian climate

The recent identification of large deposits of sulphates by remote sensing and *in situ* observations has been considered evidence of the past presence of liquid water on Mars. Here we report the unambiguous detection of diverse phyllosilicates, a family of aqueous alteration products, on the basis of observations by the OMEGA imaging spectrometer aboard the Mars Express spacecraft. These minerals are associated with Noachian outcrops, which is consistent with a hydrological cycle, sustaining the long-term contact of igneous rocks with liquid water. We infer main families of hydrated alteration products detected—phyllosilicates and sulphates—result from different processes. These occurred during two distinct climatic episodes: an early Noachian Mars, resulting in the hydrated silicates, followed by a more acidic environment, in which sulphates formed.

of hydrated minerals on Mars provides a second, independent process. Hydrated sulphates have been observed with O (Observatoire pour la Minéralogie, l'États, les Glaces et l'Environnement) on board the European Space Agency (ESA) mission, in numerous light-toned layered deposits in Meris, Azam Chaos, and Terra Meridiani¹ and in deposits in the north polar cap². Observations in Terra Meridiani identify a range of a variety of sulphates in layered rocks also in active hydrologic system to account for these deposits.

The presence of phyllosilicates on Mars has been previously suggested on the basis of *in situ* elemental analyses of the Viking Landers¹, the identification of smectites in some SNC (Shergottite-Nakhchivan-Chassigny) meteorites², and remote sensing infrared observations³. An unambiguous detection of water-bearing phyllosilicates has been reported over large areas⁴. Here we present an overview of the detection of phyllosilicates made by OMEGA, as we discuss their geological context inferred from analyses of imaging data. Phyllosilicates represent a very specific family of highly abun-


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ABSTRACT

The region surrounding the Masrith Valley outflowing diverse phosphatic minerals in the channel floor, phosphatic minerals.

...the more complex aqueous chemistry than previously inferred from proposed models of martian geochemical evolution with

RESEARCH ARTICLES
Aqueous

Global Mineralogical and Petrological Data Derived from the OMEGA Database

OMEGA/Mars Express

[illegible]

The earliest observations of Mars by spacecraft showed that water had substantial emission of thermal energy, and channeled and accumulated material in the form of rivers and oceans.

(1) However, fundamental questions remain. Was water-driven activity on its surface transient or persistent, the latter being a prerequisite for any habitable surface environments?

PHYSICAL RESEARCH LETTERS, VOL. 35, L1220*

Compositional stratigraphy
Mawrth Vallis, Mars
J. J. Wray,¹ B. L. E.

red outcrops in and around the
features diagnostic of the
McRitchie smectite
mineral zone.

[illegible]

possible the suggested that these deposits may have a volcanic origin (Loizeux et al., 2007). Alternatively, Mawth (MRO) in this study, we use Mars P sites, all of which are layered silicates. The HIRSE, proving, would be bearing the

2. **Compositional Stratigraphy**
[5] The spatial and temporal relationships between the layers are well suited to the infrared and Raman spectroscopy techniques.

the 25–32 cm-pixel images of composition, *et al.*, 2007]. Dorens observations (~18

CRISM camera [46] to identify the geographic relationships among the images and CRISM targeted at 30 m/pixel) of the $\sim 300 \times 400$ km

JOURNAL OF GEOPHYSICAL RESEARCH

osilicates in the Mawrth Vall...

Mars Express has discovered large outcrops of volcanic rocks in the northern region of Mars

cuts the unit of 2.5°N). The region is rich in phyllosilicates in the full surface from 0.9 μm to 2.6 μm . We have examined this region with full coverage of the highlands. OMEGA has spatial resolution of 1 μm and 2.2 μm , revealing the presence of phyllosilicates. These observations have been identified by the presence of spatially associated iron minerals. The OMEGA data show the presence of iron minerals in the highlands, which is consistent with the presence of iron minerals in the highlands.

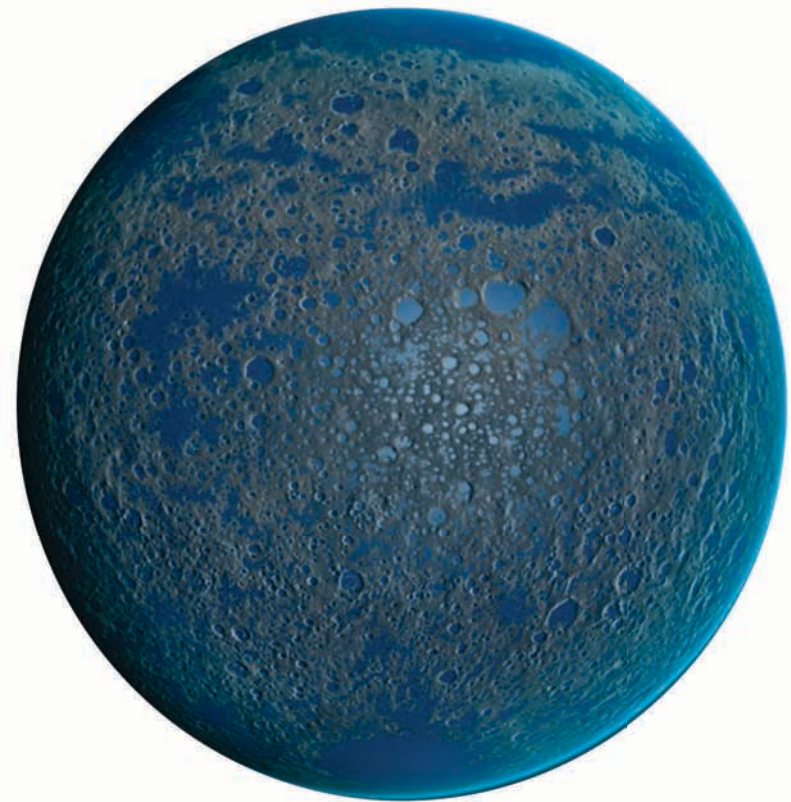
Secondary absorption bands at 1.4 μm , 1.9 μm , and 2.1 μm are characteristic of Fe- and Mg-OH minerals. The bright-orange areas on visible HRSC images such as nontronite-rich areas, mostly on the plateau, correspond to the phyllosilicate-rich areas. The brown residual buttes correspond to the silicate-rich areas.

...ity of 300 km \times 400 km. This unit implies different climatic and geologic environments.

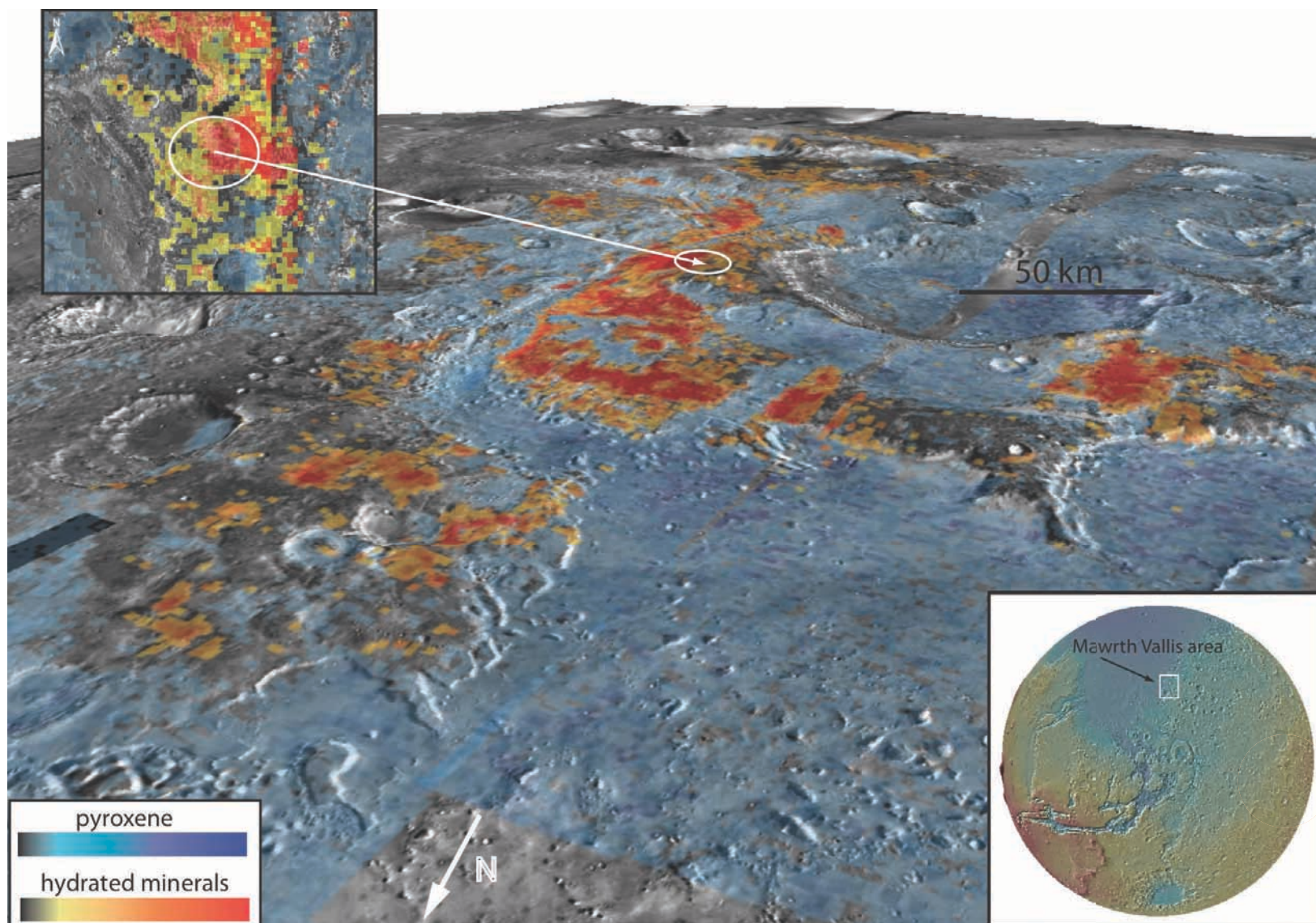
South Vallis region of Mars, *J. Geophys. Res.*, **112**, E08805.

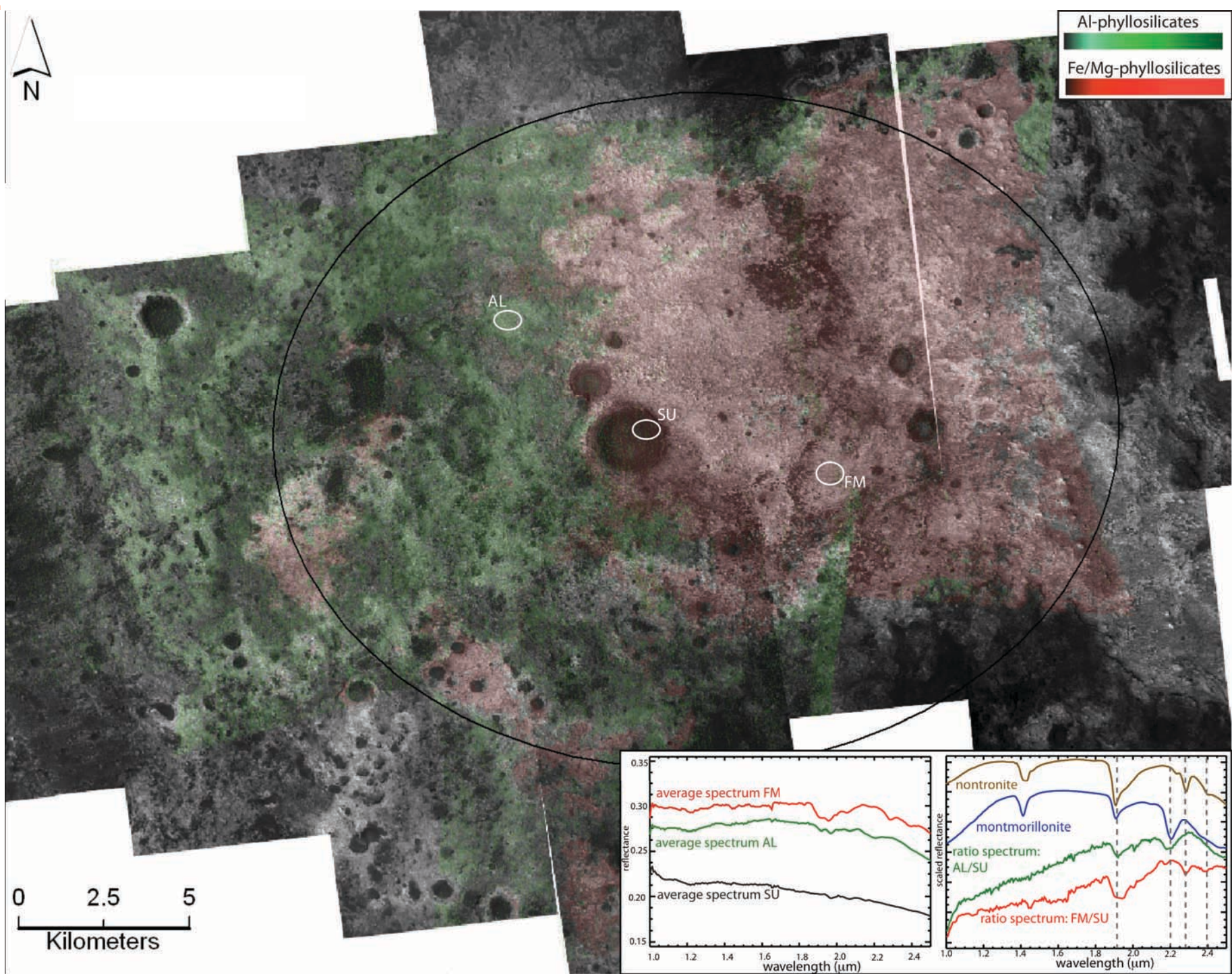
MAWRTH VALLIS FOR MSL: KEY POINTS, UNIQUE CHARACTERISTICS

- **Mineralogically diverse** site, both in the ellipse and in the region
- **Lithologically diverse** site that captures multiple environments
- **Both** in-situ, ancient crustal **bedrock and remobilized sediments**
- **Many** types of science **targets**
- Extremely **ancient section** of rocks probing an enigmatic and important epoch in Solar System history
- Opportunity to **sample rocks** from the deep Noachian up **through the global transition** into the Hesperian



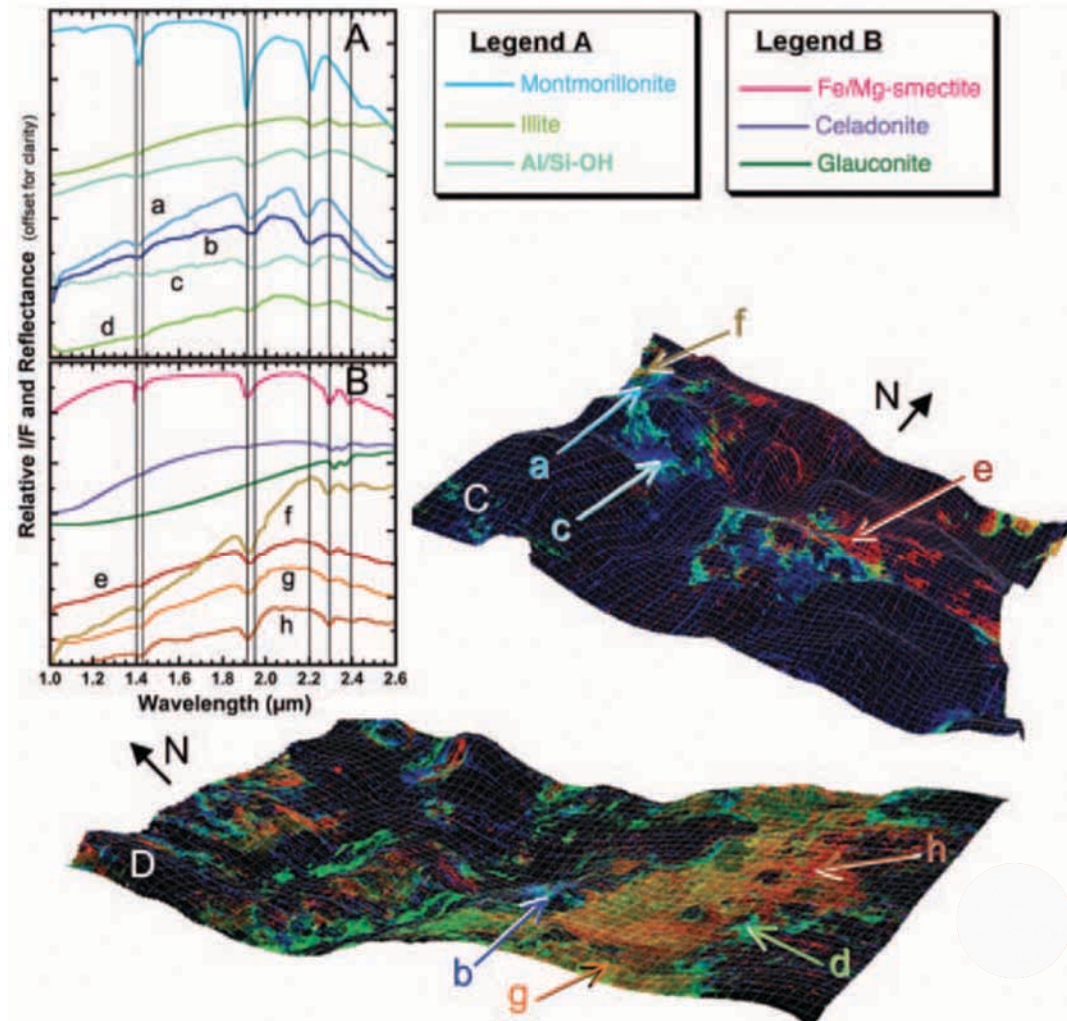
GEOGRAPHIC CONTEXT





MINERALOGICAL DIVERSITY: CHEMICAL GRADIENTS?

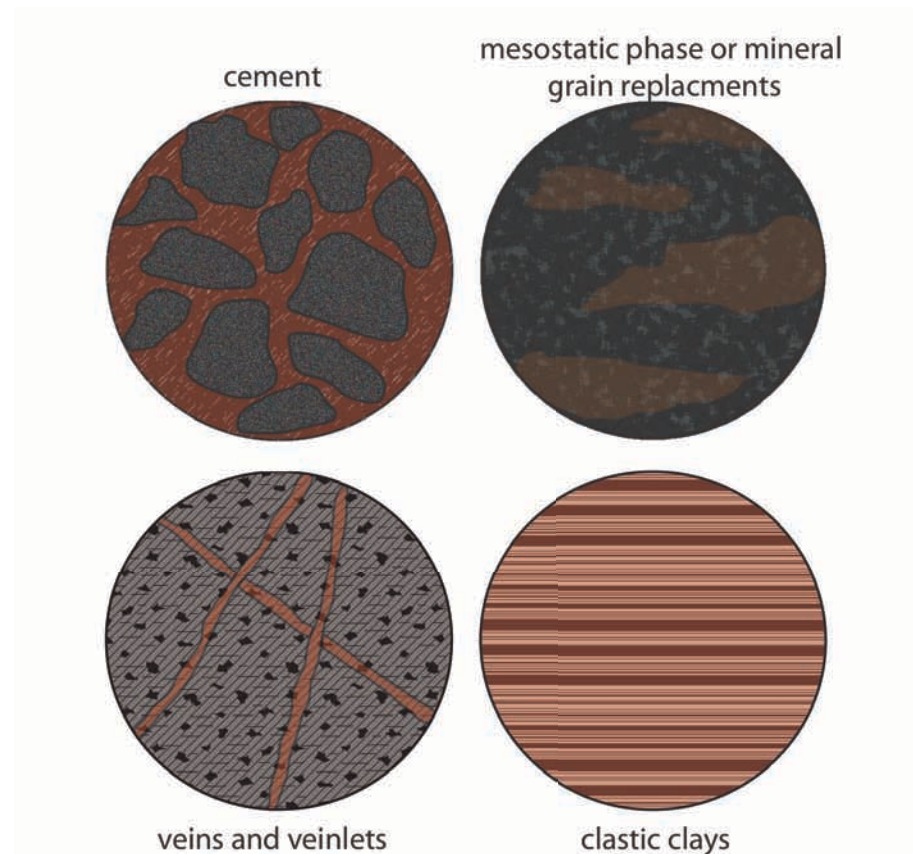
- Follow the minerals:
 - Fe/Mg-smectites
 - Al-smectite
 - Kaolinite
 - Opaline silica
 - Fe²⁺ hydrated phase
 - Sulfates
 - Other hydrated phases
- Diverse mineralogy indicates that we have multiple environments in which to:
 - Search for biomarkers
 - Build a more complete picture of habitable environments at Mars



Bishop et al., Science, 2008

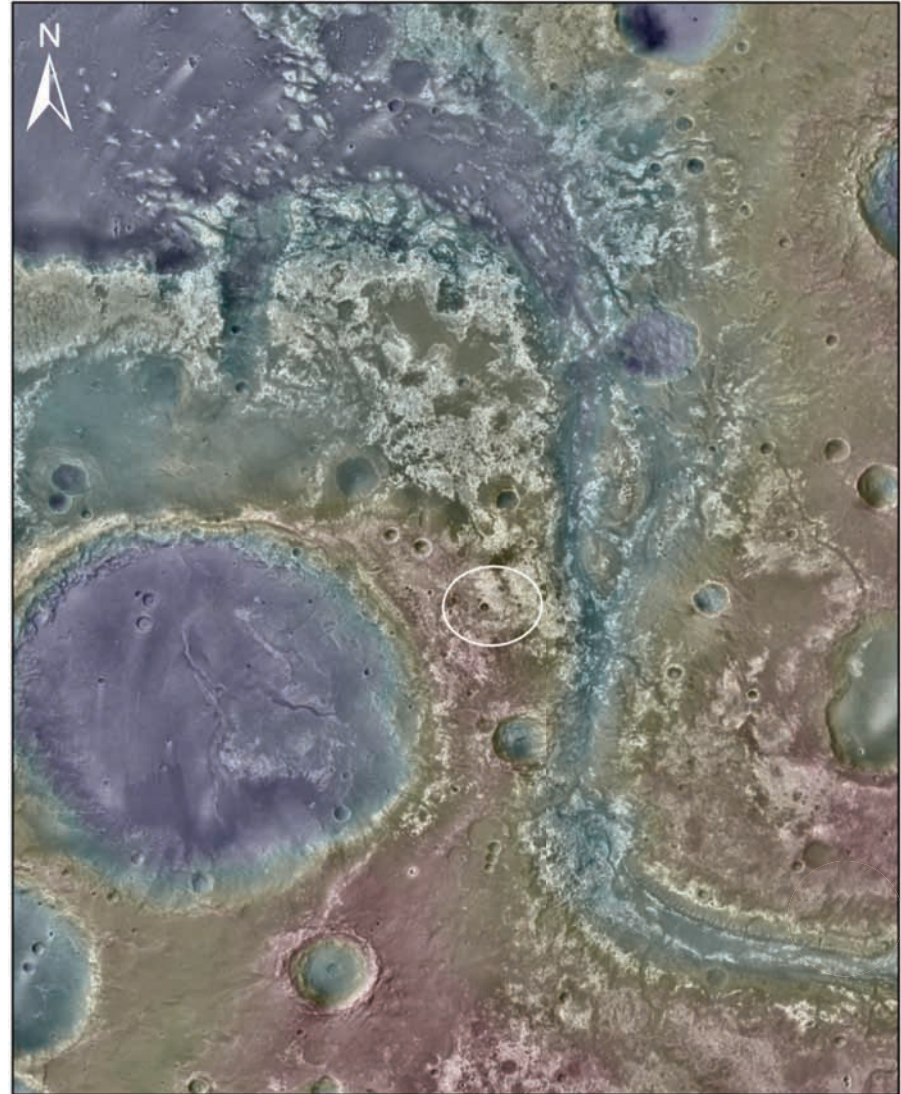
LITHOLOGIC CONTEXT OF MINERALS DETECTED BY INFRARED OBSERVATIONS

- Why type of rocks do the clays occur within?
- Cannot be just one lithology because of the wide range of geomorphology-lithology inferred from images

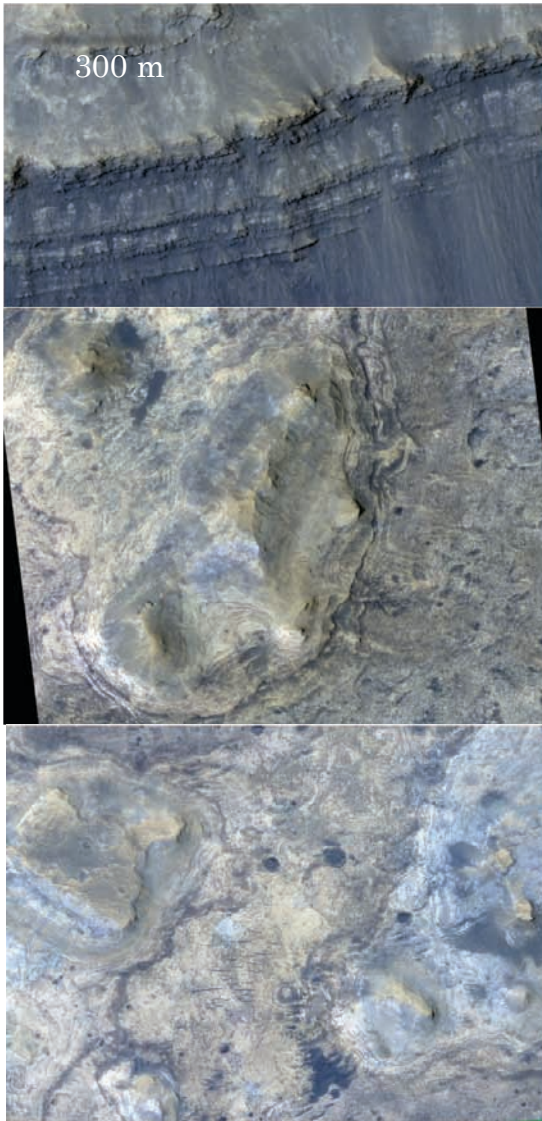


GEOMORPHOLOGY OVERVIEW

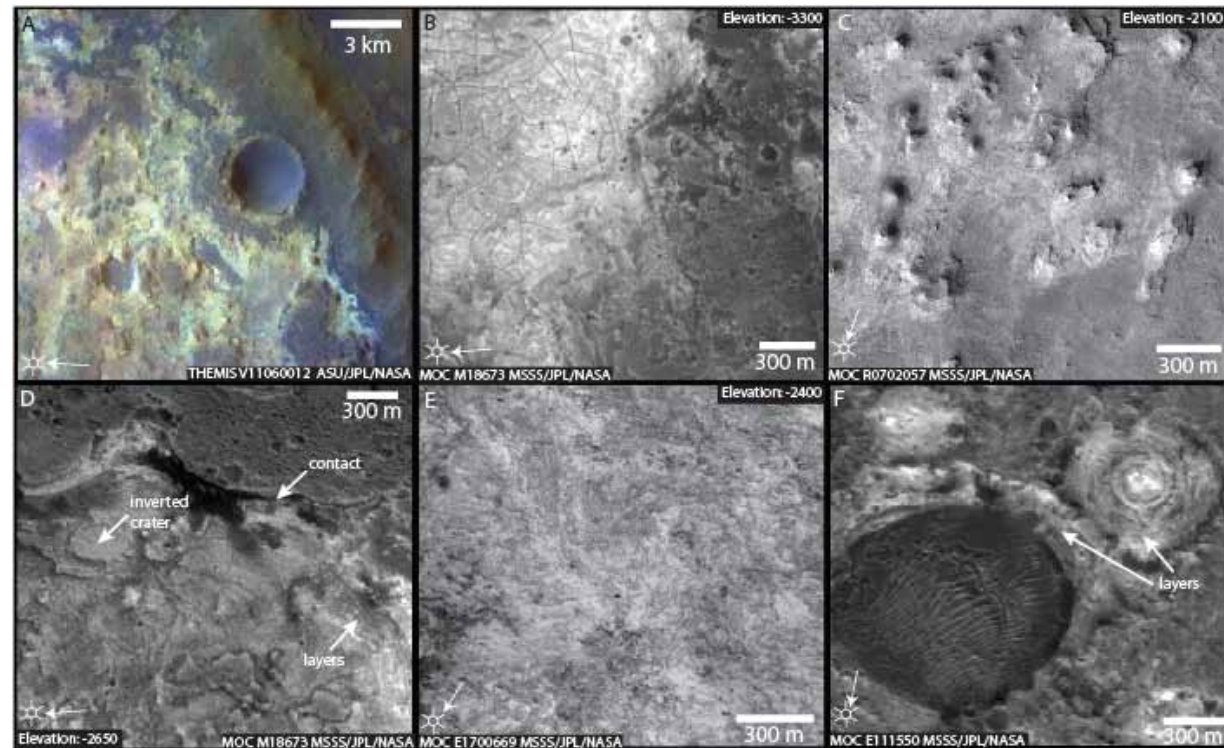
- Layers everywhere
- Many expressions of layered units
- Erosion and redeposition by fluvial and eolian activity



GEOMORPHOLOGY AND LITHOLOGY OF THE CLAY-BEARING ROCKS



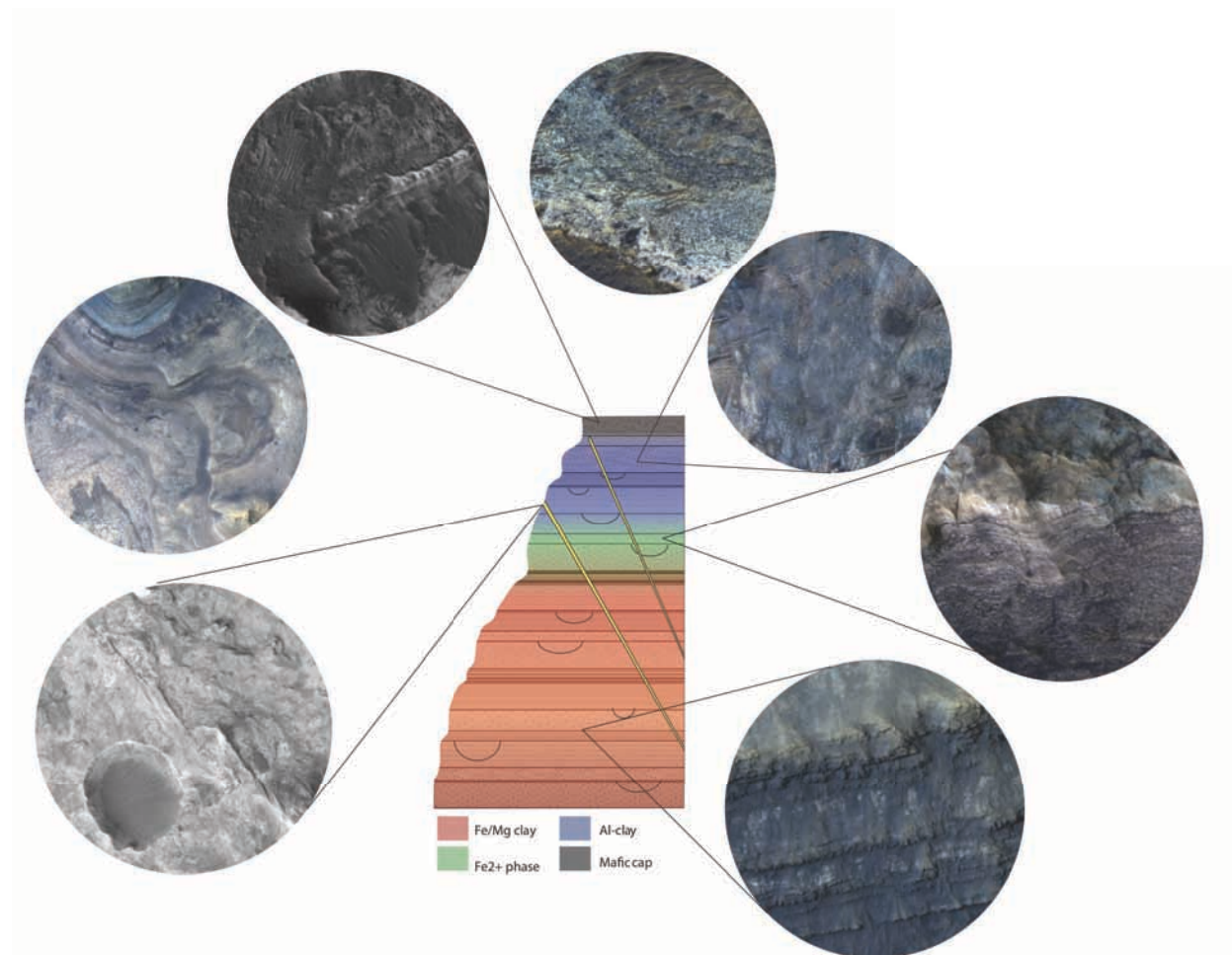
- There are a number of geomorphic expressions that indicate a range of lithologies



Michalski and Noe Dobrea, *Geology*, 2007

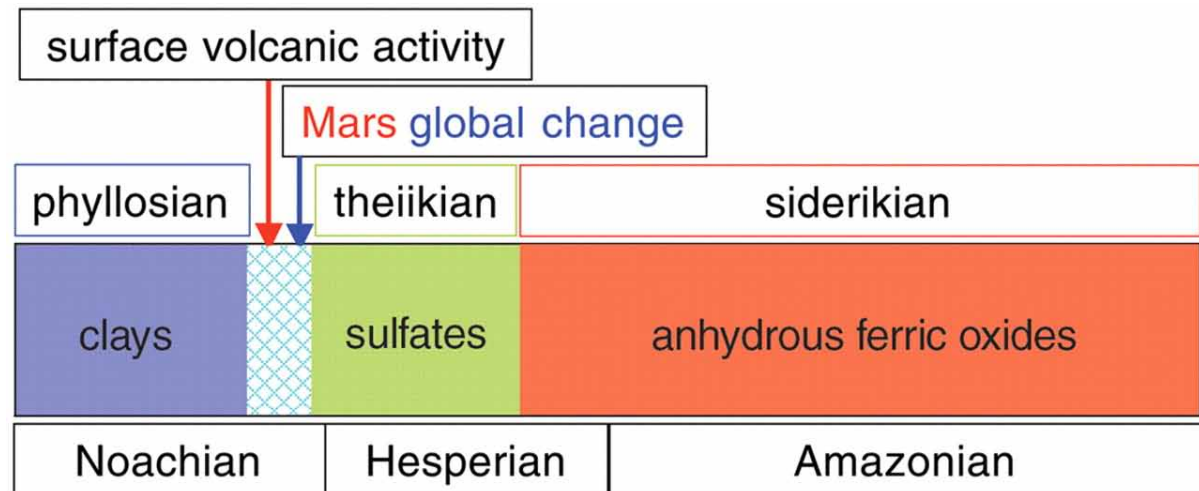
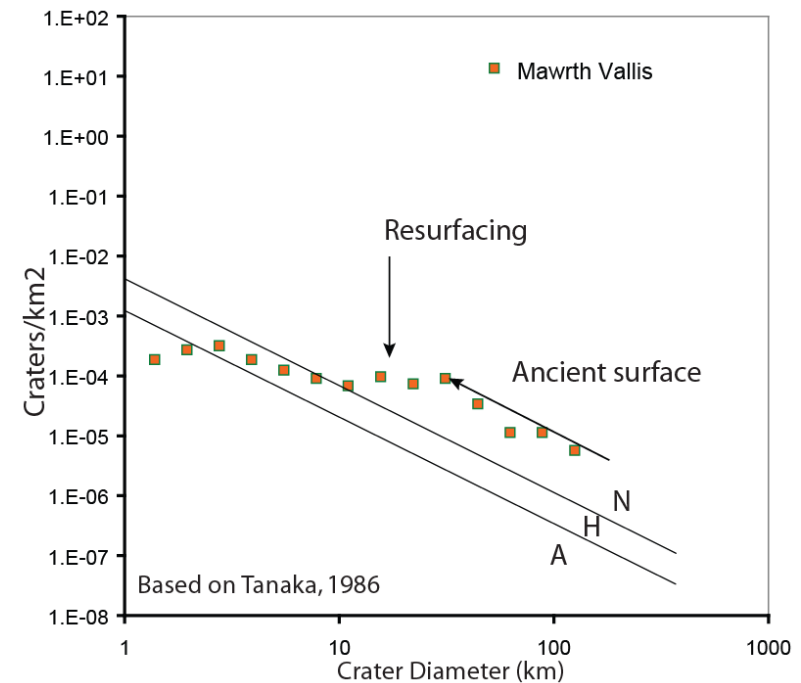
MULTIPLE SCIENCE TARGETS

- Hedge our bets by visiting multiple targets, each with intrinsic merit



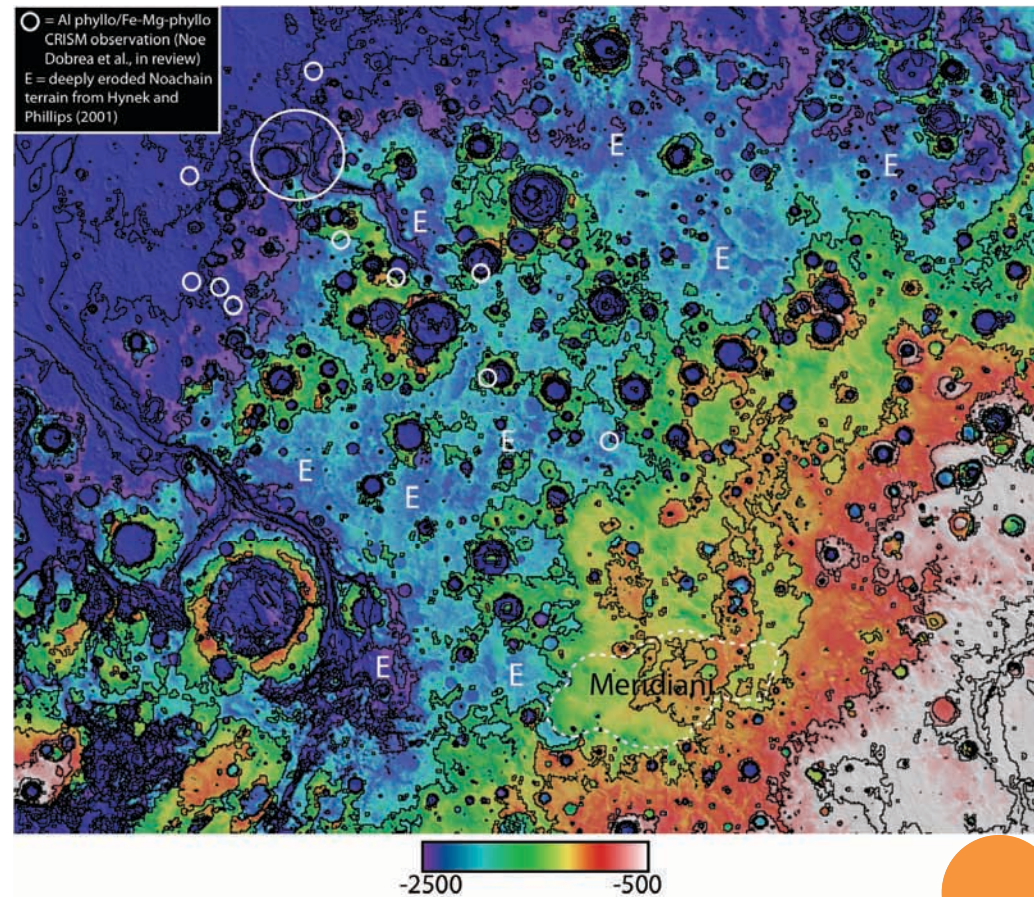
TRAVERSING MARS' AQUEOUS HISTORY

- Ancient, in-situ bedrock
- Younger, reworked, clay-bearing rocks
- Sulfate-bearing rocks
- Hesperian, dark cap unit



WHY DO WE SEE SPECIAL GEOLOGY AT MAWRTH VALLIS?

- Localized environment?
Or
- Unusual erosion of the region?
- Connection to the global picture



TESTABLE HYPOTHESES

Key observables:				
	Source of sediment	Texture and bedding	Composition	Geologic contacts
Volcanic Model	Ash fall	angular glass shards (MAHLI, CheMin), laminated bedding (MastCam, MAHLI)	Mineralogy dominated by glass and secondary phases (APXS, CheMin, ChemCam)	Depositional contact, if in lacustrine system, unconformable contact if on land (MastCam, MAHLI, ChemCam, CheMin, APXS)
	Ash flow	angular glass shards (MAHLI, CheMin), cross bedding related to surge (MastCam, MAHLI)	Mineralogy dominated by glass and secondary phases (APXS, CheMin, ChemCam)	Depositional contact, if in lacustrine system, unconformable contact if on land (MastCam, MAHLI, ChemCam, CheMin, APXS)
	Obliquity driven dust and ice deposits	very fine grained textures (MAHLI), uniquely dust or aggregates of dust	Mineralogy may be dominated by secondary phases, could contain evidence for primary feldspar and pyroxene (CheMin, APXS, ChemCam)	Depositional; composition probably cuts bedding because water source is likely groundwater from ice melt (APXS, ChemCam, MastCam, MAHLI, CheMin)
Sedimentary Model	Eolian silt and sand	rounded sand grains in cross bedded rocks (MastCam, MAHLI)	Abundant primary feldspar, possibly primary oxides (CheMin, APXS, ChemCam)	Depositional, composition follows bedding (APXS, ChemCam, MastCam, MAHLI, CheMin)
	Fluvial silt and sand	rounded sand grains interbedded with silt-dominated deposits, coarsening upward sequence(s) (MastCam, MAHLI)	Abundant primary feldspar, possibly primary oxides (CheMin, APXS, ChemCam)	Depositional, composition follows bedding (APXS, ChemCam, MastCam, MAHLI, CheMin)
	Impact ejecta	fragmented, angular clasts spanning a range of grain sizes; impact glass (MastCam, MAHLI, CheMin)	Basaltic primary minerals (CheMin), meteoritic elements (CheMin, APXS, ChemCam)	Series of unconformable contacts, composition probably does not follow bedding because source of water is likely to be groundwater (APXS, ChemCam, MastCam, MAHLI, CheMin)
Pedogenic Model	same as above, overprinted on any of the above	Could be overprinted on any of the above, but may also contain vugs, various "soil" structures, evidence for impact gardening	Could be overprinted on any of the above, but may also contain higher values of immobile elements and oxide mineals in pedogenic horizons (CheMin, APXS, ChemCam)	Pedogenic horizons should contain disrupted lower contacts, composition should not uniquely follow primary bedding (CheMin, APXS, ChemCam)



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