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
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

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

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<th>MGS/TES</th>
<th>Mex/OMEGA</th>
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<td>Adjacent occurrences of mono- and polyhydrated sulfates</td>
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<td>In situ measurements reveal geologic history</td>
<td>Improved resolution of vertical stratification</td>
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<td>Adjacent occurrences of mono- and polyhydrated sulfates, gypsum, Fe oxides</td>
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<td>Al- and Fe/Mg-clays at Nili and Mawrth</td>
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<td>Massive phyllosilicates</td>
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<td>Unknown hydrated mineral associated with dozens highland craters</td>
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<td>~10K highland outcrops in craters, chasmata; chlorite + other phyllosilicates</td>
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<td>High-Si deposits at Home Plate</td>
<td>Widespread hydrated silica in layered deposits on Hesperian plains</td>
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**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.
2. Deeply Excavated Phyllosilicates

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

CRISM false color

Layers with polyhydrated sulfate

Layers with monohydrated sulfate
6. Valles Layered Deposits

- **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
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.
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 hydroxylated 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 precipitates 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

![Gypsum band depth map](image)

- 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.
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.