

AV Sedimentary Geology at the Mars Exploration Rover Landing Sites

By
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Abstract

The Mars Exploration Rovers Spirit and Opportunity have both yielded evidence for aqueous and sedimentary processes at their landing sites. In Gusev crater, Spirit found only trace evidence for the action of water on the basalt-covered plains of the crater floor. This water action left thin salt-rich deposits on the surfaces of rocks and in fractures within rocks, and what appear to be magnesium sulfate salt concentrations in soils. The older rocks in the Columbia Hills, however, are layered clastic rocks that show evidence substantial aqueous alteration. At Meridiani Planum, Opportunity has found laminated rocks that we interpret to be mixed chemical and siliciclastic sediments. Environmental conditions that they record include episodic inundation by shallow surface water, evaporation and desiccation. After deposition, these rocks underwent a complex diagenetic history that resulted in recrystallization, vug formation, and growth of hematite-rich concretions. A stratigraphic section obtained within Endurance crater shows significant variation of rock chemistry and texture as a function of depth, indicating changes in depositional and/or diagenetic processes with time.

The Mars Exploration Rover Project



Mars Exploration Rover Mission



The Athena Science Payload

Remote Sensing Package



Pancam Mast Assembly (PMA)

Pancam

Mini-TES



In-Situ Package

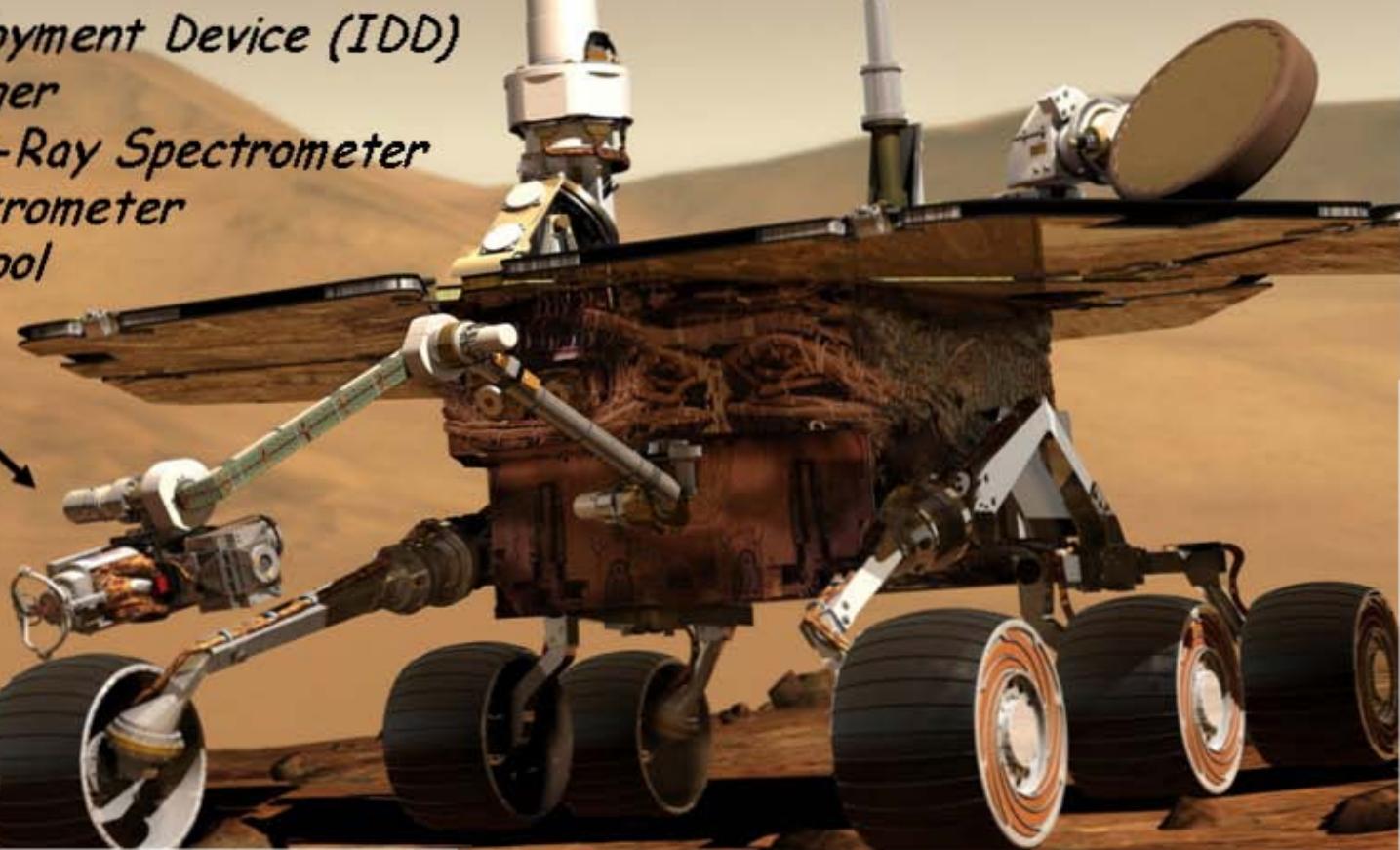
Instrument Deployment Device (IDD)

Microscopic Imager

Alpha Particle X-Ray Spectrometer

Mössbauer Spectrometer

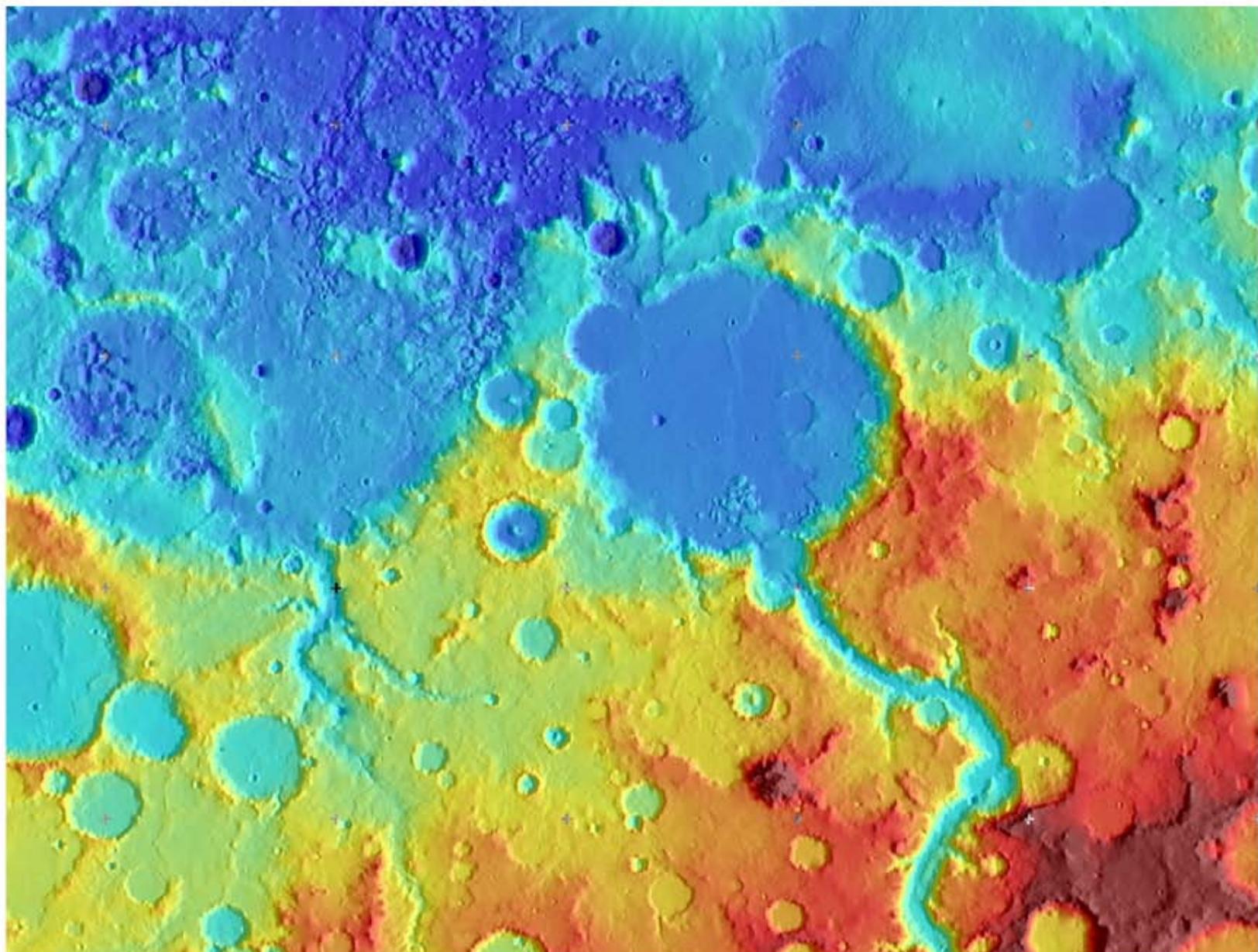
Rock Abrasion Tool



Spirit: Gusev Crater



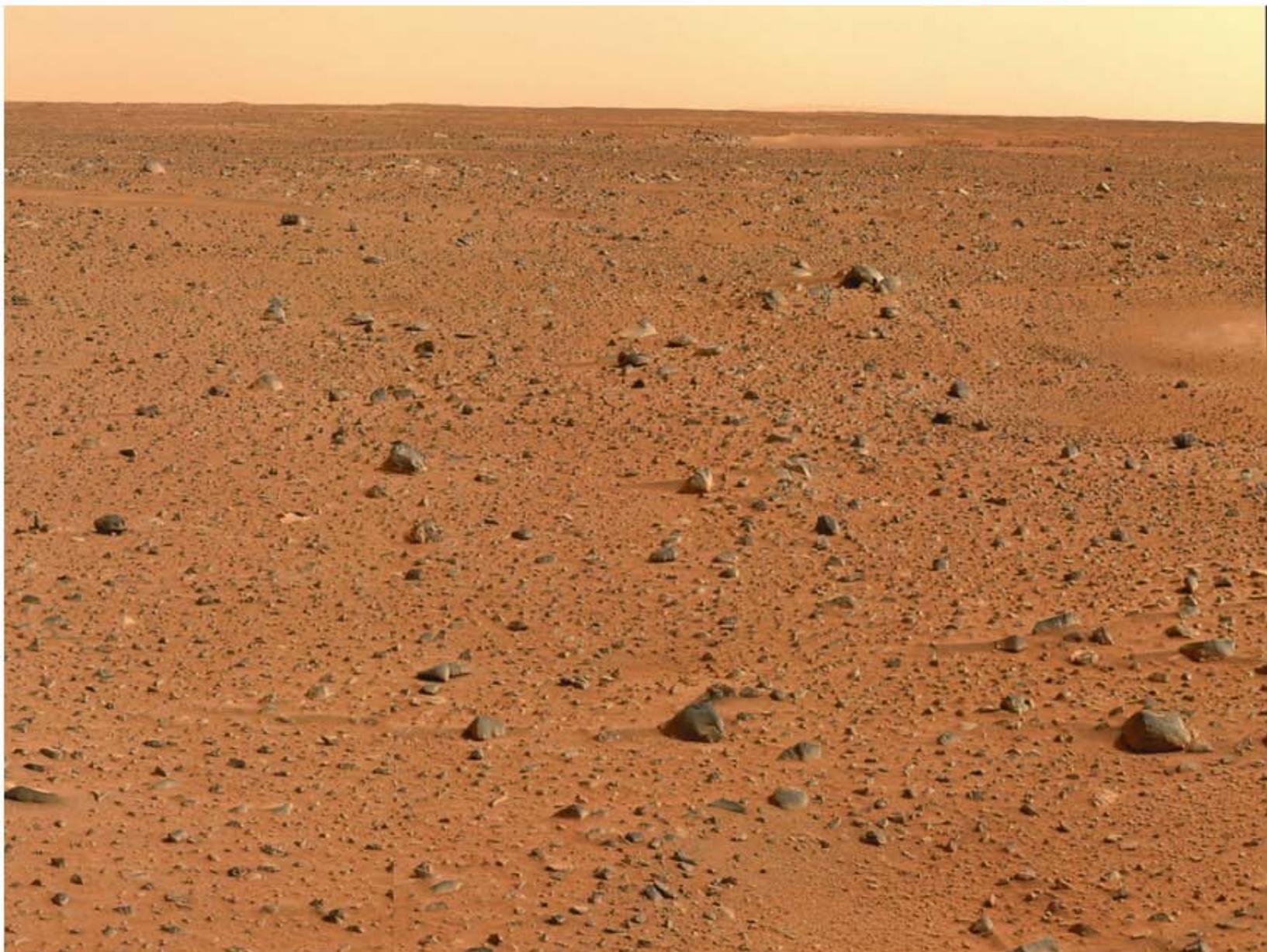
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The View From the Surface



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Adirondack



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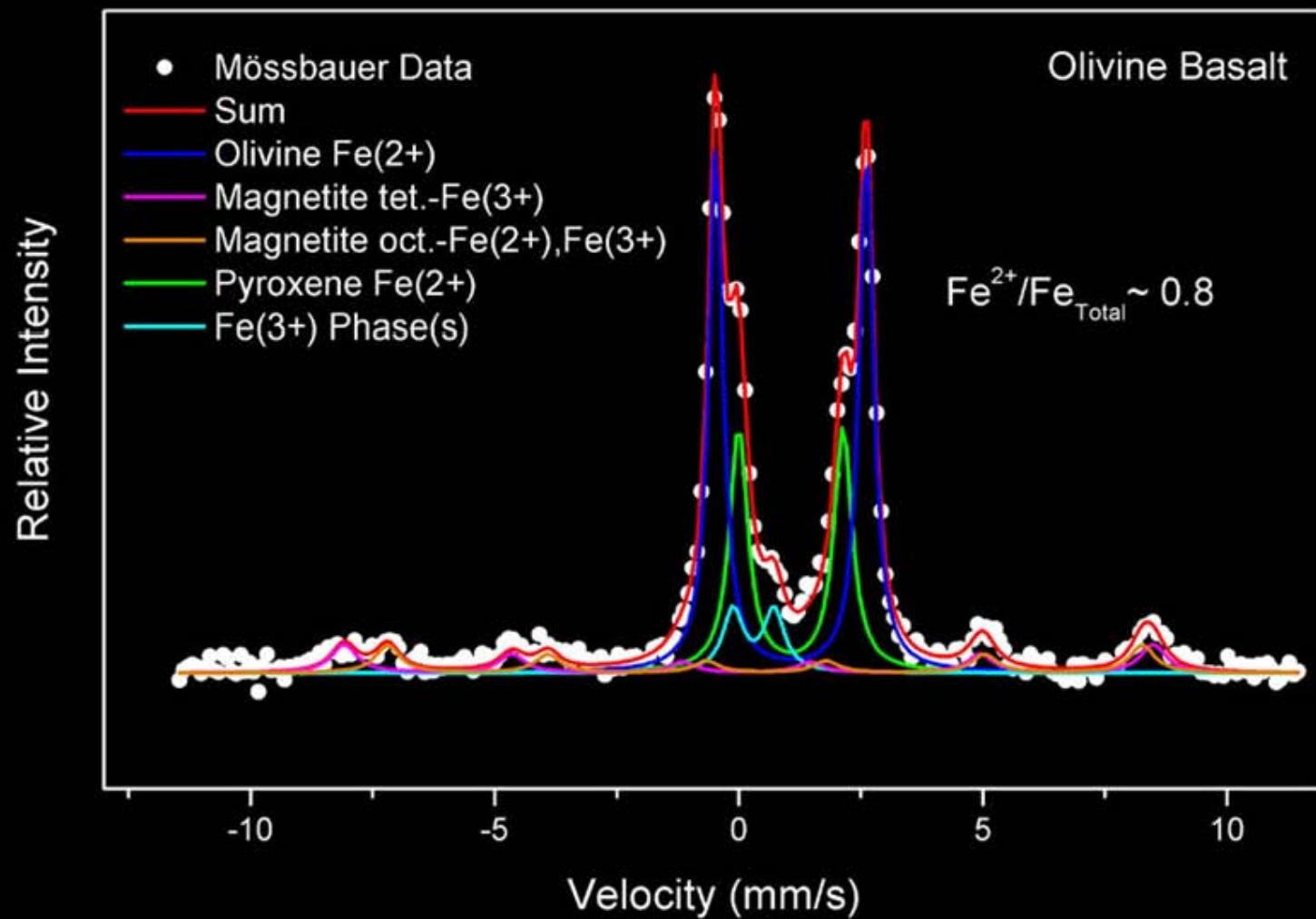


Mössbauer Spectrum of Adirondack



Mars Exploration Rover Mission

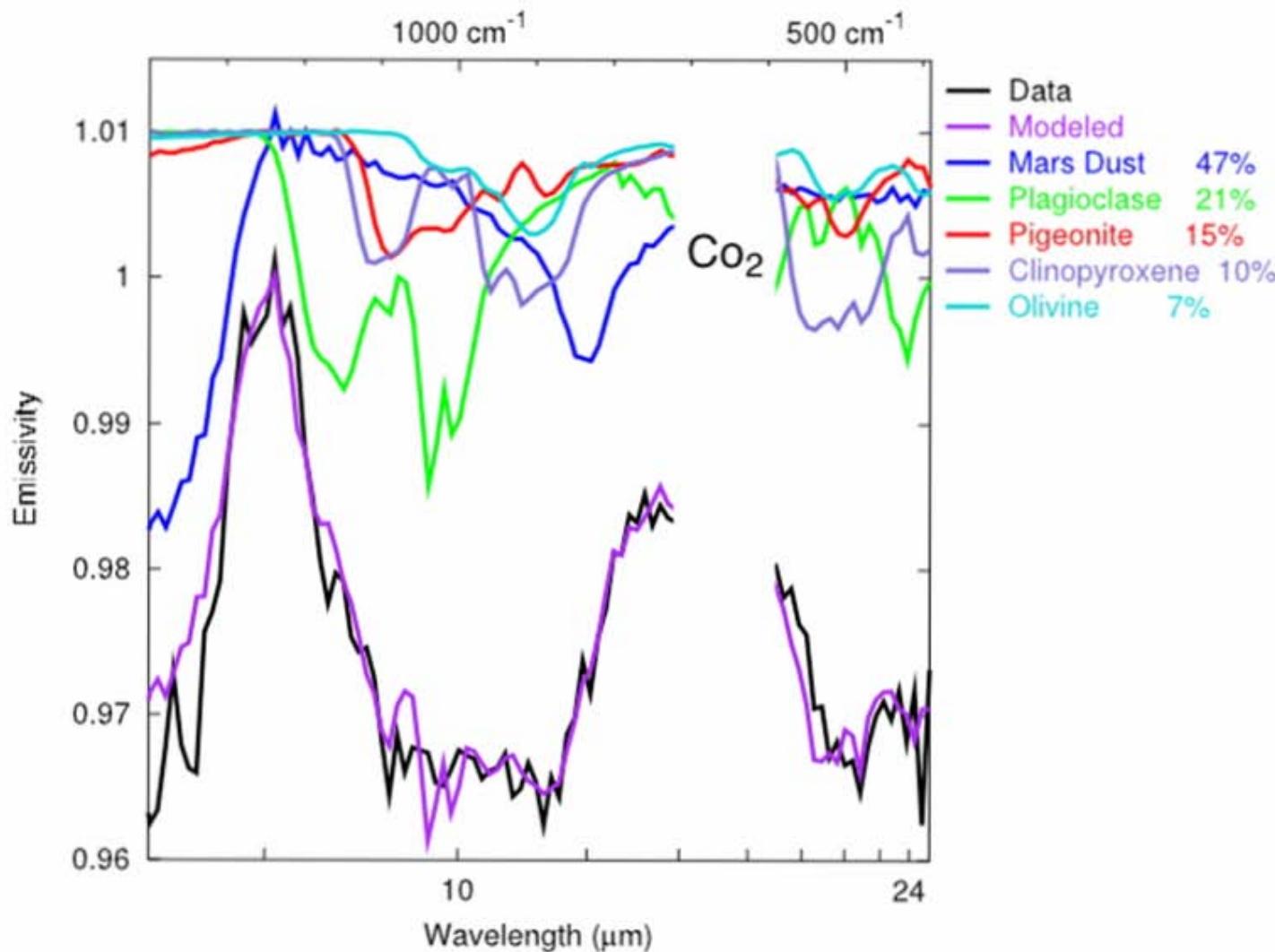
Mössbauer Spectrum of Adirondack Rock
(Sol 18, Gusev Crater, Mars)

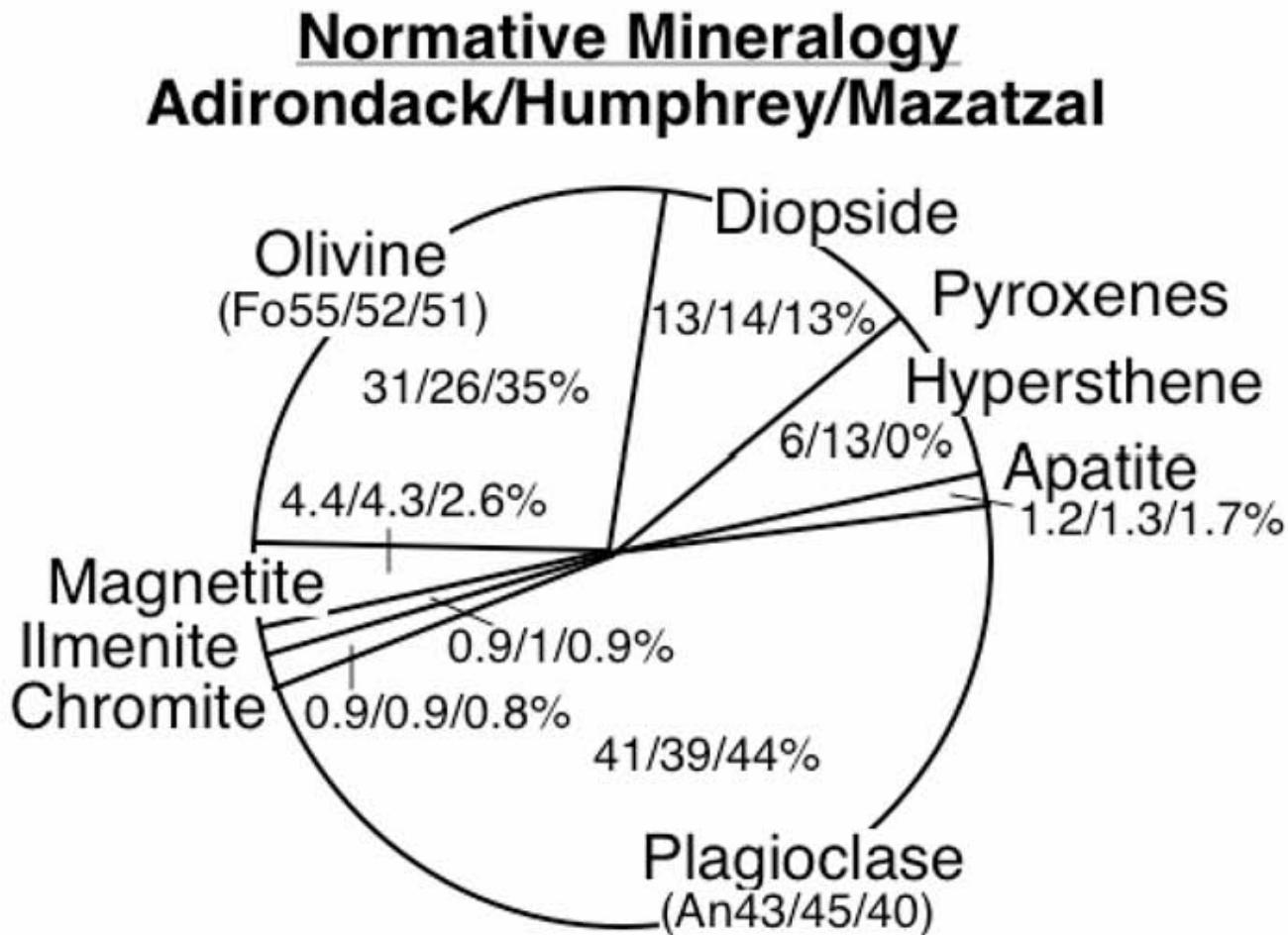


Mini-TES Mineralogy



Mars Exploration Rover Mission

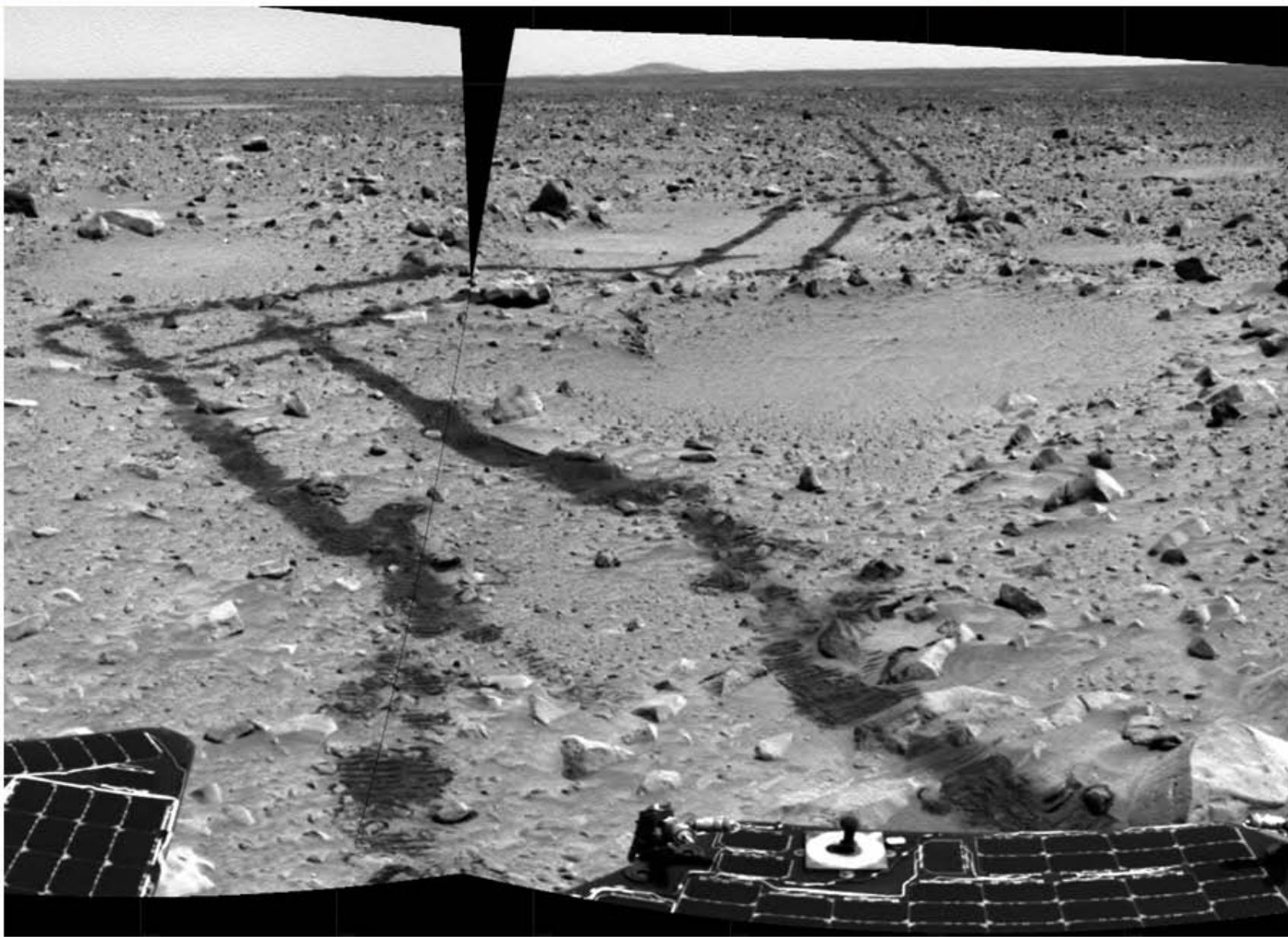




Spirit Hits The Road



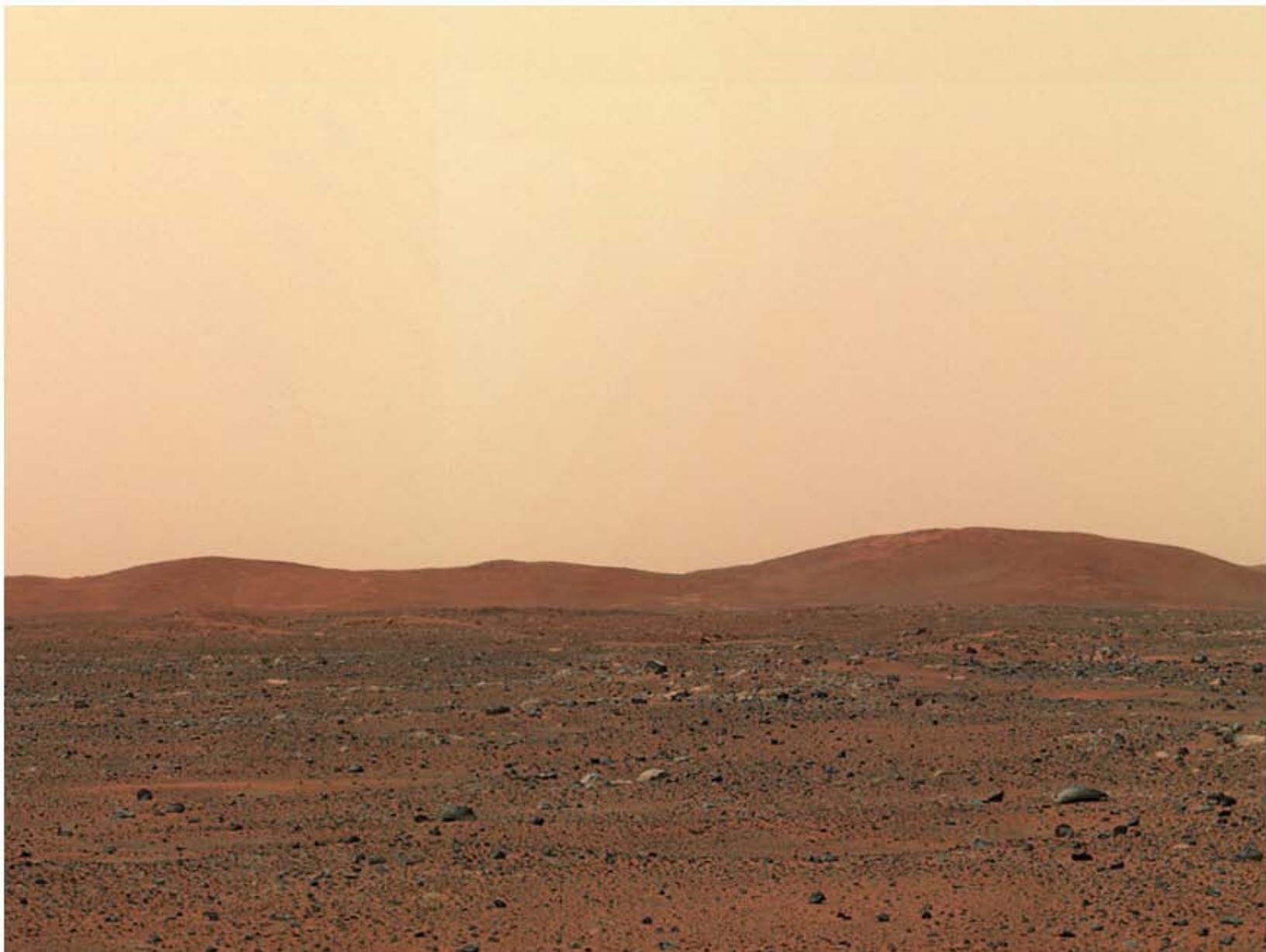
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The Columbia Hills



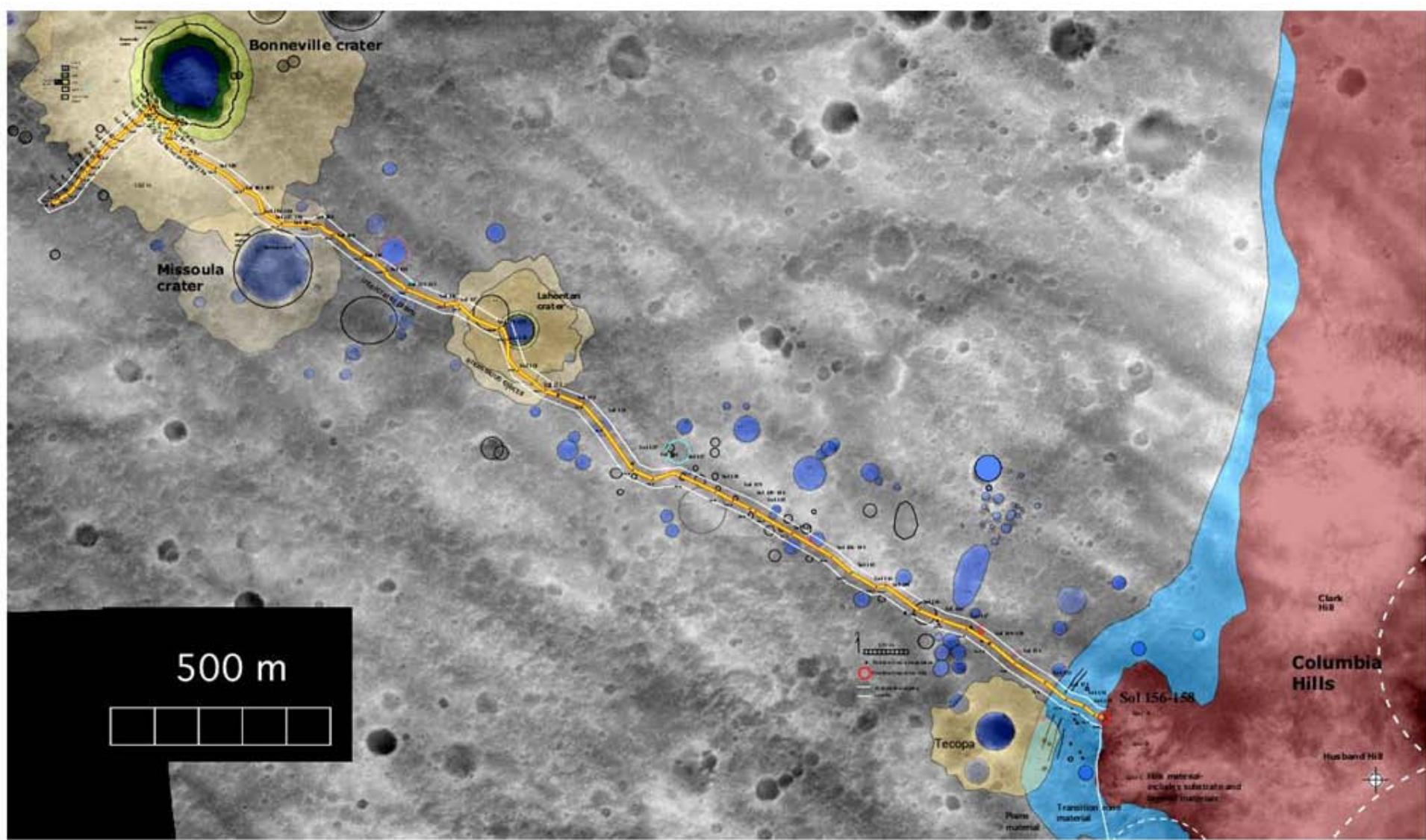
Mars Exploration Rover Mission

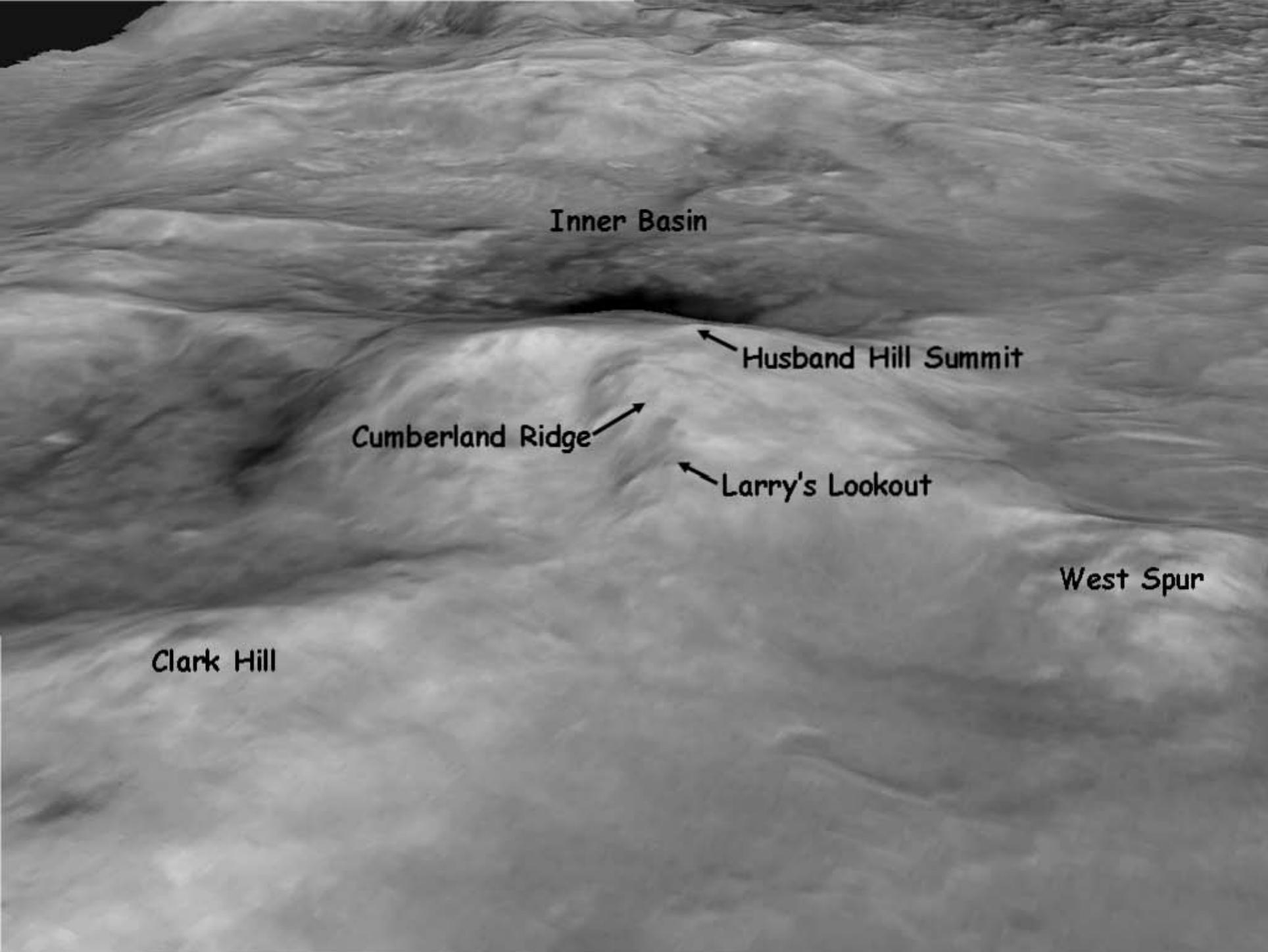


The Traverse to the Columbia Hills



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Inner Basin

Husband Hill Summit

Cumberland Ridge

Larry's Lookout

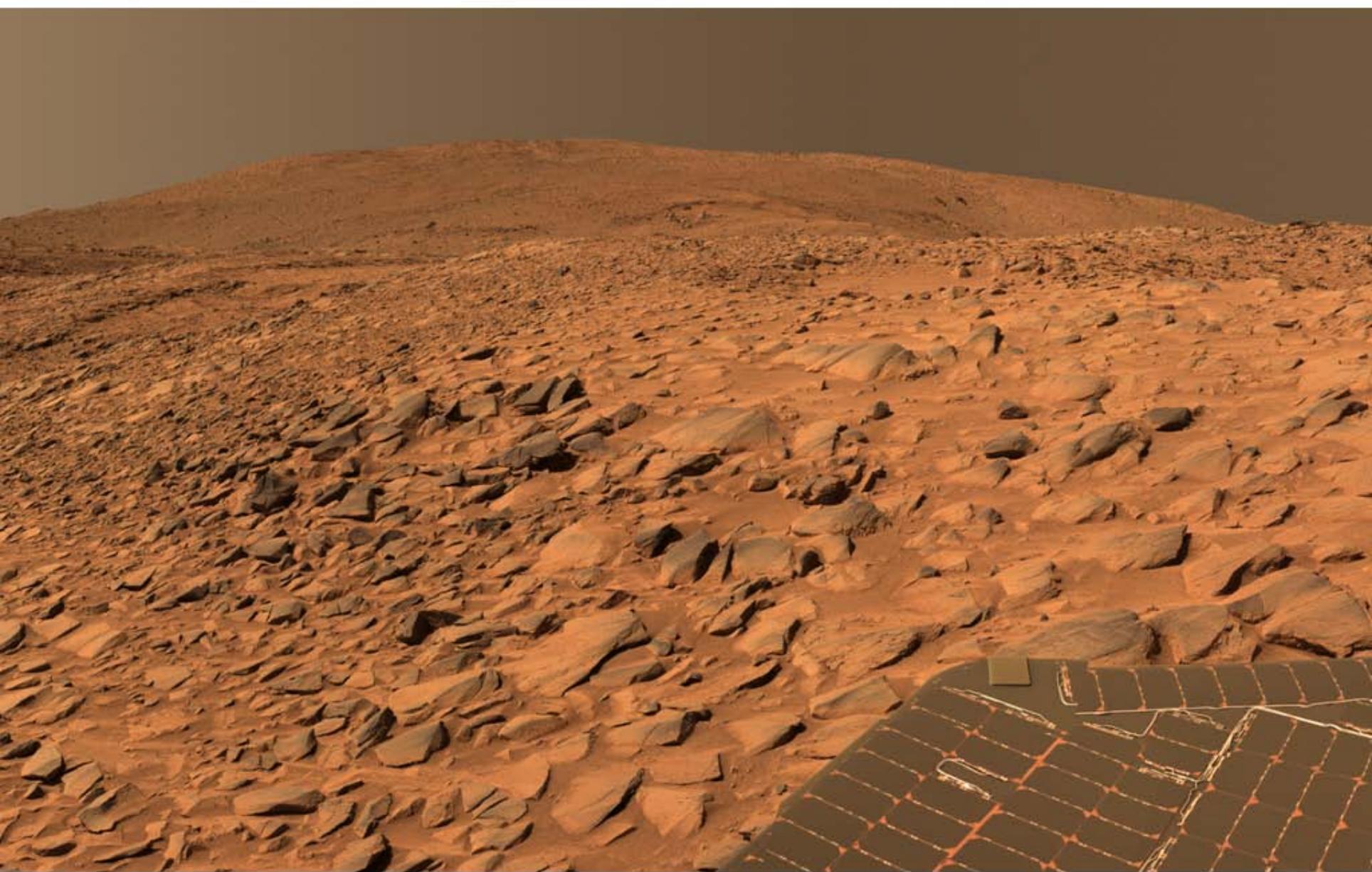
West Spur

Clark Hill

The West Spur of Husband Hill



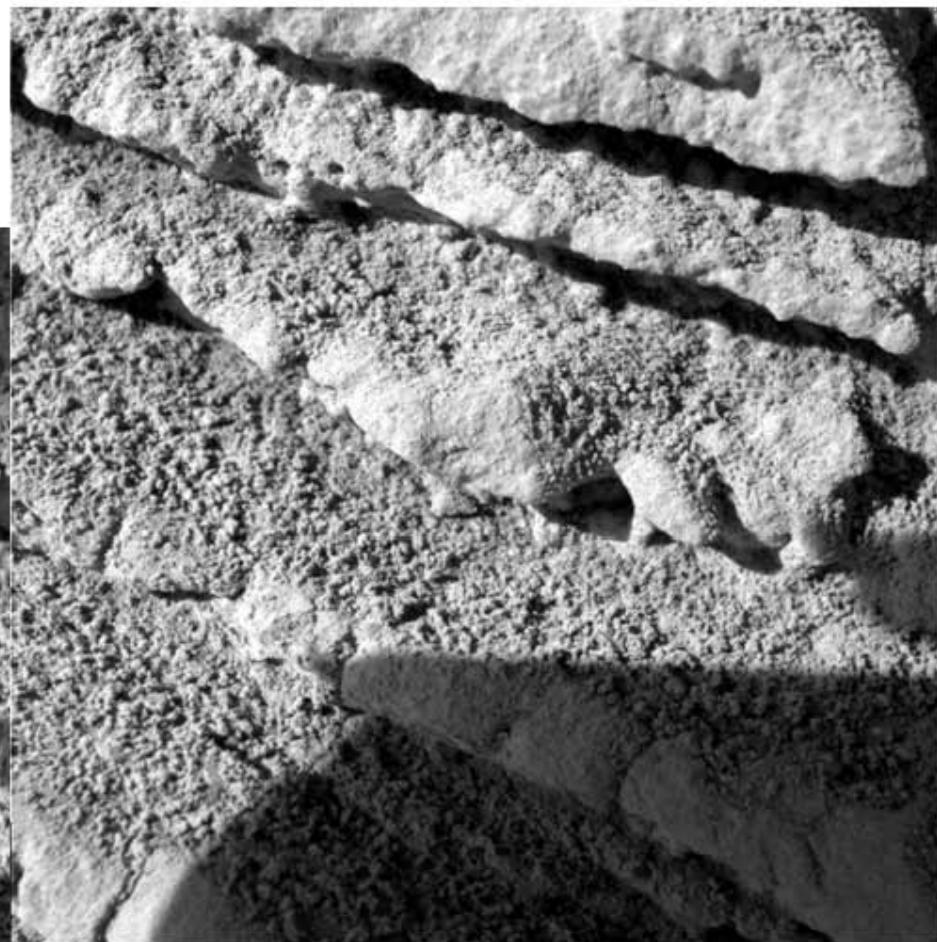
Mars Exploration Rover Mission



Tetl



Mars Exploration Rover Mission

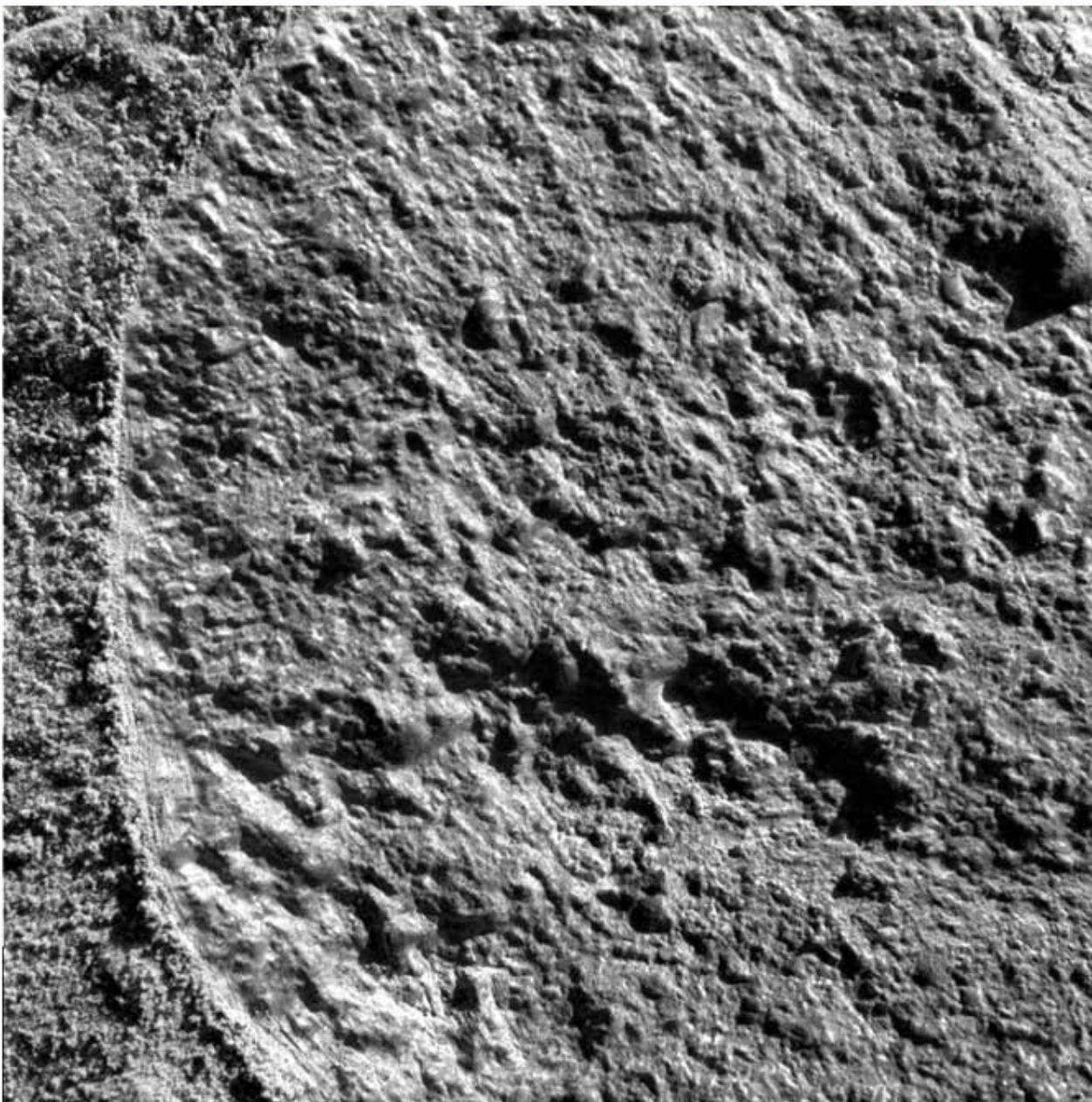


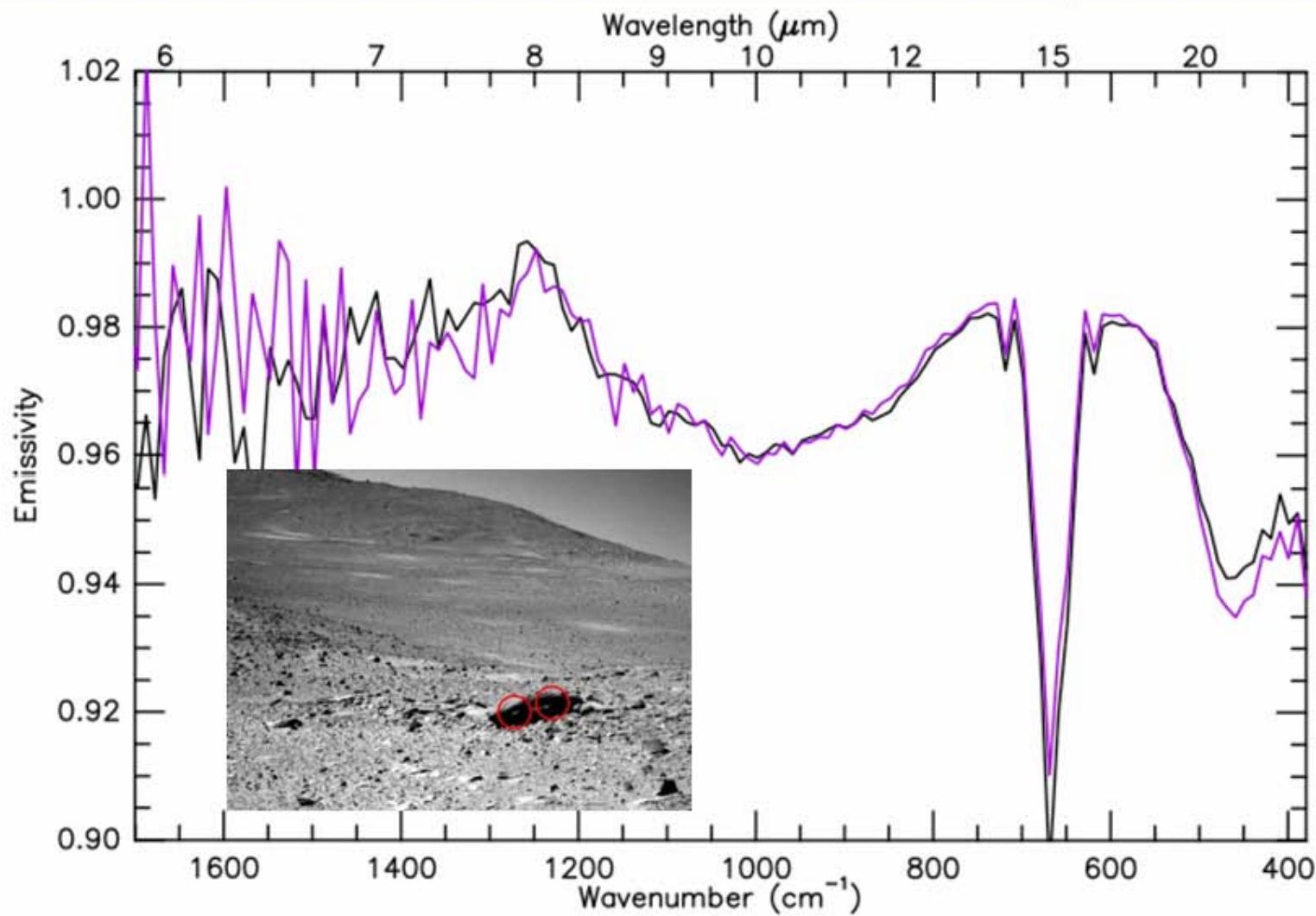
Palenque



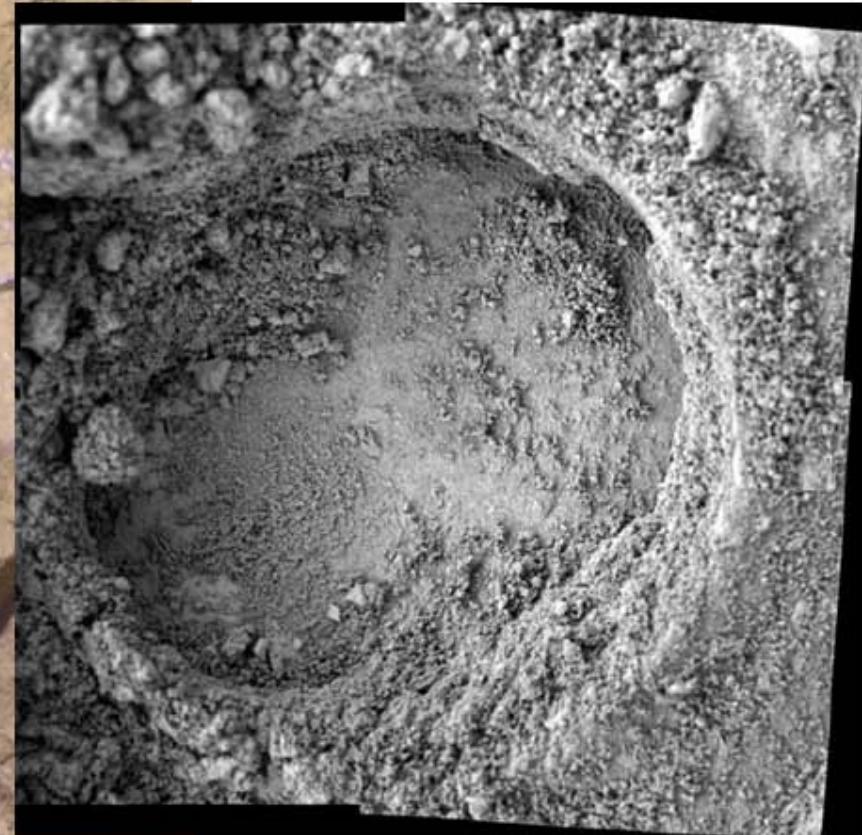
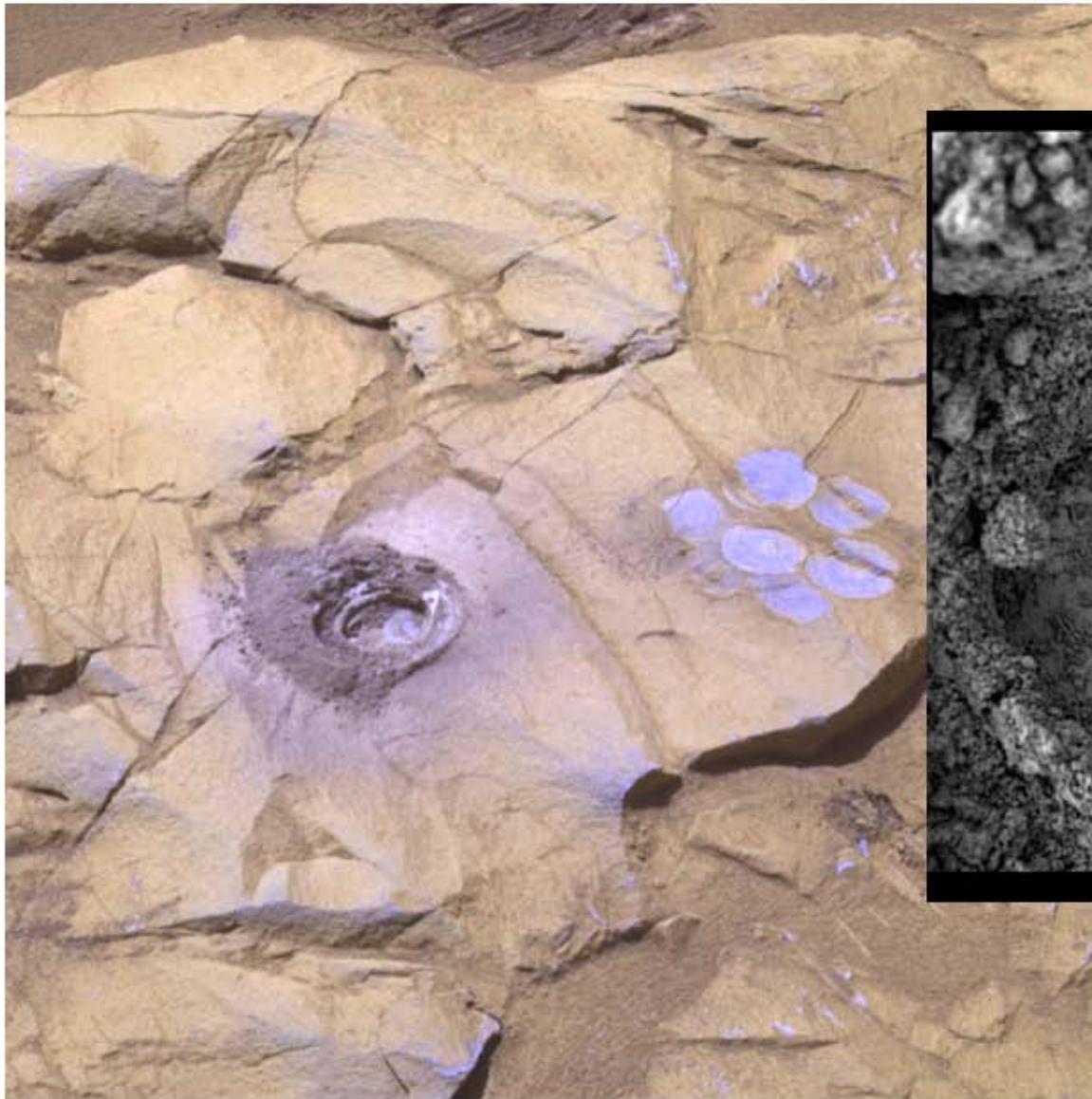
Mars Exploration Rover Mission

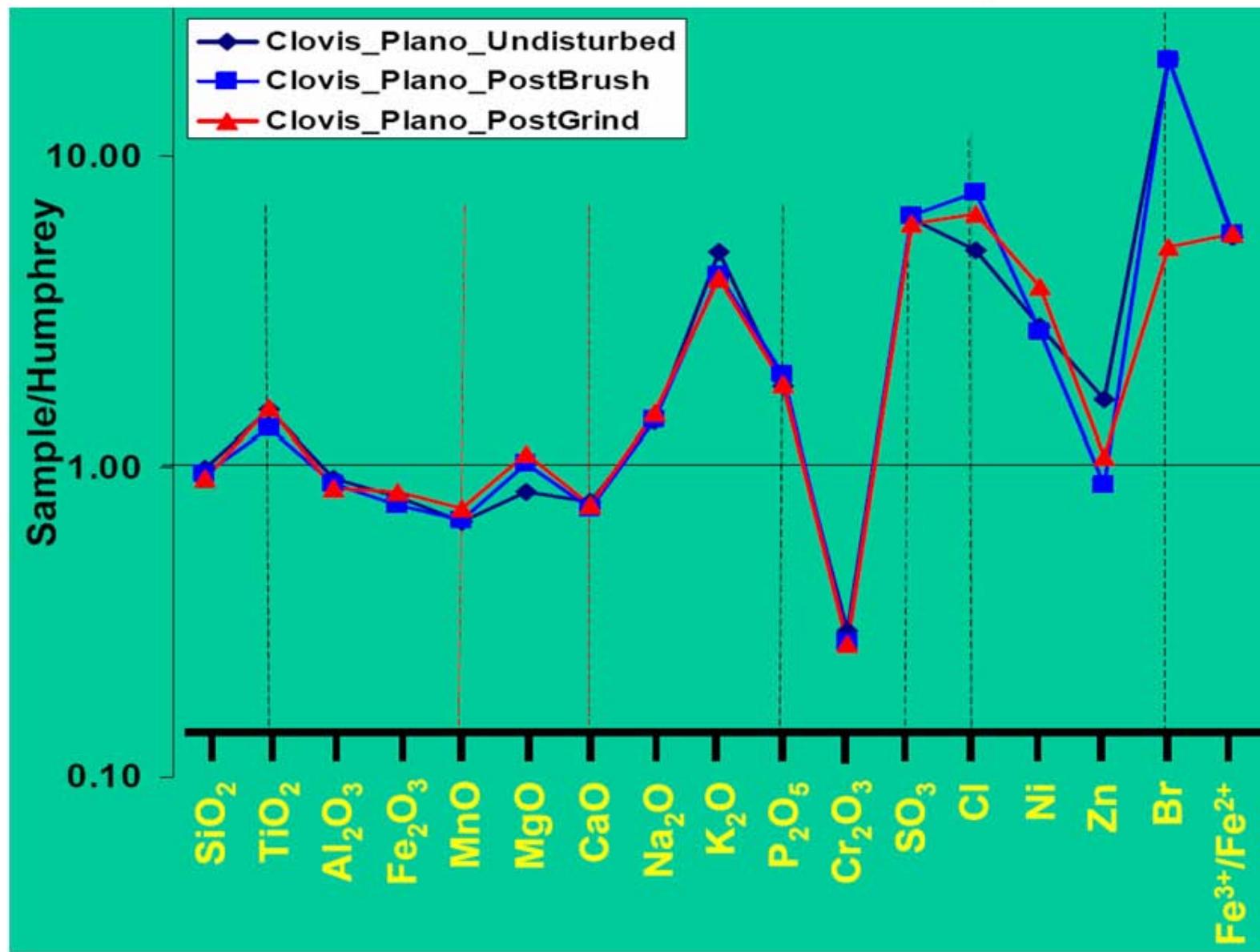




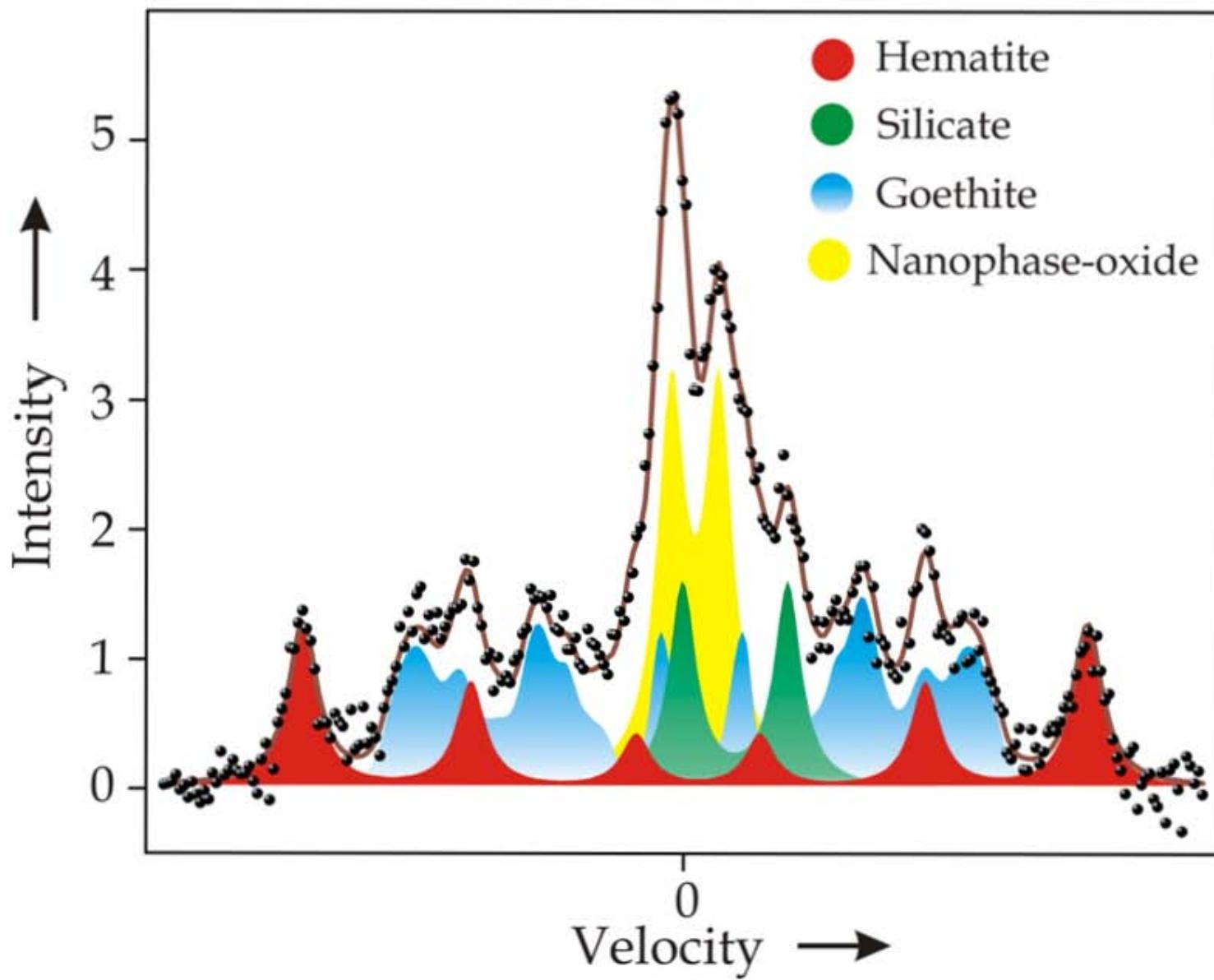


- Best fit to spectrum is dominated by basaltic glass





Mössbauer Spectrum of Clovis (200 - 220K)



West Spur Rocks: Summary



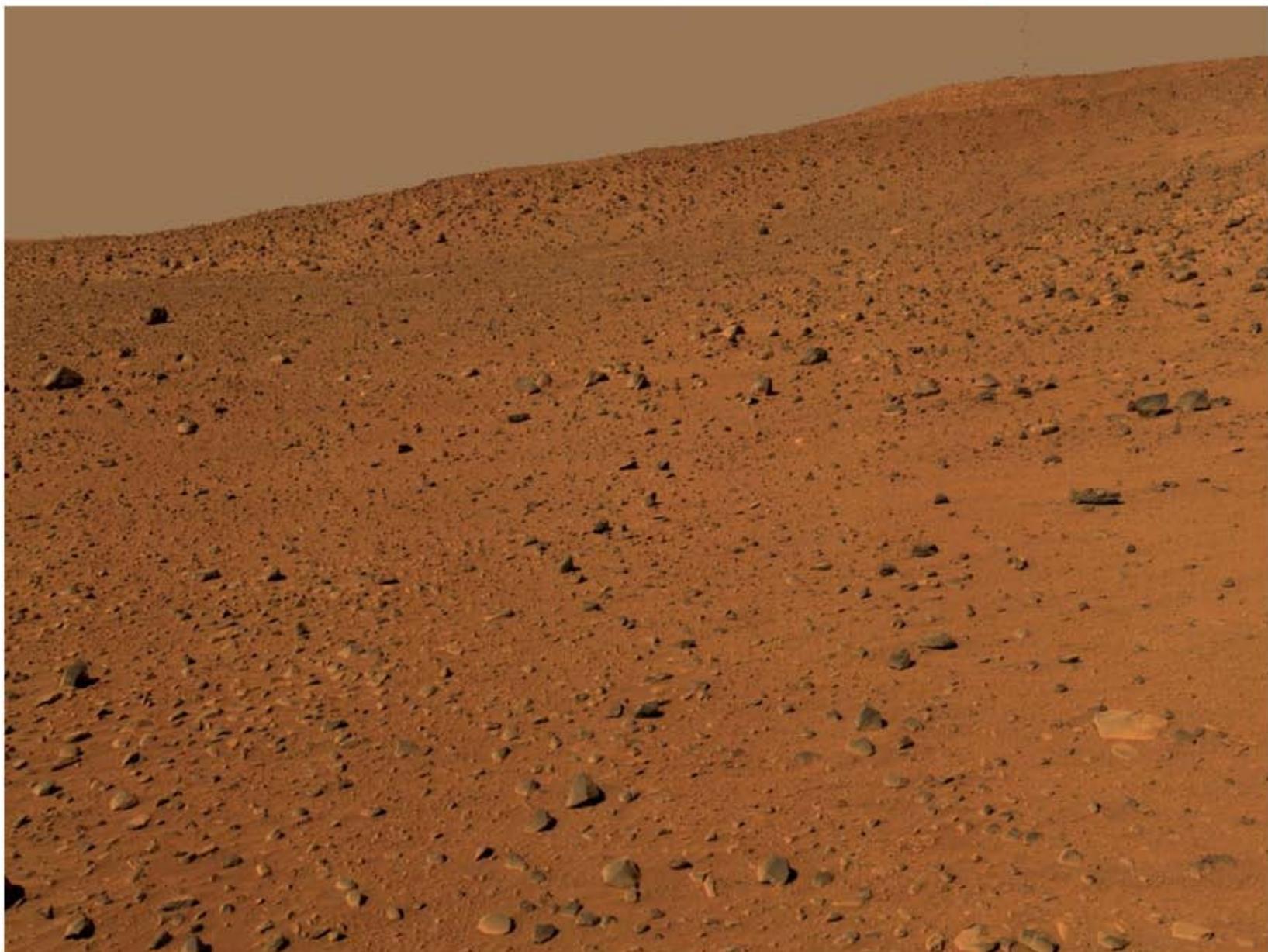
Mars Exploration Rover Mission

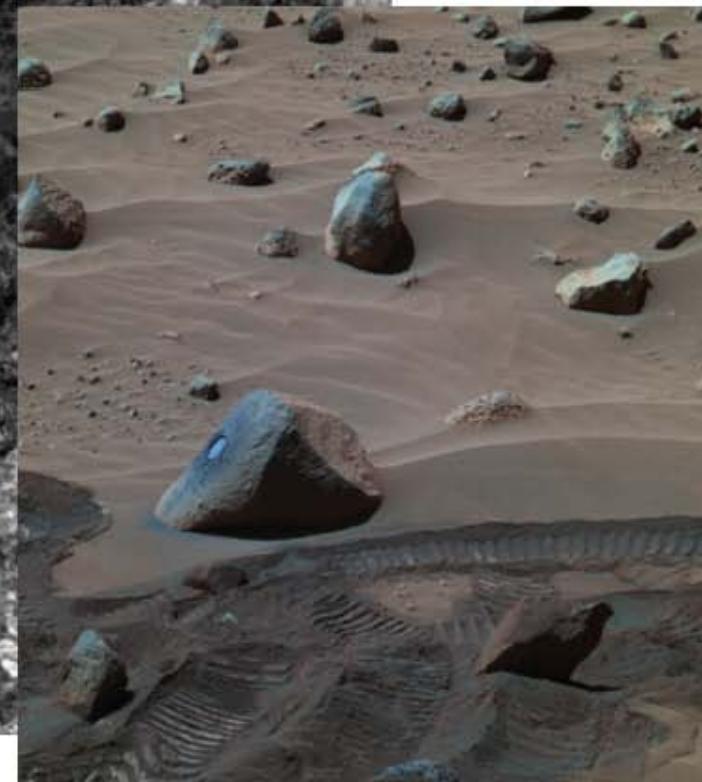
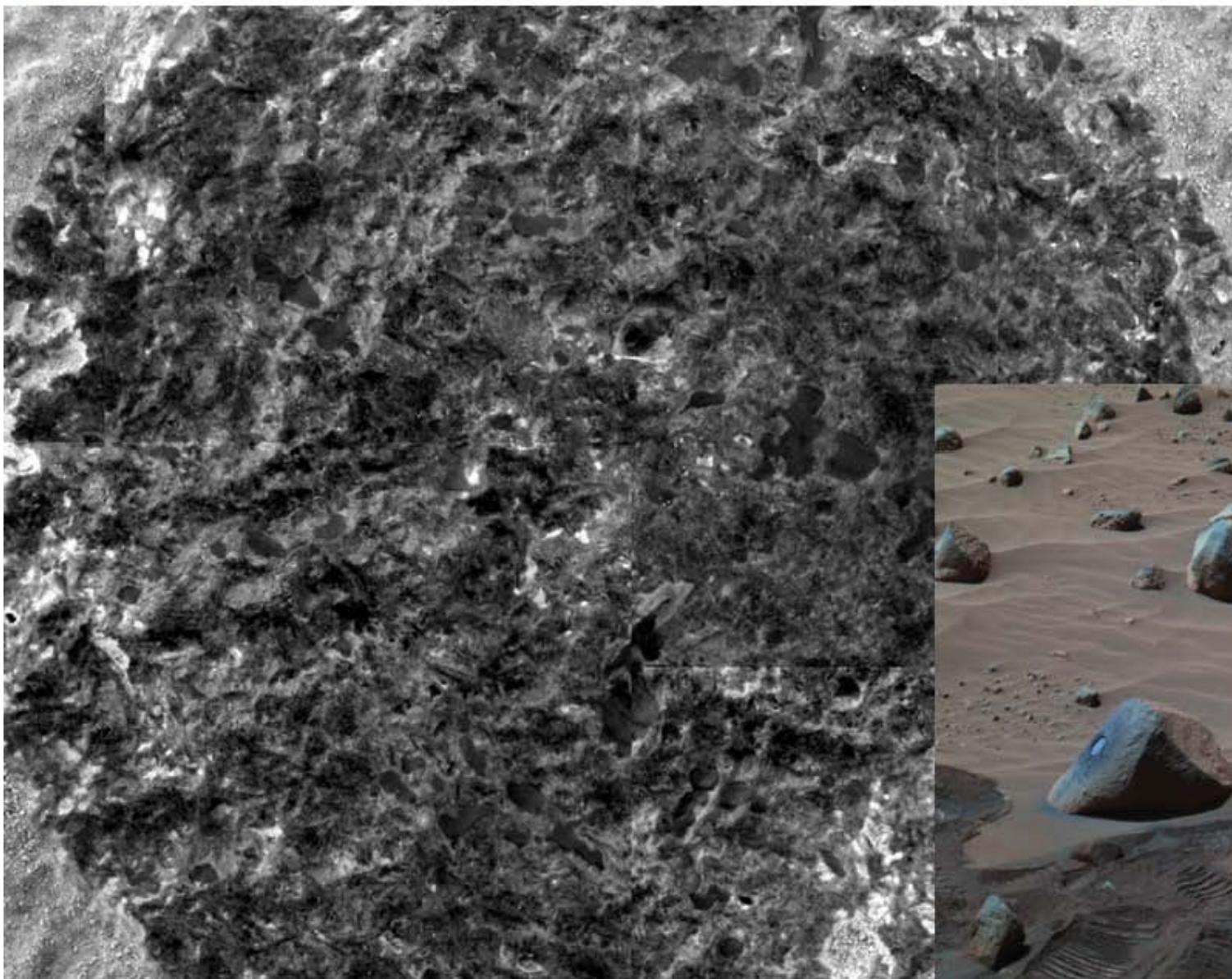
- Pancam: Massive to finely layered (some layers <1 cm thick)
- Mini-TES: Spectrum similar to basaltic glass
- MI: Poorly sorted clastic rock, with clasts up to several mm in size
- APXS: "Basaltic" chemistry, but elevated in P, S, Cl, and Br. Also high in Ni.
- Mössbauer: Little or no primary igneous mineralogy (e.g., olivine, pyroxene), much less ferrous iron than plains basalt, Fe oxides and oxyhydroxides
- RAT: Very weak and easy to grind
- Interpretation: Aqueously altered volcaniclastic or impact-generated rocks of basaltic composition. High Ni may favor impact origin.

North Flank of Husband Hill



Mars Exploration Rover Mission





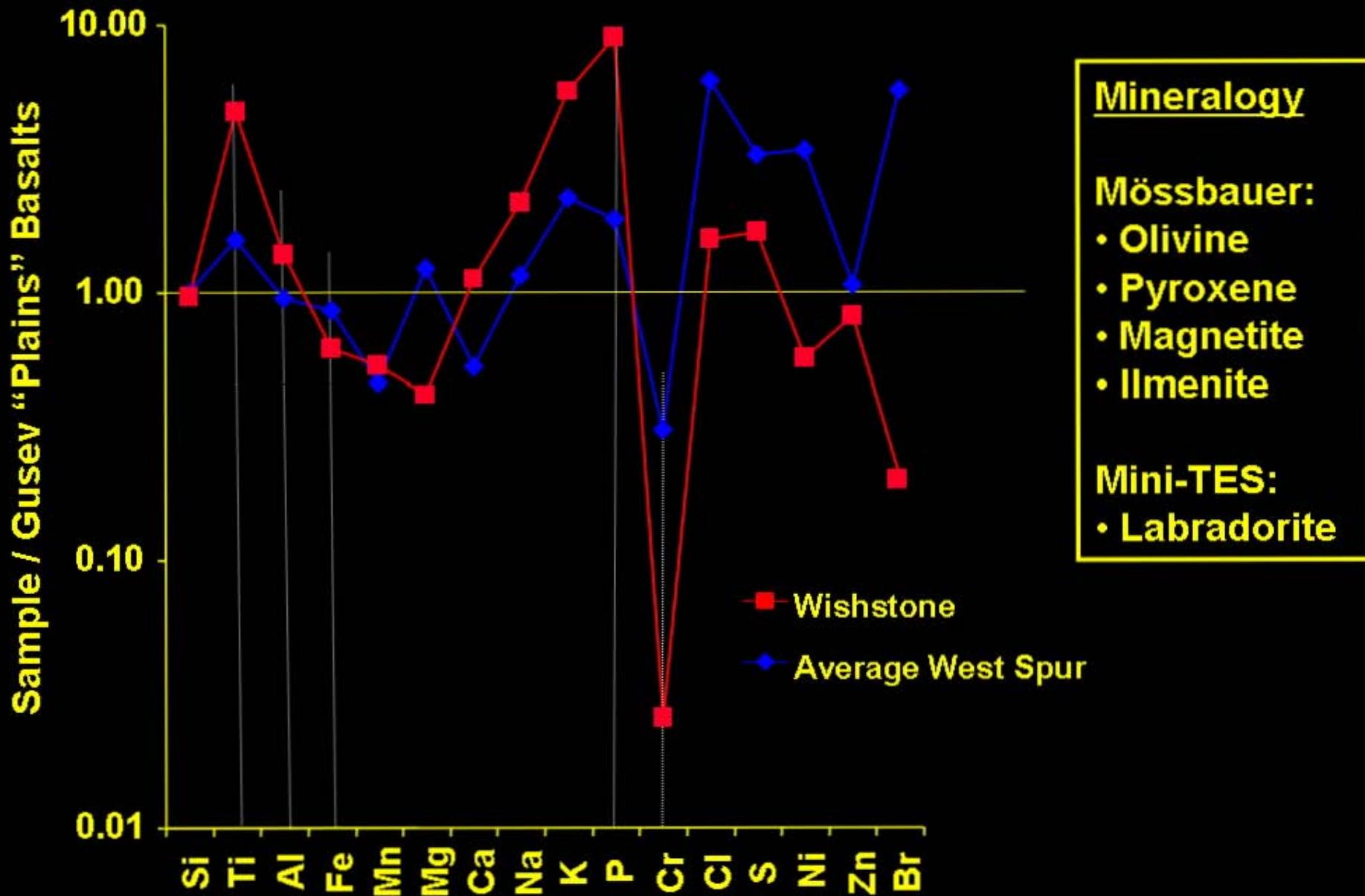
Wishstone Composition



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Mineralogy

Mössbauer:

- Olivine
- Pyroxene
- Magnetite
- Ilmenite

Mini-TES:

- Labradorite

Larry's Lookout



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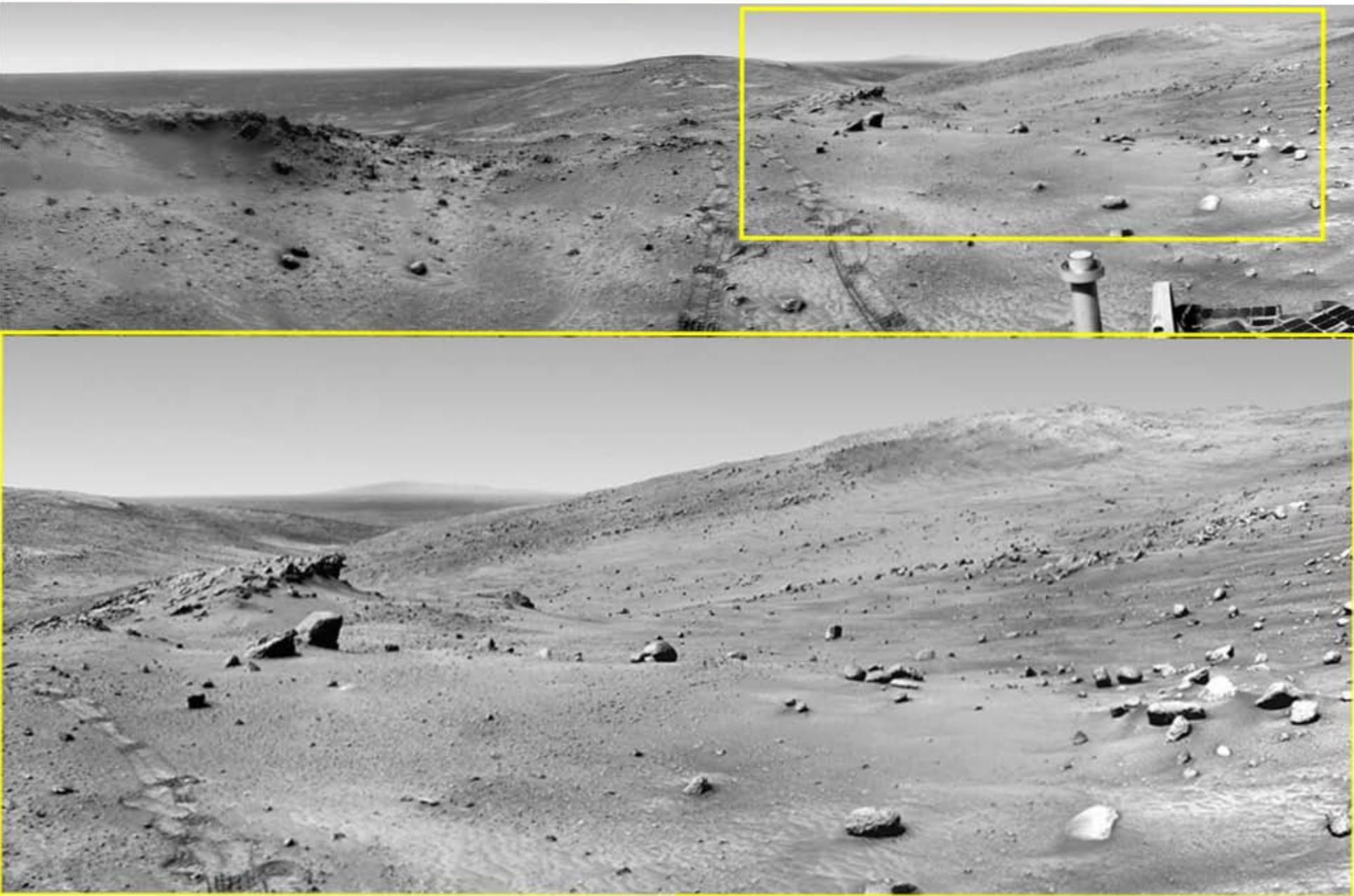
Looking Back



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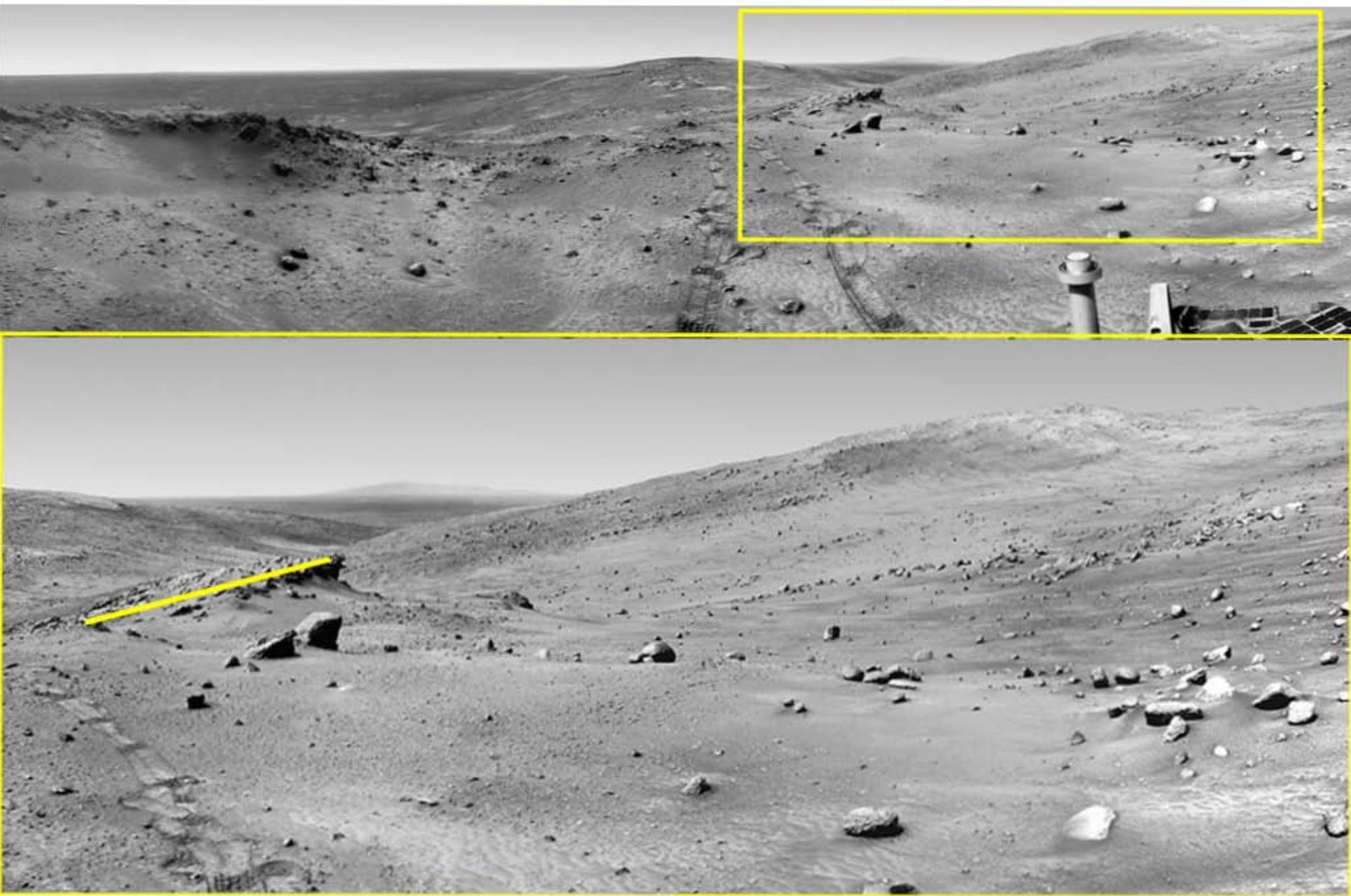
Looking Back



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Mars Exploration Rover Mission



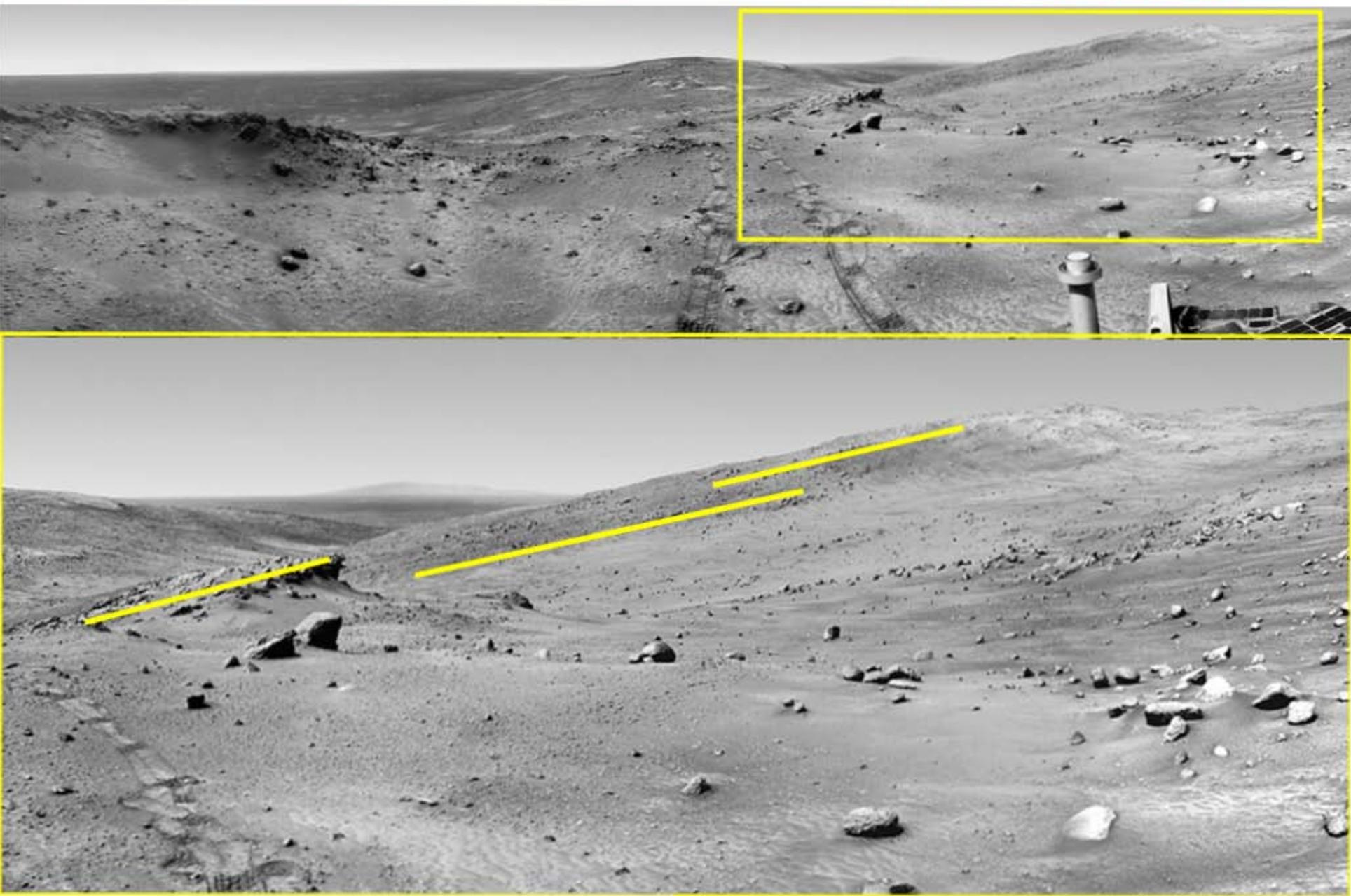
Looking Back



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Mars Exploration Rover Mission



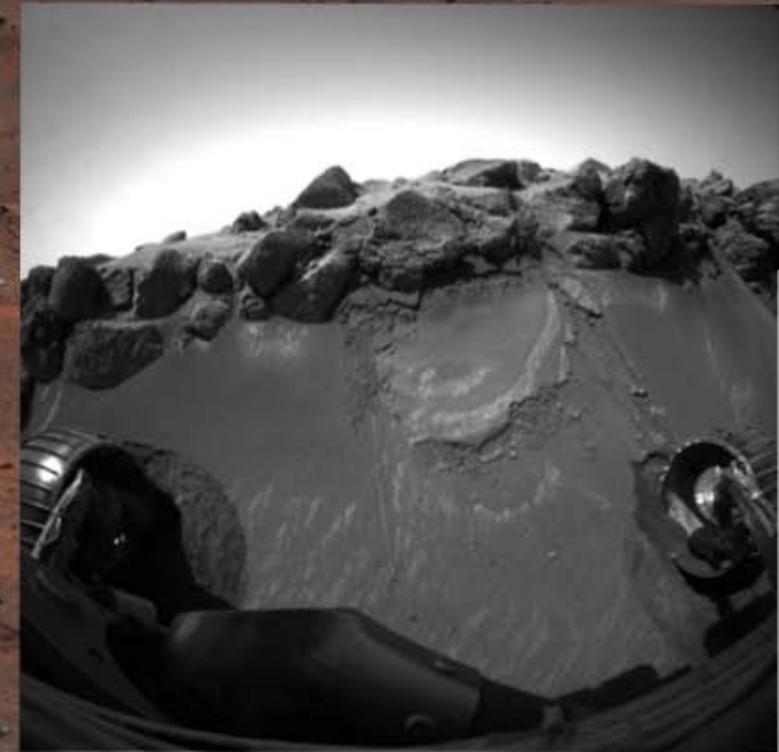
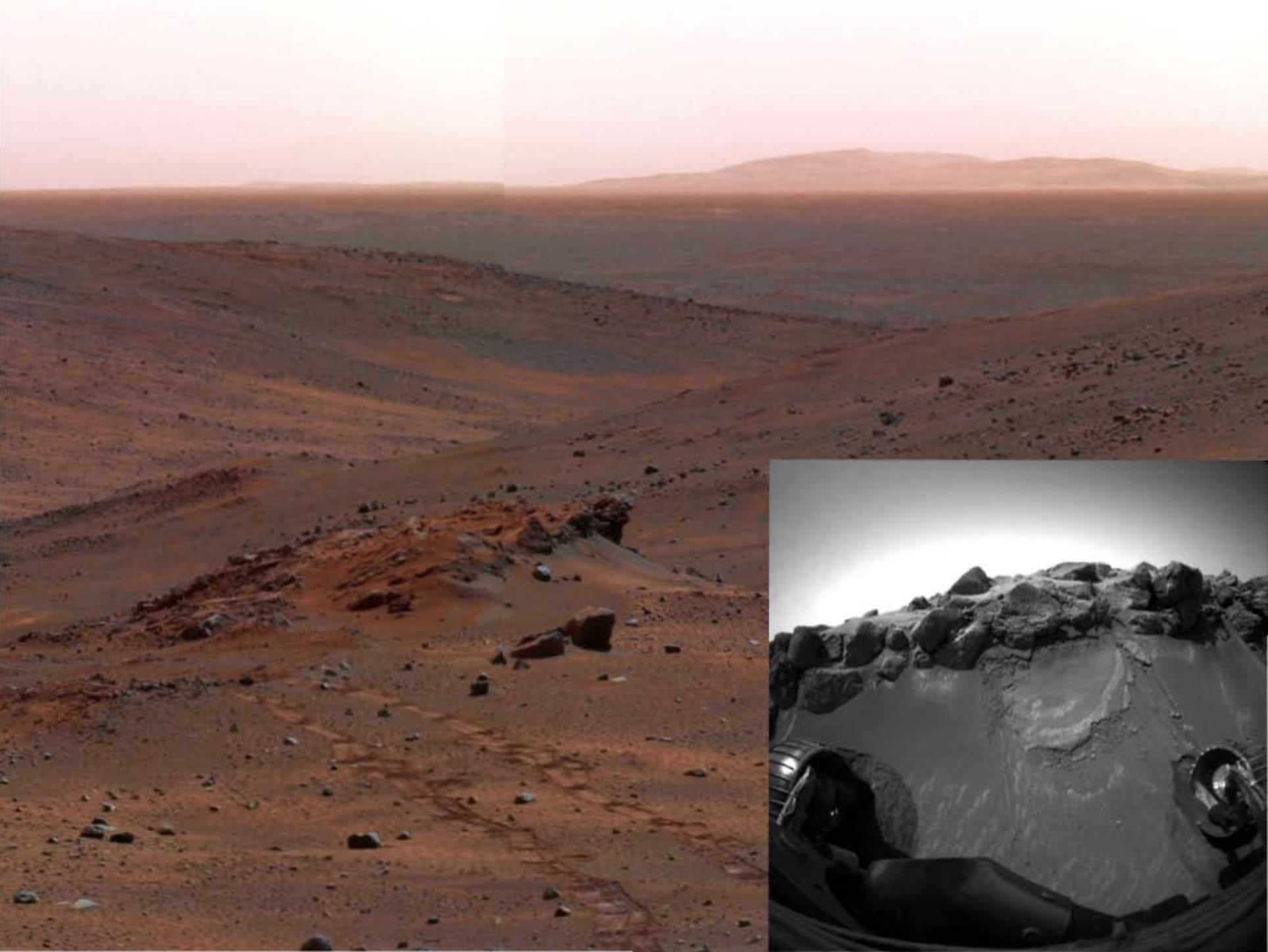
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Mars Exploration Rover Mission









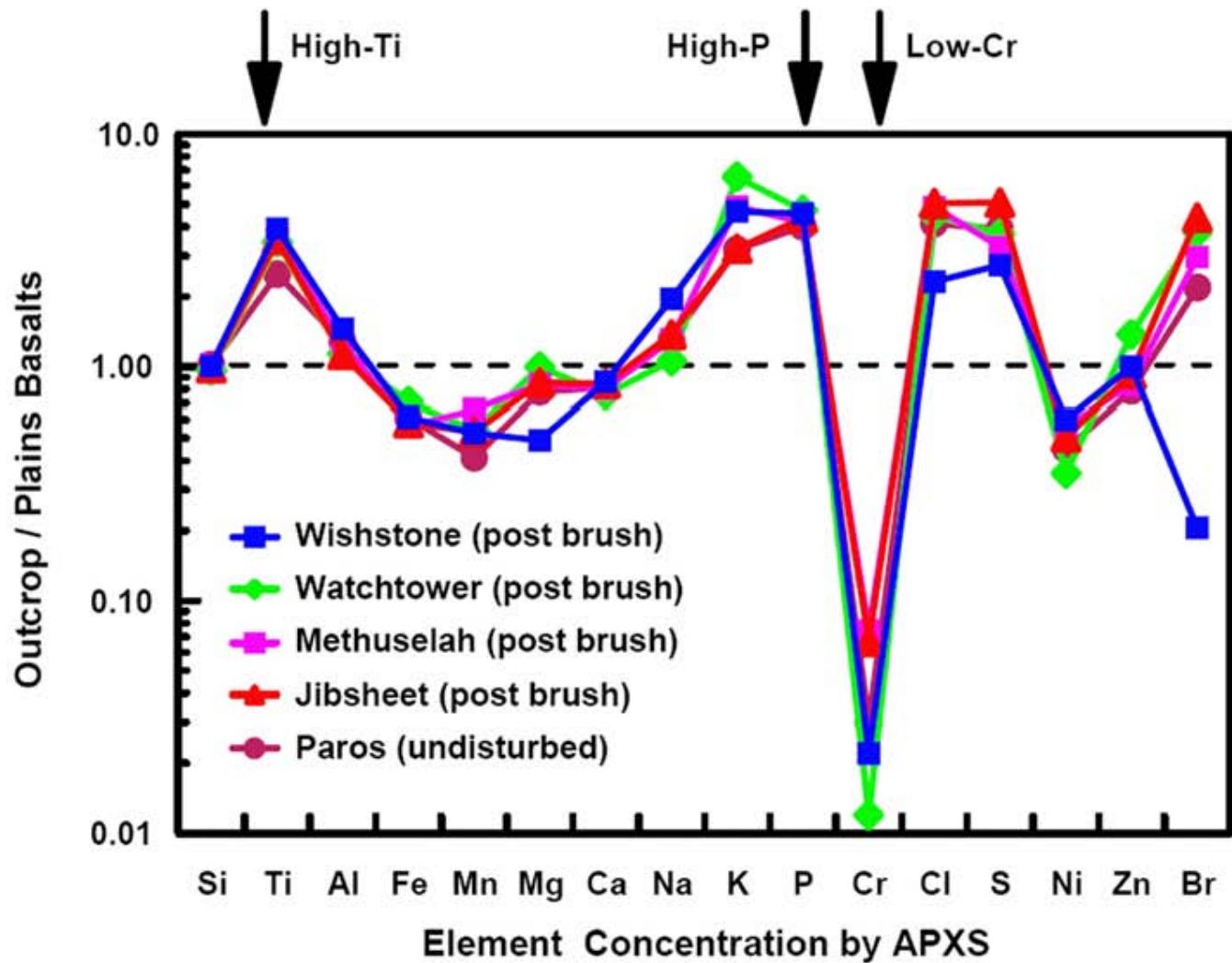


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APXS Results

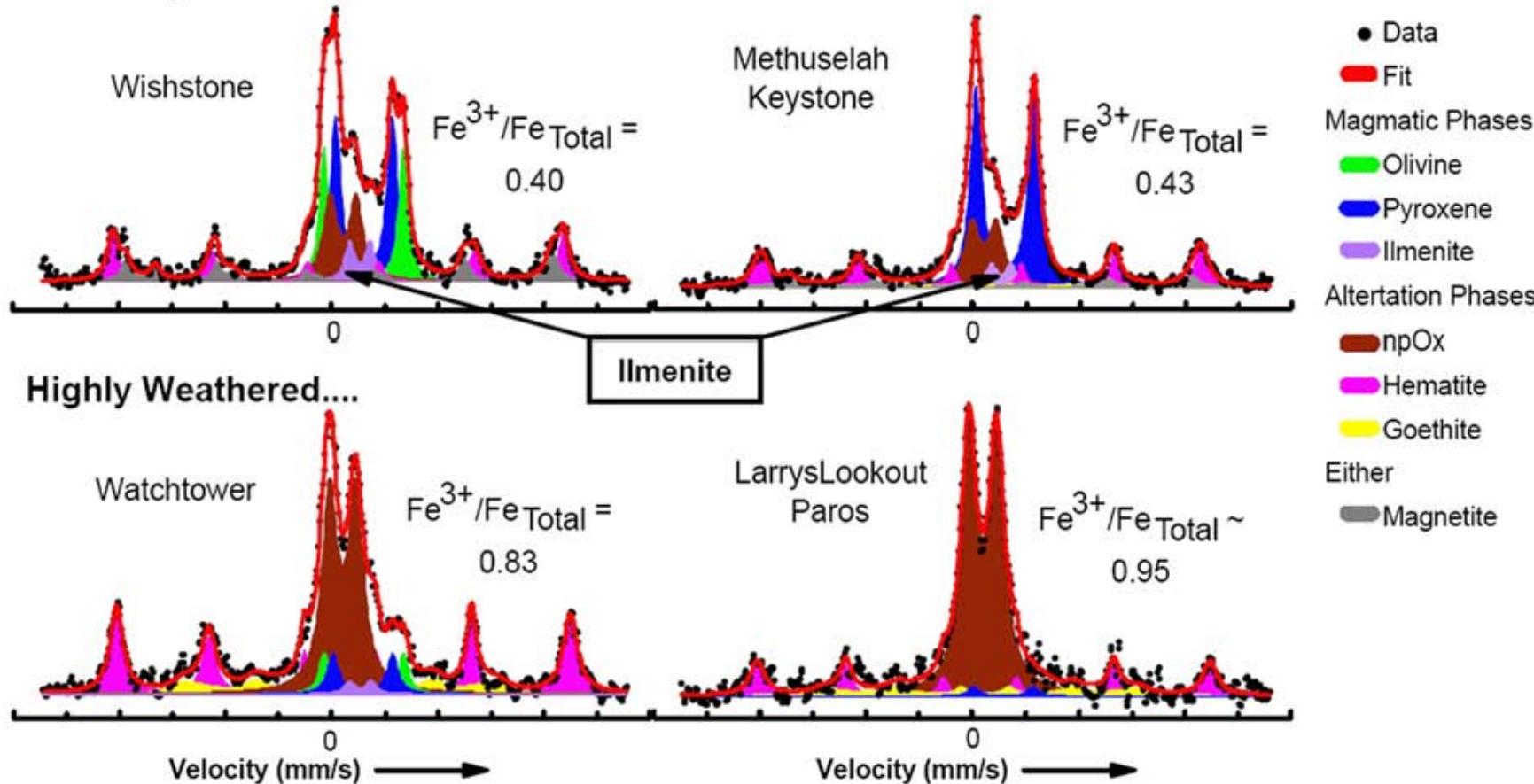
Athena

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Relatively Unweathered....



1. First identification of the mineral ilmenite (FeTiO_3)
2. Weathering at constant chemical composition implies a low water to rock ratio

Cumberland Ridge Rocks: Summary



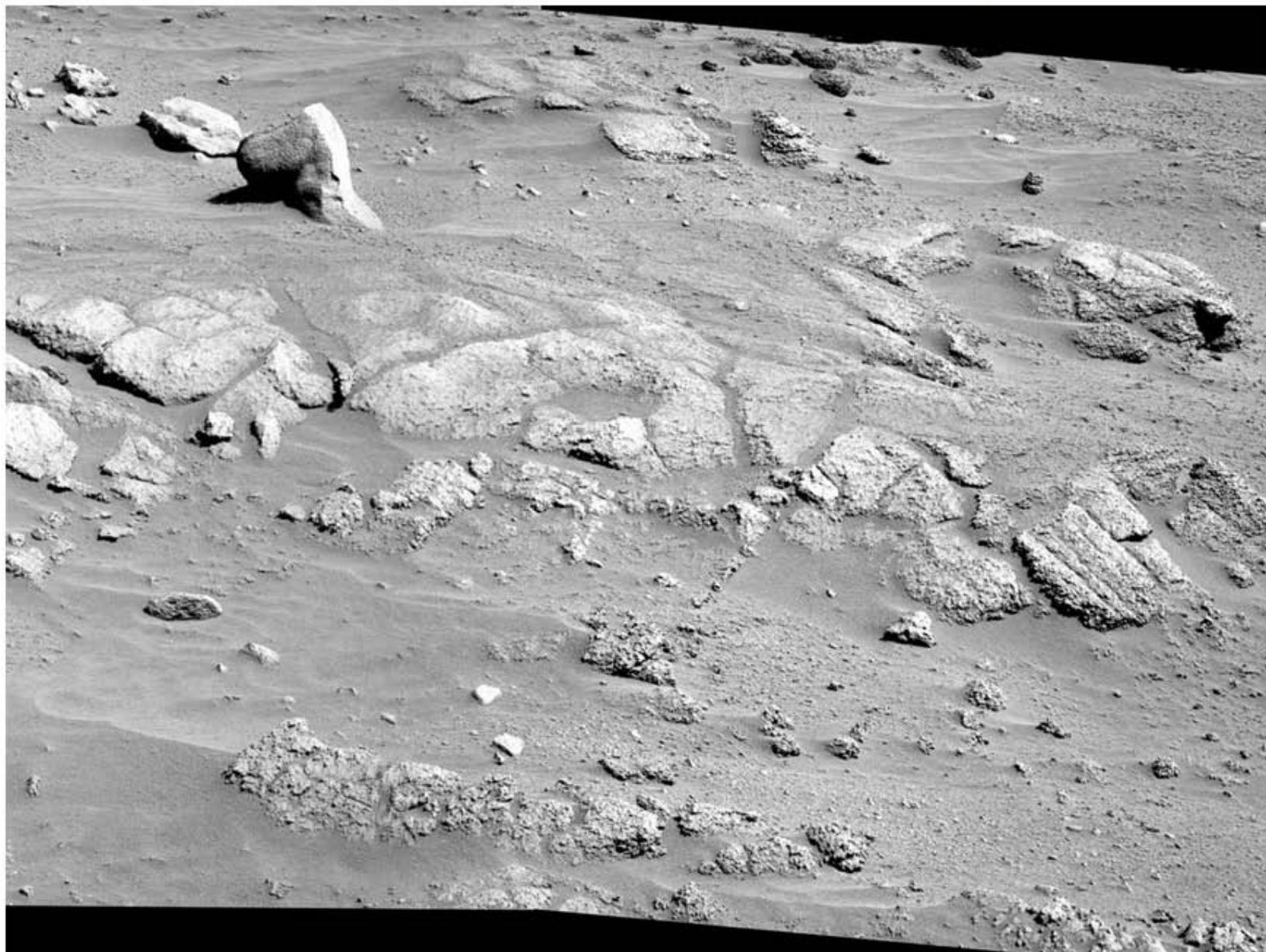
Mars Exploration Rover Mission

- A layered stratigraphic section several meters thick
- Enormous variety in texture:
 - Massive
 - Finely laminated
 - Globular
- Consistent geochemical “fingerprint” through all rocks:
 - High Ti
 - High P
 - Low Cr
- Substantial range in degree of alteration:
 - $\text{Fe}^{3+}/\text{Fe}_{\text{Total}} = 0.4 \text{ to } 0.95$; the most-heavily altered rocks contain goethite
 - Alteration varies both vertically and laterally
- Interpretation:
 - An aqueously-altered volcaniclastic succession. May include both pyroclastics and their reworked equivalents.
 - Phosphorous content is independent of degree of alteration, so the phosphorous is probably primary rather than secondary.

Alligator



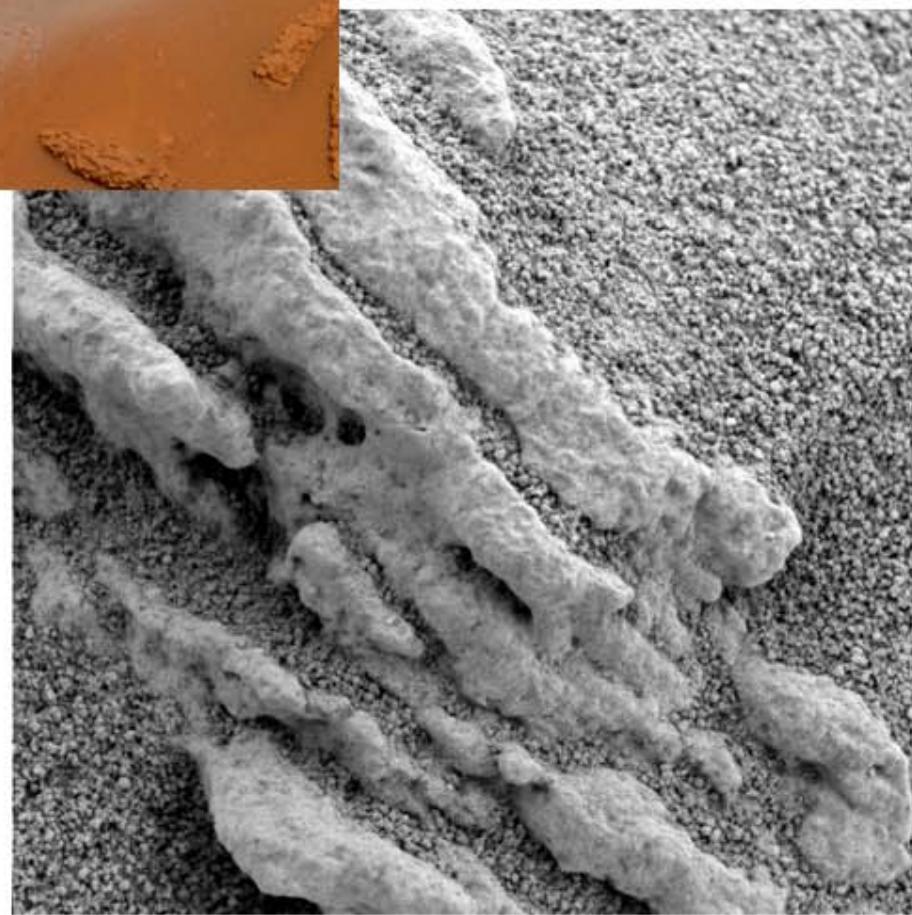
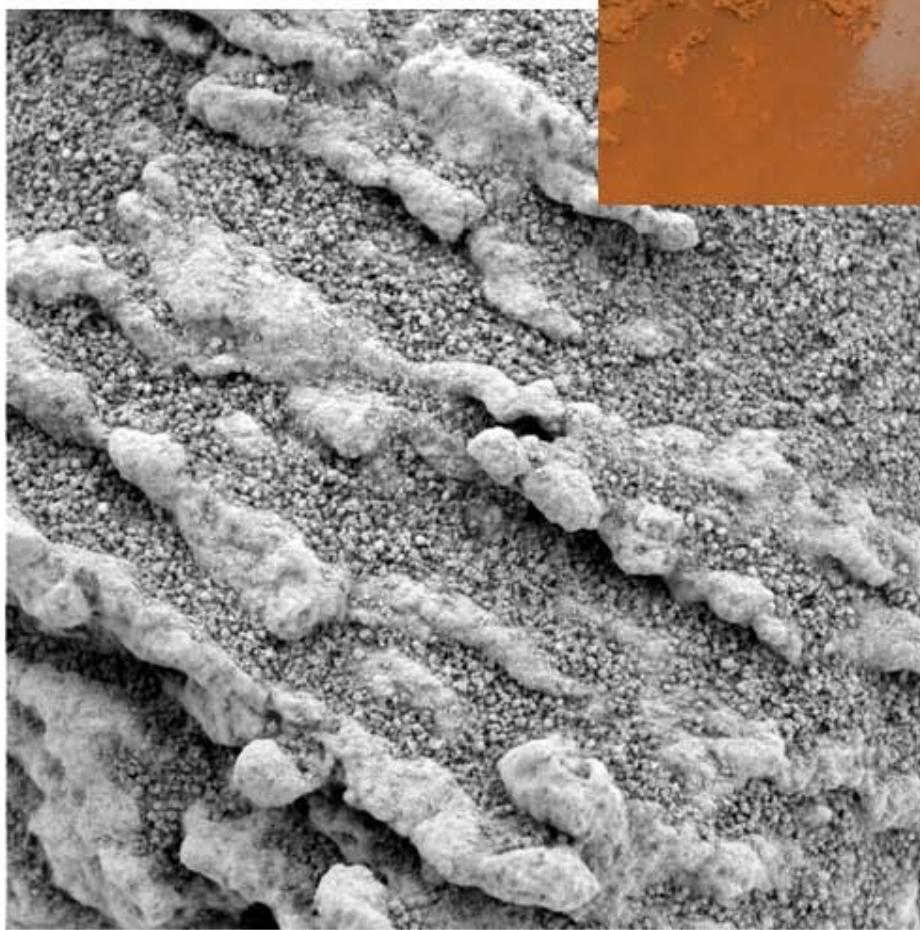
Mars Exploration Rover Mission



Peace



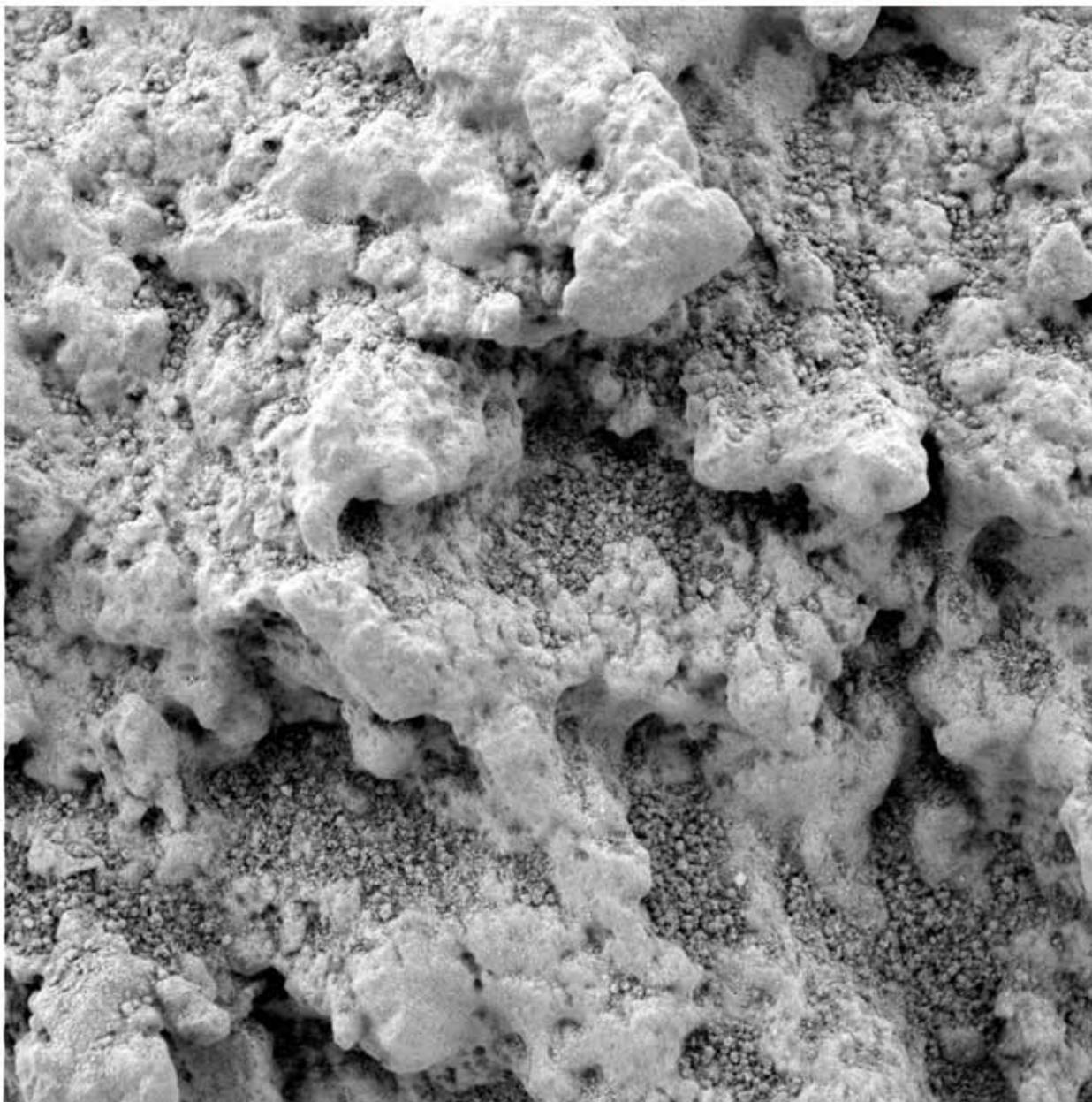
Mars Exploration Rover Mission



Peace



Mars Exploration Rover Mission



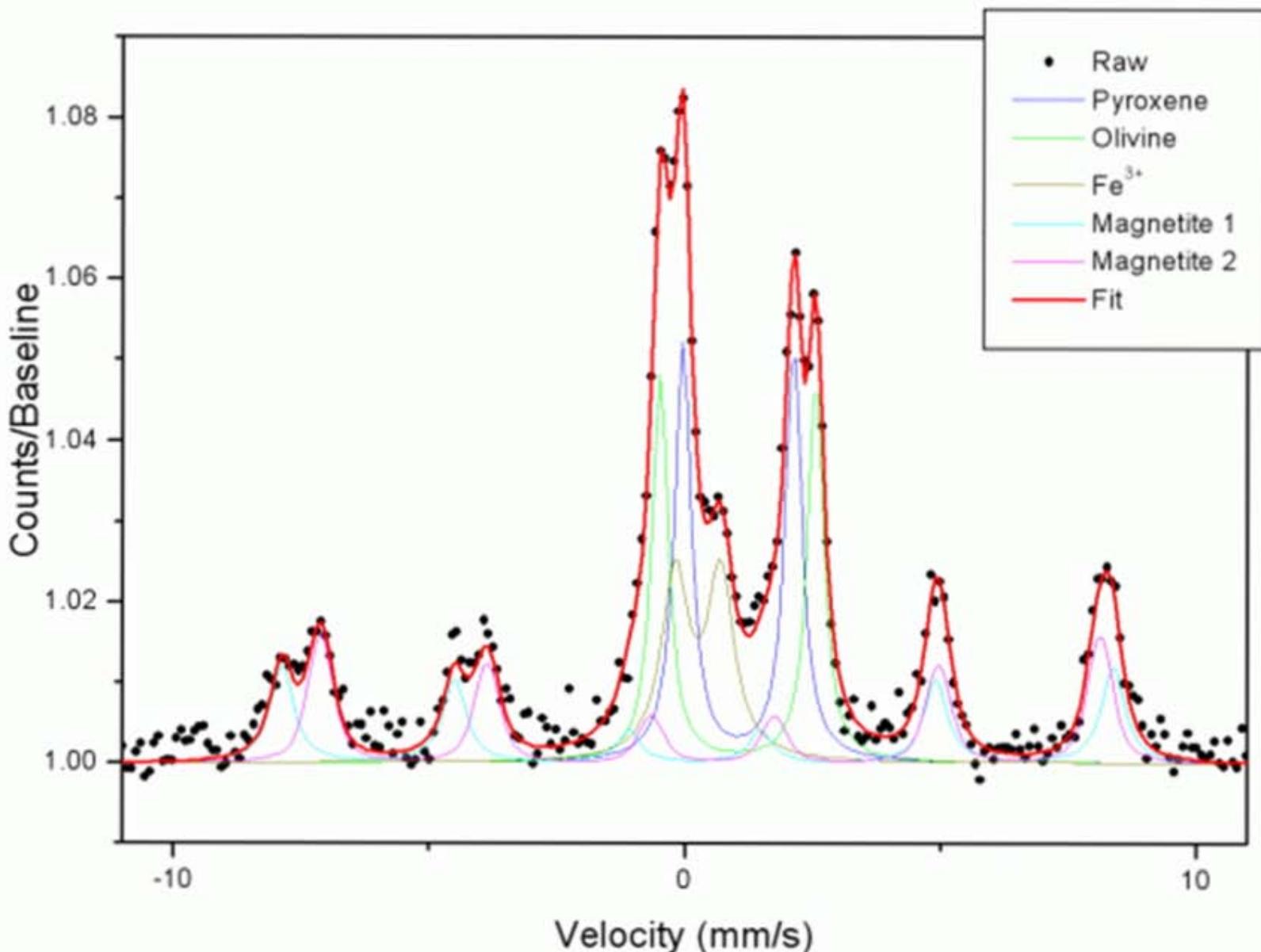
Basaltic Minerals in Peace



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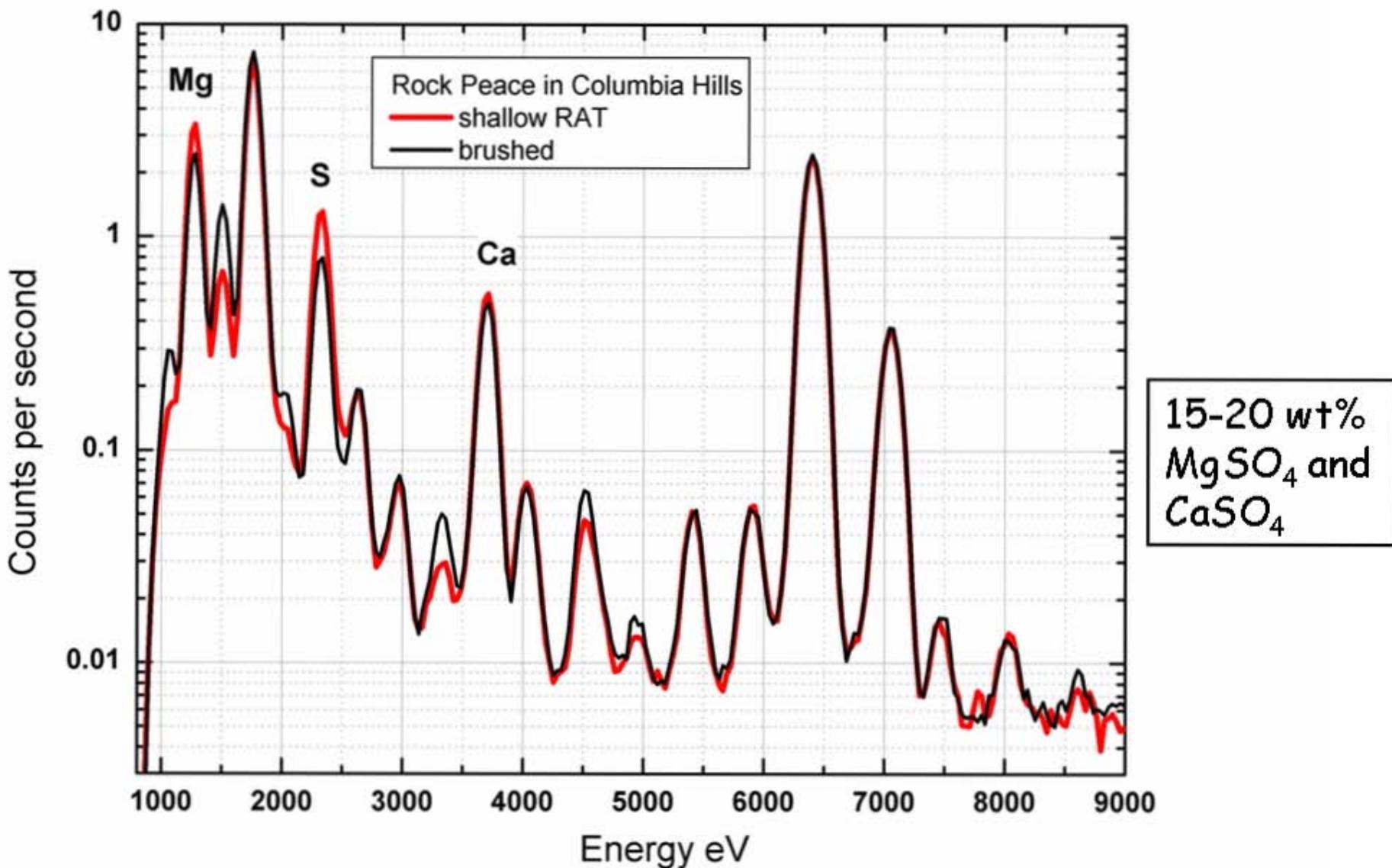
Mars Exploration Rover Mission



Sulfur in Peace



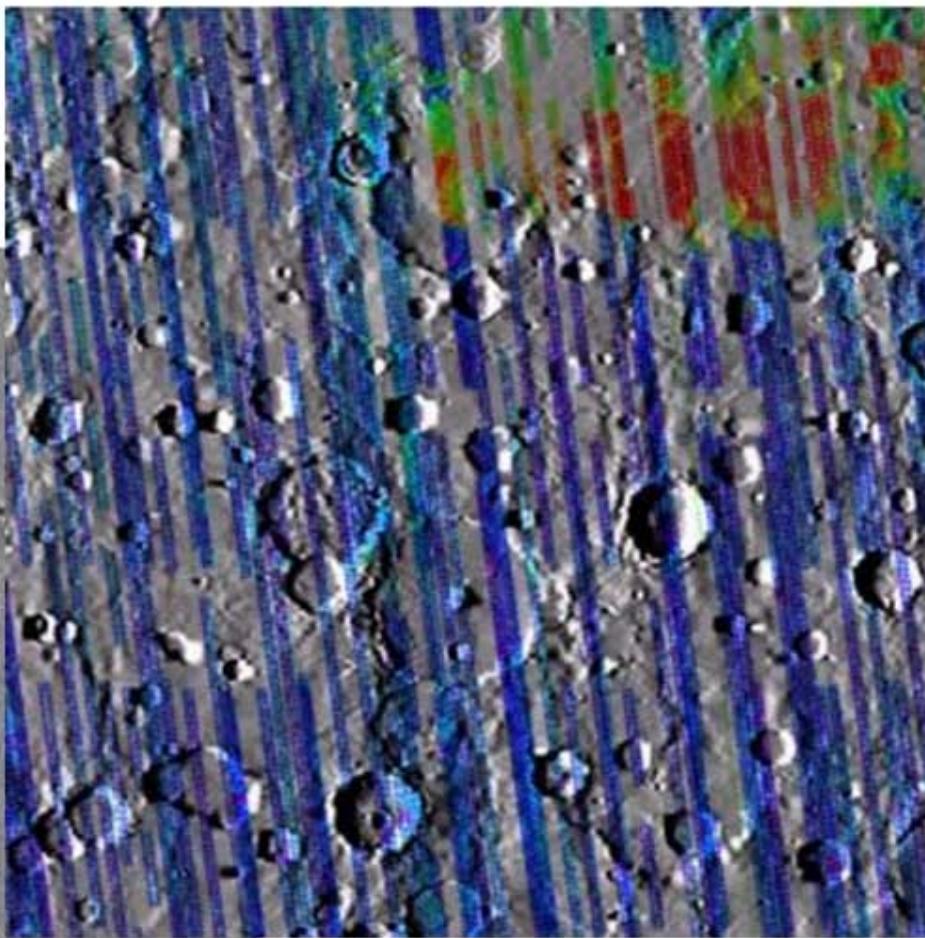
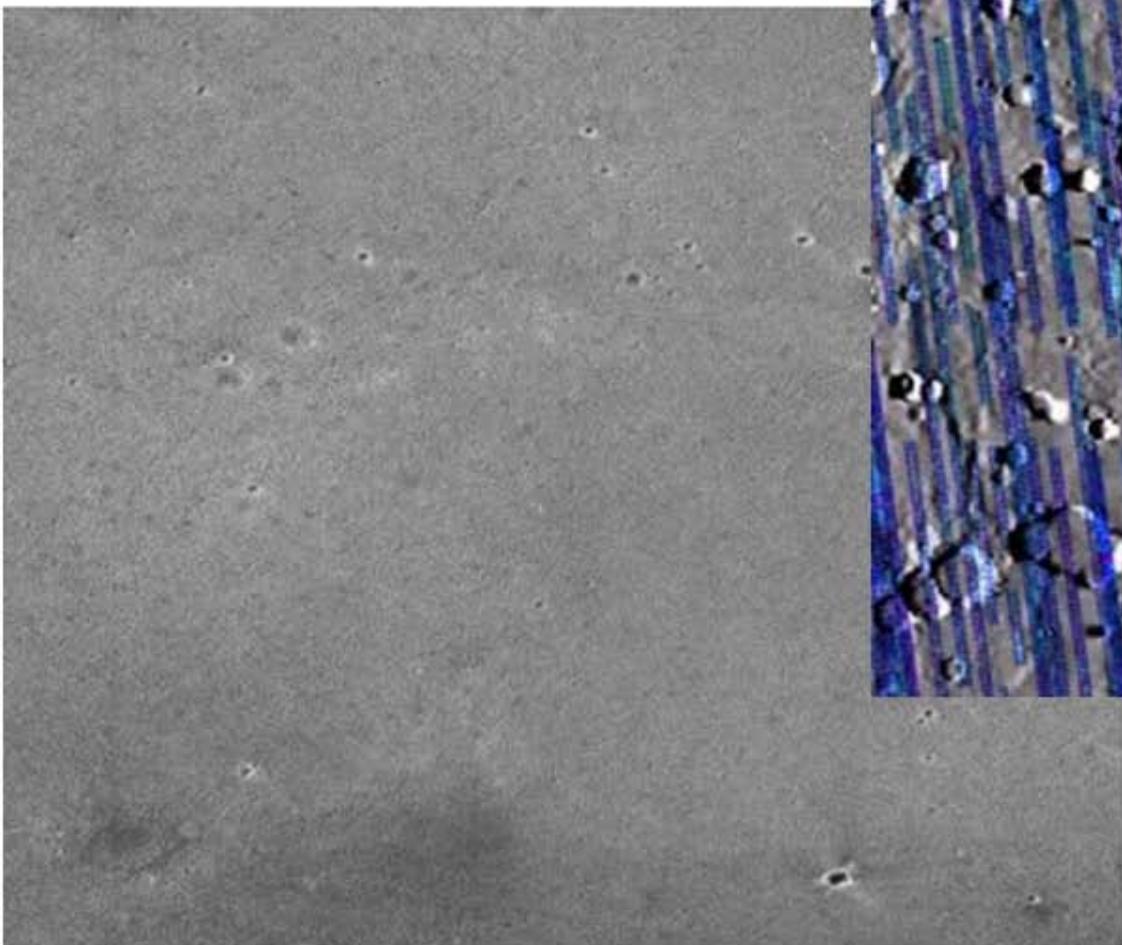
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Opportunity: Meridiani Planum



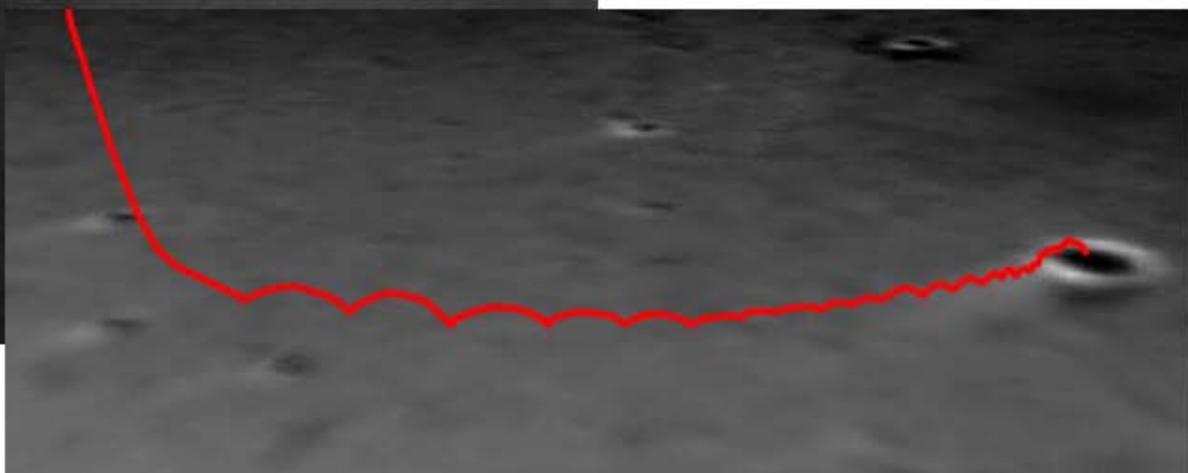
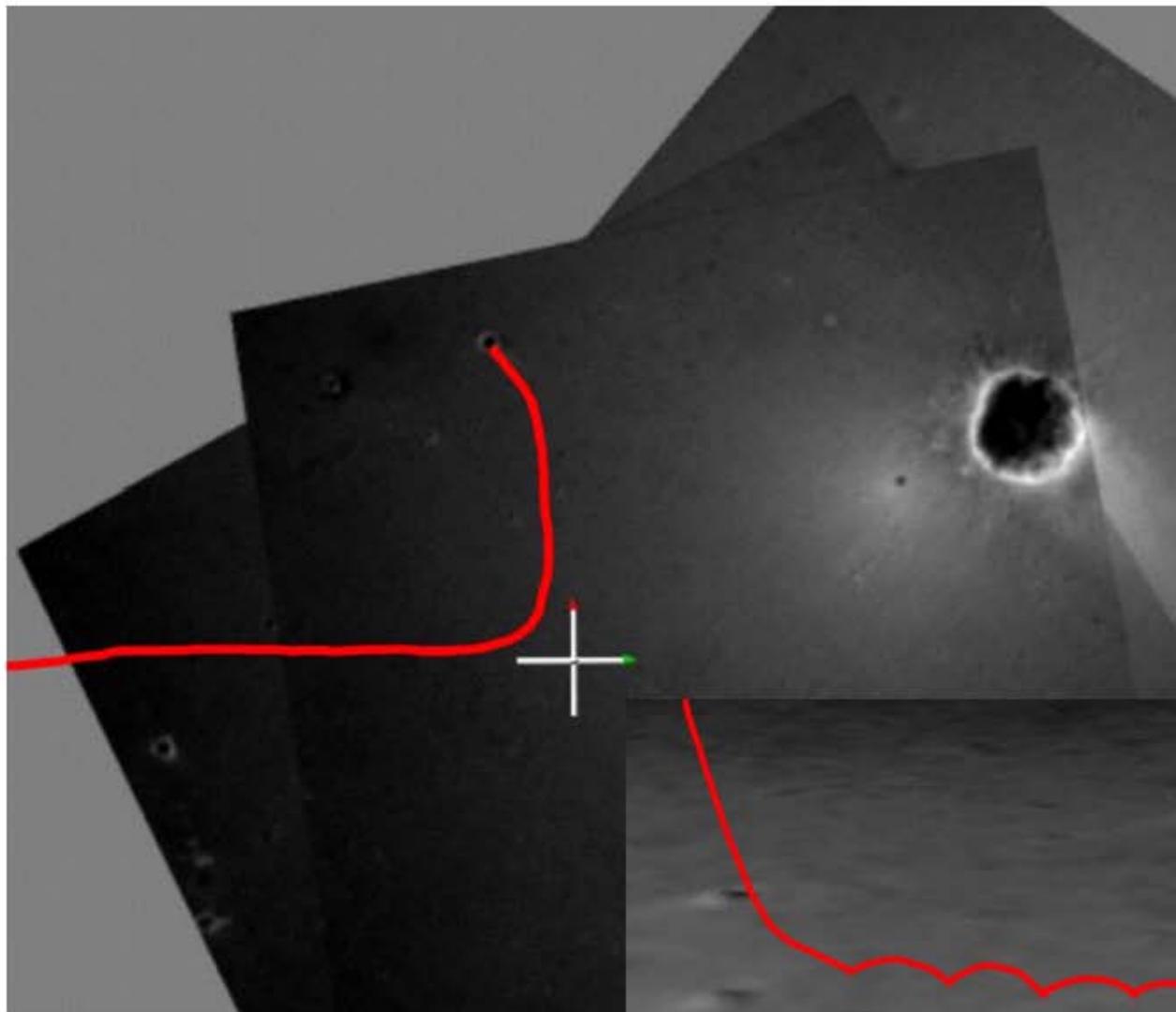
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Final Descent Trajectory



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Opportunity Ledge



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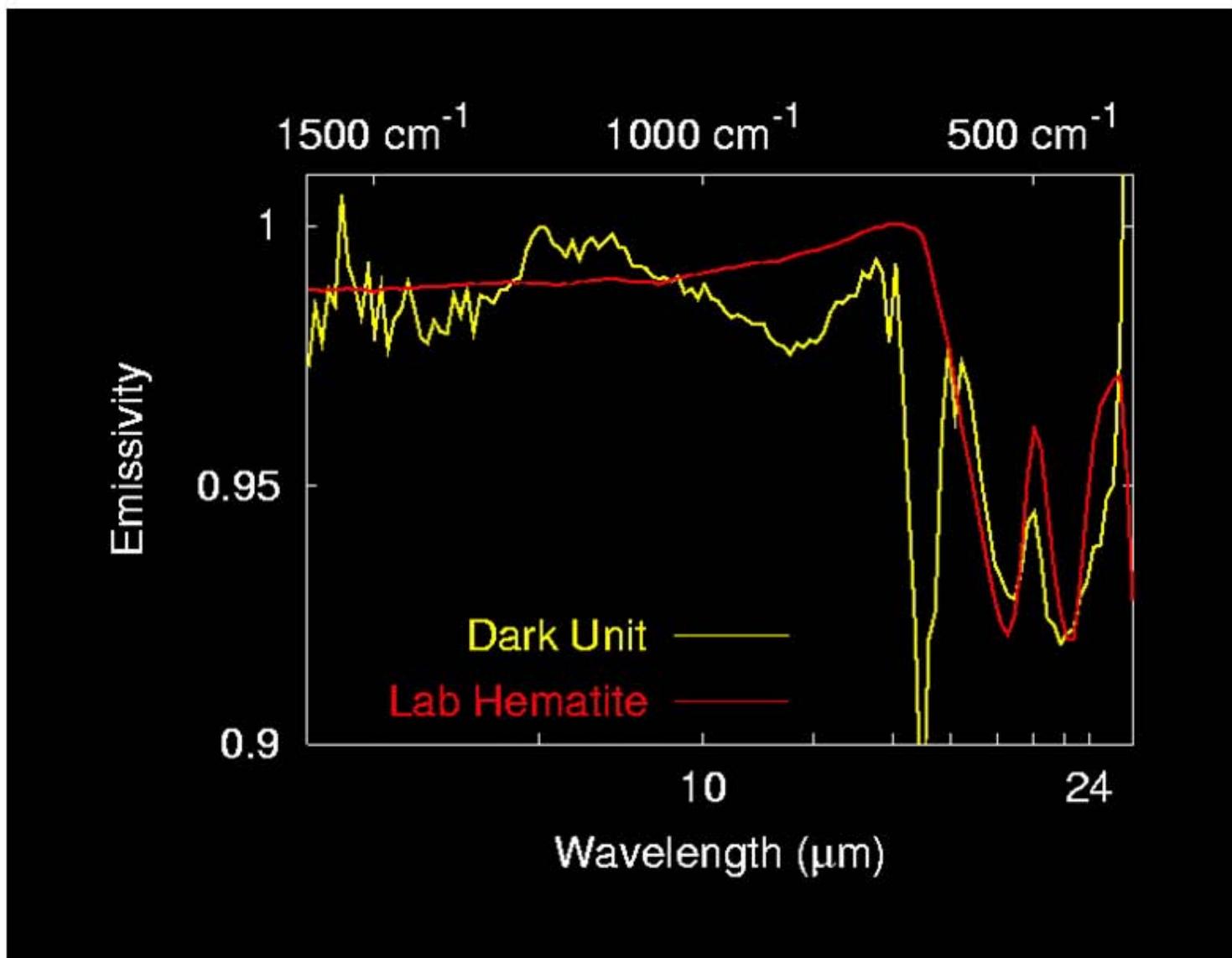
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Mini-TES on Meridiani Soil



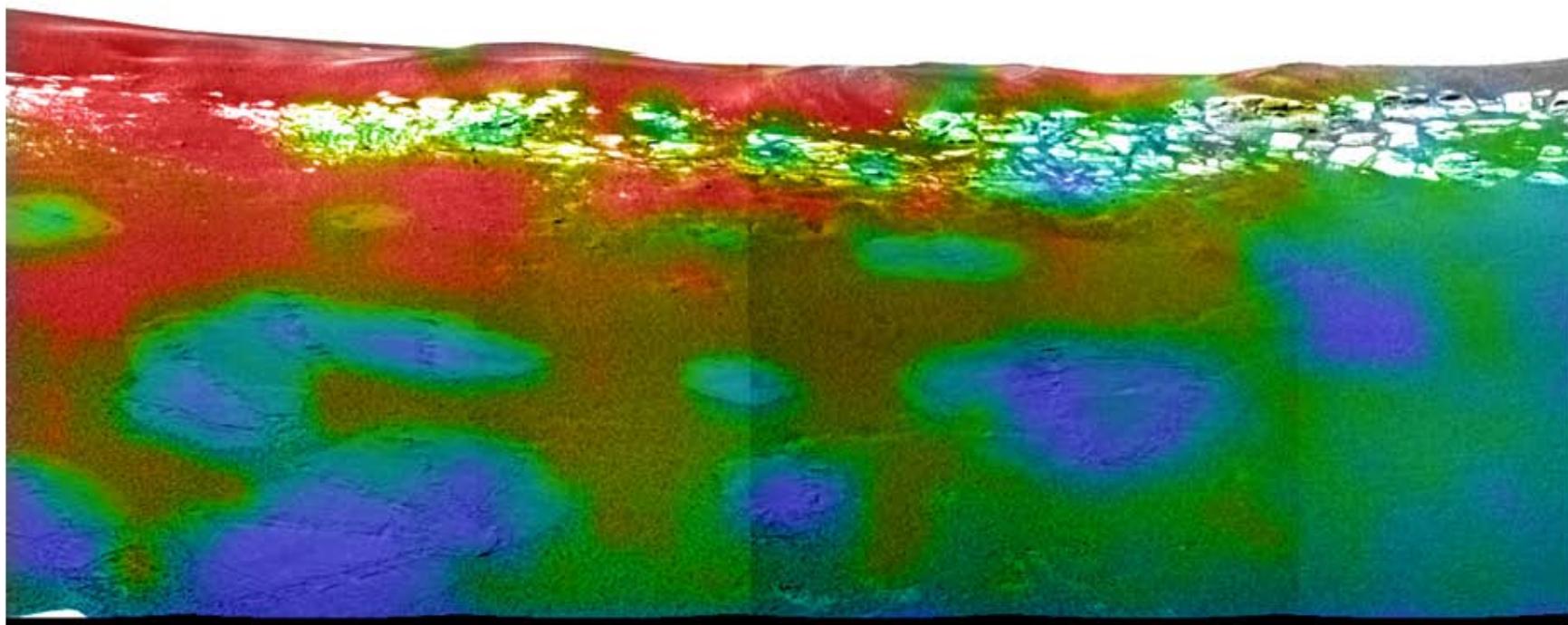
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Hematite Distribution



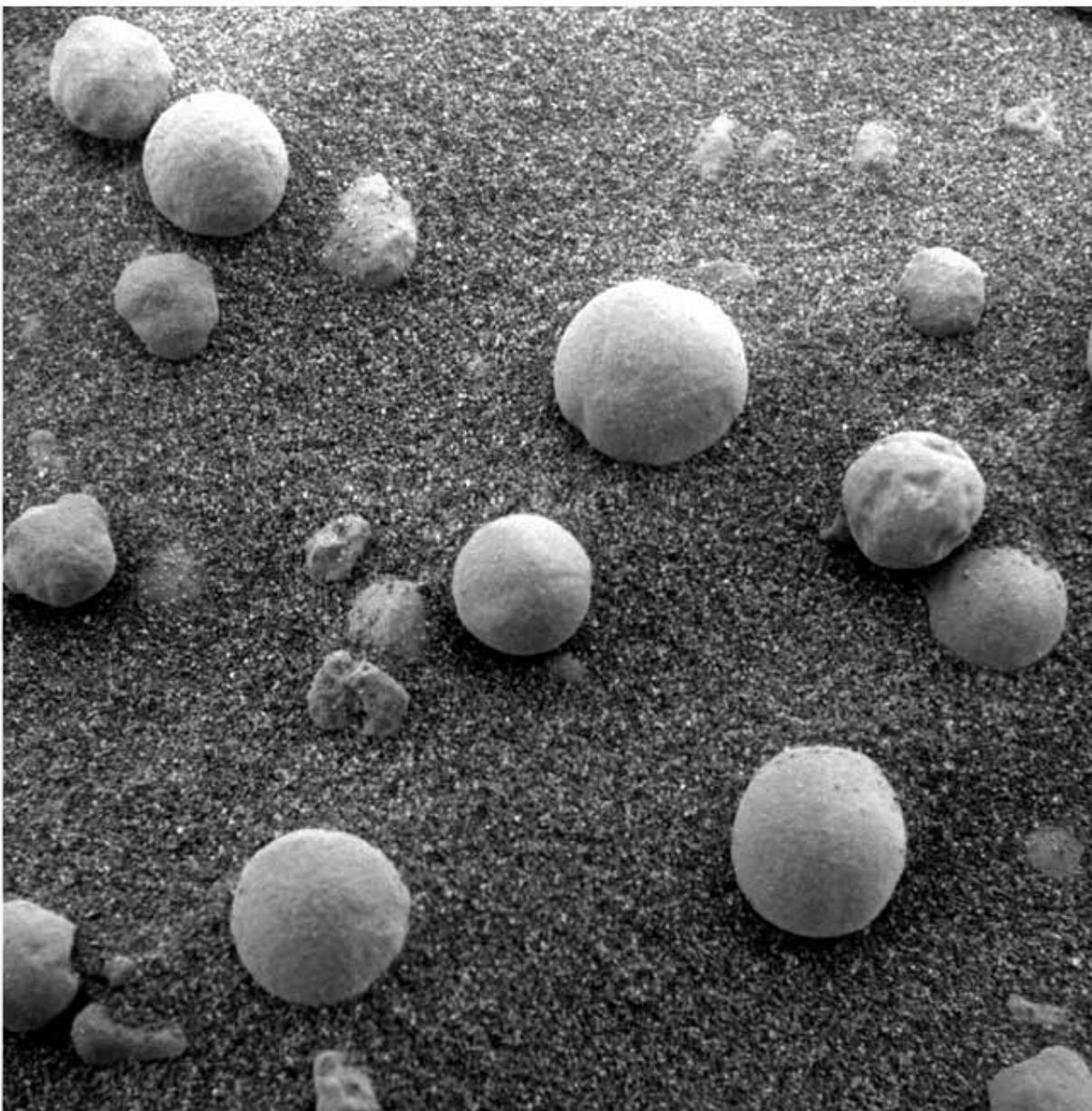
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Spherical Granules (Spherules)



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Opportunity Ledge Close-Up



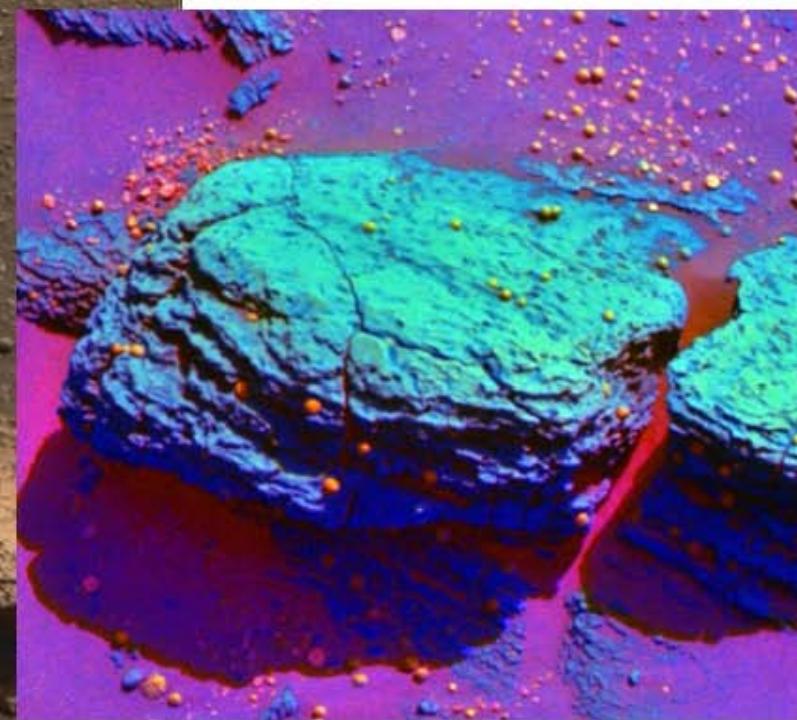
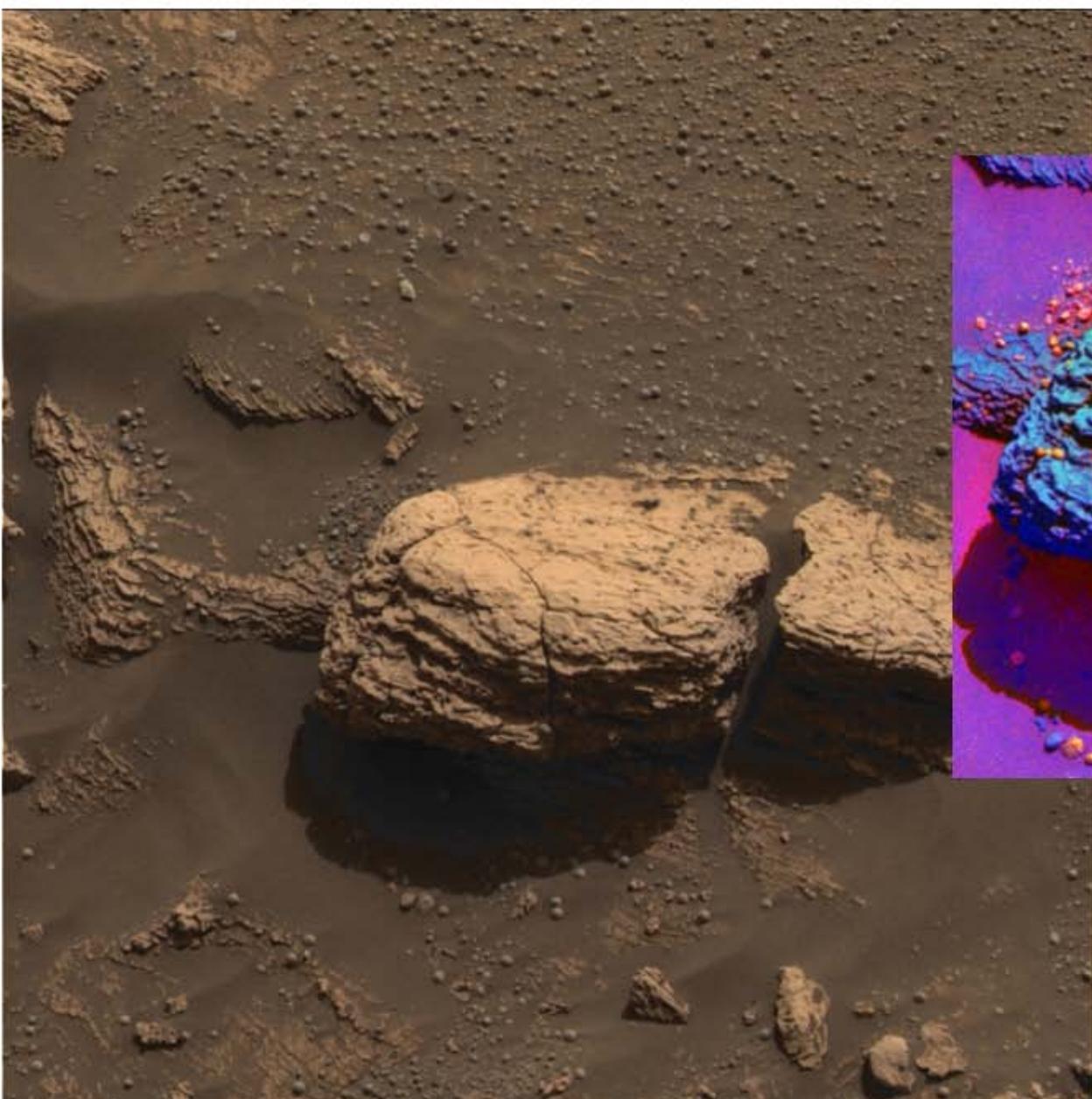
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Pancam on Stone Mountain



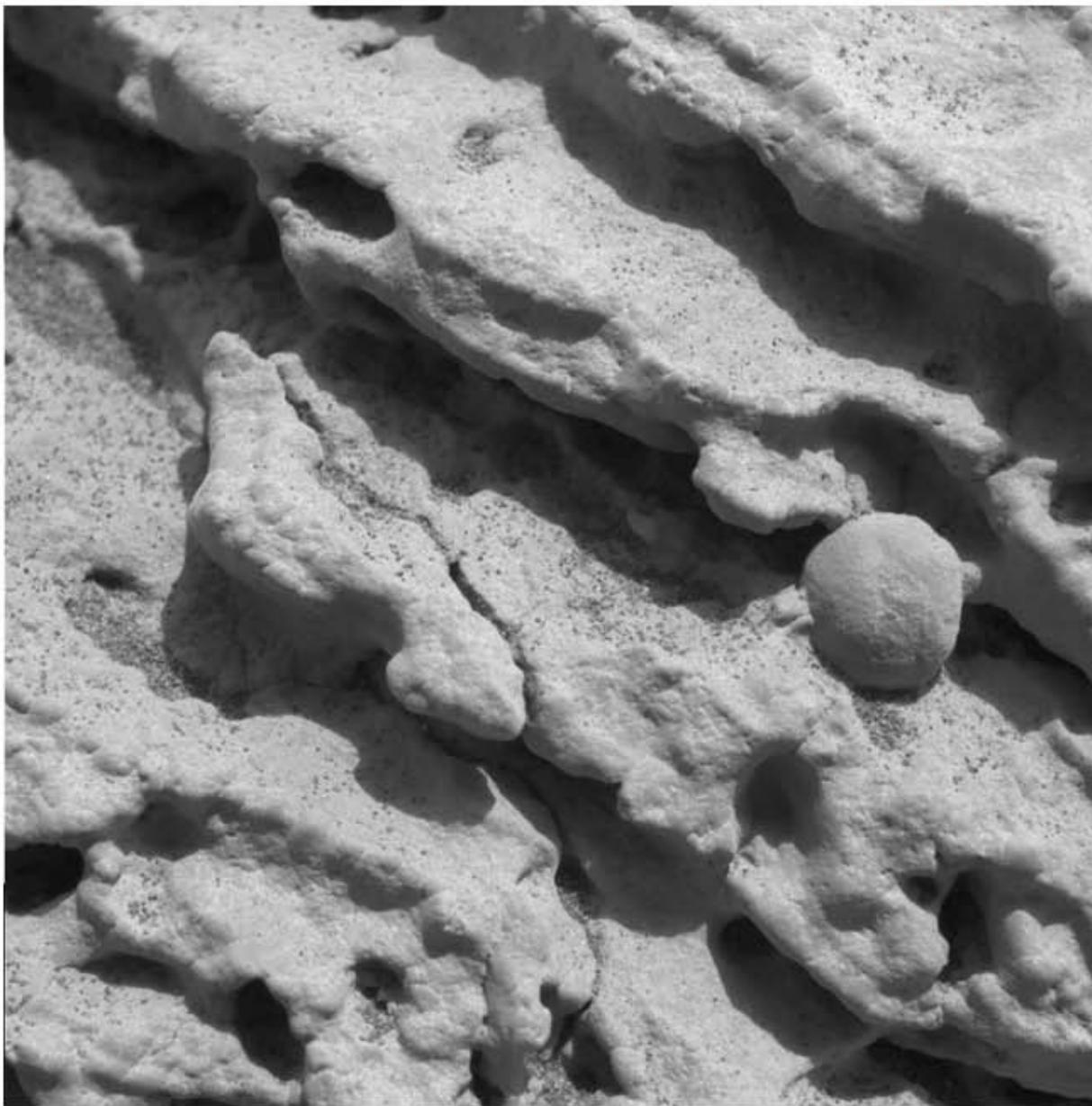
Mars Exploration Rover Mission



MI on Stone Mountain



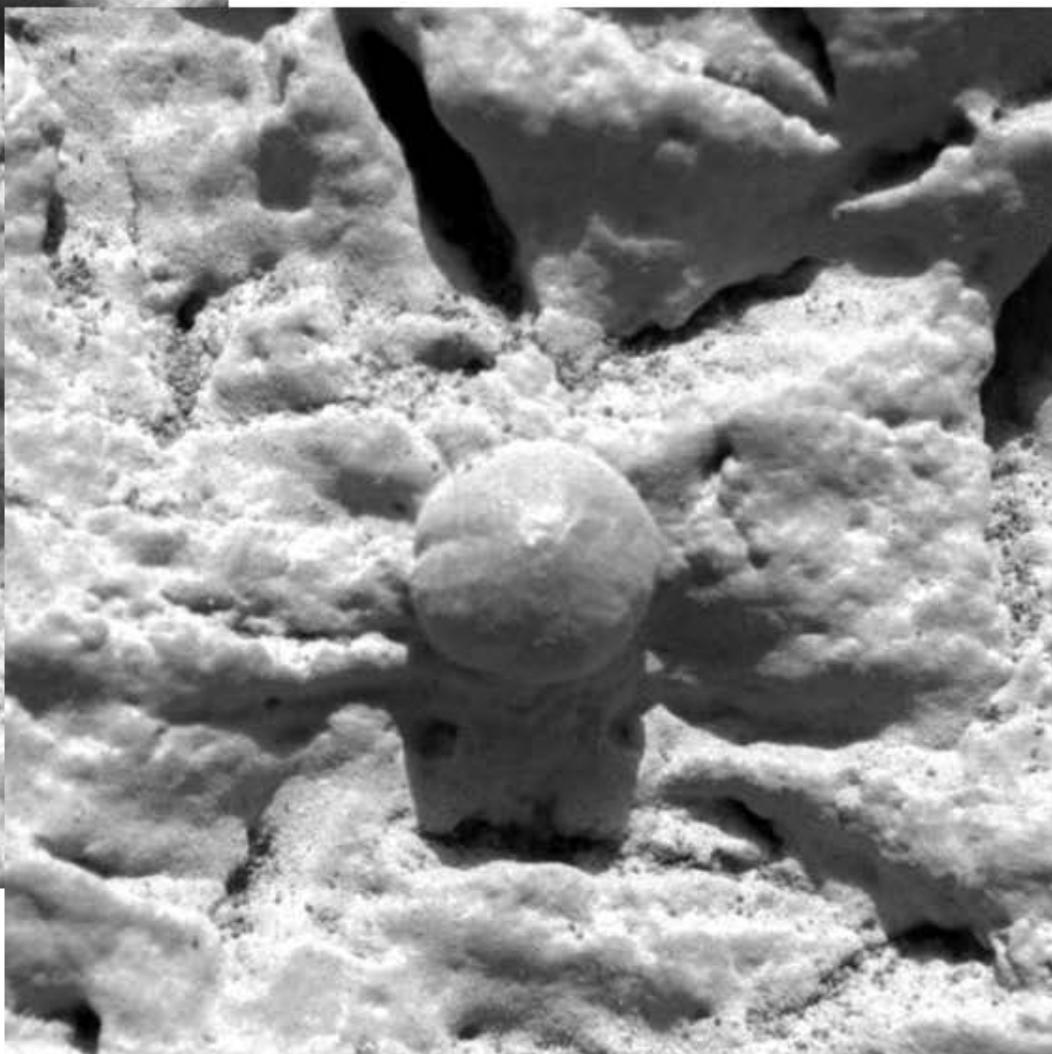
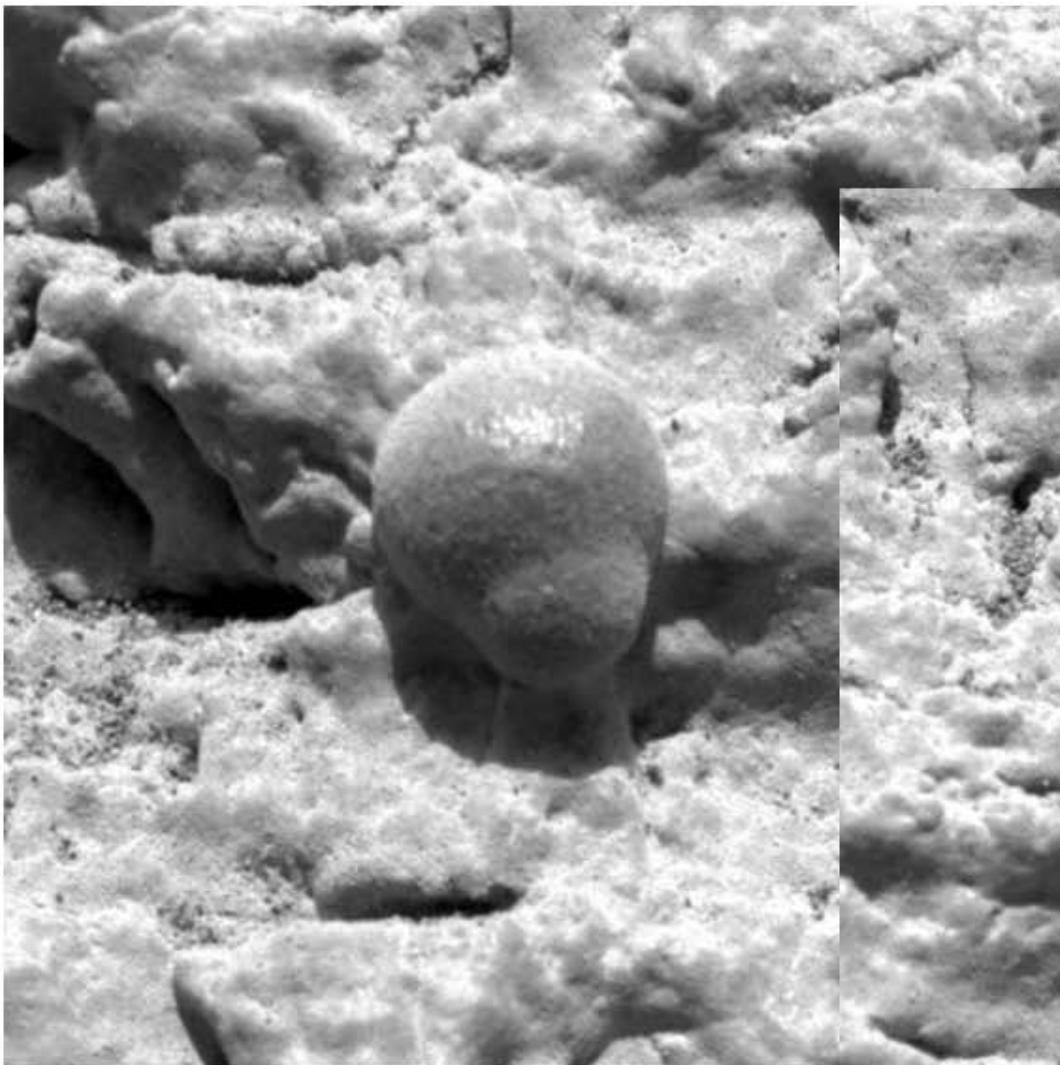
Mars Exploration Rover Mission



Spherule Morphology



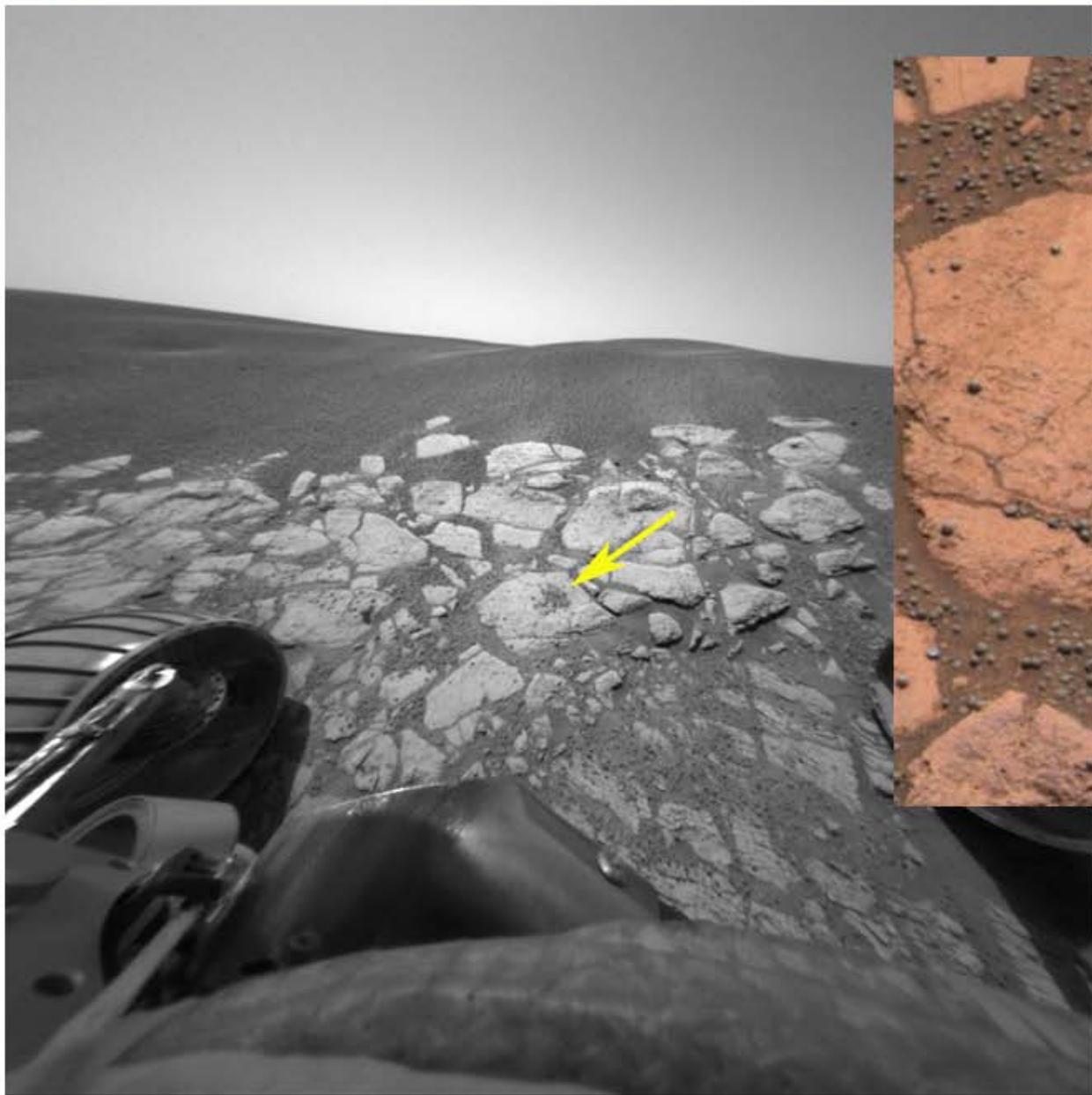
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The “Berry Bowl”



Mars Exploration Rover Mission

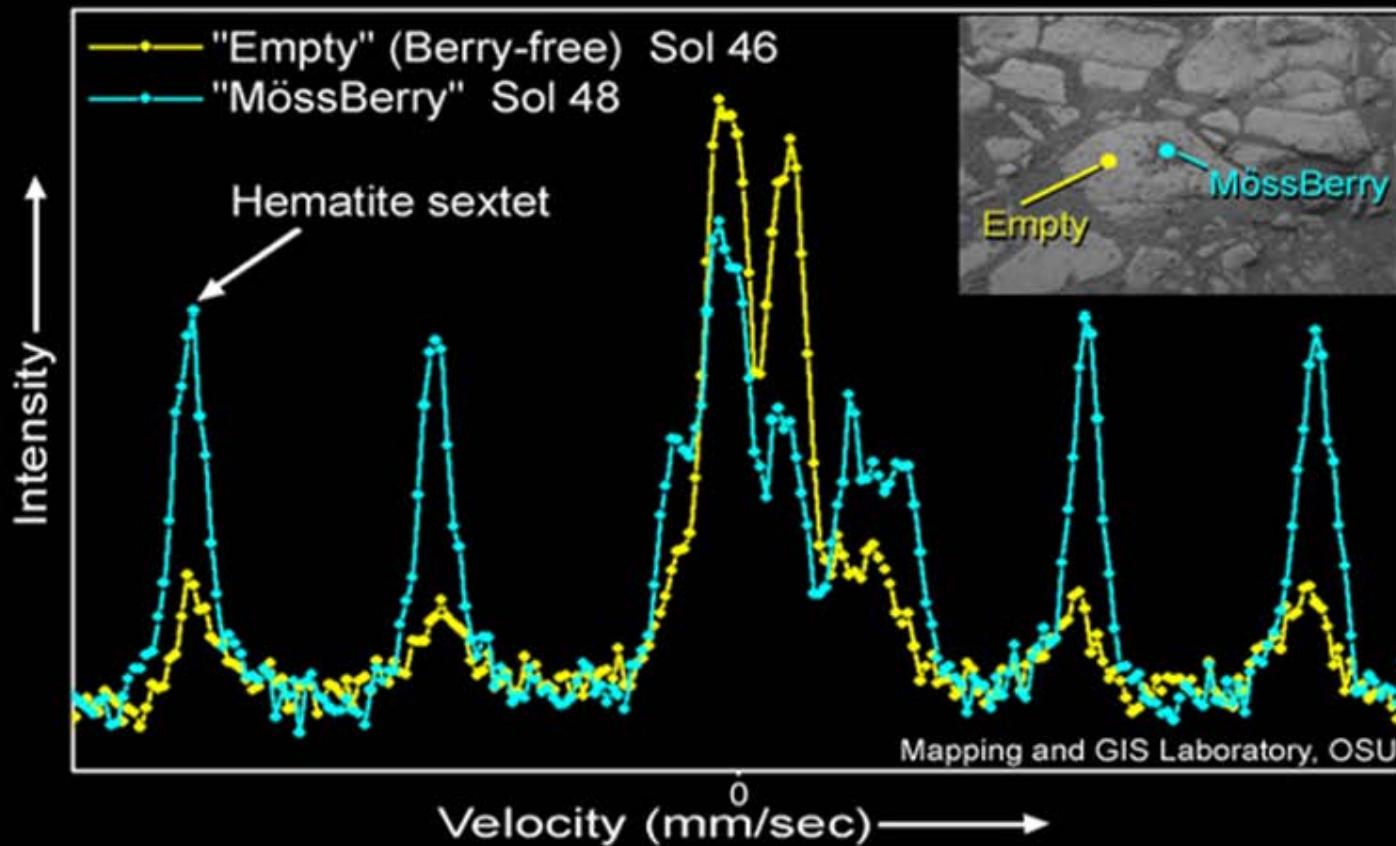


Mössbauer on the Berry Bowl



Mars Exploration Rover Mission

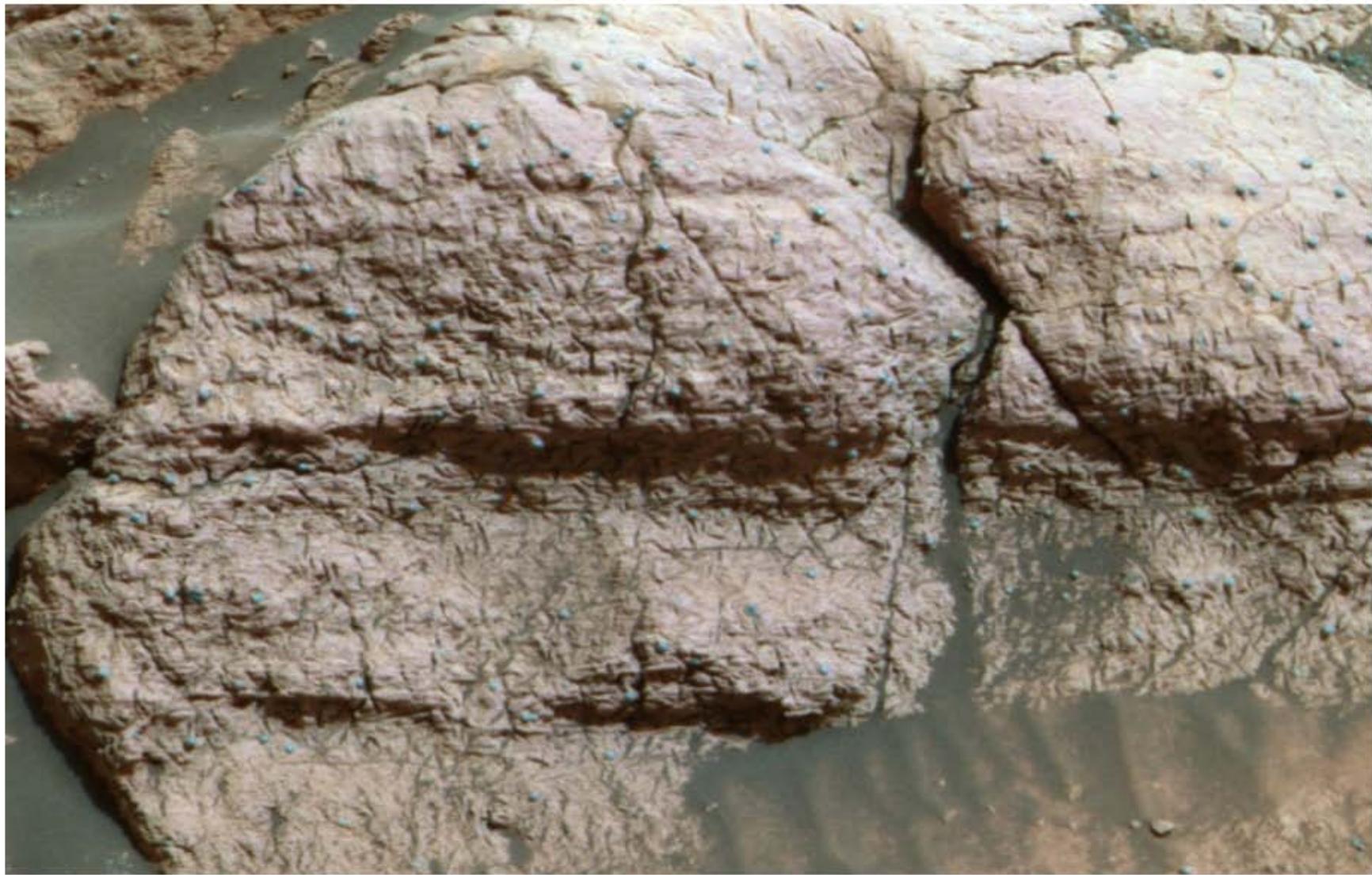
Mössbauer spectra of the BlueBerry bowl
and bare outcrop at Meridiani Planum



Pancam on El Capitan



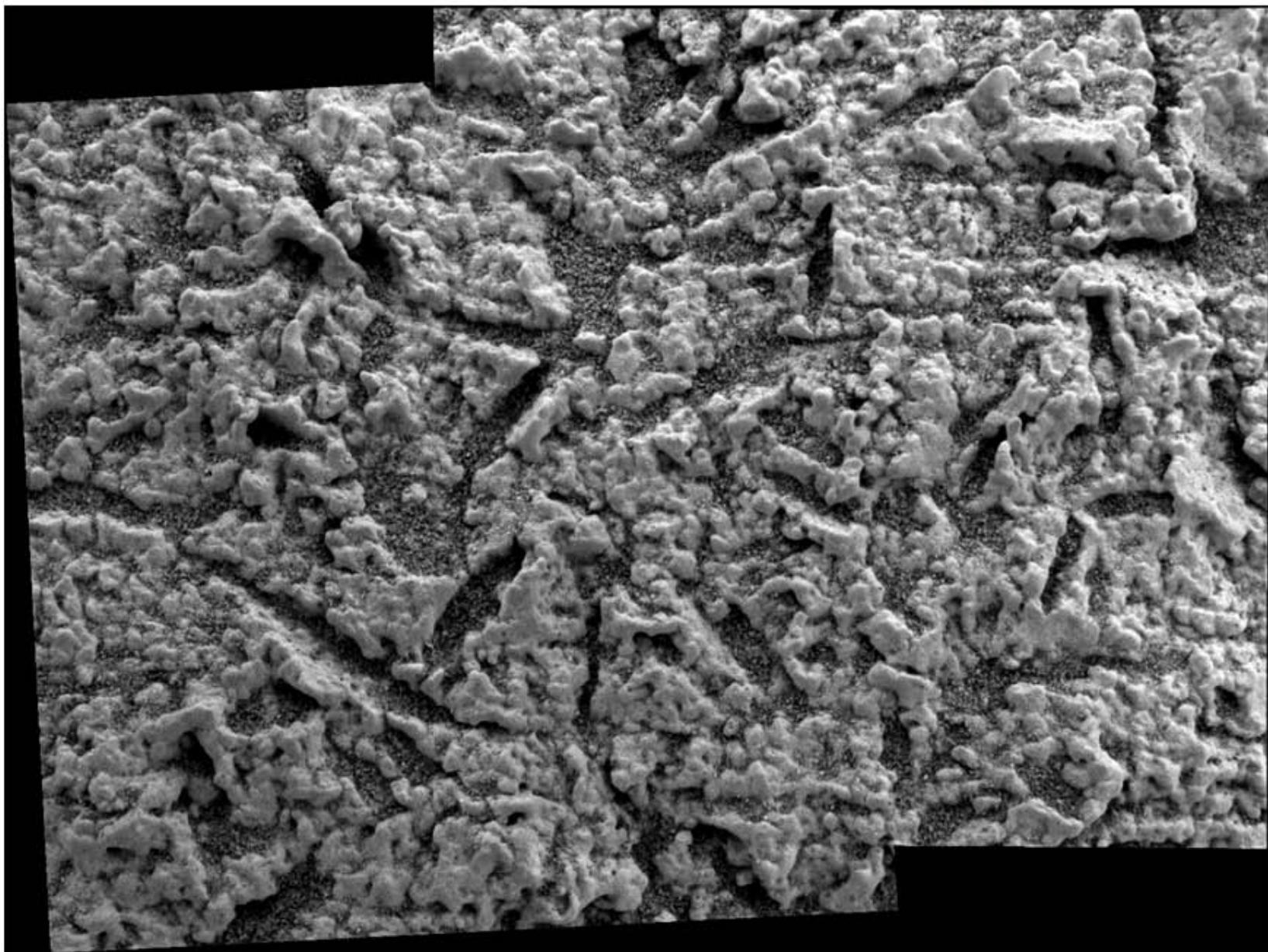
Mars Exploration Rover Mission



MI on El Capitan



Mars Exploration Rover Mission



APXS Data on El Capitan



JPL

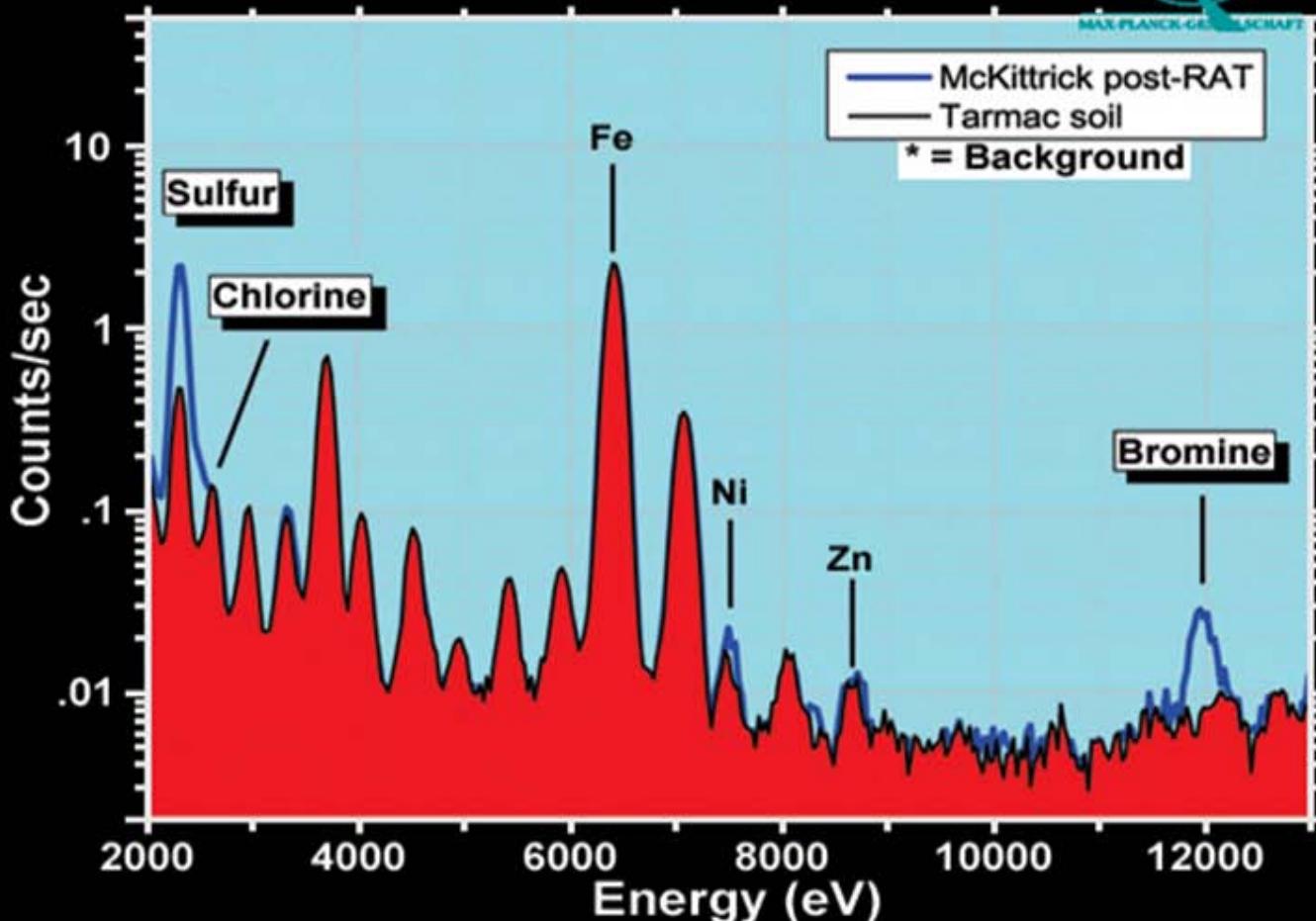
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APXS Rock and Soil X-ray Spectra at Meridiani



MAX-PLANCK-GESSELLSCHAFT

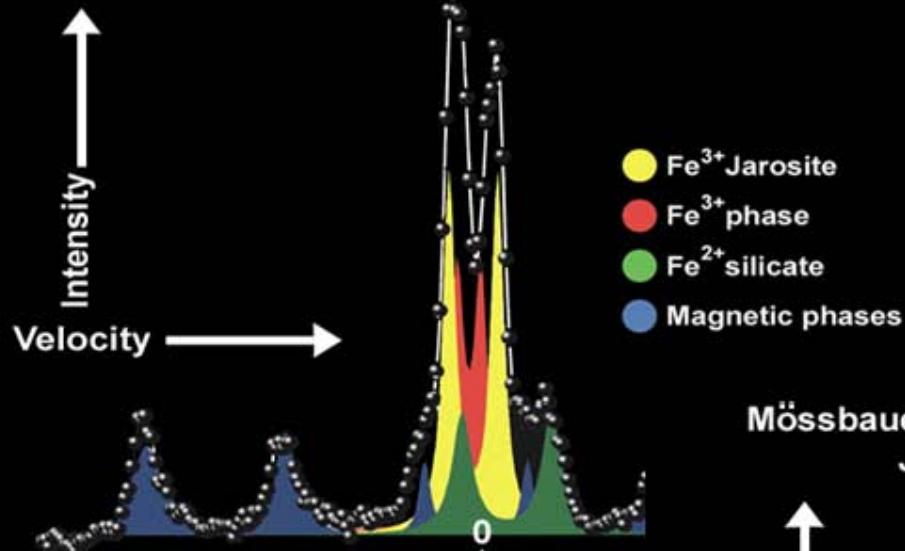


Mössbauer Data on El Capitan

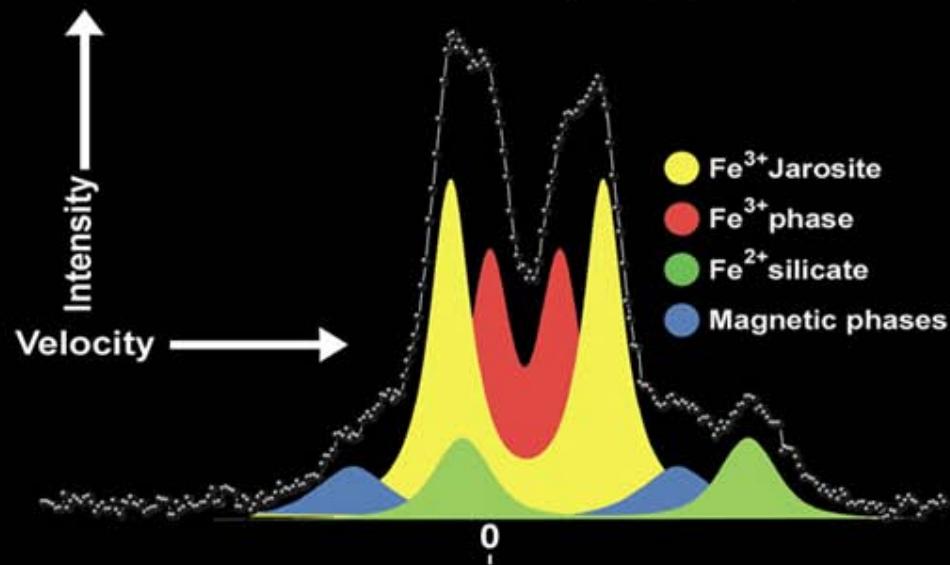


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Mössbauer Spectrum of El Capitan: Meridiani Planum
Jarosite: $(K, Na, X^{+1})Fe_3(SO_4)_2(OH)_6$



Mössbauer Spectrum of El Capitan: Meridiani Planum
Jarosite: $(K, Na, X^{+1})Fe_3(SO_4)_2(OH)_6$



Bromine vs. Chlorine

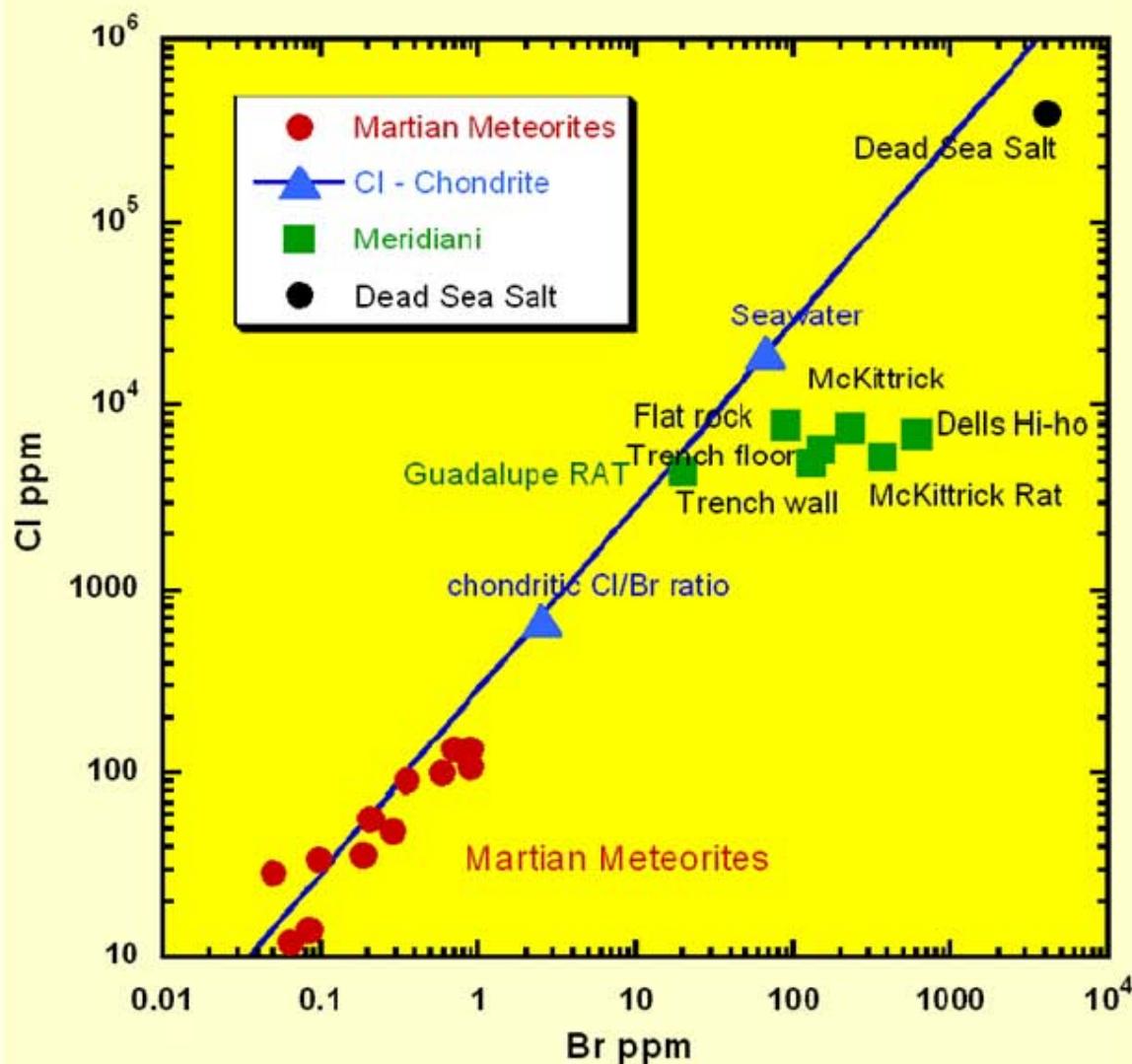


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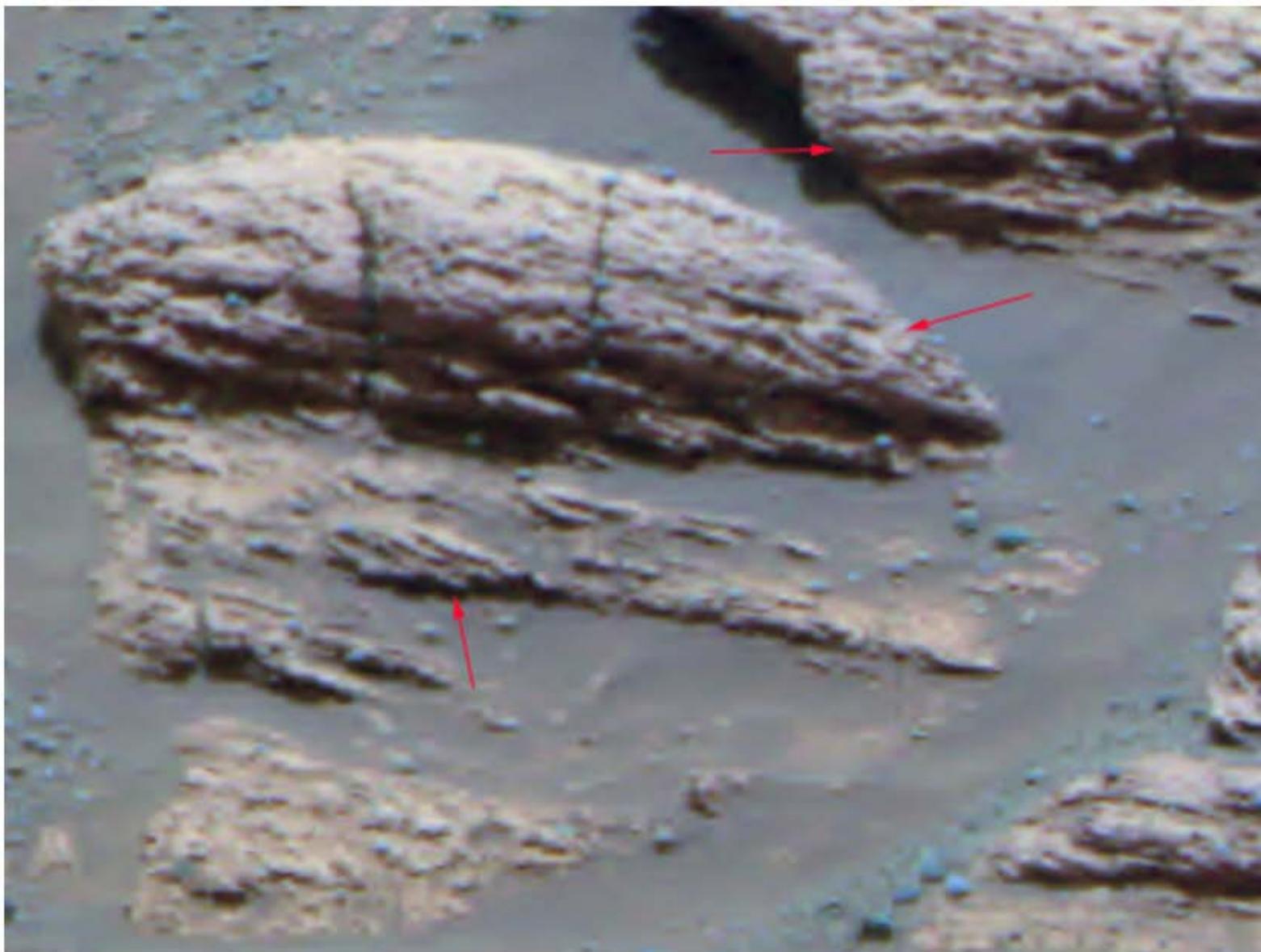
Chlorine and Bromine in samples of Meridiani Planum and Martian Meteorites



Pancam on "Last Chance"



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Current Ripples in Water



Mars Exploration Rover Mission



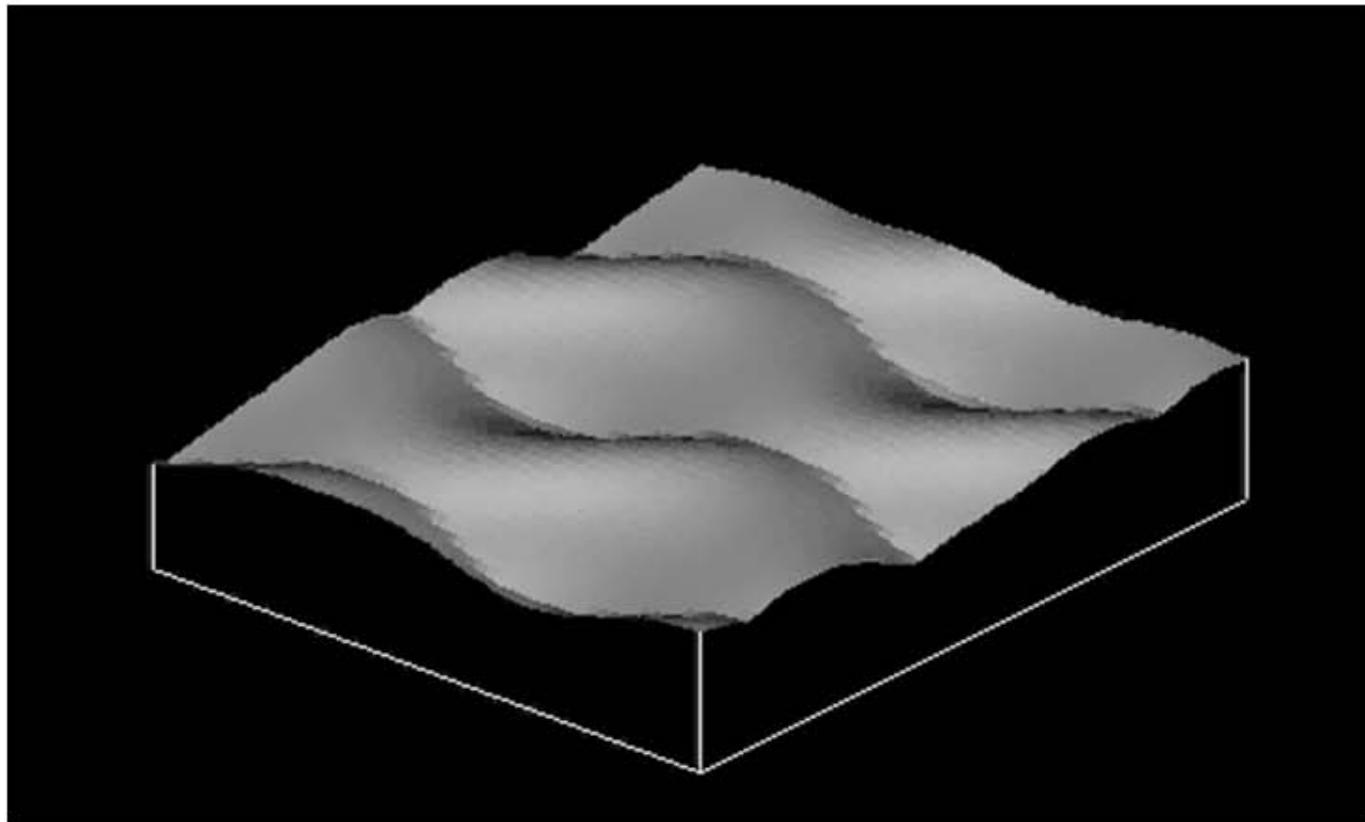
40 cm

Flume experiments by Dave Rubin, USGS

Current Ripples in Cross Section



Mars Exploration Rover Mission



Simulations by Dave Rubin, USGS

Current Ripples On Earth



Mars Exploration Rover Mission

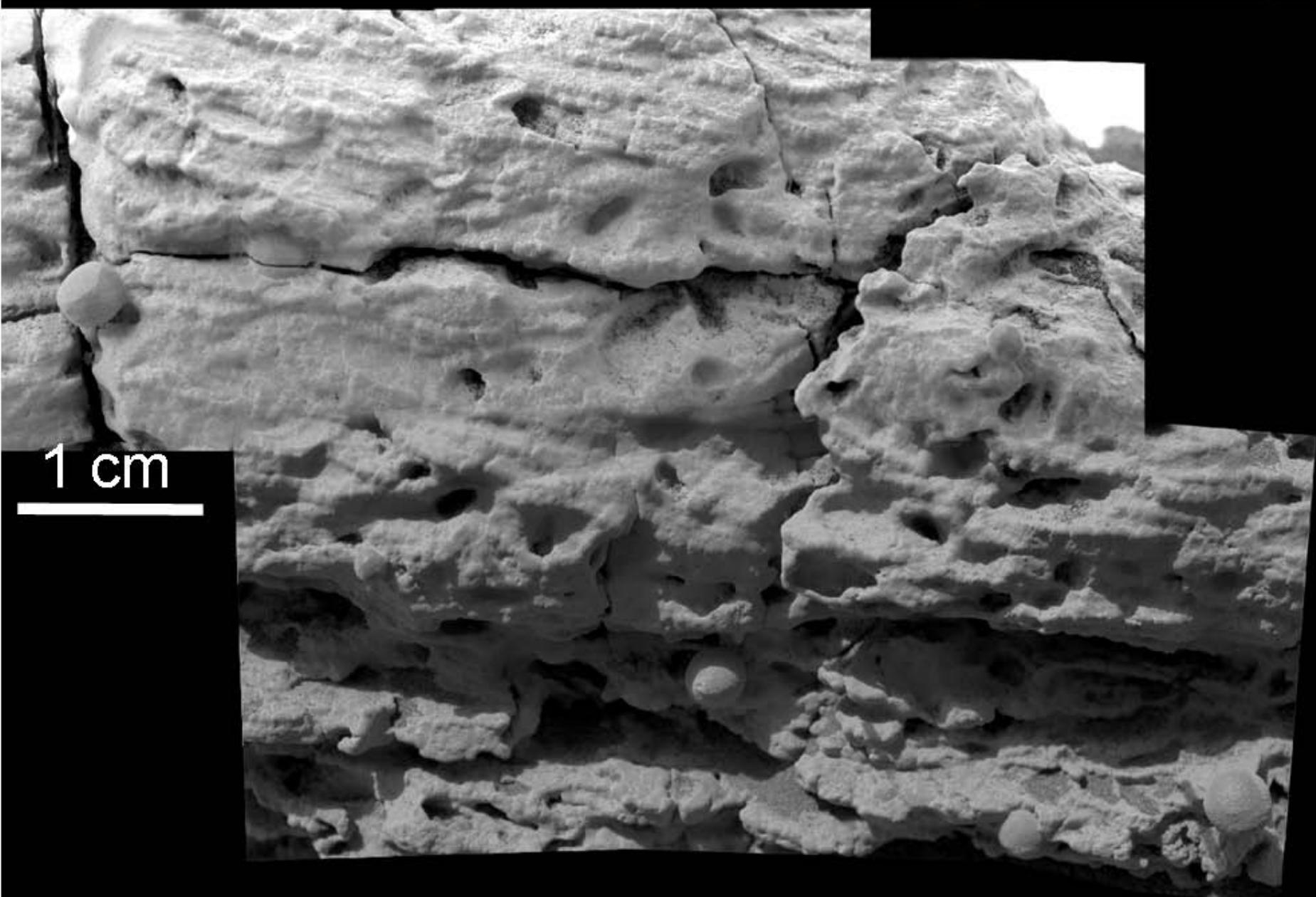


Courtesy of Dave Rubin, USGS

Current Ripples On Mars



Mars Exploration Rover Mission



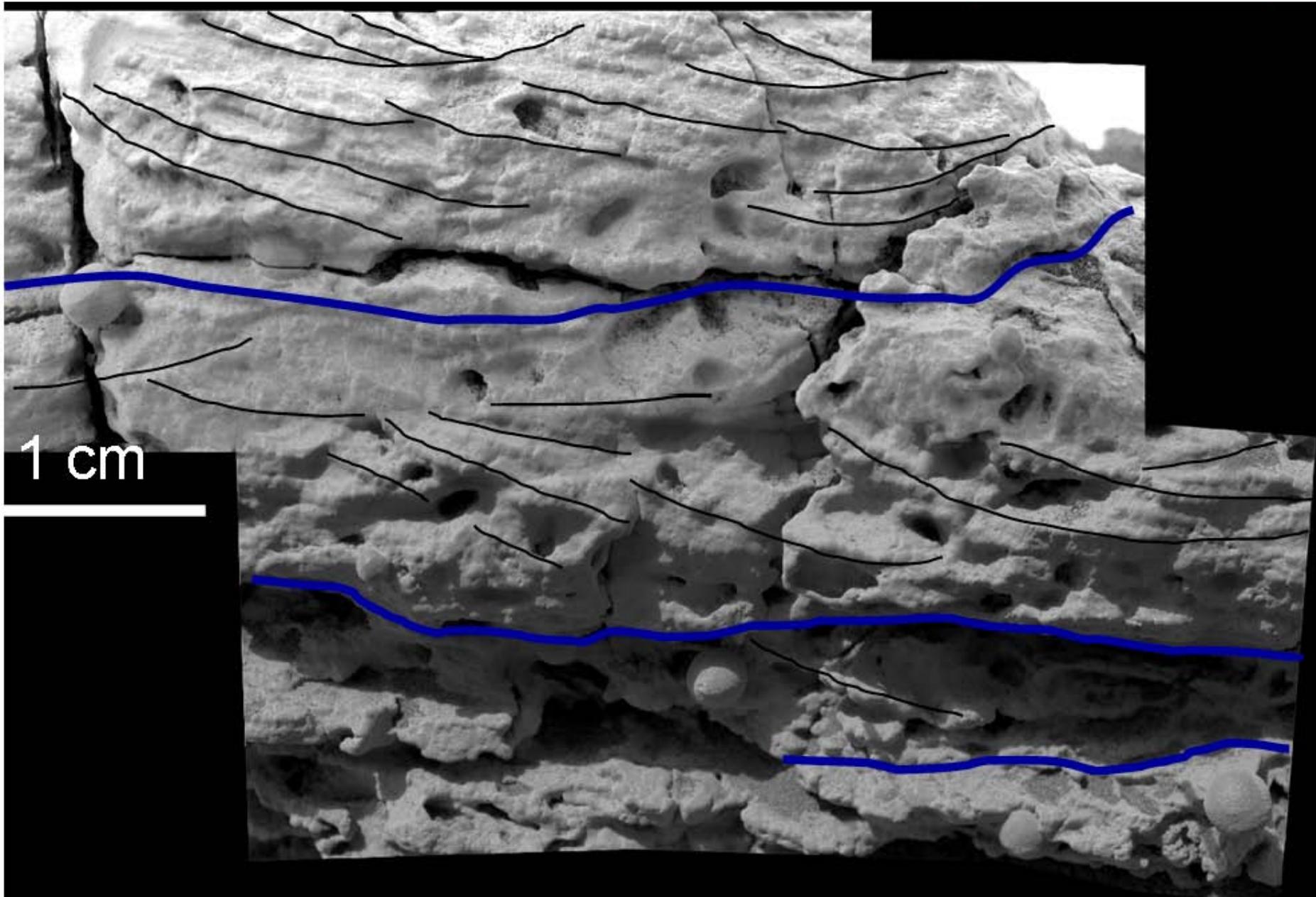
Current Ripples On Mars



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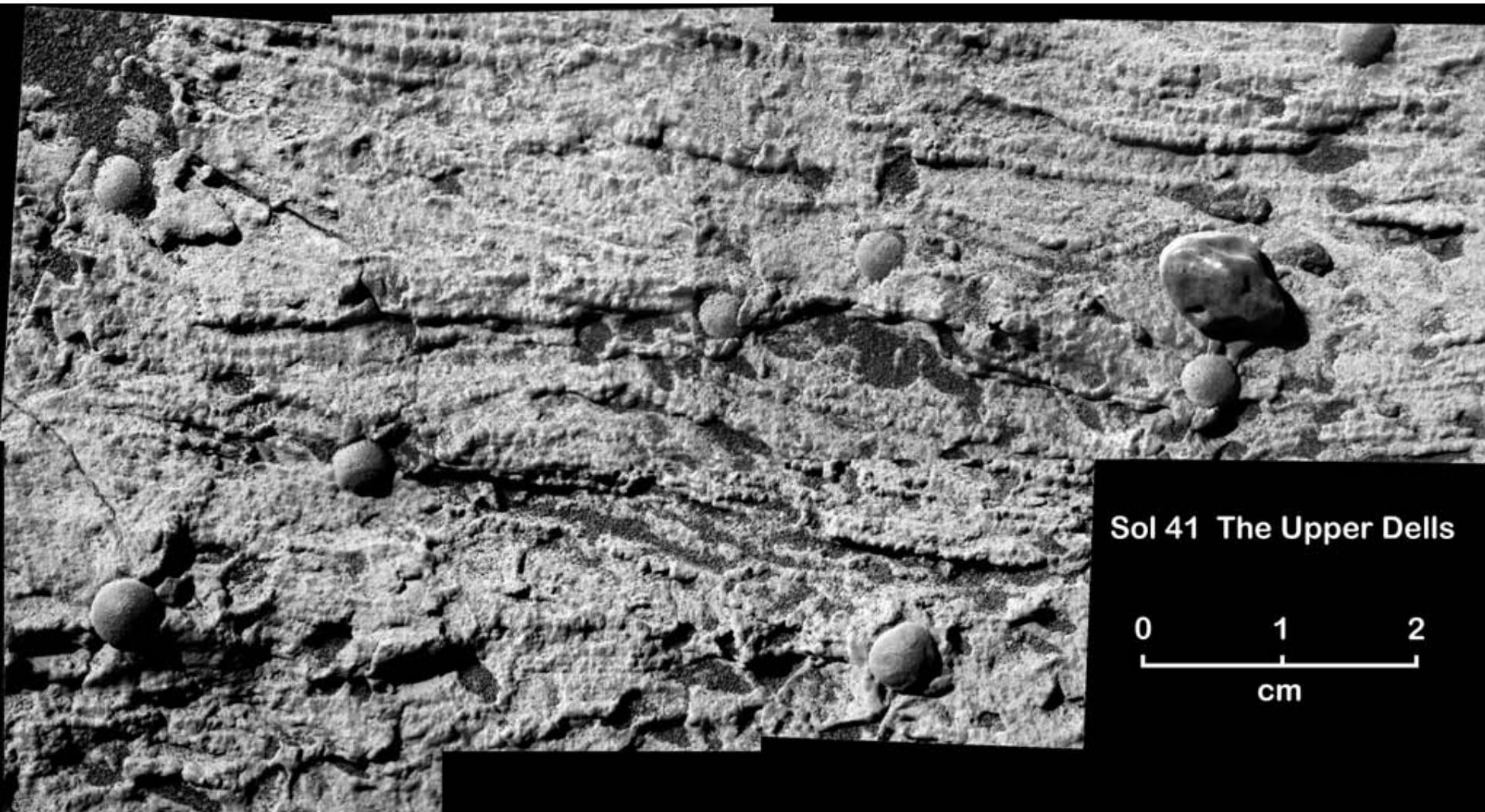
Mars Exploration Rover Mission



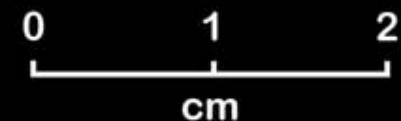
Current Ripples On Mars



Mars Exploration Rover Mission



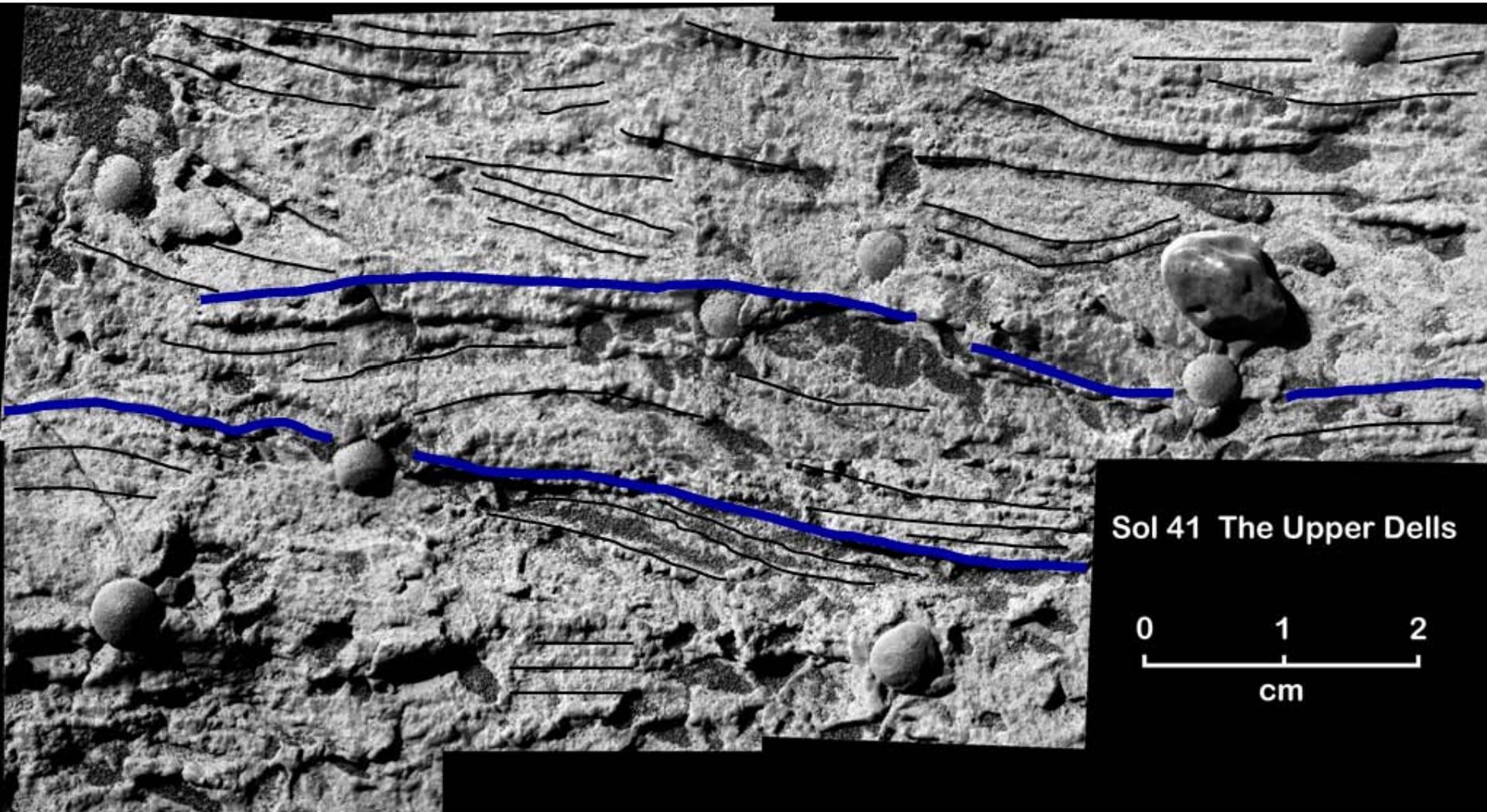
Sol 41 The Upper Dells



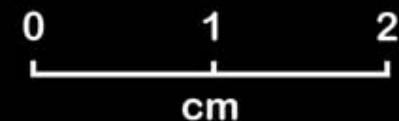
Current Ripples On Mars



Mars Exploration Rover Mission



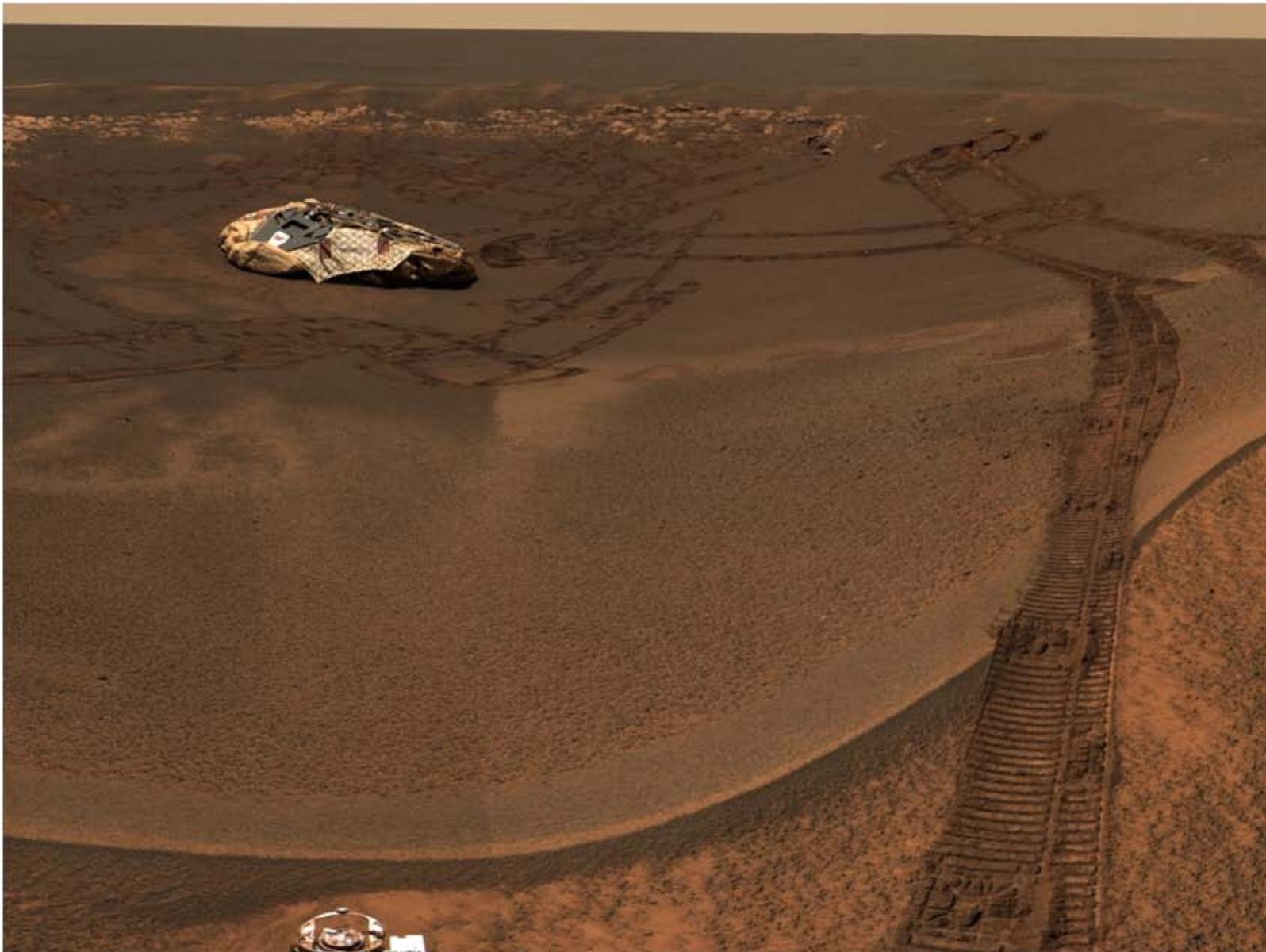
Sol 41 The Upper Dells



Farewell to Eagle Crater



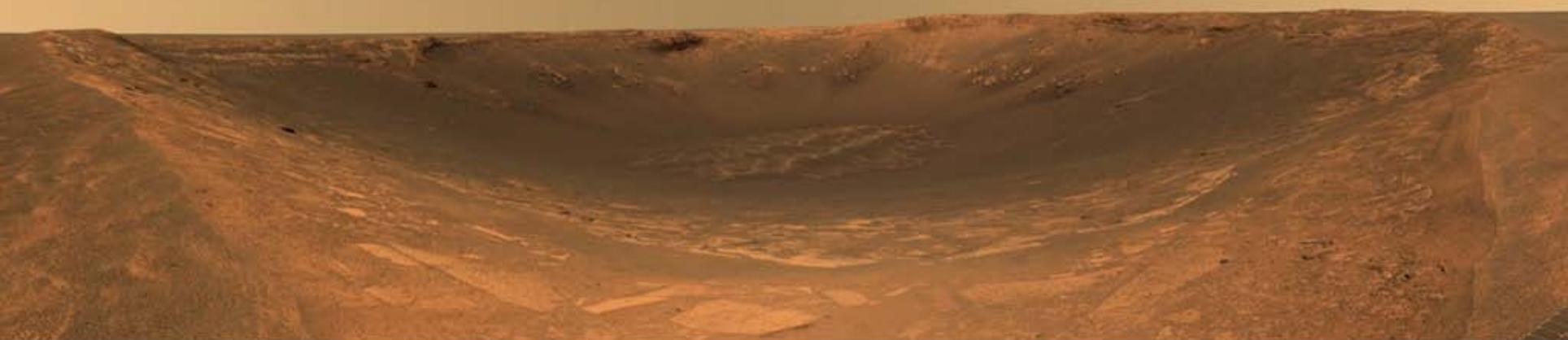
Mars Exploration Rover Mission

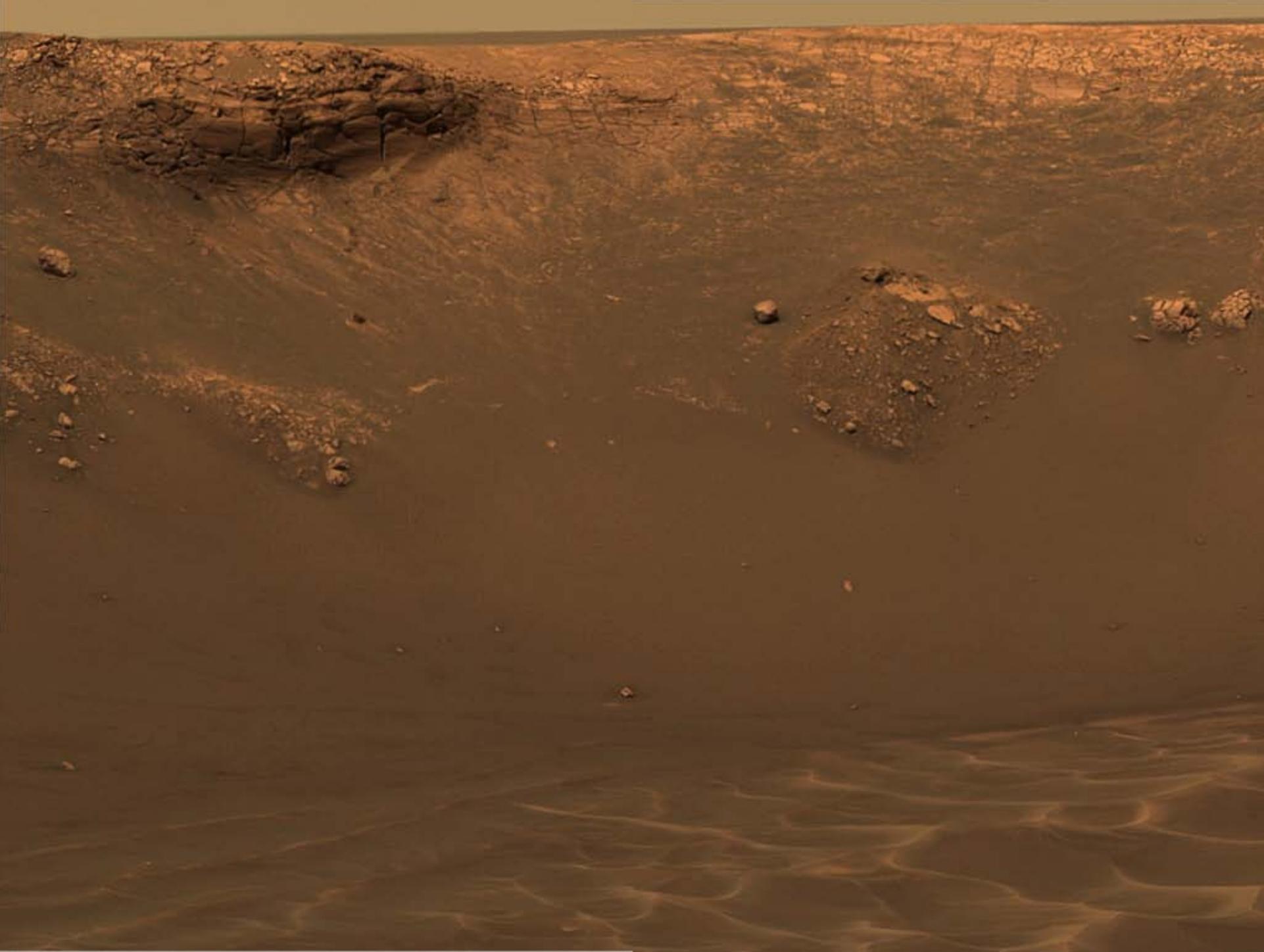


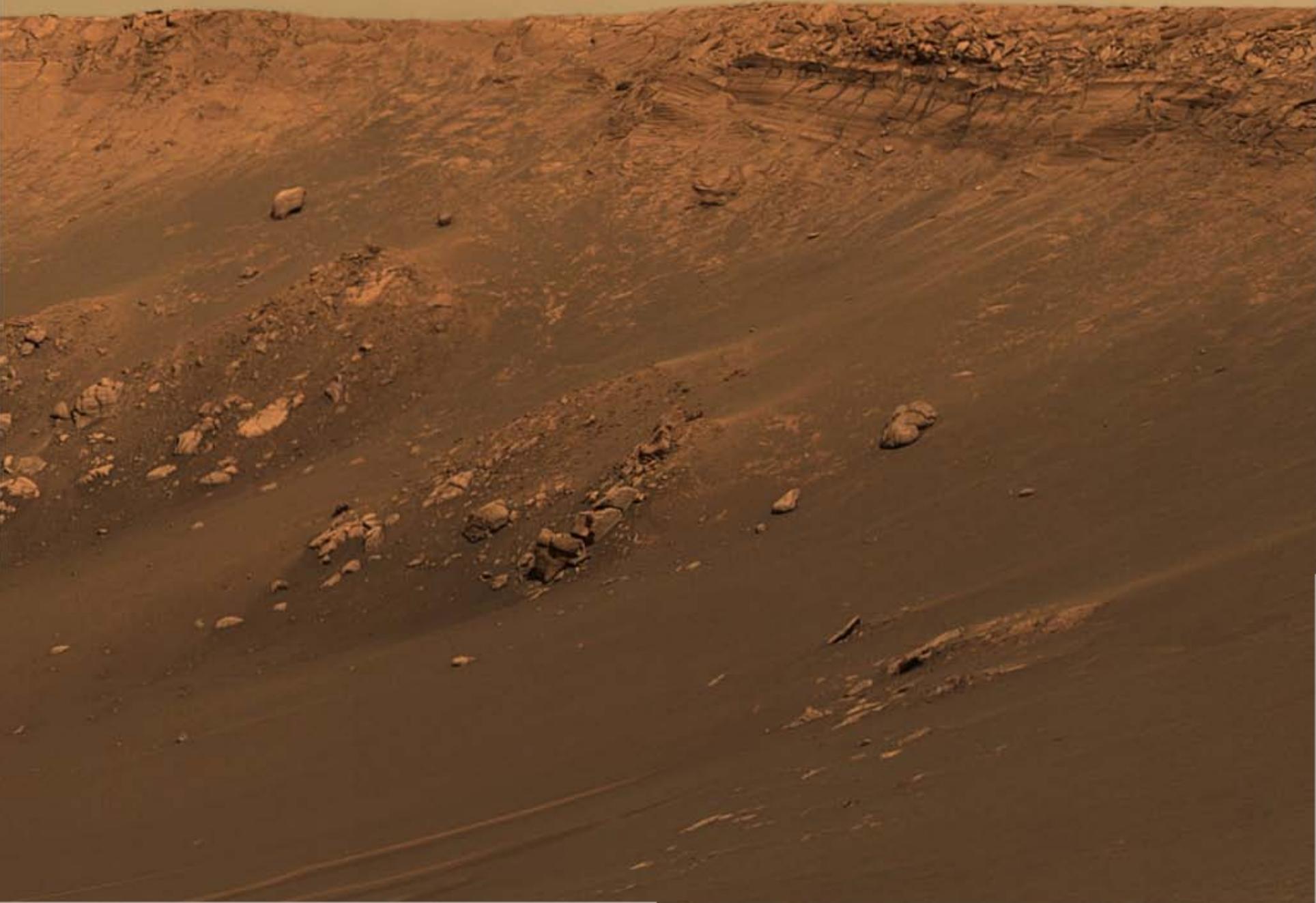
Endurance Crater

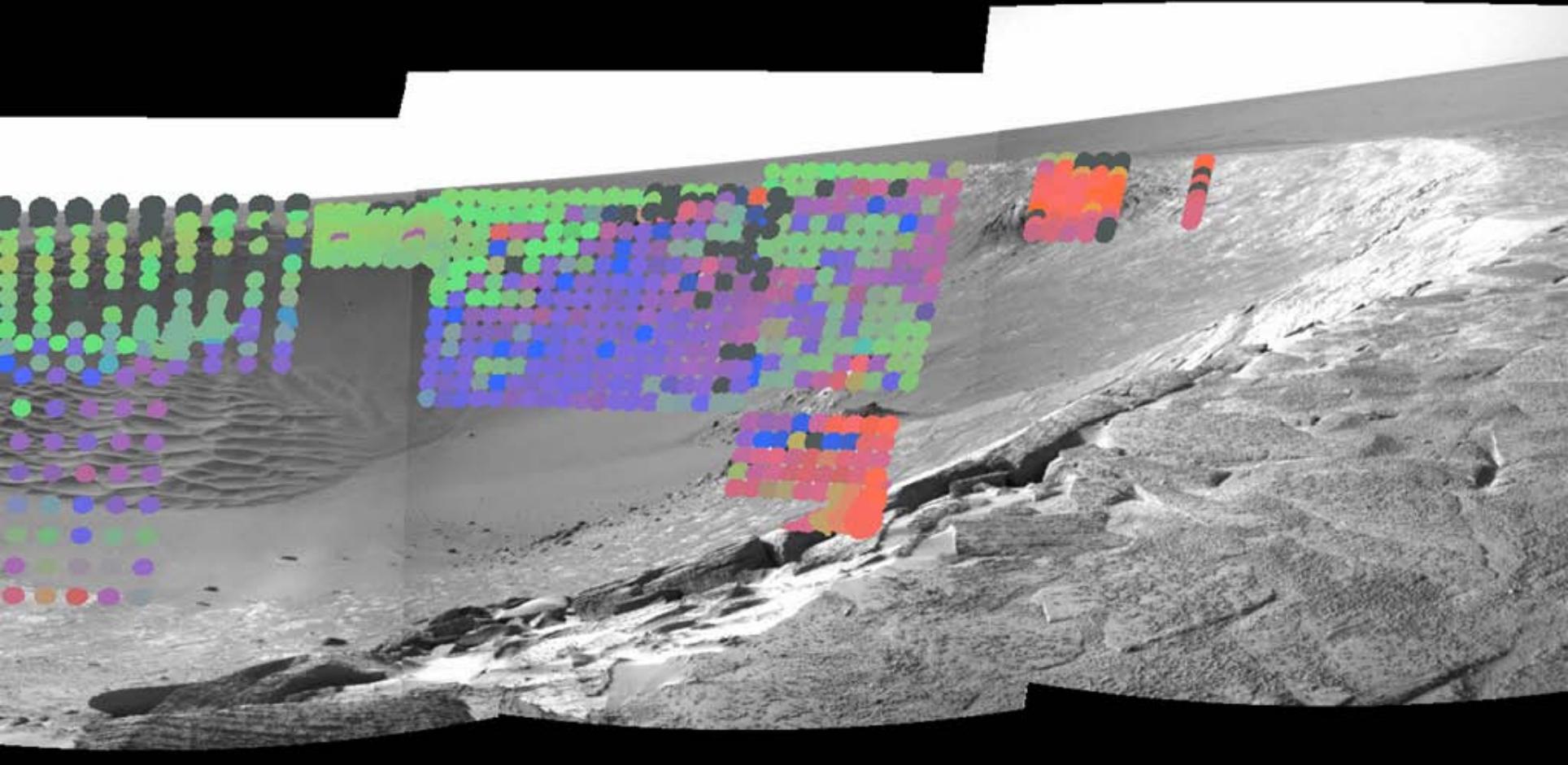


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Red = Dust + Sulfate Unit

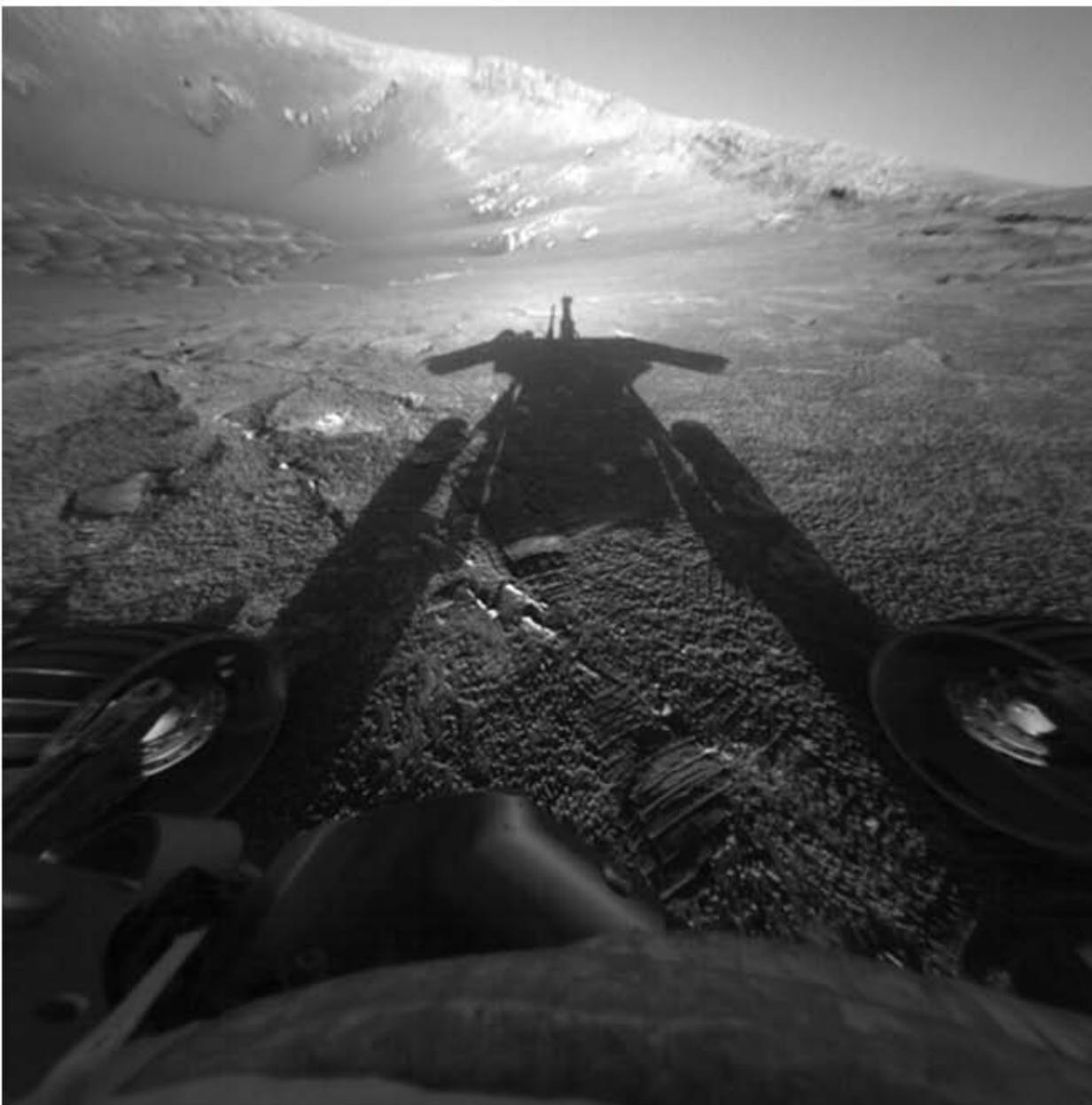
Green = Hematite + Basalt + Dust

Blue/Purple = Basalt (Plagioclase>Pyroxene>>Olivine) + Dust

In We Go...



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RAT Holes



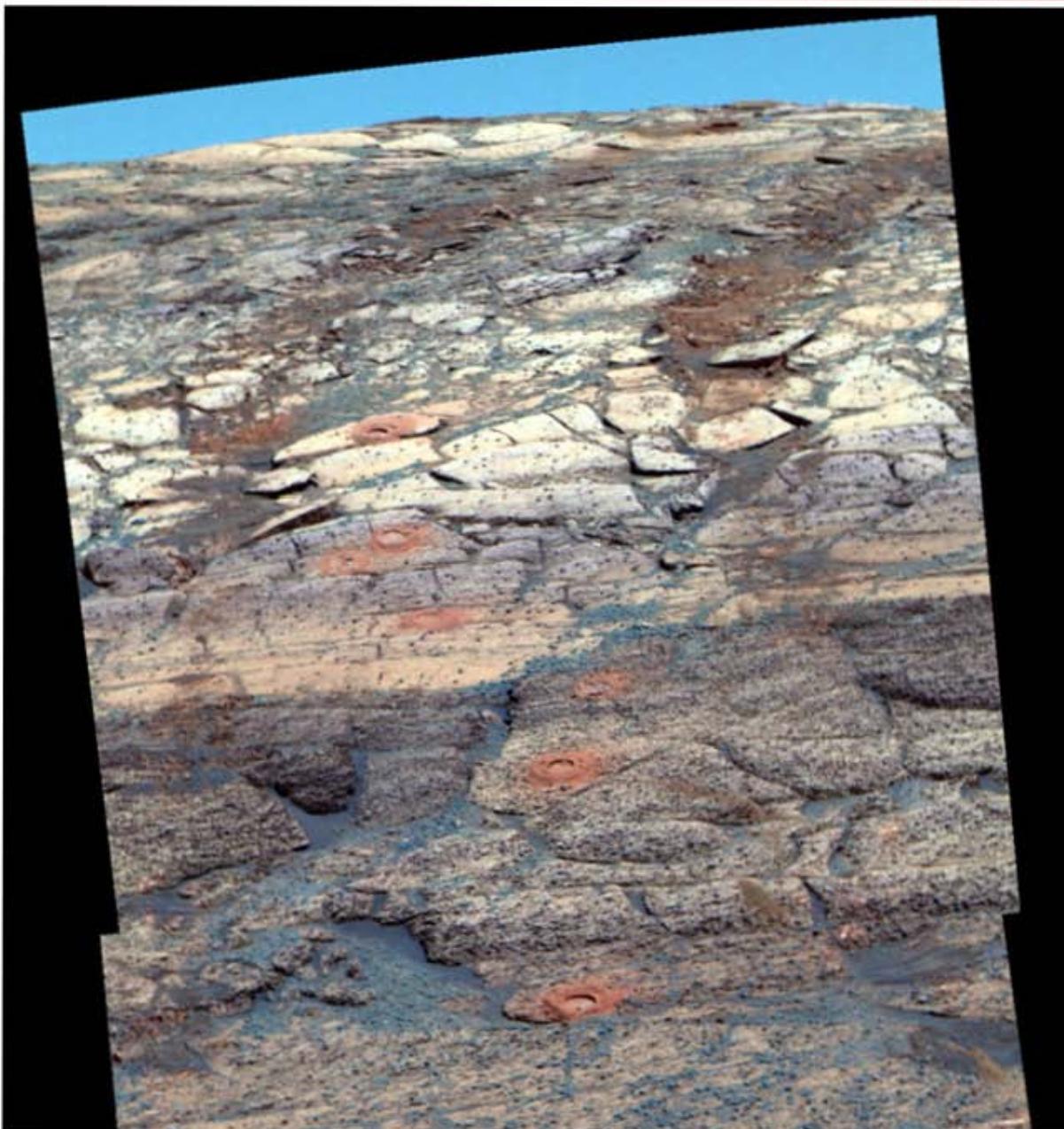
Mars Exploration Rover Mission



The Karatepe Stratigraphic Section



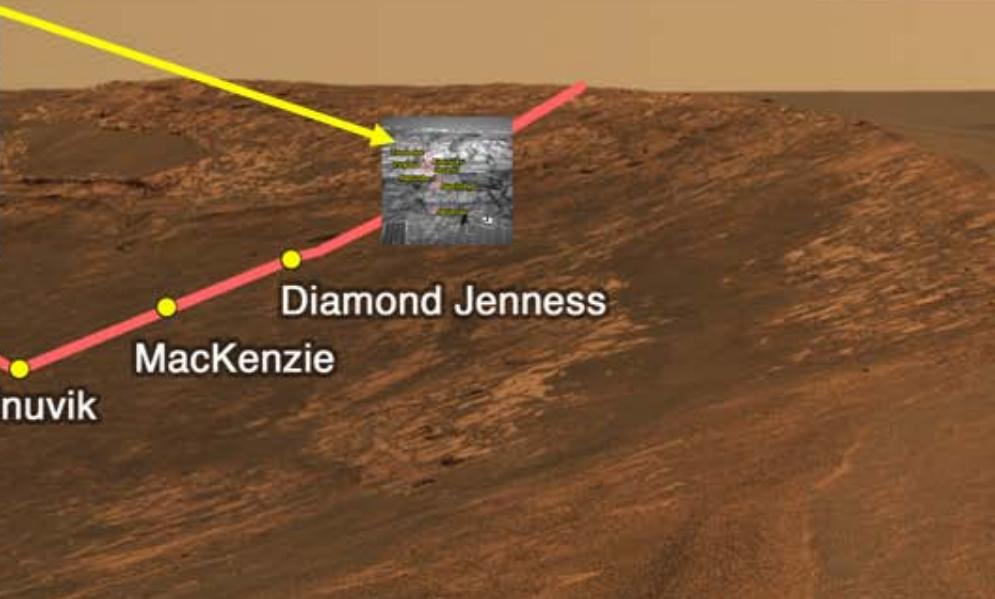
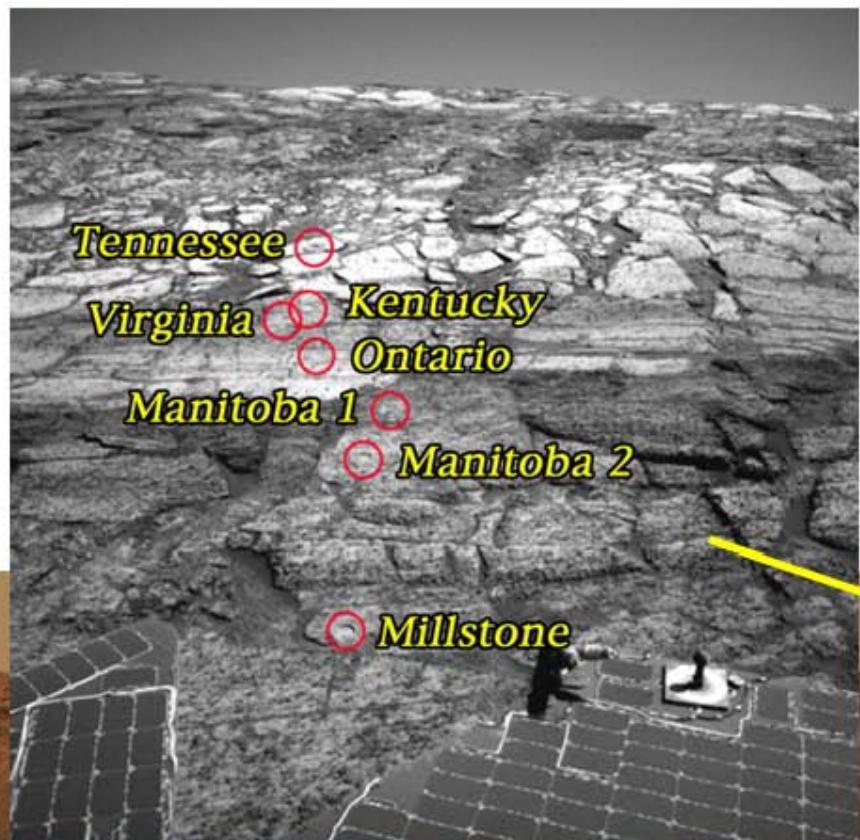
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The Karatepe Stratigraphic Section



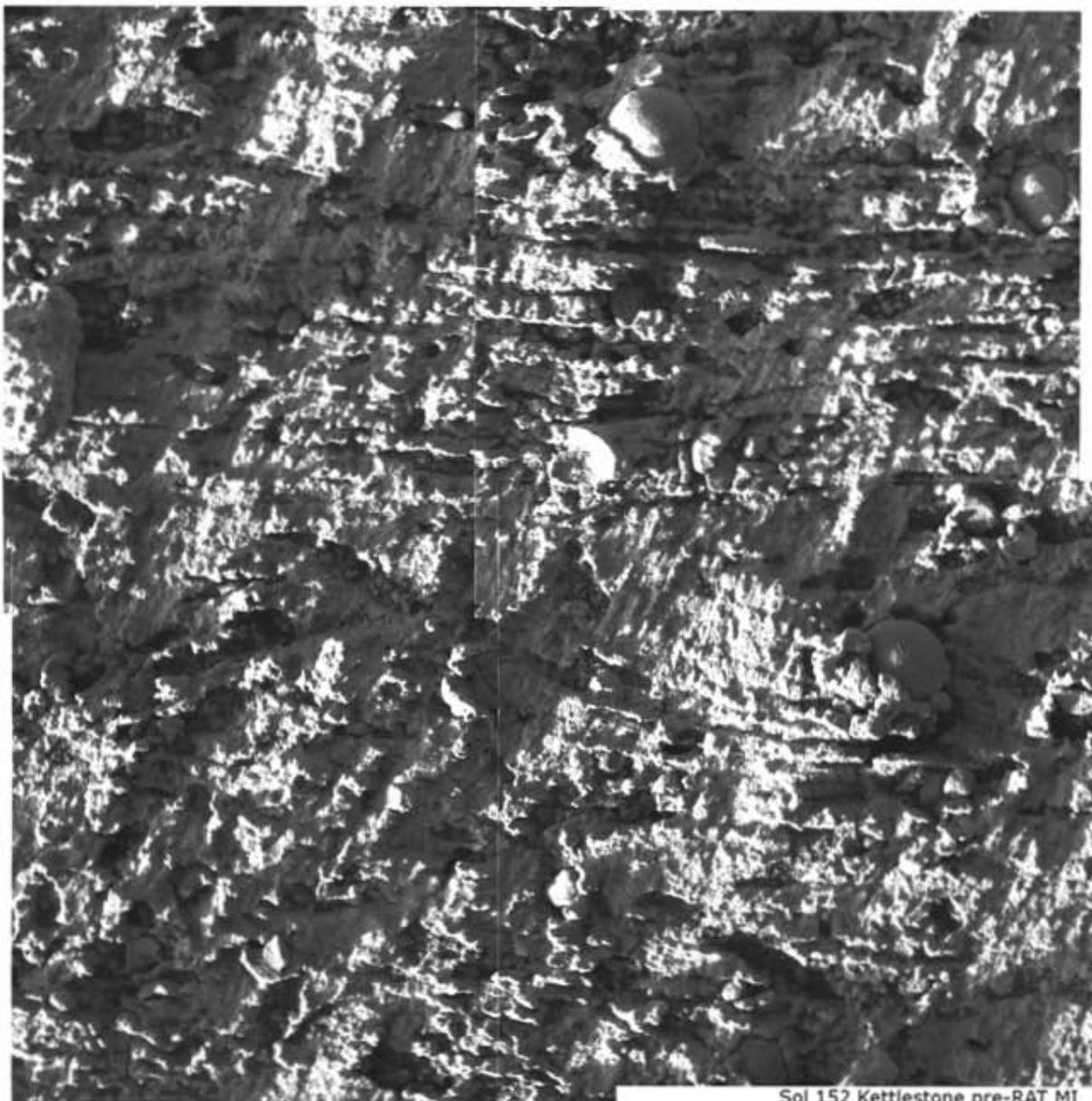
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Top of the Section: Like Eagle Crater



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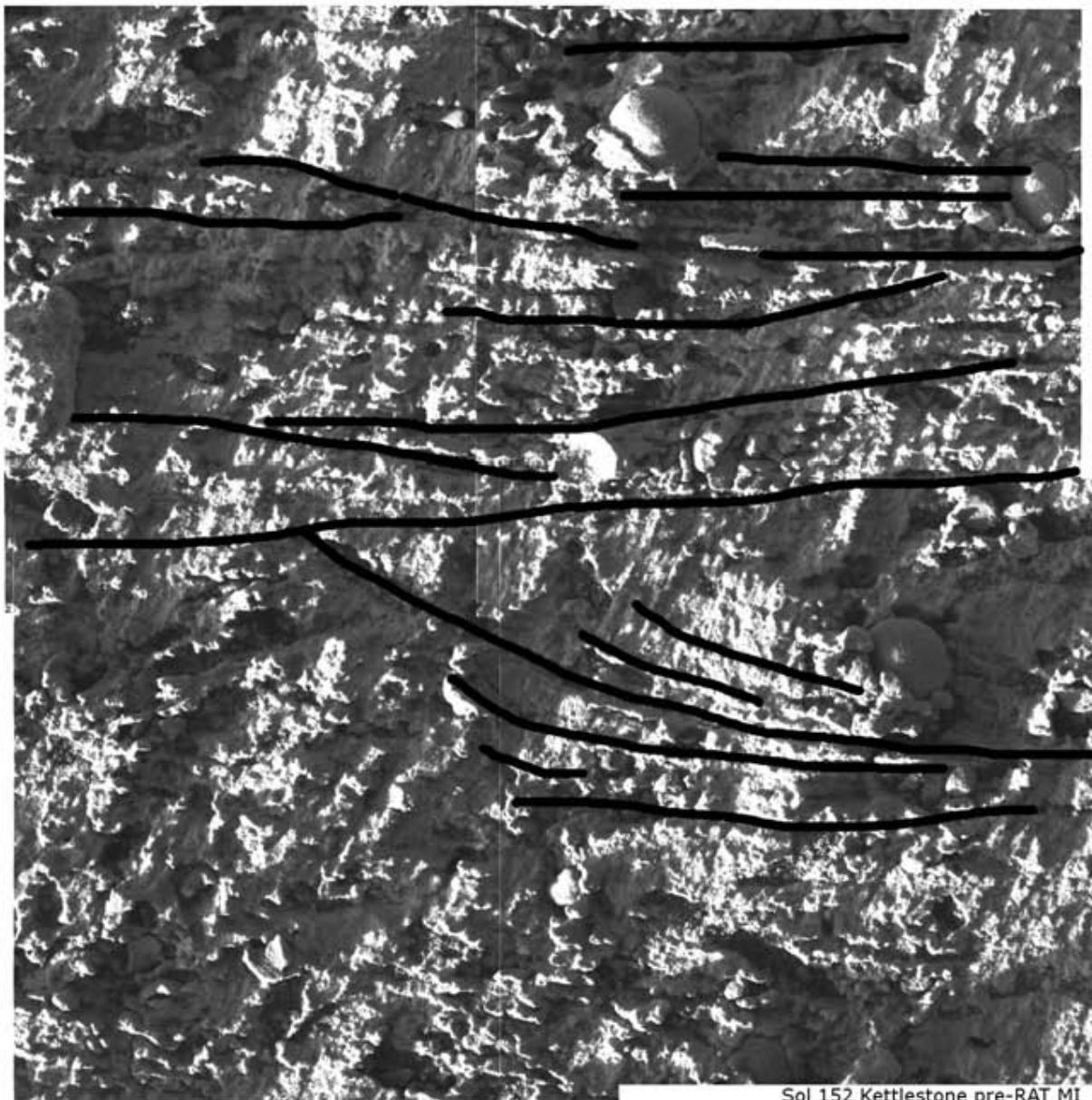


Sol 152 Kettlesite pre-RAT MI

Top of the Section: Like Eagle Crater



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Sol 152 Kettlestone pre-RAT MI

Whatanga Contact



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Changes Down Section: Texture



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Ontario



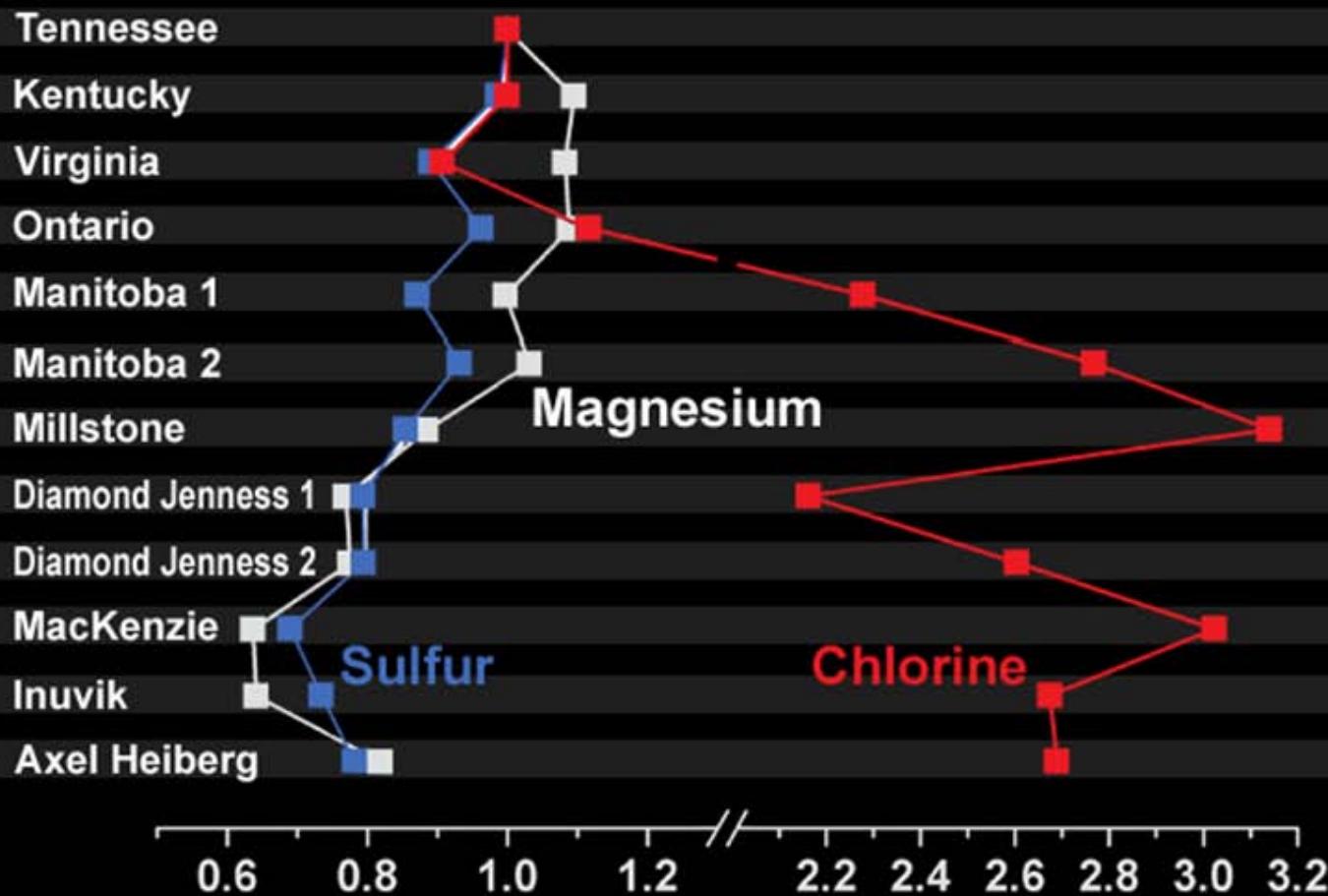
Diamond Jenness

Changes Down Section: Chemistry



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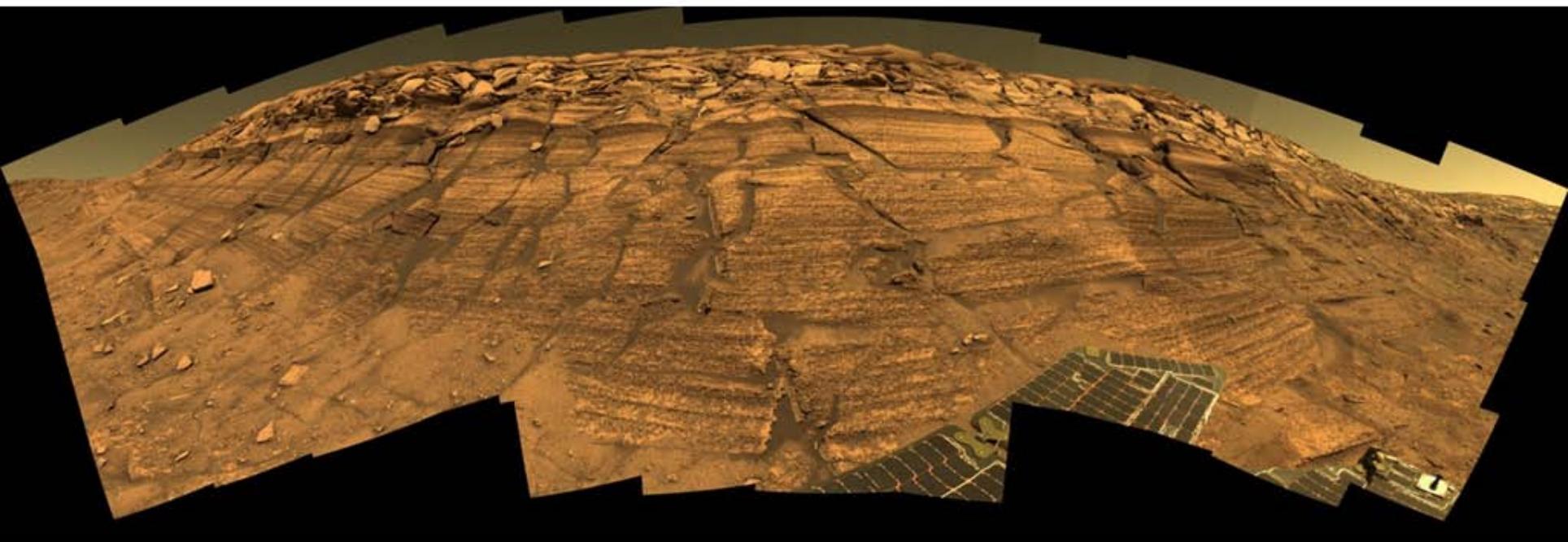
Selected Elements in Endurance Crater Rocks

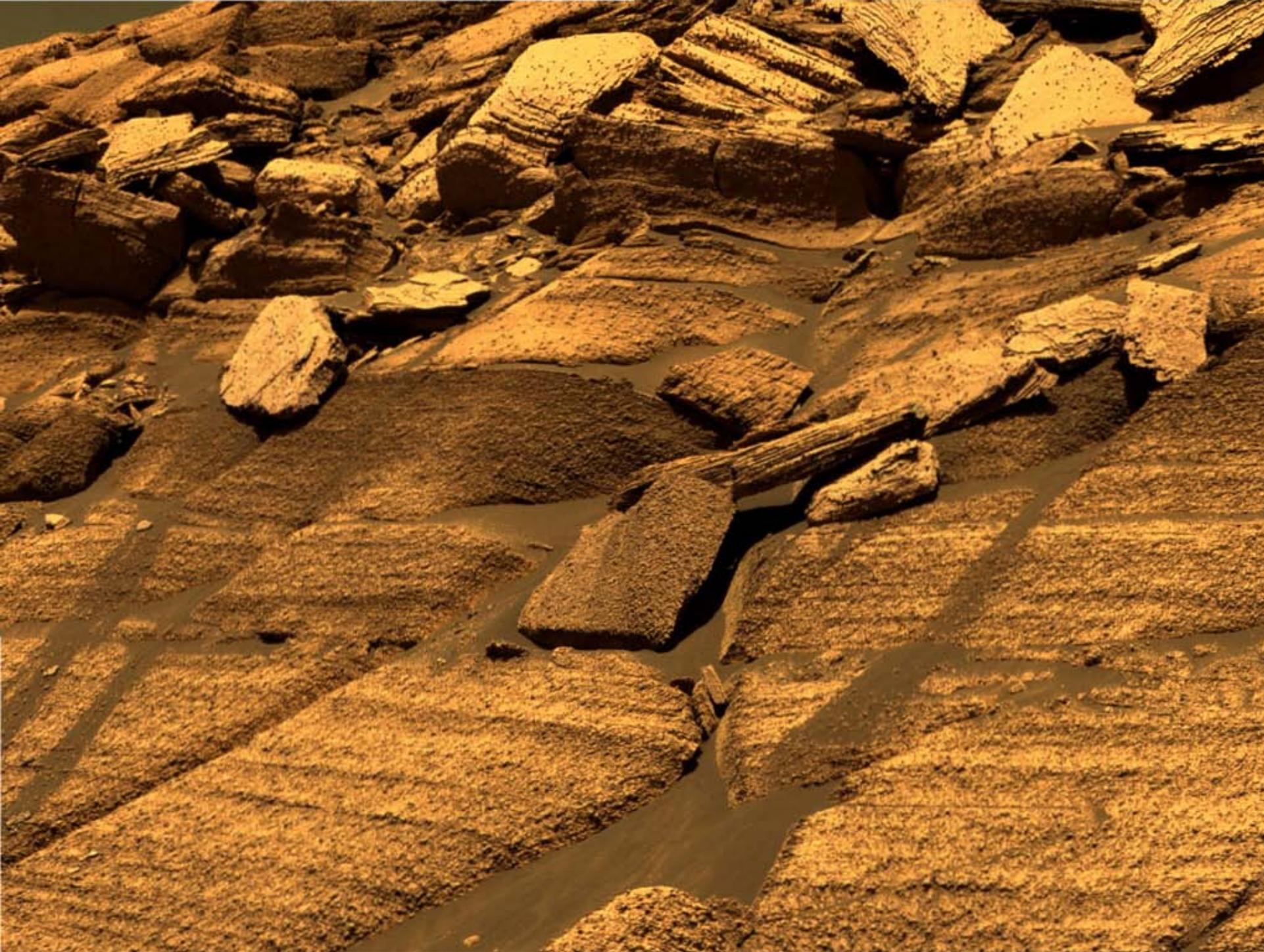


Burns Cliff



Mars Exploration Rover Mission

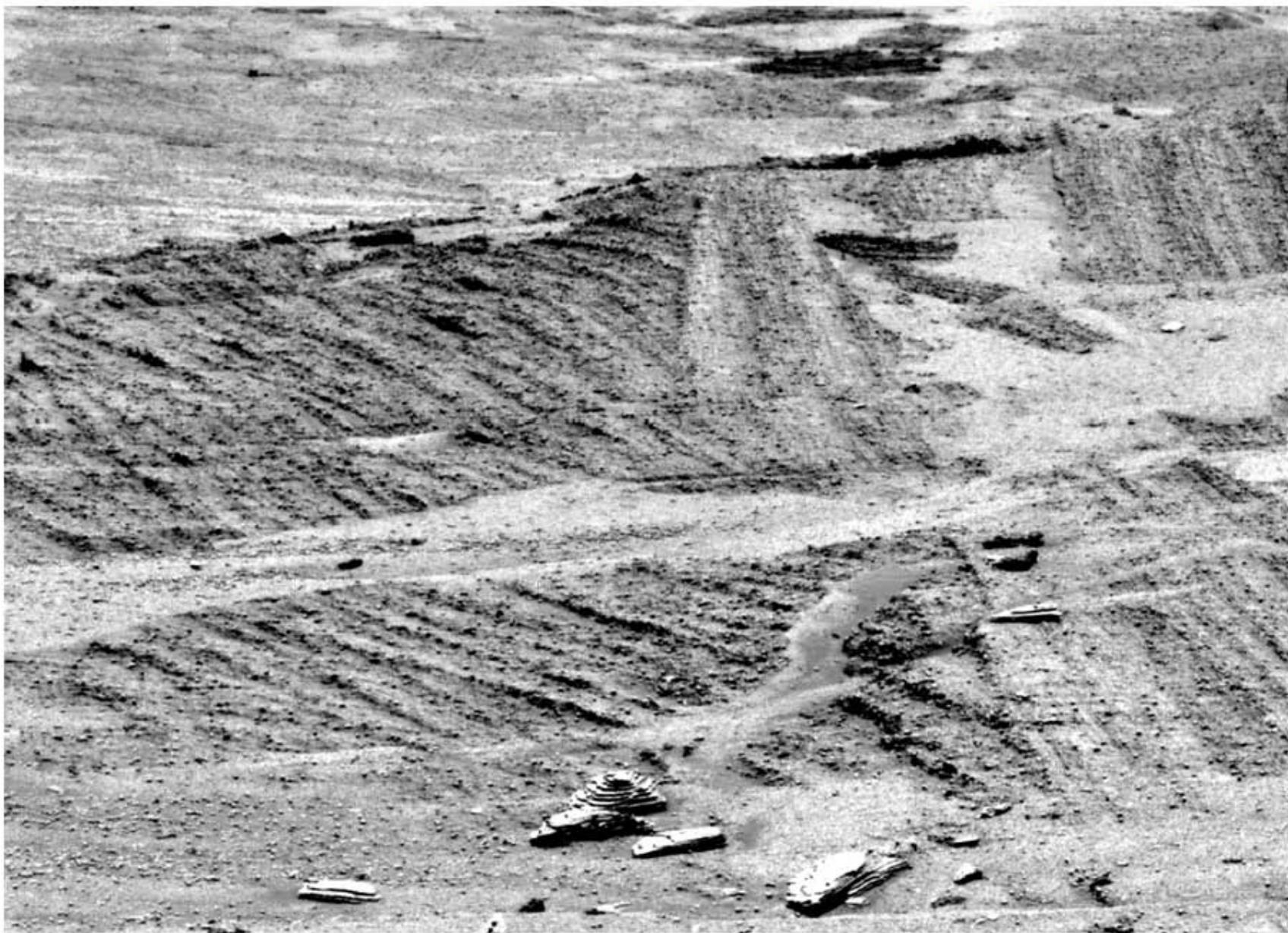




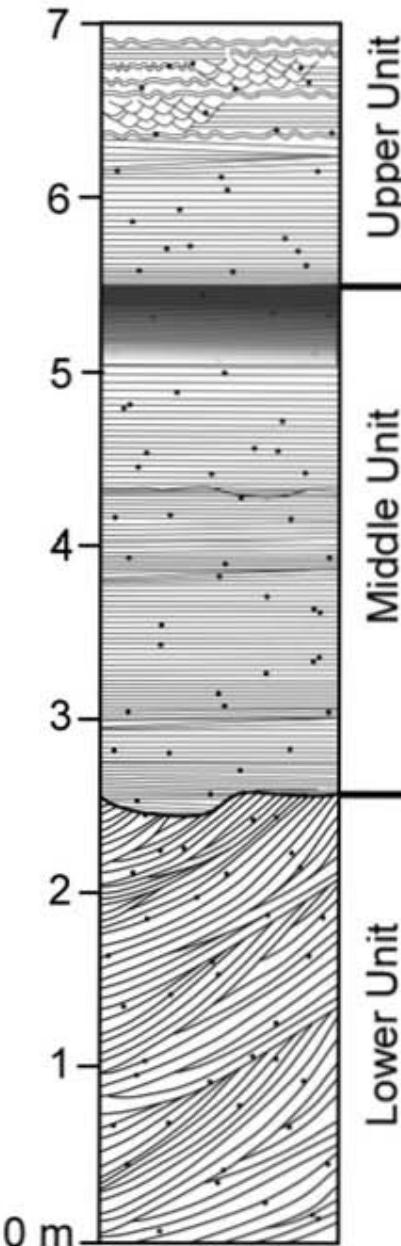
The East End of Burns Cliff



Mars Exploration Rover Mission



Meridiani Rocks: Summary



- It was once wet at Meridiani Planum.
- Rocks are a mixture of chemical and siliciclastic sediments with a complex diagenetic history.
- Uppermost strata are water-lain; lowest strata have undergone eolian reworking.
- Environmental conditions recorded include episodic inundation by shallow surface water, evaporation and desiccation.
- Conditions were “habitable”, but could have posed significant challenges to the origin of life:
 - Highly saline?
 - Highly acidic?
 - Arid and only intermittently wet?
- Aqueous precipitates (particularly concretions) might be good at preserving fossil evidence of microbial life.

The Road Ahead



Mars Exploration Rover Mission

