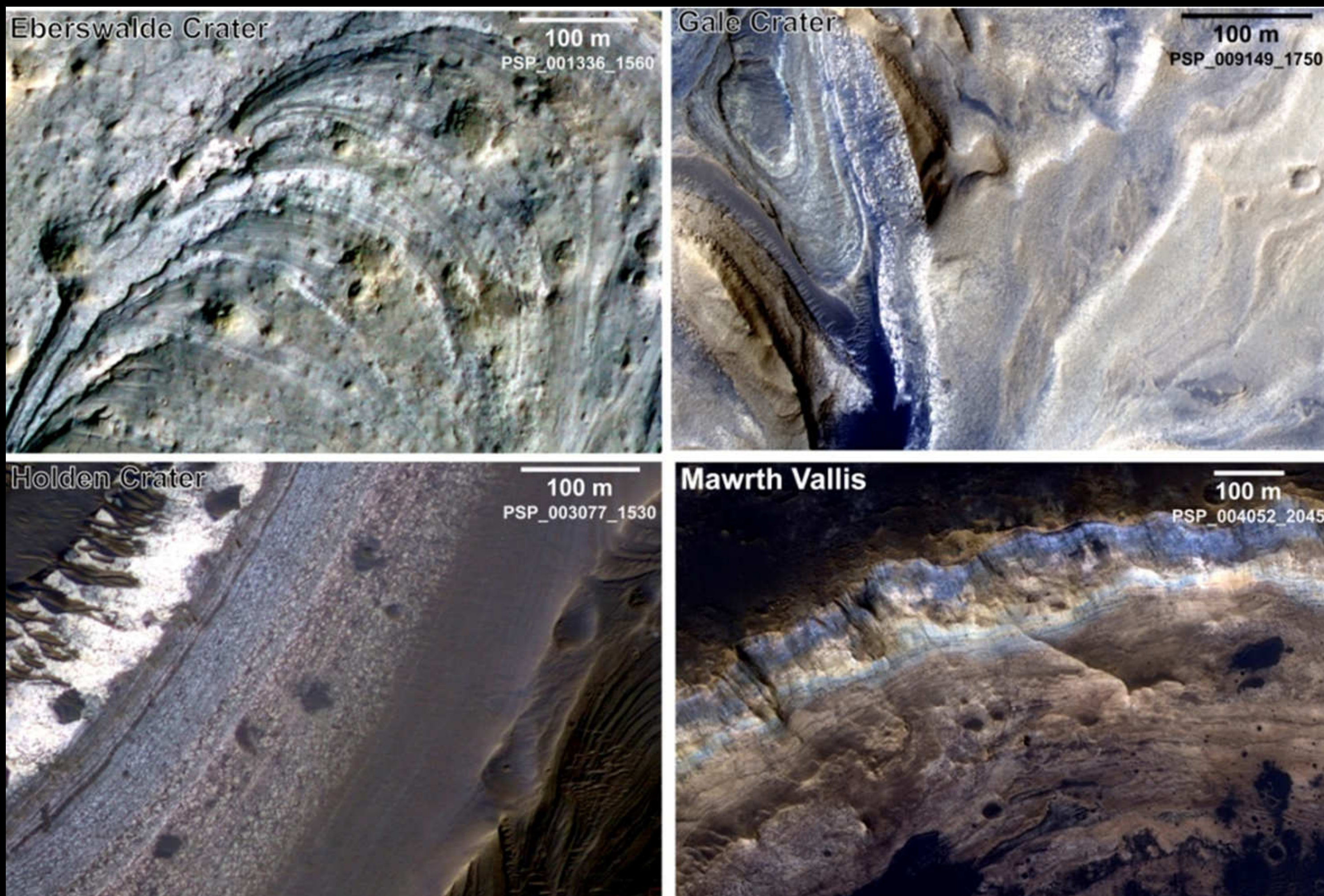
Mars Landing Site Selection Activities:

An Update on MSL and Future Missions



Matt Golombek, John Grant

(Jet Propulsion Laboratory, California Institute of Technology) **(Smithsonian Institution)**

MSL Project

J. Grotzinger, M. Watkins, A. Vasavada

History and MSL Site Selection Milestones

Mars Landing Site Selection Activities

Started with 35 Sites

Define/Refine Constraints

2006

1st Workshop

New MRO data/50 sites

Consider constraints where possible

2007

(e.g., rock abundance)

2nd Workshop

6 sites

2008

Steering Comm. adds 7th Site

3rd Workshop

4 sites

Consider Engineering constraints

2009

Call for New Site

Limited Ongoing Studies

2 imaged

2010

4th Workshop

Engineering Studies

2011

5th Workshop

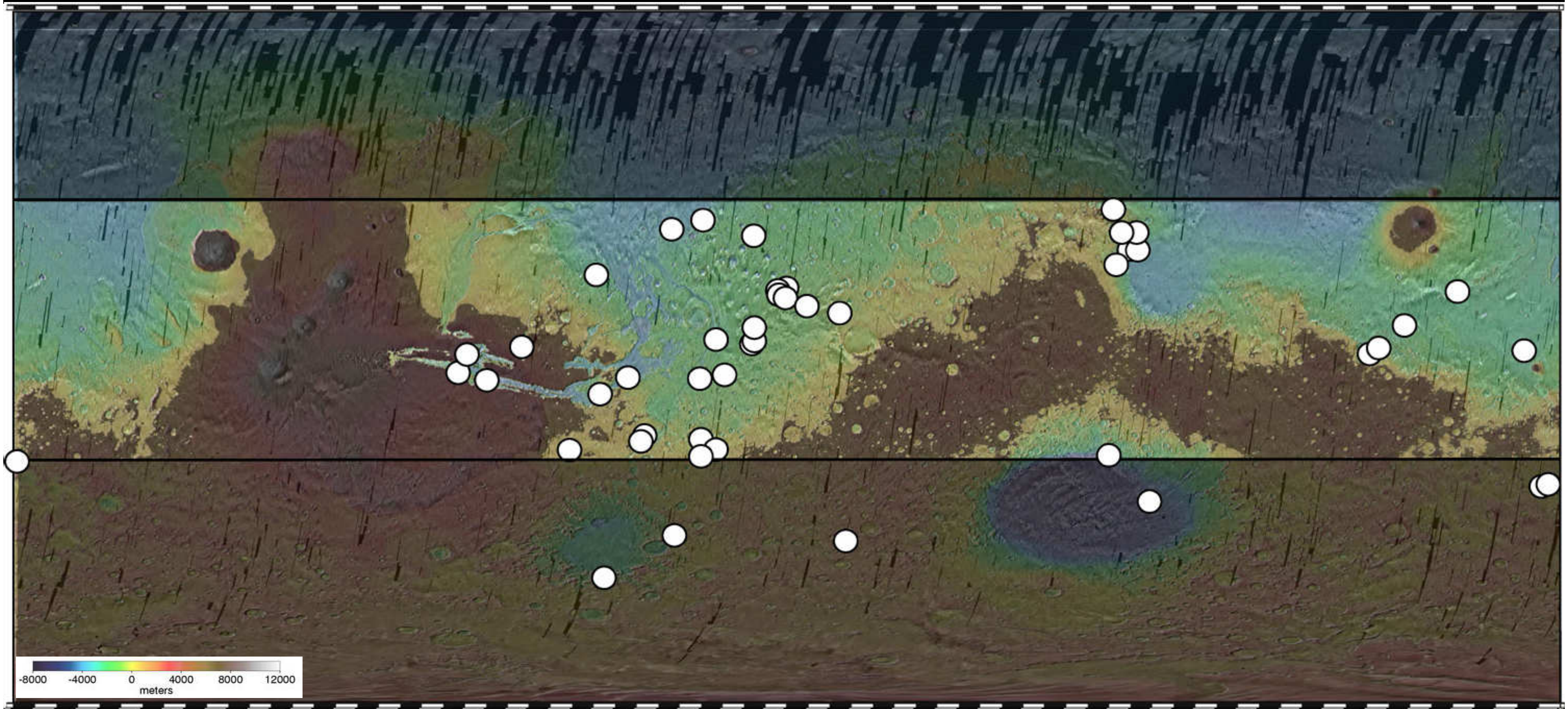
Mature Engineering constraints

(e.g., wheel actuators)

NASA HQ Selection Spring 2011

~50 Proposed MSL Landing Sites

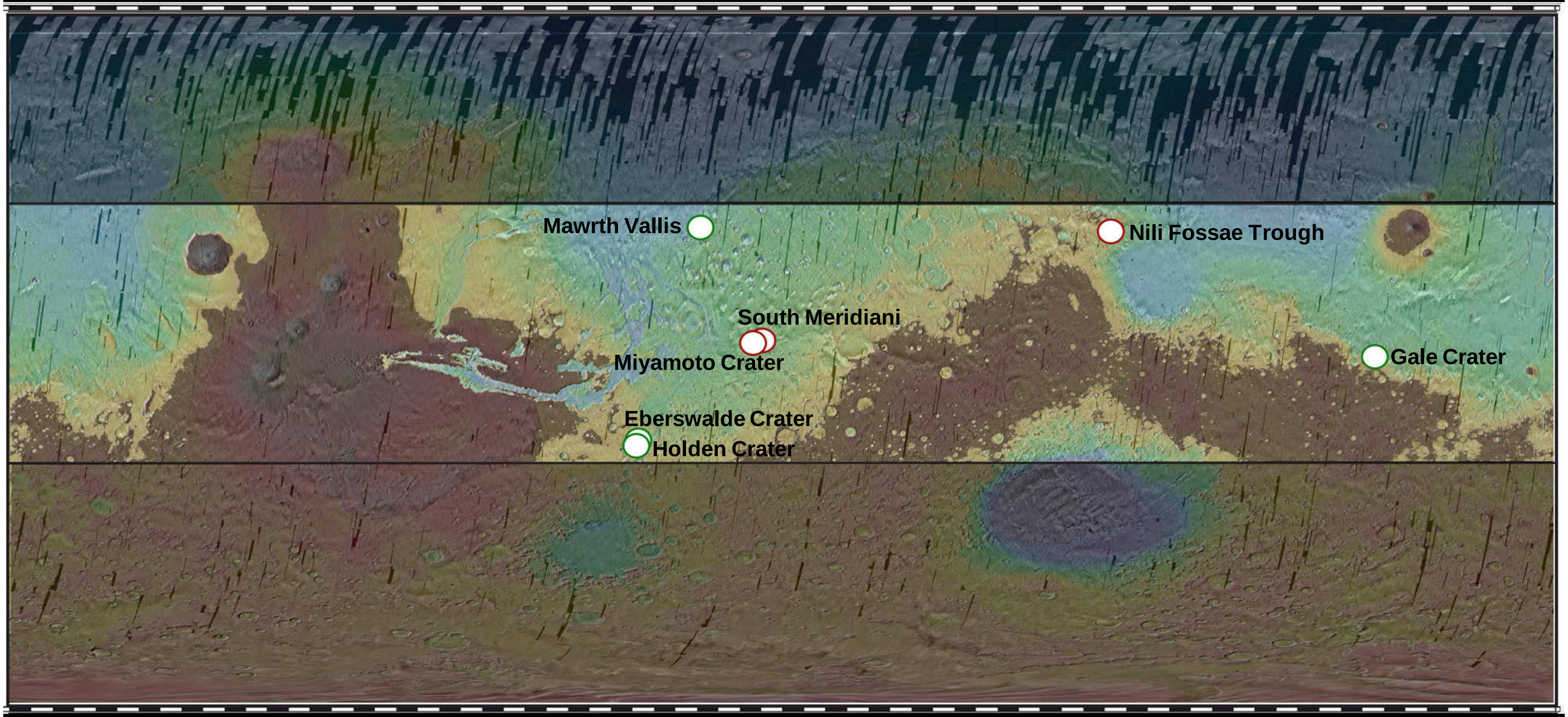
Mars Landing Site Selection Activities



Shaded areas are above +30°N, below -30°S, and above +1 km in elevation

Seven Downselected MSL Landing Sites:

Mars Landing Site Selection Activities



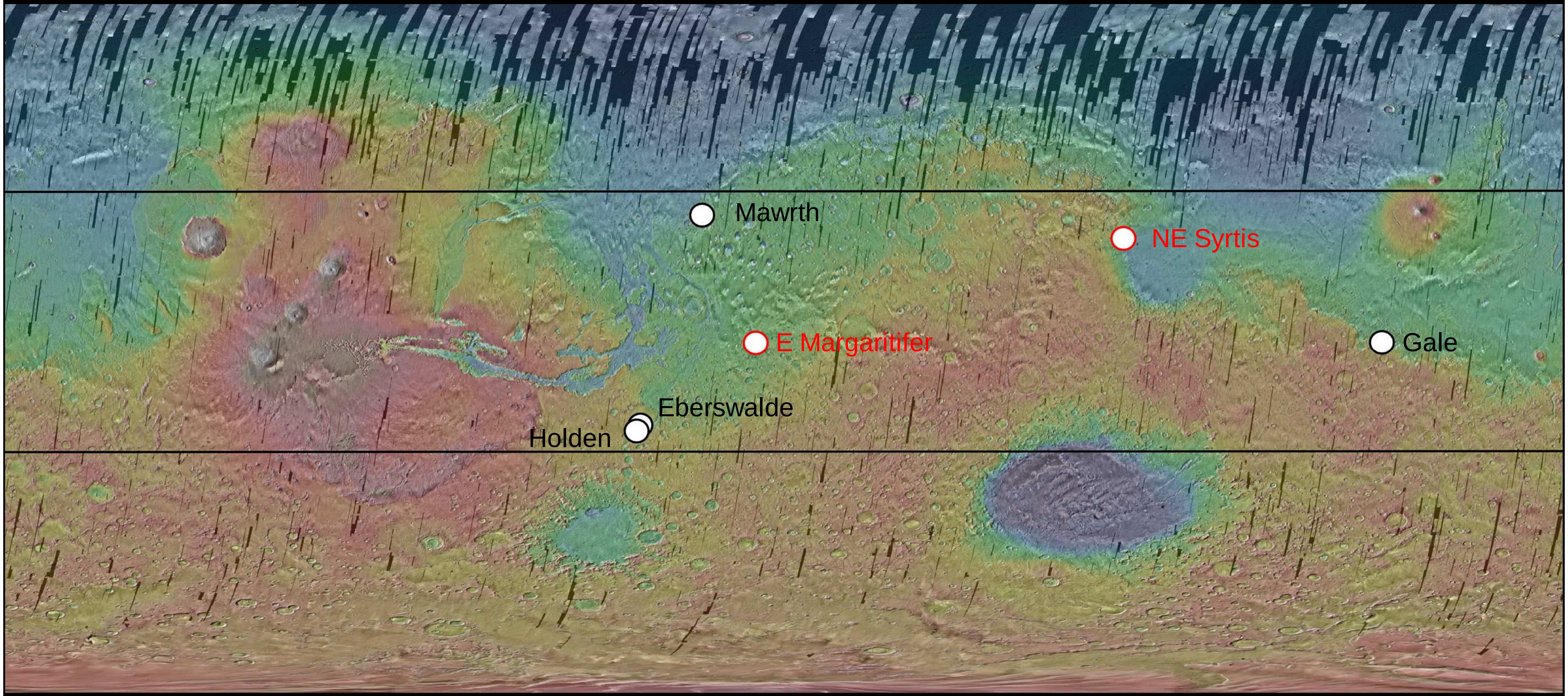
Seven Sites Receiving Highest Science Ranking:

Shaded areas above +30°N and -30°S, elevations >1 km

Green outlines denote final four sites based on science, engineering

MSL Landing Sites

Mars Landing Site Selection Activities

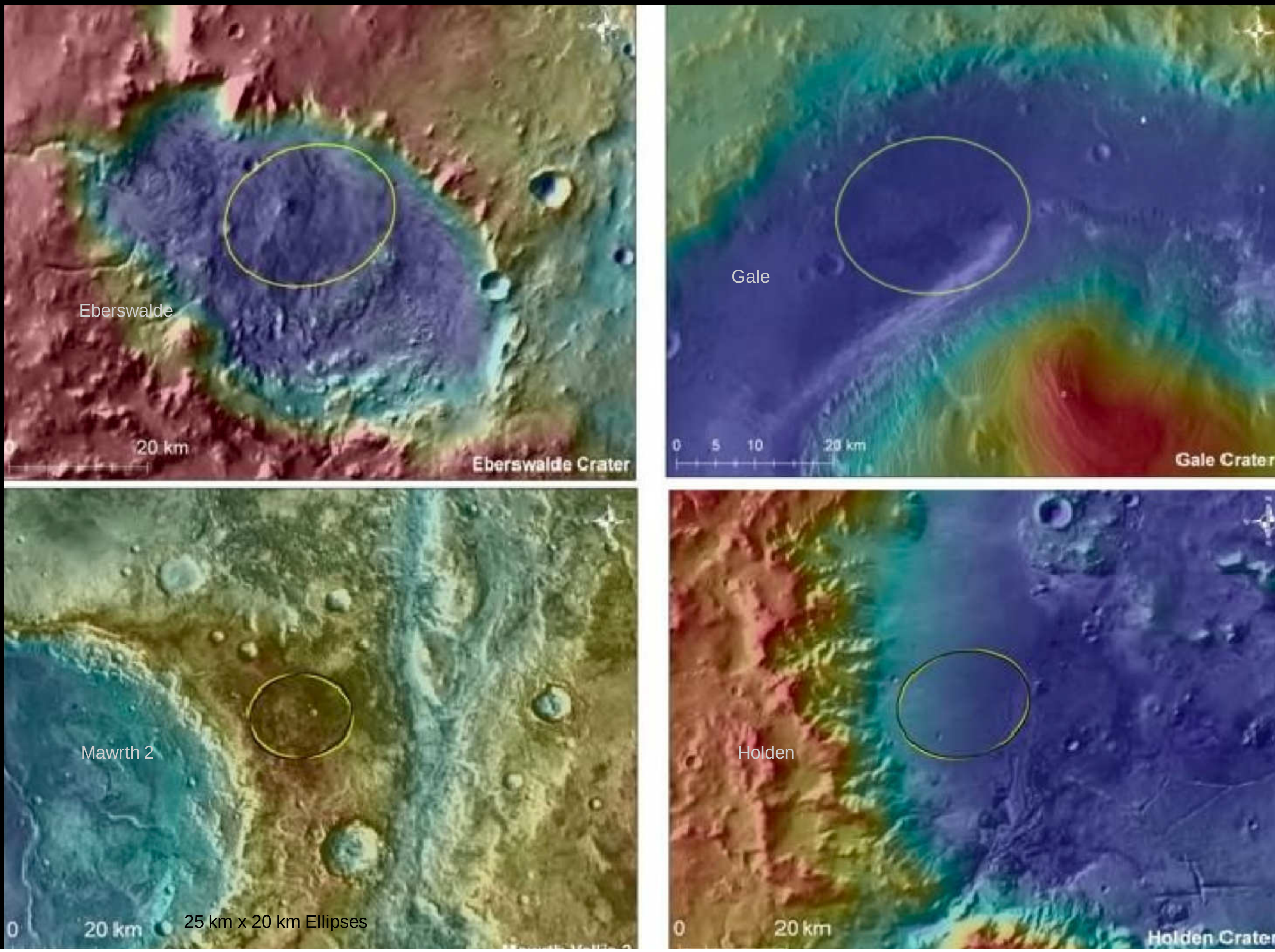


Four Sites: Mawrth, Gale, Eberswalde, Holden

Potential Sites: NE Syrtis, E Margaritifer

Final Four MSL Landing Ellipses

Mars Landing Site Selection Activities



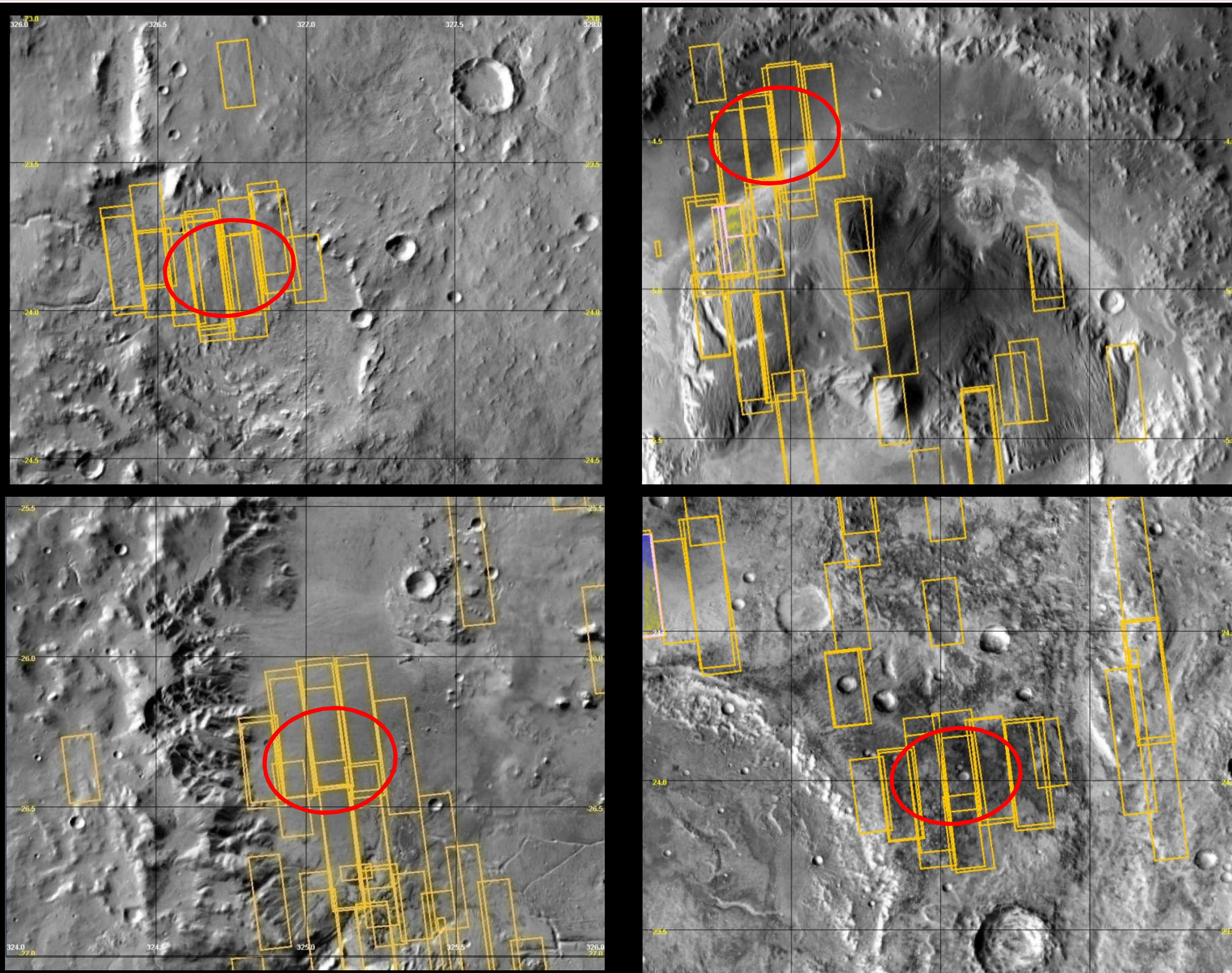
Final 4 MSL Landing Sites

Mars Landing Site Selection Activities

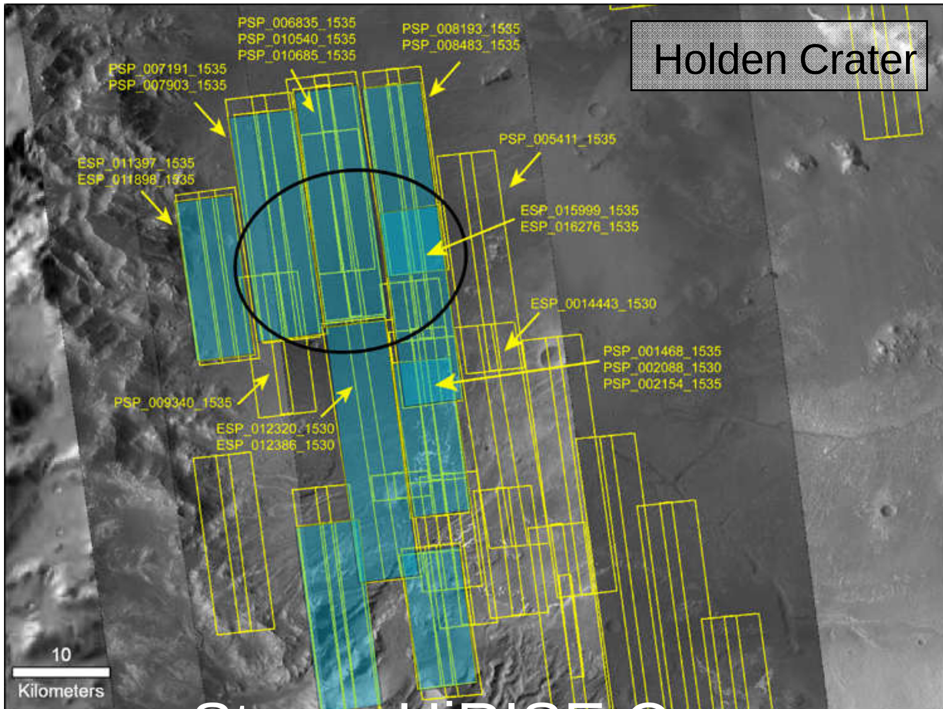
MSL LANDING SITES			
NAME	**LOCATION**	**ELEVATION**	**TARGET**
Holden Crater	26.37ºS, 325.10ºE	-1940 m	Fluvial Layers, Phyllosilicates
Mawrth Vallis (2)	24.01N, 341.03ºE	-2246 m	Noachian Layered Phyllosilicates
Eberswalde Crater	23.86°S, 326.73°E	-1450 m	Delta, Phyllosilicate
Gale Crater	4.49ºS, 137.42ºE	-4451 m	Layered Sulfates, Phyllosilicates

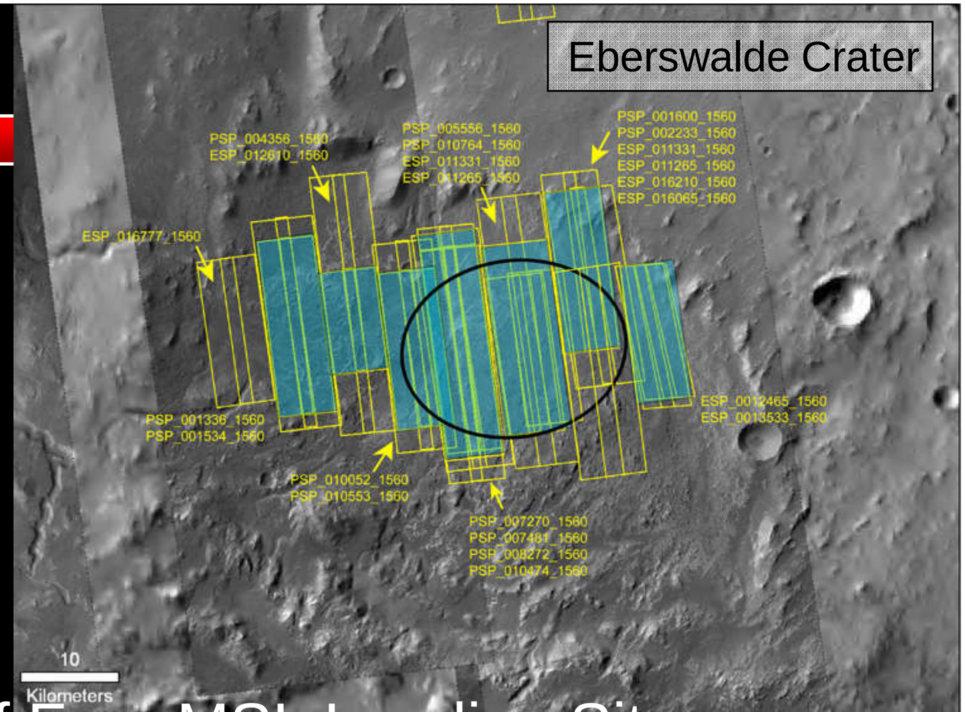
HiRISE Coverage of Four MSL Landing Sites:

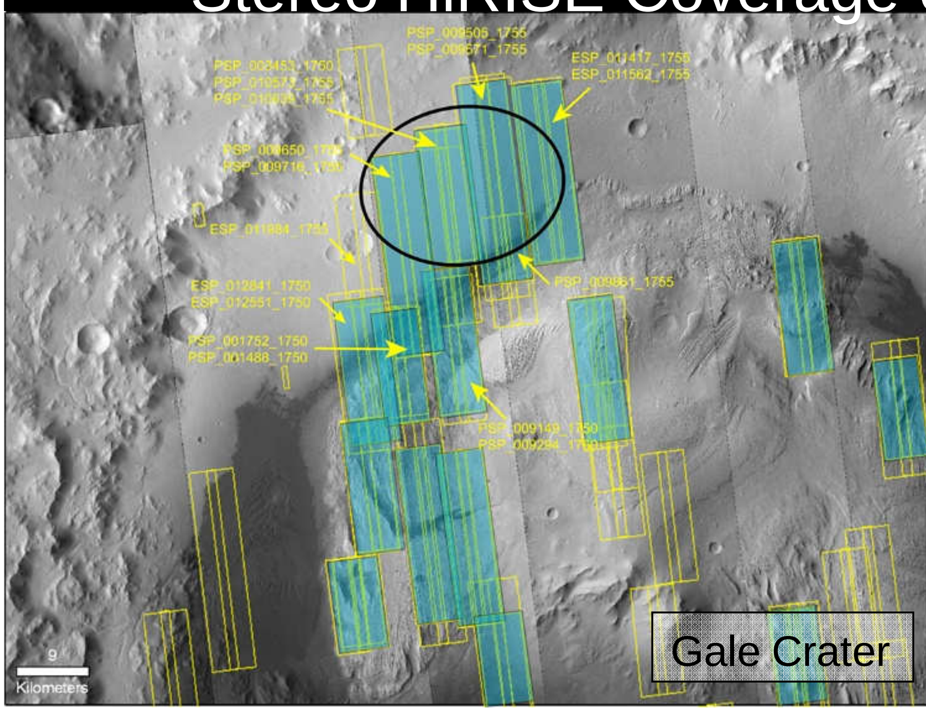
Mars Landing Site Selection Activities

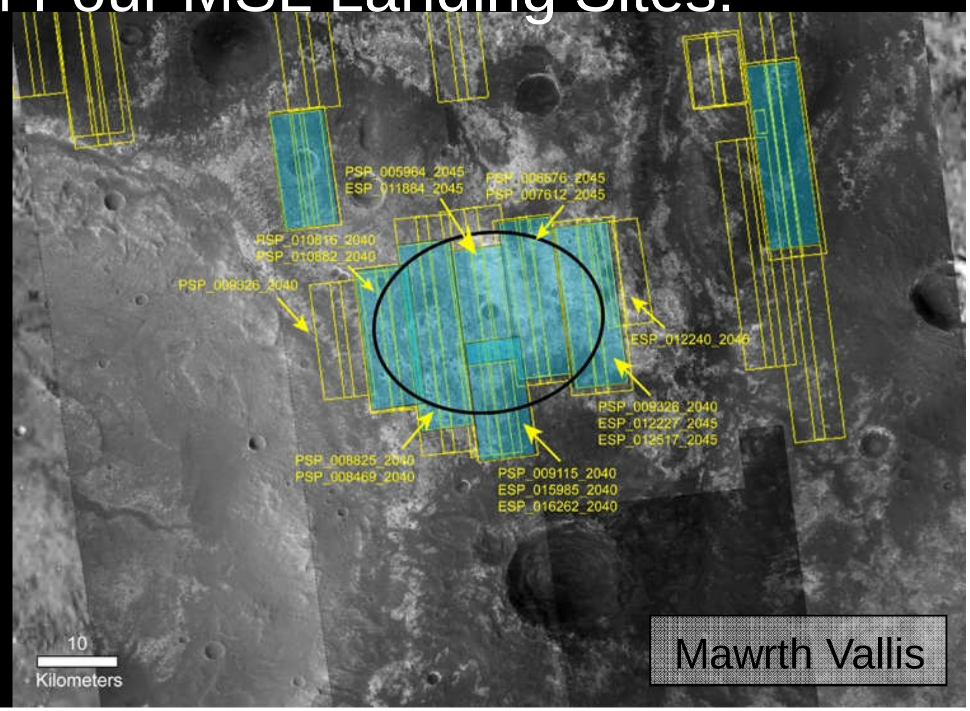


Stereo HiRISE Coverage of Four MSL Landing Sites:



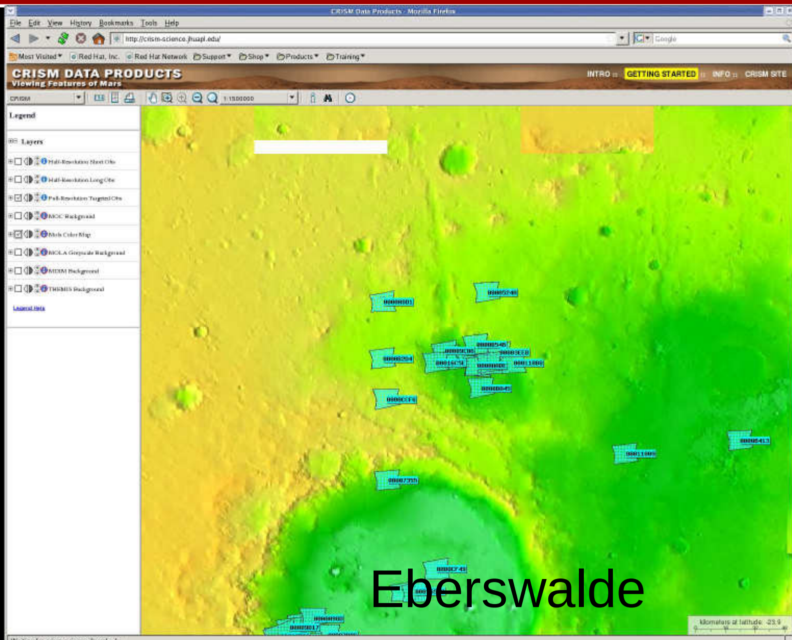


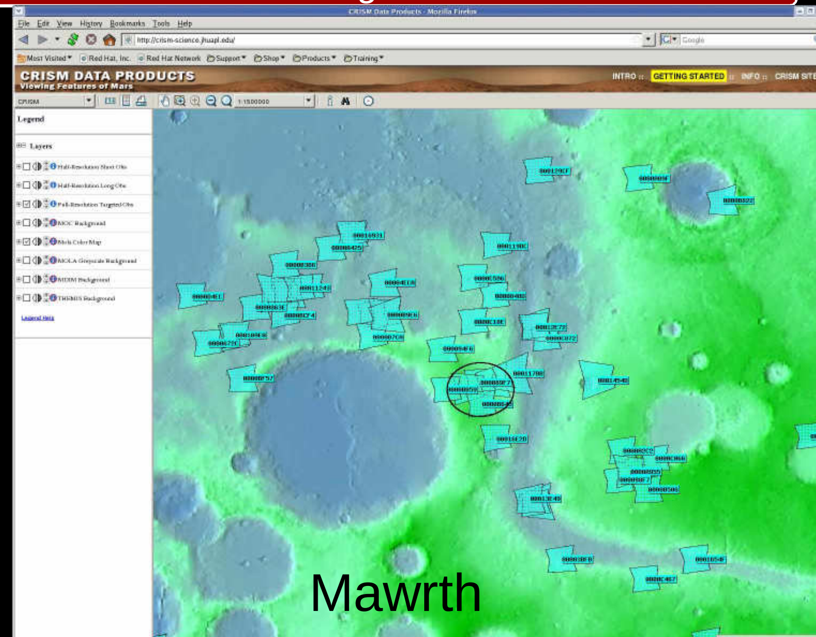


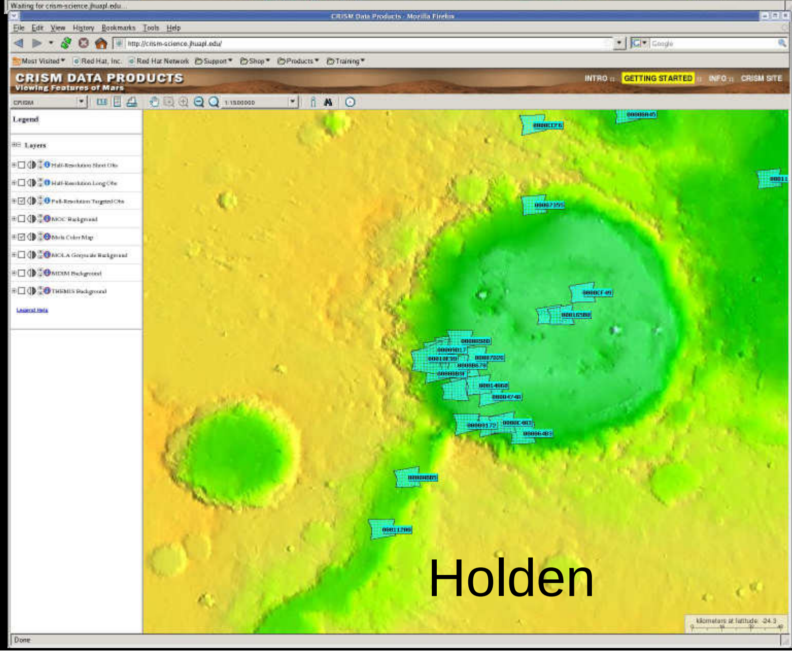


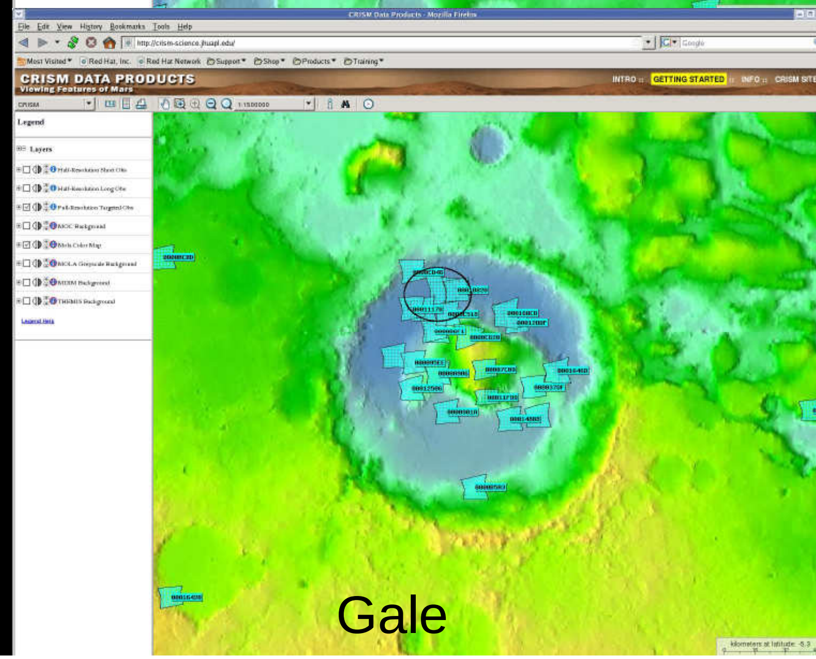
CRISM Coverage of MSL Sites

Mars Landing Site Selection Activities



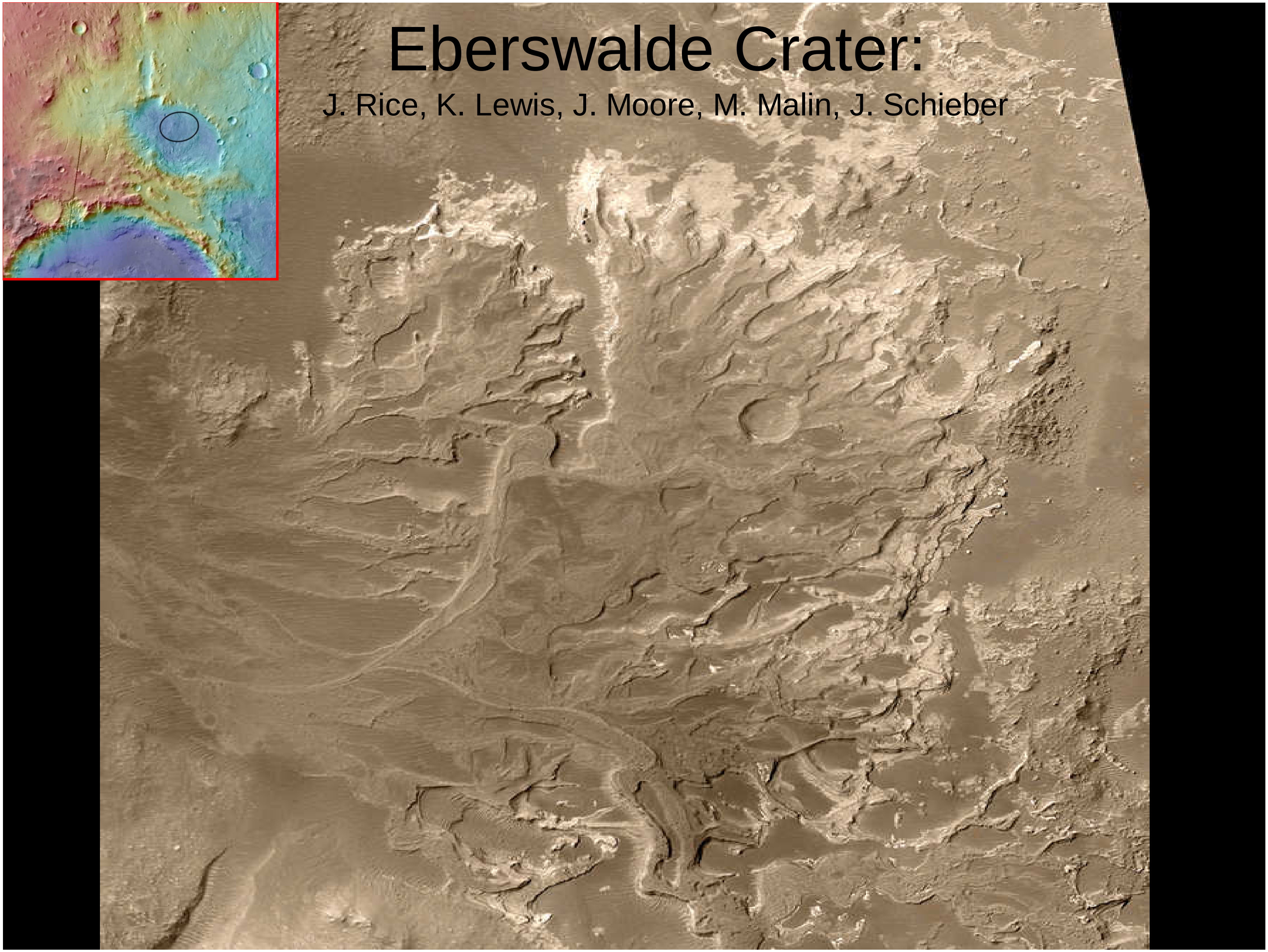




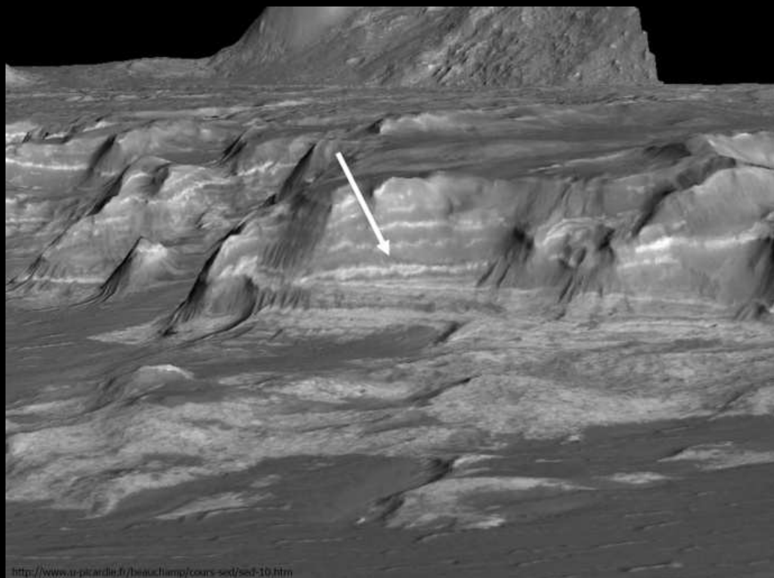


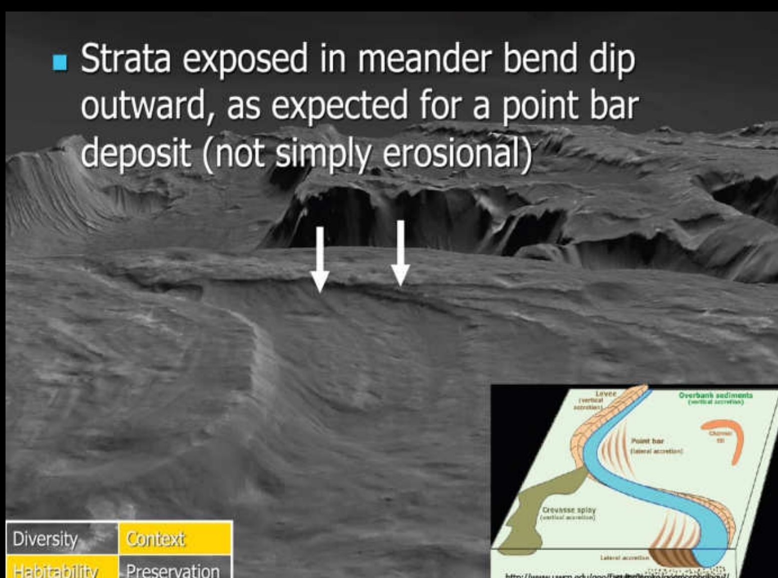
Eberswalde Crater:

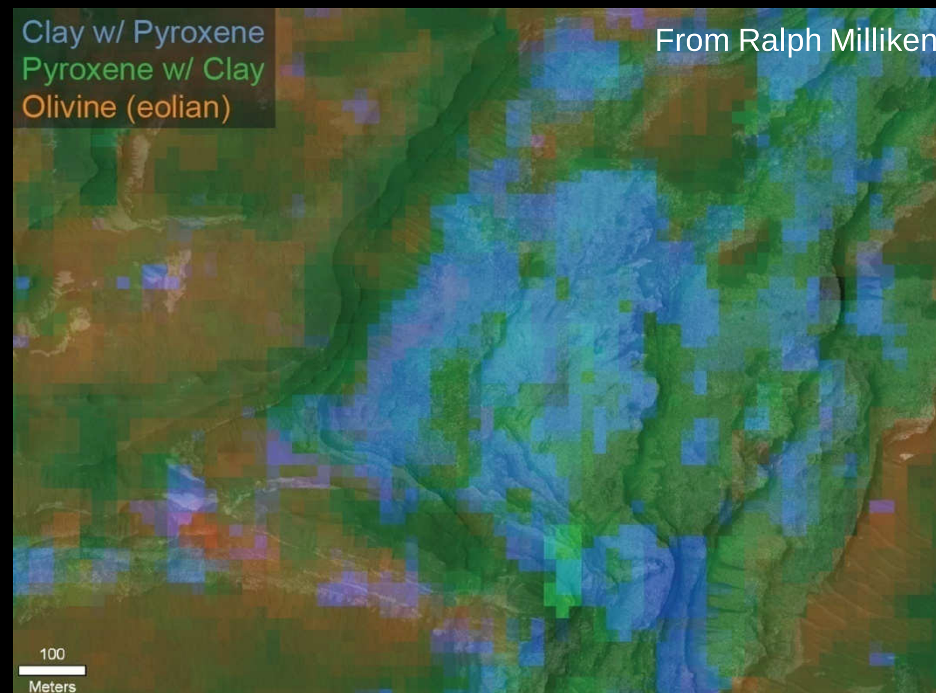
J. Rice, K. Lewis, J. Moore, M. Malin, J. Schieber



Clay-Bearing Beds in Deltaic Setting:

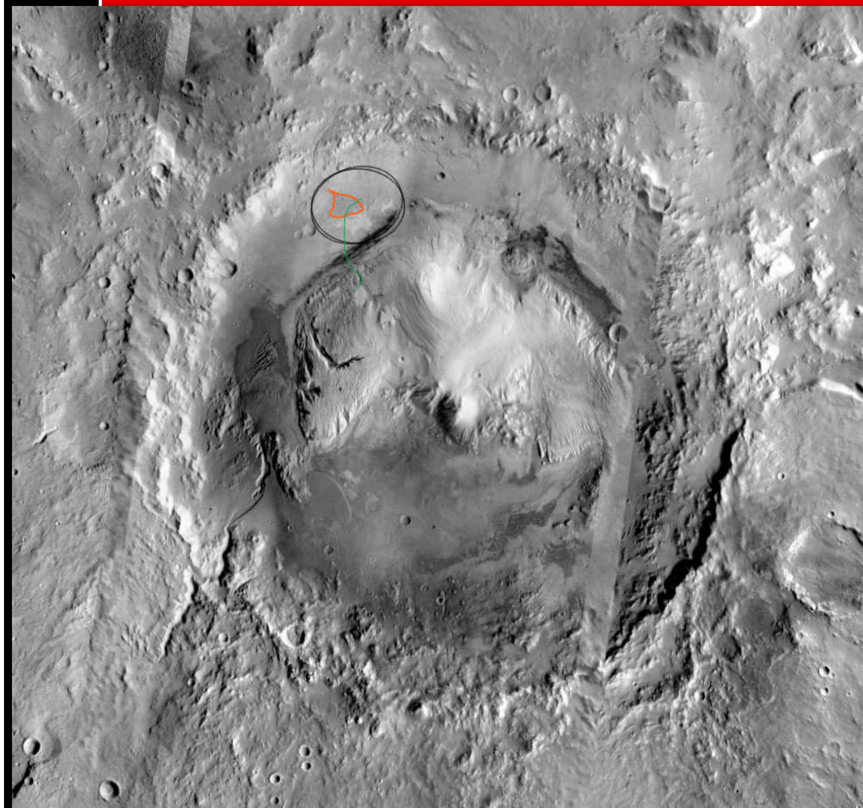




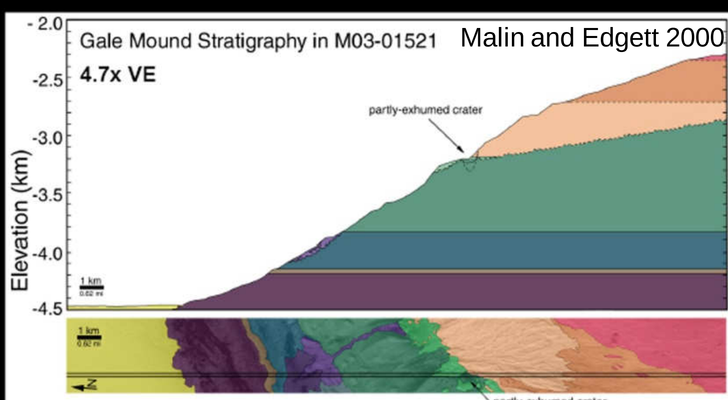


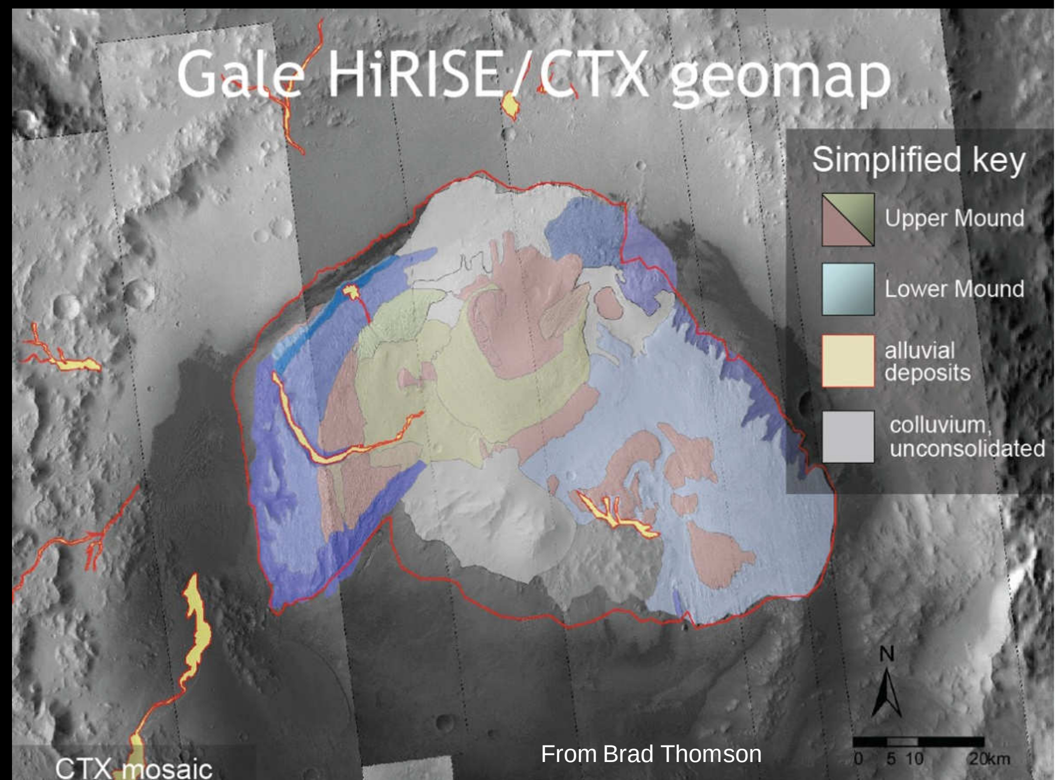
Gale Crater: K. Edgett, B. Thomson, N. Bridges, R. Milliken

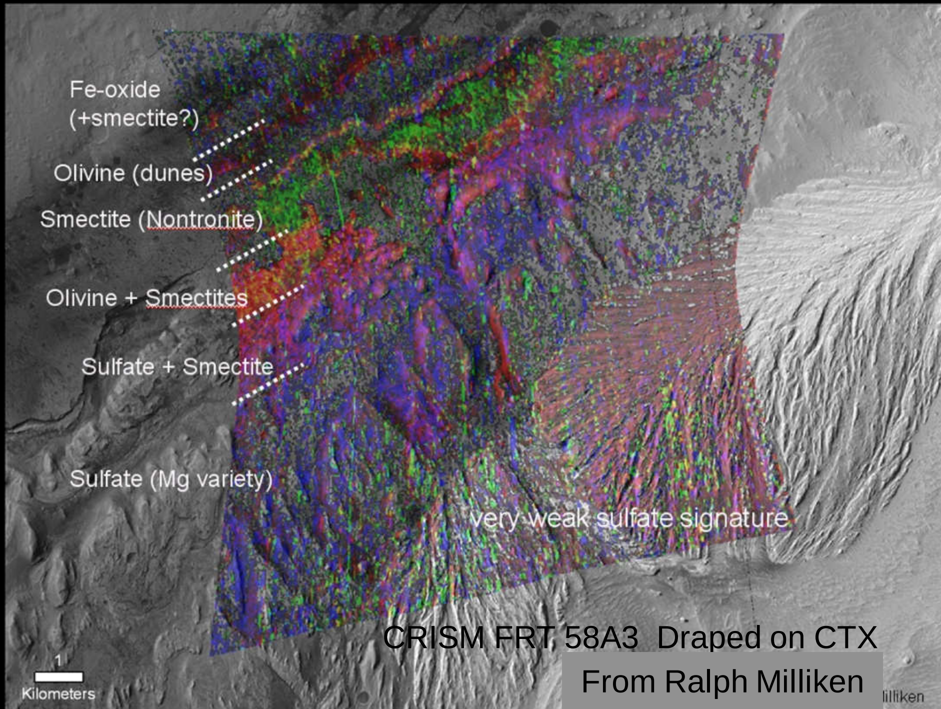
Mars Landing Site Selection Activities

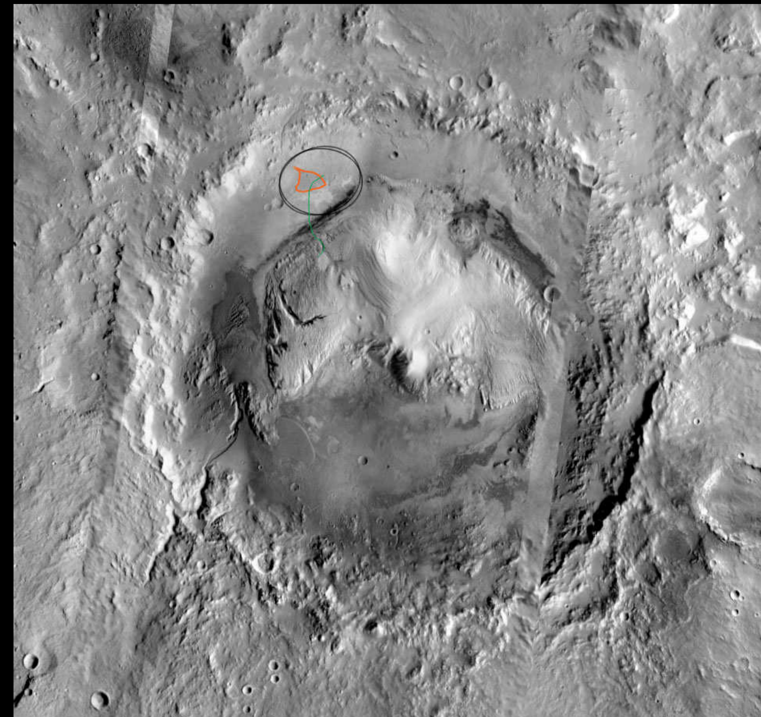


- High diversity of geologic materials with different compositions and depositional conditions
- This diversity is arranged in a stratigraphic context
- Stratigraphy records multiple early Mars environments in sequential order
- Gale is characteristic of a family of craters that were filled, buried, and exhumed, providing insights into an important martian process

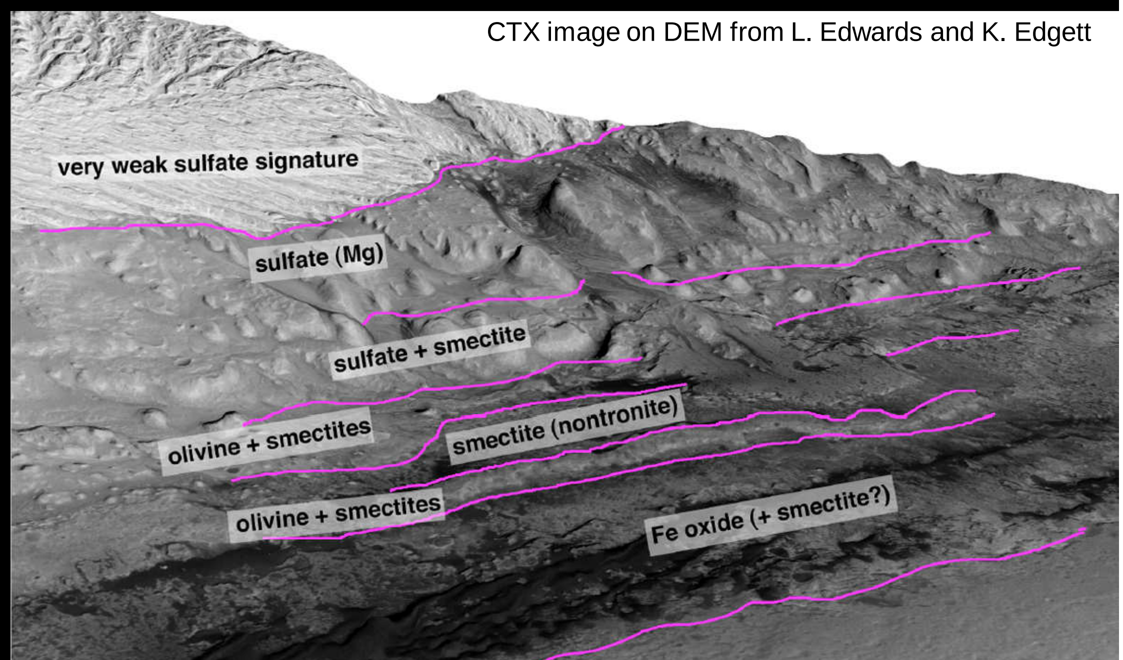




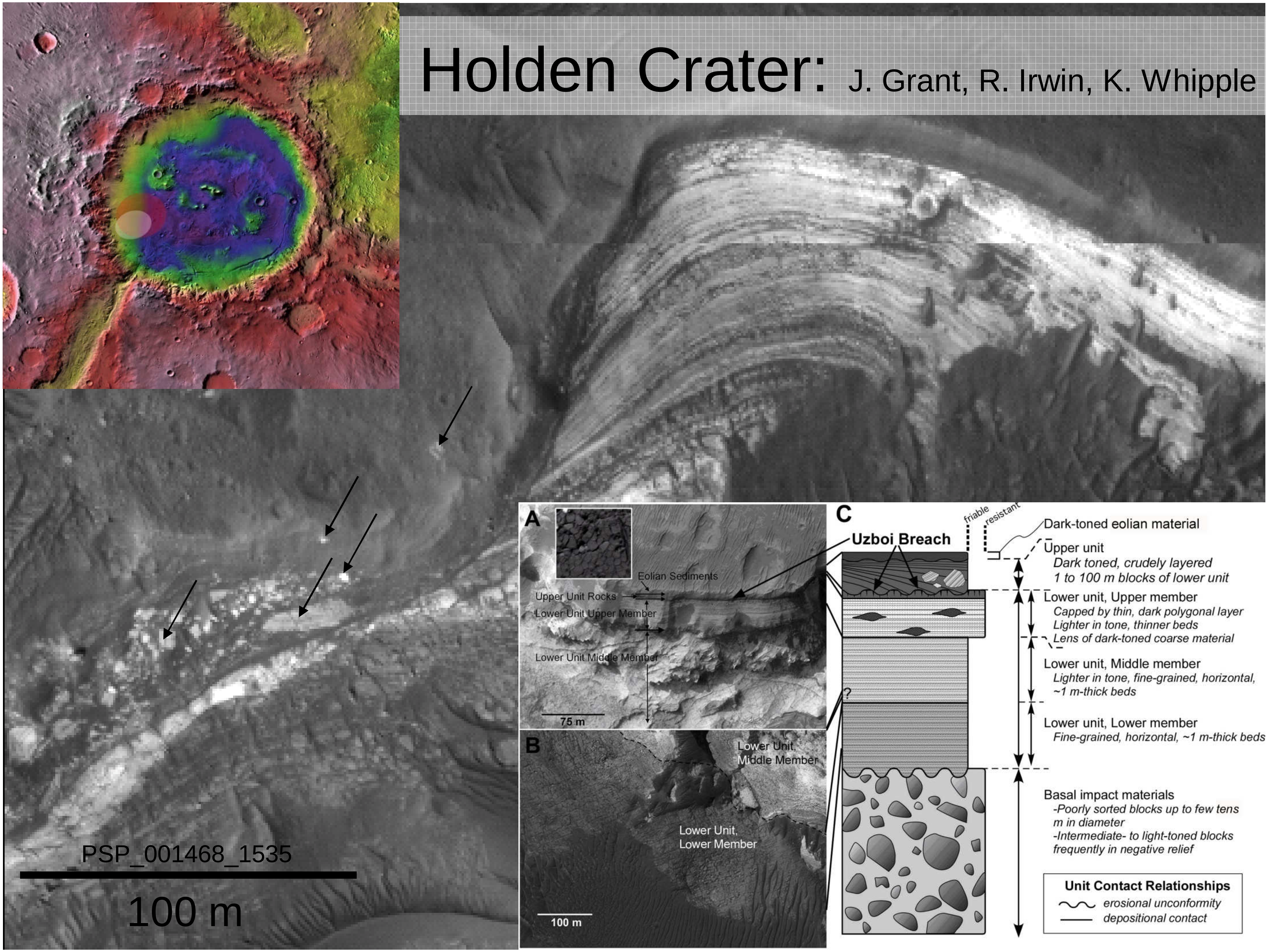

Fe-oxide
(+smectite?)
Olivine (dunes)
Smectite (Nontronite)
Olivine + Smectites
Sulfate + Smectite
Sulfate (Mg variety)
very weak sulfate signature
CRISM FRT 58A3 Draped on CTX
From Ralph Milliken
1
Kilometers

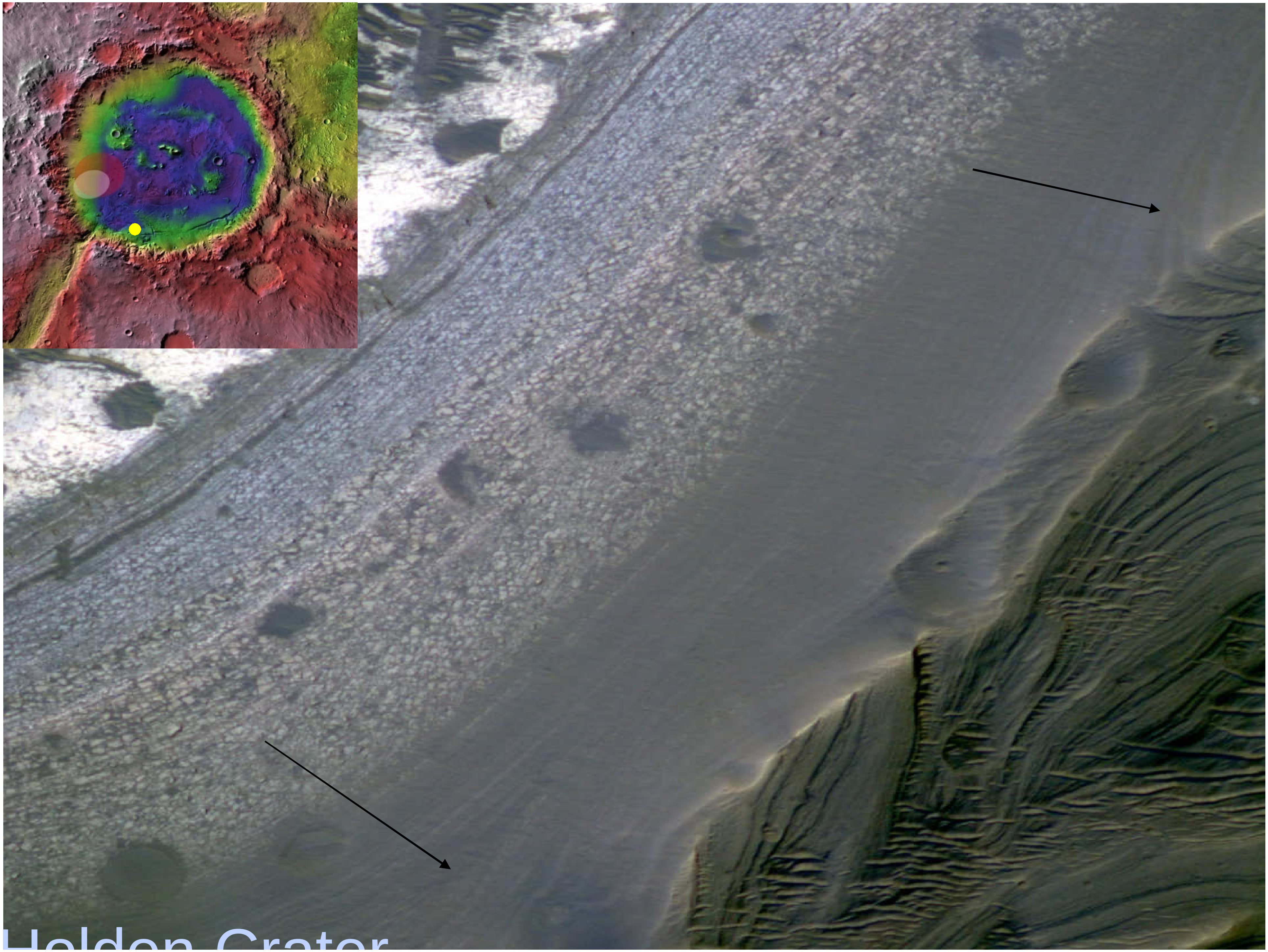


Gale Crater

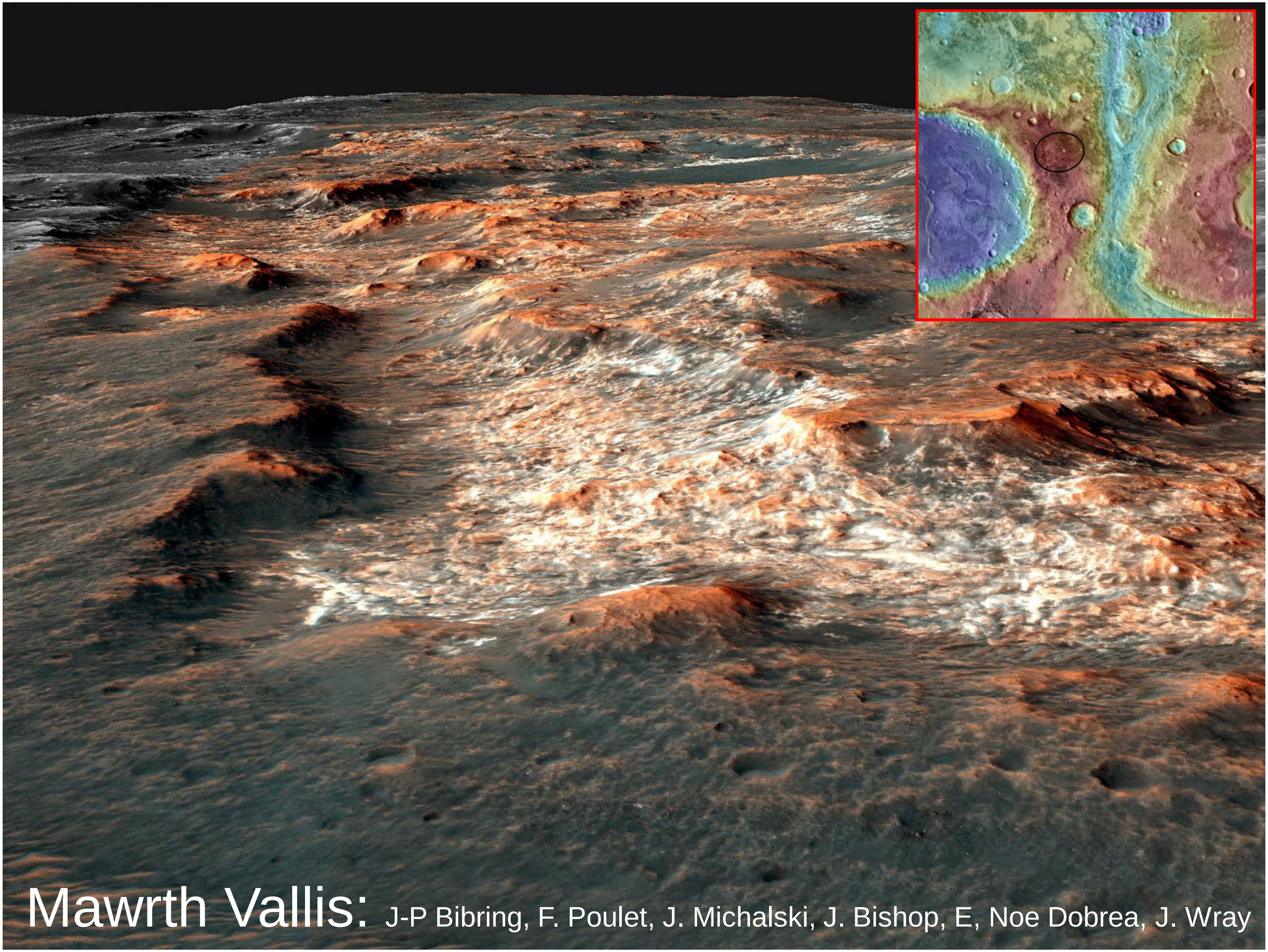

CTX image on DEM from L. Edwards and K. Edgett
very weak sulfate signature
sulfate (Mg)
sulfate + smectite
olivine + smectites
smectite (nontronite)
olivine + smectites
Fe oxide (+ smectite?)

Holden Crater: J. Grant, R. Irwin, K. Whipple



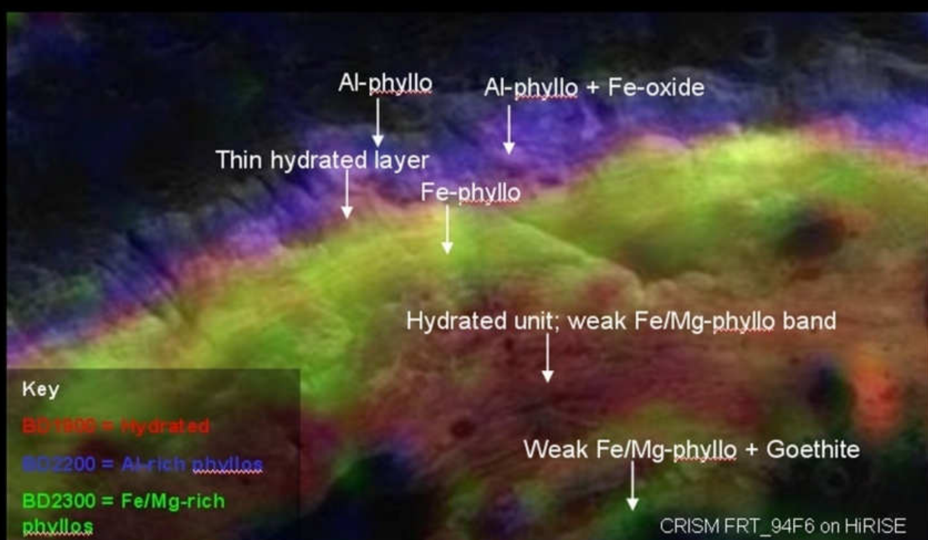


Holden Crater


Mawrth Vallis: J-P Bibring, F. Poulet, J. Michalski, J. Bishop, E, Noe Dobrea, J. Wray

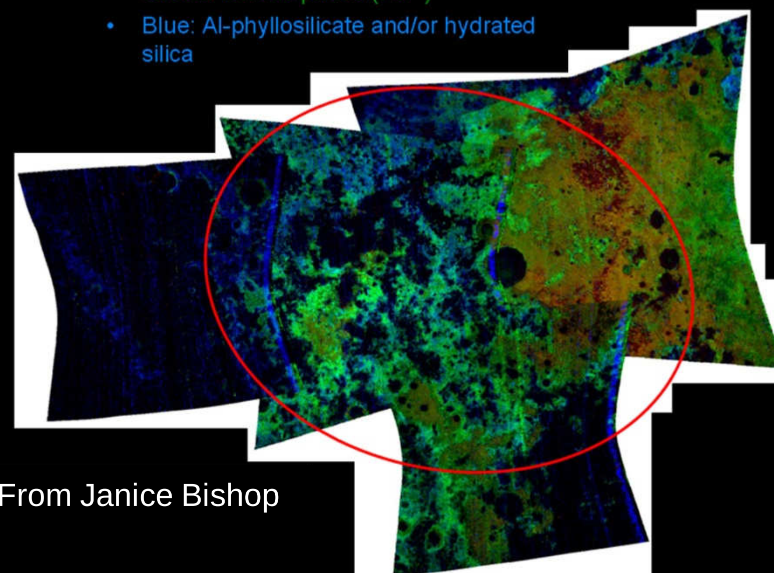
Mawrth Vallis: Phyllosilicate-Bearing Stratigraphy within the Landing Ellipse:

Mars Landing Site Selection Activities



From James Wray

- Red: Fe/Mg smectite (Fe^{3+})
- Green: ferrous phase (Fe^{2+})
- Blue: Al-phyllosilicate and/or hydrated silica



From Janice Bishop

Courtesy of Janice Bishop

Potential New MSL Site Sites:

Mars Landing Site Selection Activities

Taking Advantage of Launch Delay – Respond to New Disoveries/New Sites Identified by MRO

Call for new sites in August 2009

- Five Sites Met Criteria: Mineralogic/Morphologic Compelling; As safe as existing sites
- Steering Committee, Project Review Dec. 11, 2009
  - Science and Safety
- Strong Consensus NE Syrtis, E Margaritifer Potentially Compelling
  - NE Syrtis – Diverse Noachian Mineralogy (Phyllo, Serp, Carb)
  - E Margaritifer – Chlorides, Phllosilicates

MRO Imaging Mostly Complete

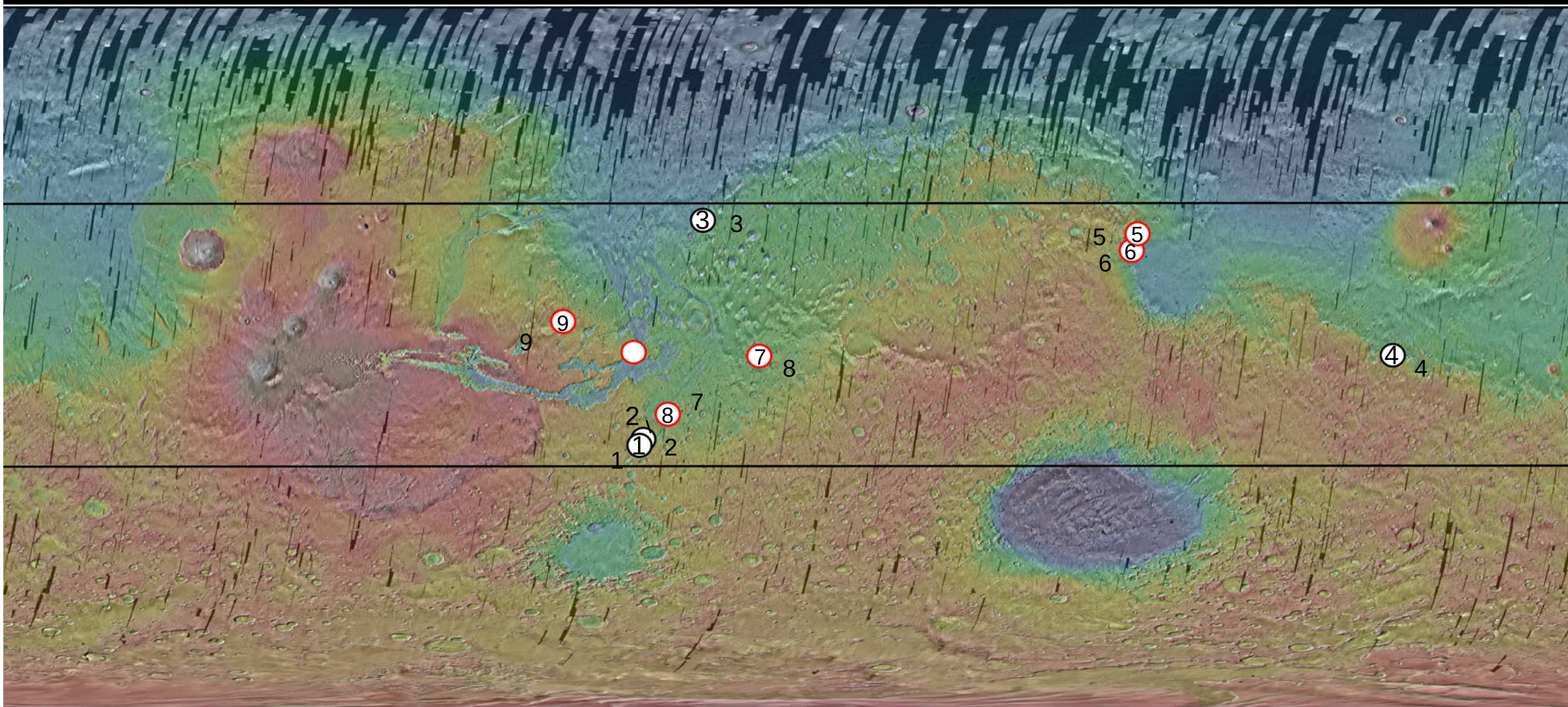
- Complete Stereo HiRISE Covergae of Ellipses
- Completing CRISM Covergae of Ellipses

Steering Committee & Project Review of Two Sites, early May 2010

- Science – Materials Available, Preservation Aqueous Environment
- Safety – Comparison to Existing 4 Landing Sites
- Recommend whether One Additional Site Should be Added

Newly Proposed Candidate MSL Landing Sites

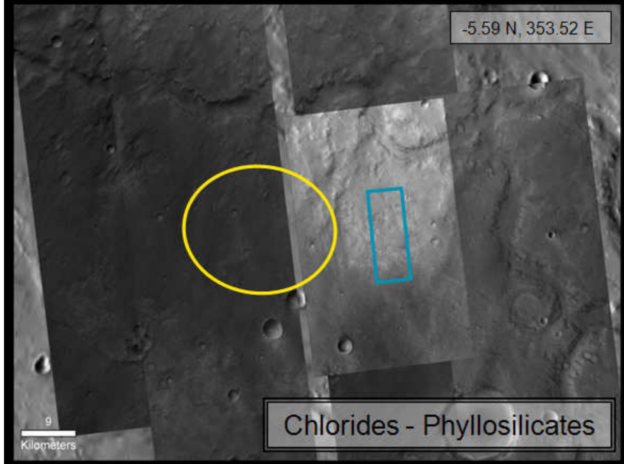
Mars Landing Site Selection Activities

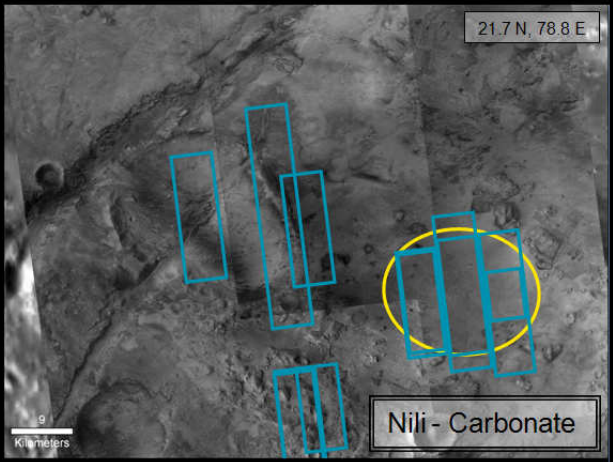


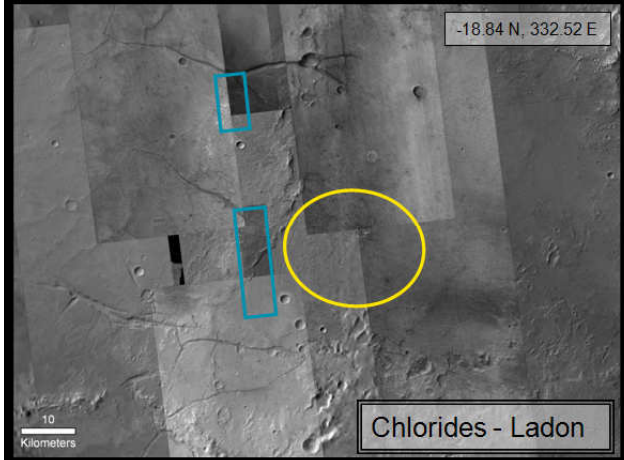
1. Holden Crater
2. Eberswalde
3. Mawrth Vallis
4. Gale Crater
5. Nili Carbonate
6. NE Syrtis
7. Ladon - Chlorides
8. E Margaritifer Chlorides - Phyllo
9. Xanthe Terra fan delta

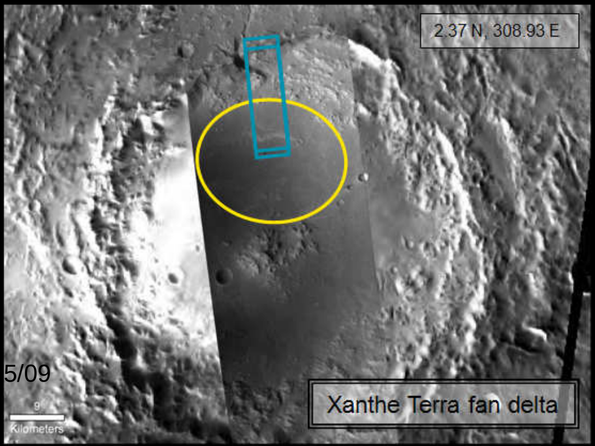
Landing Site Selection Activities

New Proposed MSL Landing Sites







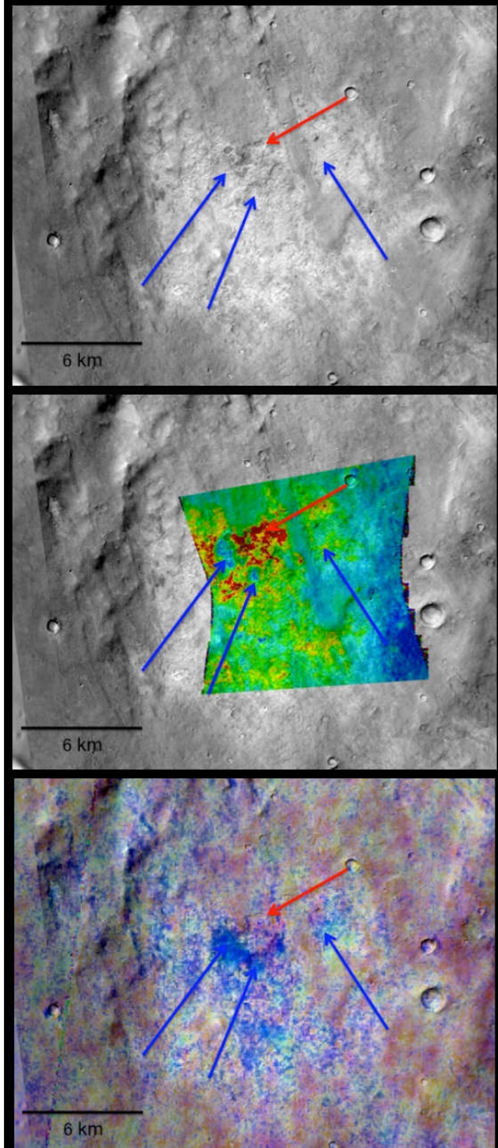


HiRISE Coverage
Dec. 2009

5.6S, 353.5E	-1.2 km	E Margaritifer
18.8S, 332.5E	-2.1 km	Ladon basin
21.7N, 78.8E	-1.5 km	Nili Carbonate
16.7N, 76.9E	-2.6 km	NE Syrtis
2.3N, 309E	-2.1 km	Xanthe Terra crater

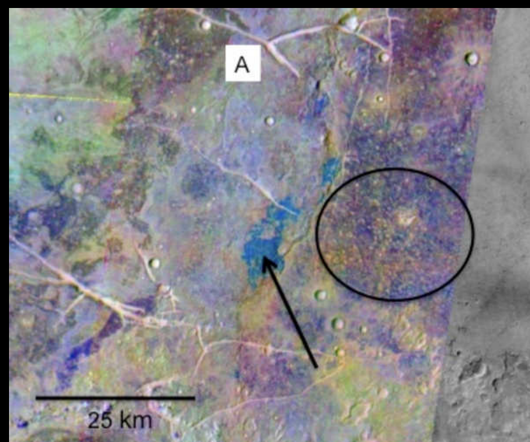
A Thumbnail View of the Newly Proposed Sites:

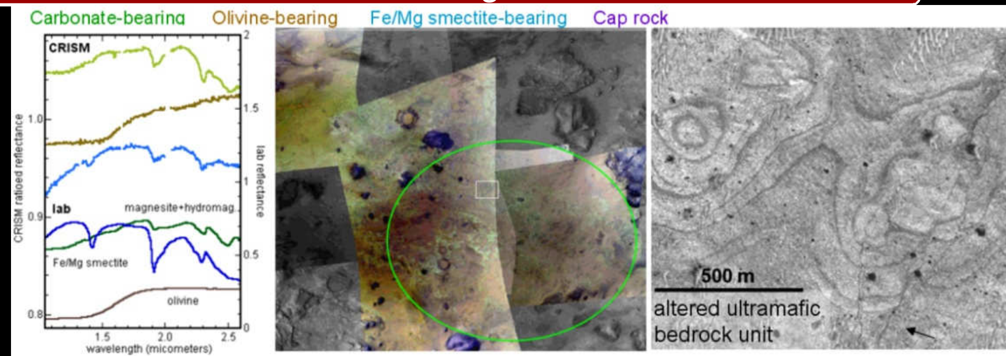
Mars Landing Site Selection Activities



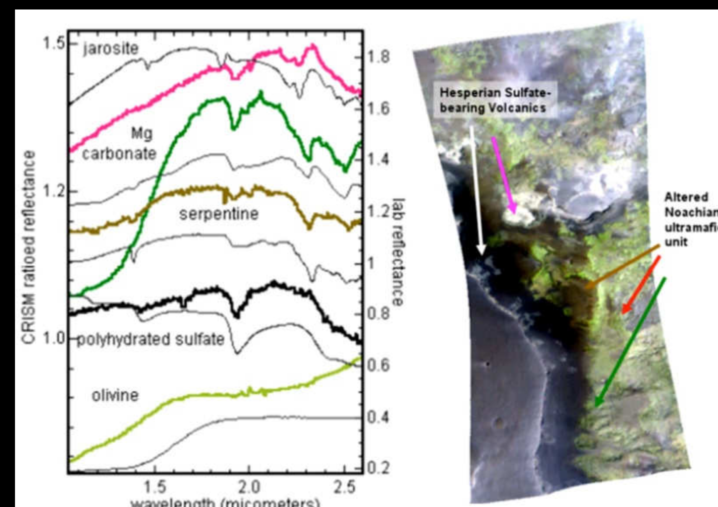
East Margaritifer Chloride

Ladon Basin Chloride

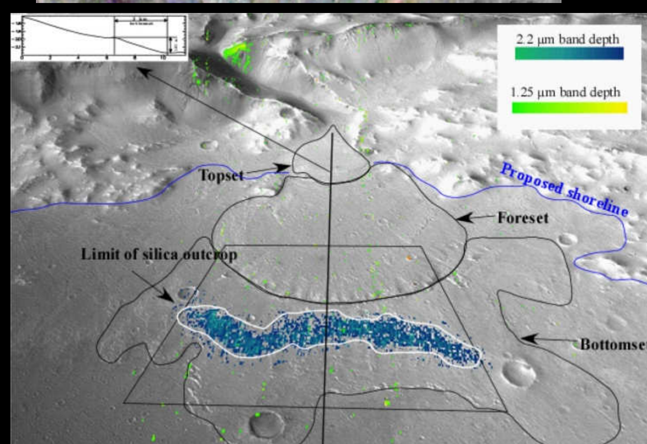




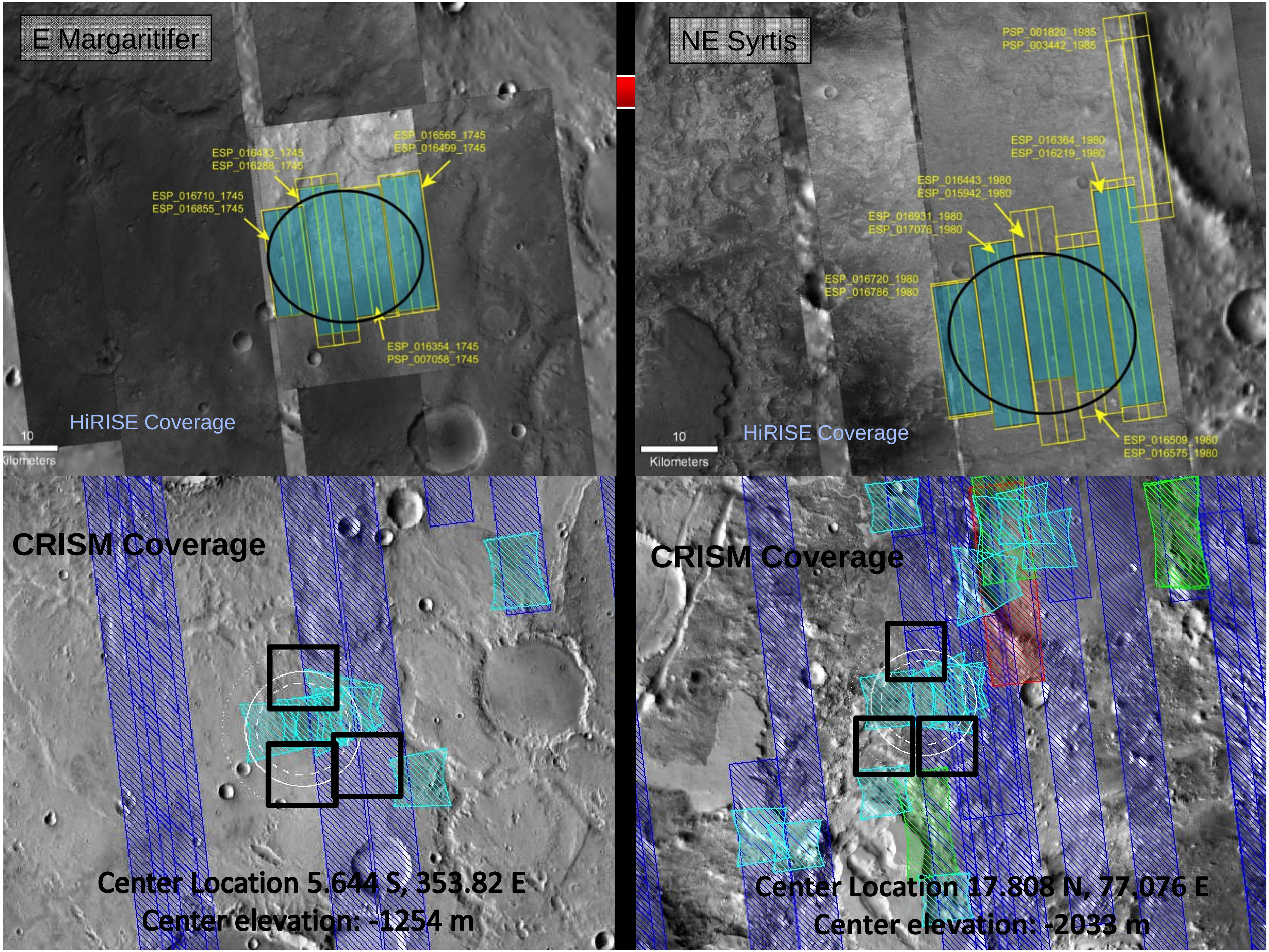
Nili Carbonate



NE Syrtis



Xanthe Delta



E Margaritifer
ESP_016565_1745
ESP_016499_1745
ESP_016433_1745
ESP_016288_1745
ESP_016710_1745
ESP_016855_1745
ESP_016354_1745
PSP_007058_1745
HiRISE Coverage
10
Kilometers
NE Syrtis
PSP_001820_1985
PSP_003442_1985
ESP_016364_1980
ESP_016219_1980
ESP_016443_1980
ESP_015942_1980
ESP_016931_1980
ESP_017076_1980
ESP_016720_1980
ESP_016786_1980
ESP_016509_1980
ESP_016575_1980
HiRISE Coverage
10
Kilometers
CRISM Coverage
Center Location 5.644 S, 353.82 E
Center elevation: -1254 m
CRISM Coverage
Center Location 17.808 N, 77.076 E
Center elevation: -2033 m

Martian surface properties from joint analysis of orbital, Earth-based, and surface observations

M. P. GOLOMBEK, A. F. C. HALDEMANN, R. A. SIMPSON, R. L. FERGASON, N. E. PUTZIG, R. E. ARVIDSON, J. F. BELL III, AND M. T. MELLON

ABSTRACT

Surface characteristics at the five sites where spacecraft have successfully landed on Mars can be related favorably to their signatures in remotely sensed data from orbit and from the Earth. Comparisons of the rock abundance, types and coverage of soils (and their physical properties), thermal inertia, albedo, and topographic slope all agree with orbital remote-sensing estimates and show that the materials at the landing sites can be used as "ground truth" for the materials that make up most of the equatorial and mid-latitude regions of Mars. The five landing sites sample two of the three dominant global thermal inertia and albedo units that cover ~80% of the surface of Mars. The Viking Landers 1 and 2, *Spirit*, and Mars Pathfinder landing sites are representative of the moderate-to-high thermal inertia and intermediate-to-high albedo unit that is dominated by crusty, cloddy, and blocky soils (duricrust) with various abundances of rocks and bright dust. The *Opportunity* landing site is representative of the moderate-to-high thermal inertia and low-albedo surface unit that is relatively dust-free and composed of dark eolian sand and/or increased abundance of rocks. Interpretation of radar data confirms the presence of load bearing, relatively dense surfaces controlled by the soil type at the landing sites, regional rock populations from diffuse scattering similar to those observed directly at the sites, and root-mean-squared (RMS) slopes that compare favorably with 100 m scale topographic slopes extrapolated from altimetry profiles and meter scale slopes from high-resolution stereo images. The third global unit has very low thermal inertia and very high albedo, indicating that it is dominated by meter thick deposits of bright red atmospheric dust that may be neither load-bearing nor trafficable. The landers have thus sampled the majority of likely safe and trafficable surfaces that cover most of Mars and shown that remote-sensing data can be used to infer the surface characteristics, slopes, and surface materials present at other locations.

21.1 INTRODUCTION

Understanding the relationship between orbital remote-sensing data and the surface is essential for safely landing spacecraft and for correctly interpreting the surfaces and materials globally present on Mars. Understanding the surfaces and materials globally present on Mars is also fundamentally important for inferring the erosional, weathering, and depositional processes that create and modify the Martian surface layer (Christensen and Moore, 1992). Although relatively thin, this surface layer or regolith, composed of rocks and soils, represents the key record of geologic processes that have shaped it, including the interaction of the surface and atmosphere through time via various chemical alteration, weathering, and eolian (wind-driven) processes.

Most of our detailed information about the specific materials that make up the Martian surface comes from the *in situ* investigations accomplished by the five successful landers. The first successful landings were the Viking landers in 1976, part of two orbiter/lander pairs that were launched in 1975 (Soffen and Young, 1972). Although the overriding impetus for the Viking Landers was to determine if life existed on Mars, both stationary landers carried imagers, seismometers, atmospheric science packages, and magnetic and physical properties experiments as well as the sophisticated life detection experiments. The Viking Landers imaged the landing sites, determined the chemistry of soils at the surface and in shallow trenches, and determined physical properties of surface materials by digging trenches with their sampling arms (Soffen, 1977).

The Mars Pathfinder (MPF) mission, launched 20 years later in 1996, was an engineering demonstration of a low-cost lander and small mobile rover (Golombek, 1997). The lander carried a stereoscopic color imager, which included a magnetic properties experiment and wind sock, and an atmospheric structure and meteorology experiment. The 10 kg rover (Sojourner) carried engineering cameras, ten technology experiments, and an Alpha Proton X-ray Spectrometer for measuring the elemental composition of surface materials. The MPF rover traversed about 100 m around the lander, exploring the landing site and characterizing surface materials in a few hundred square meter area (Golombek *et al.*, 1999a; see also Chapters 3 and 12).

The Mars Exploration Rovers (MERs) *Spirit* and *Opportunity* landed twin moderate-sized rovers in early 2004 which have explored over 7 and 10 km, respectively, of the surface at two locations. Each rover carries a payload that includes multiple imaging systems consisting of stereo Navigation Cameras (Navcam), the color stereo Panoramic Cameras (Pancam), and the Miniature Thermal Emission Spectrometer (Mini-TES), all on a 1.5 m high mast. The rovers also carry an arm that can brush and grind away the outer layer of rocks (the Rock Abrasion Tool or RAT) and can place an Alpha Particle X-Ray Spectrometer (APXS),

The Martian Surface: Composition, Mineralogy, and Physical Properties, ed. J. F. Bell III. Published by Cambridge University Press.

Surface Characteristics

Mars Landing Site Selection Activities

Chapter from New Mars Book

Direct Relationship between Surface Characteristics at Landing Sites and Remote Sensing Signatures from Orbit

Surface - Cohesion, Particle Size of Fine Component and Rocks, topo maps

Orbit - Thermal Inertia, Albedo, Dust Index, Rock Abundance, Rocks, topo maps

Comparison & Data Improved Past 12 years Successful Prediction of MPF, MER, PHX Landing Sites

Site Characterization

- Extensive Acquisition & Analysis Orbiter Data
  - Create Data Products that Address Engineering Constraints
  - CDP Supports Generation of Data Products
  - HiRISE DTMs & Photoclinometry, Rock Maps, Thermal Inertia, MOLA Slopes, CTX DTMs, Radar Analysis
- Support Engineering Landing Simulations & Safety Analysis
  - Engineering Constraints on Landing Sites
    - Latitude, Elevation, Ellipse Size, Slopes (many scales),
    - Rocks, Radar Reflectivity, Load Bearing (thermal inertia & albedo)
  - Greatest Concern is Slopes and Rocks at Rover Scale
  - Rocks – Safety Concern
    - Rocks >0.6 m high [1.2 m diameter] – landing stability and loads
  - m scale slopes concern – appears stable beyond 15° to 20-25°
  - km scale and 100 m slopes important for radar
    - May be less of a concern at these sites
  - Physical material properties will be important for trafficability analysis

Surface Characterization

Mars Landing Site Selection Activities

- 3 Sites Relatively Dust Free; 4th Target Layers
  - Competent Load Bearing Surfaces, Radar Reflective
- All Sites ~Meet 0.2-10 km Relief/Slope Constraint
  - Rough Eberswalde, Gale, Mawrth, Holden Smooth
- 2-5 m Slopes:
  - Rough Eberswalde, Gale, Mawrth, Holden Smooth
- Rock Abundance
  - Rocky Eberswalde, Gale, Mawrth, Holden Few Rocks
- Combining Rocks & 2-5 m Slopes - Most Important Characteristics
  - Rough/Rocky Eberswalde, Gale, Mawrth, Holden Smooth/Few Rocks
- Additional Data Analysis & Landing Simulations
  - Will Determine Relative Safety
  - Traverse Requirements and Scenarios

Science versus Safety Trade

Landing Simulations - Determine Relative Safety of Sites

Example of Risk versus Reward Trade

*Eberswalde Concerns with 100 m & 2-5 m slopes and rocky, Southern latitude, well understood depositional environment, quiet water clay deposits, address MSL science objectives directly

*Gale some rock and slope concerns (edge of ellipse), target materials require traverse outside of ellipse, sulfates and phyllosilicate layers present, unknown depositional setting, with poor geologic context or age of materials

*Mawrth some slope concerns, non "go to" site, Fe & Al phyllosilicates of LN age present, but uncertain depositional and/or diagenetic setting

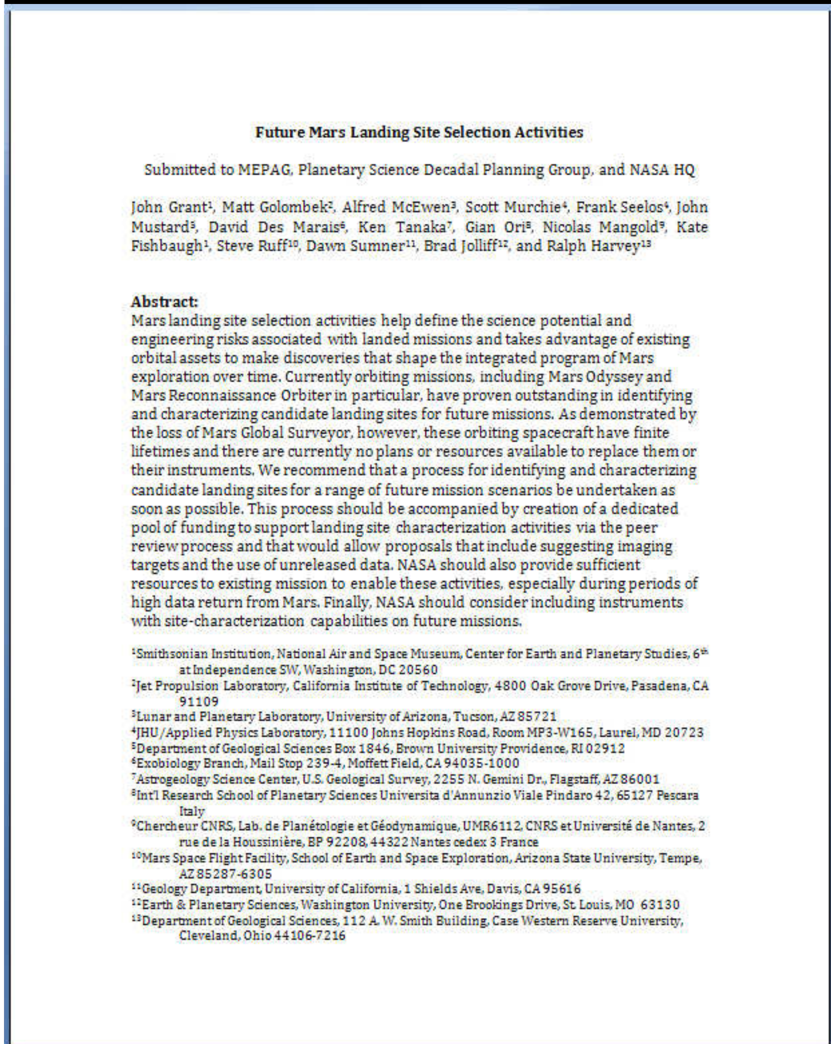
*Holden no safety concerns, target materials require traverse outside of ellipse, Southern latitude, layered phyllosilicates in lacustrine or fluvial setting, well understood geologic context

Future MSL Site Selection Activities

- E Margaritifer & NE Syrtis sites
  - Evaluated early May 2010
  - One may be added to list of four
- Fourth Community Workshop Sept. 27-29 near JPL
  - In depth discussion science merits and surface characteristics
- PSG Working Group - detailed look at sites
  - Science targets & traversability
  - Chaired by Ken Edgett & Dawn Sumner, involve community via site advocates
- Fifth Community Workshop in March/April 2011
  - Findings of PSG Working Group
  - Final discussion of science merits & surface characteristics
- Independent Peer Review
- Selection by HQ in April 2011

Planning Future Site Selection Activities:

Mars Landing Site Selection Activities



Future Mars Landing Site Selection Activities

Submitted to MEPAG, Planetary Science Decadal Planning Group, and NASA HQ

John Grant[1], Matt Golombek[2], Alfred McEwen[3], Scott Murchie[4], Frank Seelos[4], John Mustard[5], David Des Marais[6], Ken Tanaka[7], Gian Ori[8], Nicolas Mangold[9], Kate Fishbaugh[1], Steve Ruff[10], Dawn Sumner[11], Brad Jolliff[12], and Ralph Harvey[13]

Abstract:
Mars landing site selection activities help define the science potential and engineering risks associated with landed missions and takes advantage of existing orbital assets to make discoveries that shape the integrated program of Mars exploration over time. Currently orbiting missions, including Mars Odyssey and Mars Reconnaissance Orbiter in particular, have proven outstanding in identifying and characterizing candidate landing sites for future missions. As demonstrated by the loss of Mars Global Surveyor, however, these orbiting spacecraft have finite lifetimes and there are currently no plans or resources available to replace them or their instruments. We recommend that a process for identifying and characterizing candidate landing sites for a range of future mission scenarios be undertaken as soon as possible. This process should be accompanied by creation of a dedicated pool of funding to support landing site characterization activities via the peer review process and that would allow proposals that include suggesting imaging targets and the use of unreleased data. NASA should also provide sufficient resources to existing mission to enable these activities, especially during periods of high data return from Mars. Finally, NASA should consider including instruments with site-characterization capabilities on future missions.

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Presented at last MEPAG; Unanimous Support; White paper to Decadal Survey

Orbital assets exist now that can provide data for a wide variety of candidate landing sites

These orbiters and instruments have finite capabilities and lifetime (MGS) and instruments with equivalent or better/unique capabilities might not fly before possible landings in 2018 and beyond

Solicit Candidate Landing Sites for Future Missions [All Missions and Concepts]

Begin Imaging to Support Investigations; MRO Agreed to 3-4 Targets per Cycle

Workshops to Discuss Merits of Sites; Steering Committee to Review, Prioritize Sites

Funding to Support Site Investigations

Future Landing Sites:

Mars Landing Site Selection Activities

- Call for sites (for range of future missions) made late last year, resulted in 15 candidates
- Call for CDP, additional candidate sites (proposals submitted March 1st)
  - Expected to fund 5-10 proposals for 25K for 1 year
  - Possibility for renewal
- New sites reviewed by Steering Committee to assess merits and rank for imaging by MRO
- Steering Committee represents broad interests (Astrobiology to SR and others)
  - Steering Committee includes John Grant, Matt Golombek (co-chairs), Dave Des Marais, Brad Jolliff, Nicolas Mangold, Alfred McEwen, John Mustard, Gian Ori, Steve Ruff, and Ken Tanaka
  - Ellipses generally 10 km X 15 km (or 15 km), many focused on MAX-C but others specified by proposer
  - Steering Committee Chairs work with proposers to establish image footprints

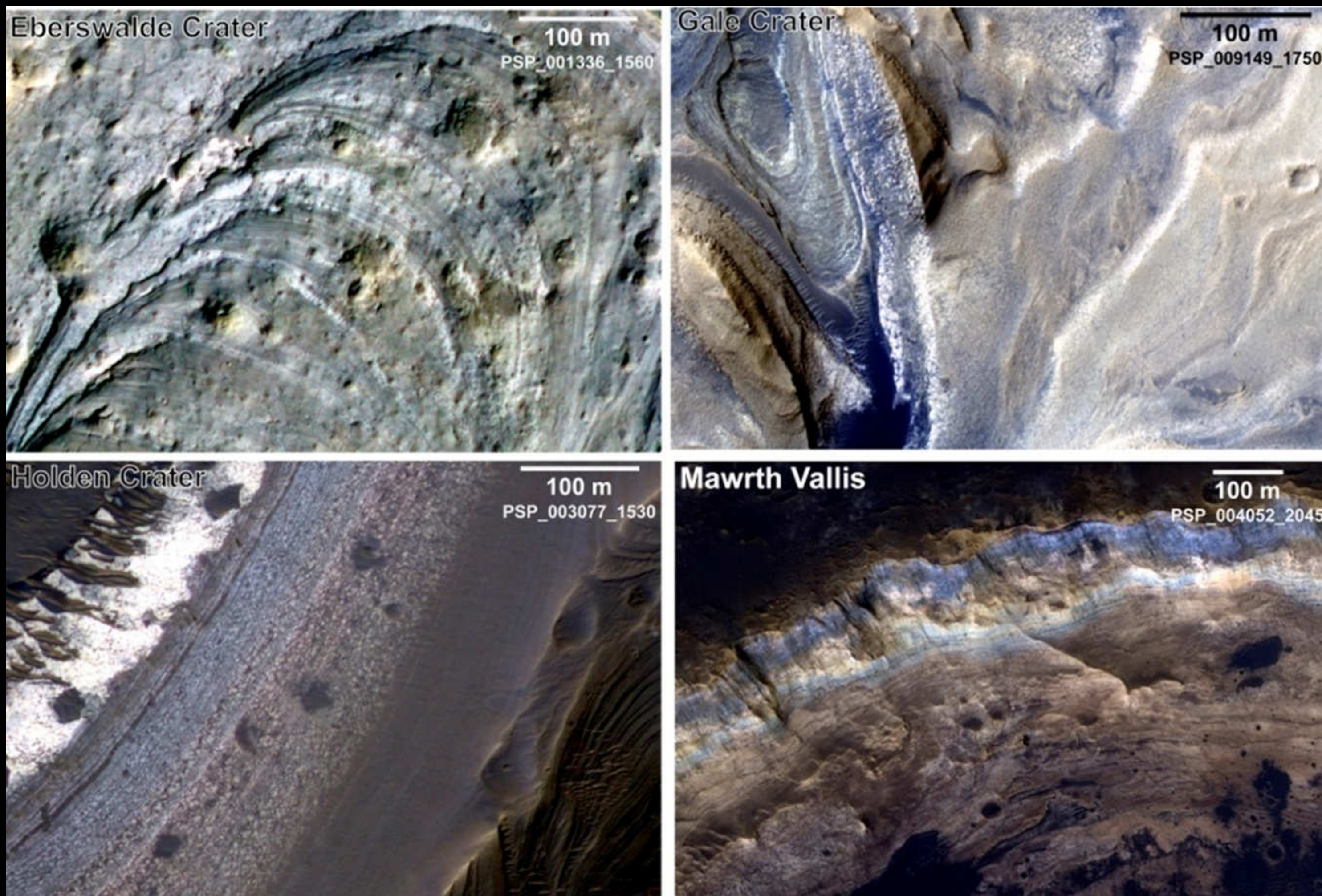
New Candidate Landing Sites Submitted:

Mars Landing Site Selection Activities

Name	Location	Elevation km (MOLA)	Target	Mission, Ellipse
Antoniadi Crater [Smith et al.]	20.34°N, 62.91°E	+0.1	Granitoid, phyllosilicates, zeolites	MAX-C 15 km Ellipse
Columbus crater [Wray et al.]	28.8°S, 194.0°E	+0.9	Intracrater layers kaolinite, smectites, jarosite, mono- and polyhydrates sulfates	Rover 15 km ellipse MAX-C
Vernal Crater [Oehler & Allen]	4.25°N, 354.34°E	-1.98	Potential Spring Deposits	Rover 15 km ellipse
Acidalia Planitia [Oehler & Allen]	40.16 N, 333.22 E	-4.5	Mounds Interpreted as Mud Volcanoes	Rover 15 km ellipse
Acidalia Mensa [Oehler & Allen]	46.63 N, 331.35 E	-4.5	Mounds Interpreted as Mud Volcanoes	Rover 15 km ellipse
Avire Crater [Harrison]	41.25°S, 159.86°W	-0.77	Gullies, mid-latitude fill material, layered lobate features, dunes	Rover 15 km ellipse, MAX-C, Special Region
Kamnik Crater [Harrison]	37.49°S, 161.87°W	+2.3	Gullies, mantling material, mid-latitude "fill"	Rover 1 km ellipse inside crater, or outside, Special Region
Naruko Crater [Harrison]	36.55°S, 161.80°W	+2.7	Gullies, mantling material, mid-latitude "fill"	Rover 1 km ellipse inside crater, or outside, Special Region
Terby Crater [Grotzinger et al.]	27.79°S, 74.17°E	-4.9	Layered mound, possible evaporates, phyllosilicates	Rover 15 km x 10 km ellipse
Melas Chasma [Grotzinger et al.]	9.806°S, 76.507°W	-1.7	Sublacustrine fans, clinoforms, folds, channels, opaline silica	Rover 15 km x 10 km ellipse
N Pole A [Milkovich & Hecht]	89.0˚N, 280.0˚E	-2.5	Polar layered deposits, ice	Mars Scout, thermal drill, 250 km x 25 km ellipse
N Pole B, The saddle [Milkovich & Hecht]	84.0˚N, 34.0˚E	-3.0	Polar layered deposits, ice	Mars Scout, thermal drill, 250 km x 25 km ellipse
Paleolake in Ismenius Cavus [Wray et al.]	33.5˚N, 17.0˚E	~-3.0	Phyllosilicates in crater breached by Mamers Vallis. Well formed delta on NE wall	Astobio/MAX-C, 15 X 15 km ellipse
Southern Meridiani [Wiseman and Arvidson]	3.2˚S, 354.5˚E	-1.5	Land on and traverse from sulfates to phyllosilicates in highlands	15 X 15 km ellipse, MAX-C
N Pole C, Gemini Lingula [Milkovich & Hecht]	82.2˚N, 354.0˚E	-3.3	Polar layered deposits, ice	Mars Scout, thermal drill, 250 km x 25 km ellipse

May Future Landing Sites

Mars Landing Site Selection Activities



Be as Compelling as these for MSL