Investigations of Surface & Atmosphere Characteristics in Support of MSL Safety Evaluations

M. Golombek
E. Noe, J. Griffes, T. Parker
R. Milliken, C. Heinlein, V. Hanus

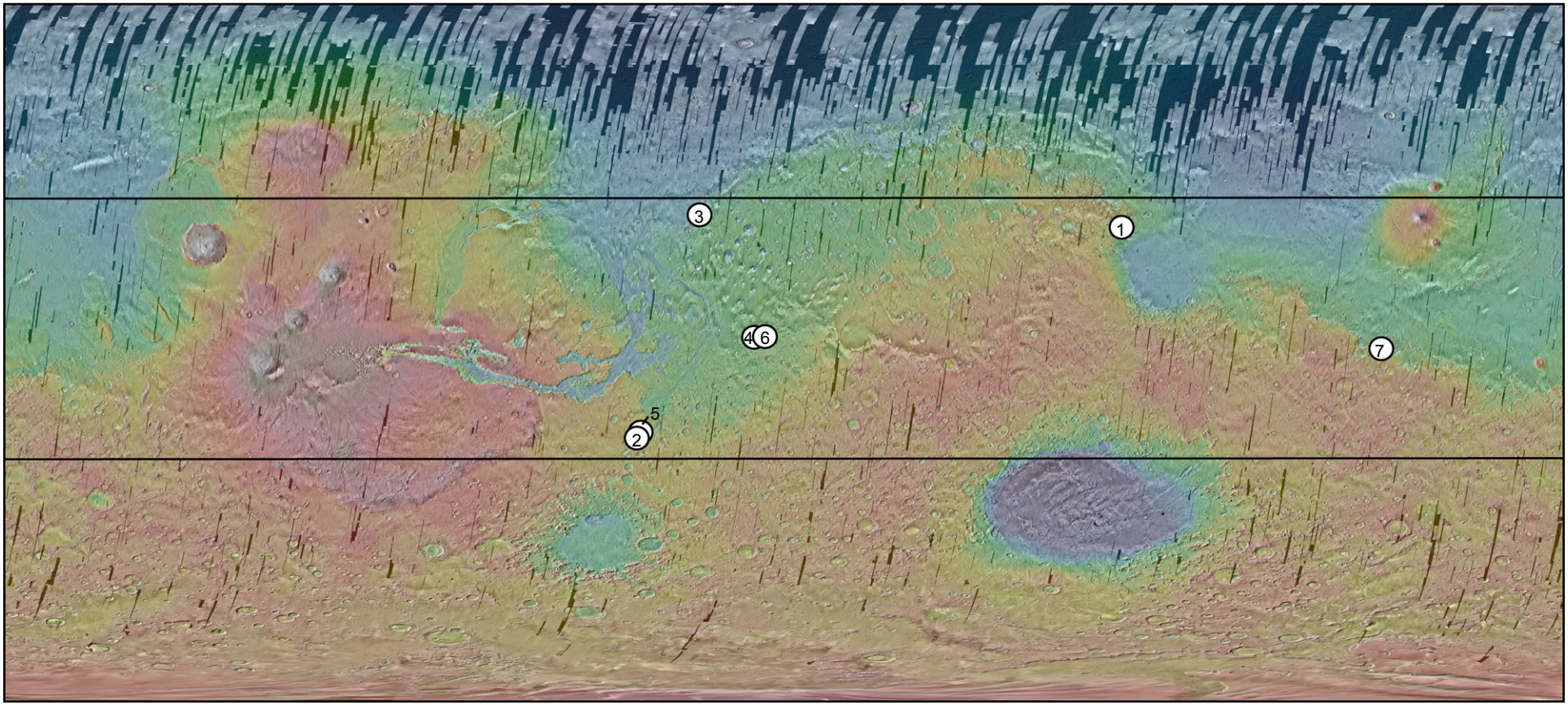
Highlighting work (see posters) by:
A. Vasavada and the Council of Atmospheres
R. Kirk, E. Howington-Kraus et al.: USGS Flagstaff – HiRISE Digital Elevation Models
R. Beyer: SETI NASA Ames – HiRISE Photoclinometry
L. Edwards, J. Bowman, A. Wright, Ames; M. Malin – CTX Digital Elevation Models
R. Ferguson: USGS Flagstaff – THEMIS Thermal Inertia
A. Huertas, M. Golombek: JPL – HiRISE Rock Maps
K. Larsen: CU Boulder – Earth-based Radar

Third Landing Site Workshop for Mars Science Laboratory
Doubletree Hotel, Monrovia, CA
9/15/08

Landing Site Selection

- Blend of Science and Safety
- Engineering Team …
- **None of the Landing Sites Violate the Safety Criteria Such That They Should Not be Considered at this Time – All are tenable**
- Decision to Focus on Science at this Workshop
- This Presentation Summarizes Characterization Work that will form Basis for Landing Simulations and Safety Analysis
  - Engineering work Indicates
  - Rocks – Safety Concern
    - Rocks >0.6 m high – landing stability and loads
  - m scale slopes concern – appears stable beyond 15° to 20-25°
  - km scale and 100 m slopes may be less of a concern at these sites
  - Physical material properties will be important for trafficability analysis
  - Most effort directed at slopes and rocks

MSL Landing Sites



1. Nili Fossae Trough
2. Holden Crater
3. Mawrth Vallis
4. Miyamoto Crater
5. Eberswalde Crater
6. South Meridiani
7. Gale Crater

J. Griffes, Caltech

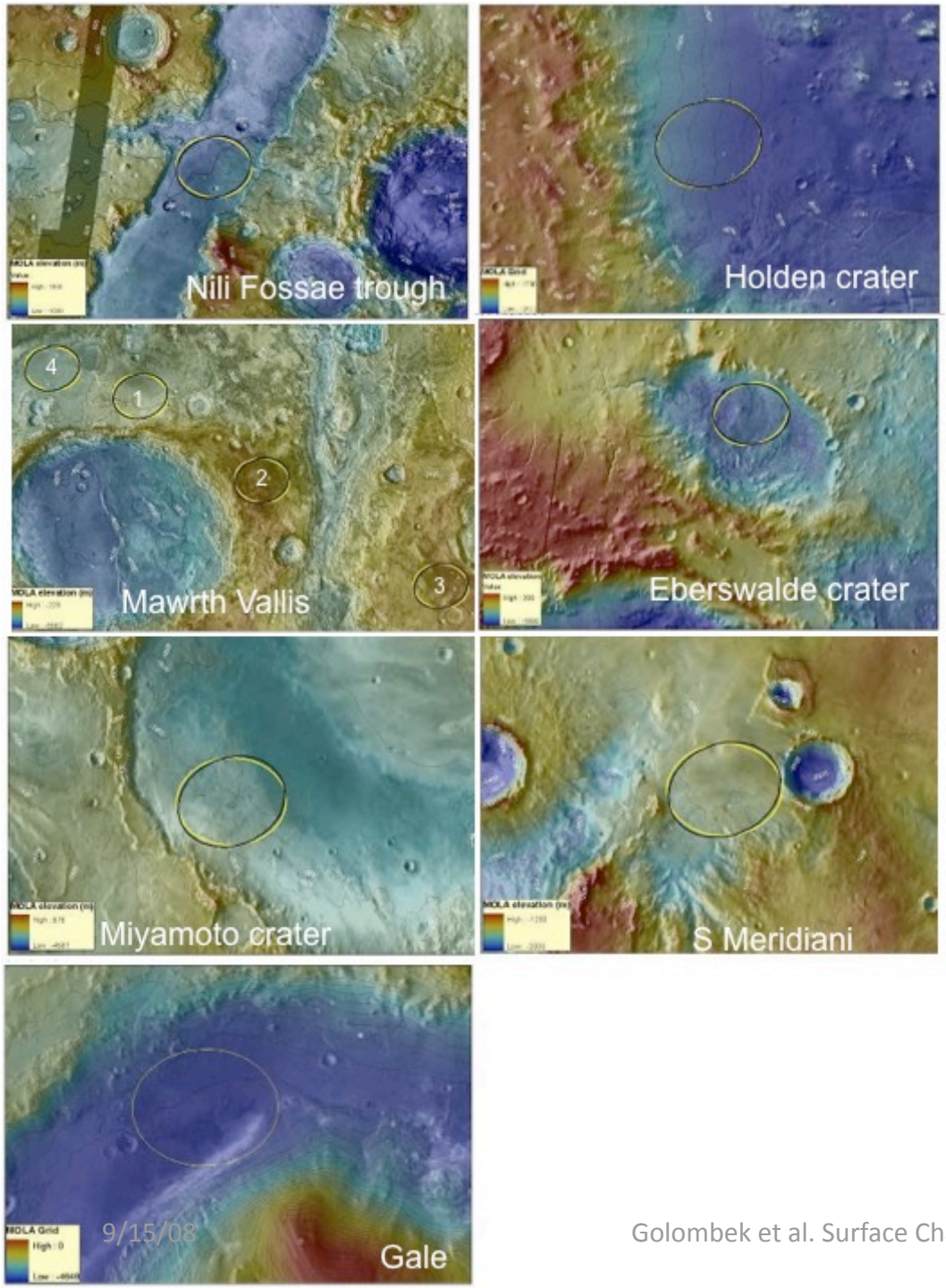
Final 7 Landing Sites

MSL Landing Sites – Final 7

MSL LANDING SITES			
NAME	LOCATION	ELEVATION	TARGET
Nili Fossae Trough	21.00°N, 74.45°E	-608 m	Noachian Phyllosilicates
Holden Crater Fan	26.37°S, 325.10°E	-1940 m	Fluvial Layers, Phyllosilicates
Mawrth Vallis Site 1 Site 2 Site 3 Site 4	 24.65°N, 340.09°E 24.01N, 341.03°E 23.19°N, 342.41°E 24.86°N, 339.42°E	 -3093 m -2246 m -2187 m -3359 m	Noachian Layered Phyllosilicates
Eberswalde Crater	23.86°S, 326.73°E	-1450 m	Delta
Miyamoto	3.34°S, 352.26°E	-1807 m	Phyllosilicates, Sulfates?
S Meridiani	3.05°S, 354.61°E	-1589 m	Sulfates, Phyllosilicates
Gale Crater	4.49°S, 137.42°E	-4451 m	Layered Sulfates, Phyllosilicates,

v. 7; 07/08/08

- These are the final landing sites
- 10 Ellipses
- All Ellipses 20 x 25 km
  - No Safe Haven Ellipses Necessary or being considered



Final 7 Sites
Final 10 Ellipses

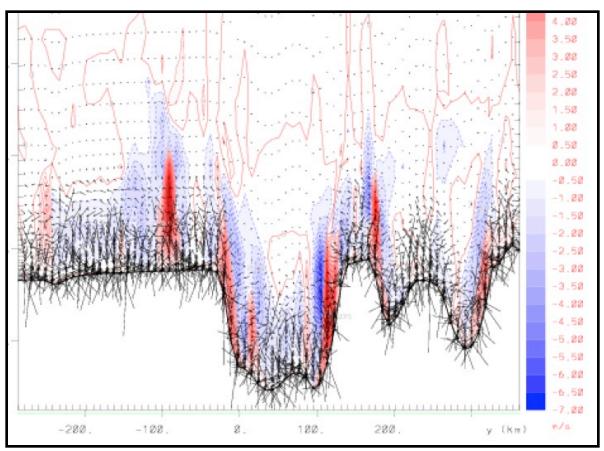
2 ellipses show azimuth variation for different launch in window

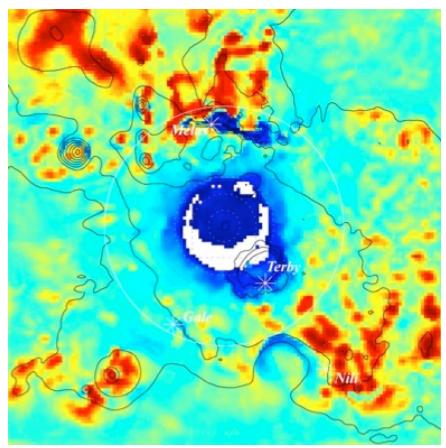
E. Noe, V. Hanus

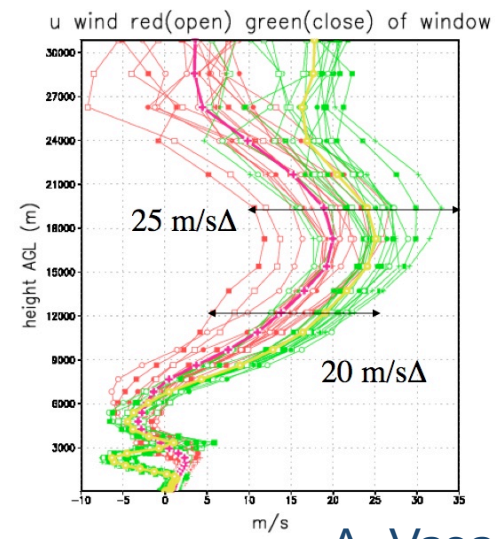
Atmospheric Characterization (1/2)

EDL-Atmosphere Working Group Operating Since 2006

- Identified atmospheric engineering/safety constraints
- Provided output and interpretation of results from General Circulation Models, mesoscale, and regional models; MarsGRAM engineering database
- Identified the types of hazards relevant for the MSL landing sites and season
- Assessed impact of dust storms, CO_2 cycle
- Observations from TES, MCS, MARCI





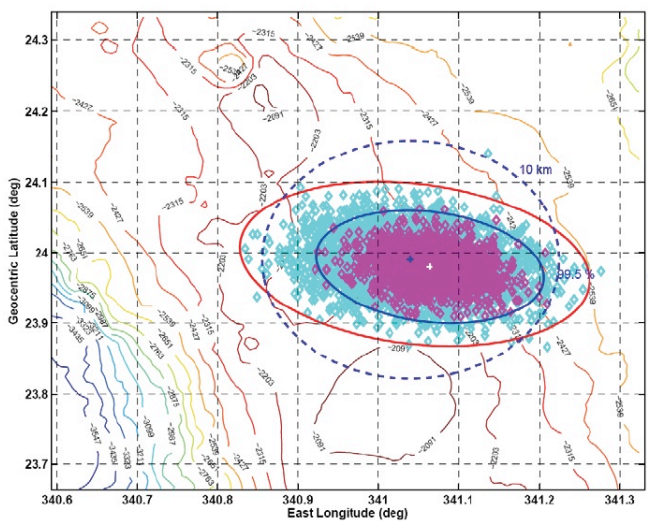


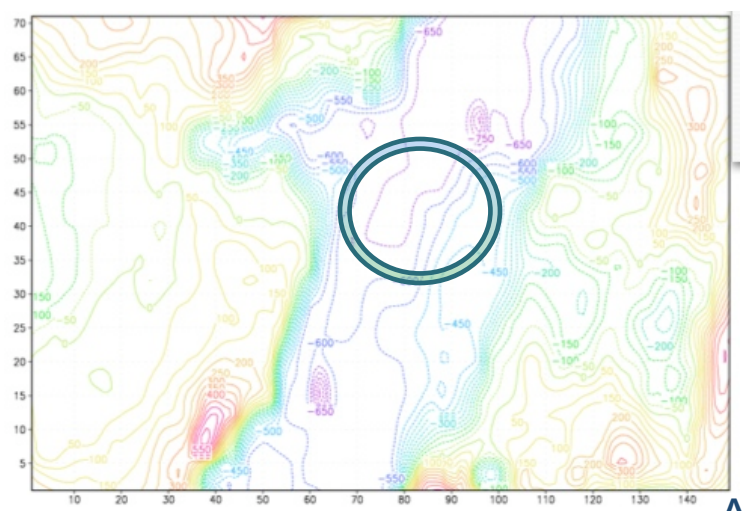
A. Vasavada

Atmospheric Characterization (2/2)

Status as of September 2008

- Completed GCM and mesoscale runs for seven landing sites
- Demonstrated end-to-end simulation capability (for Mawrth)
- Exercised risk-balancing process to be used at all sites
- Some sites have increased risk due to elevation, greater ambient winds, more turbulent boundary layer
- Will run very high-resolution models for final sites
- *All sites are viable from an atmospheric standpoint*





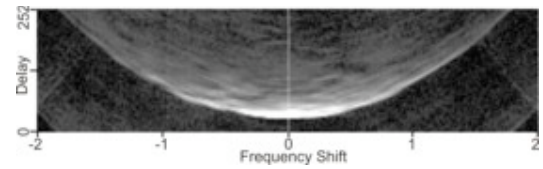
A. Vasavada

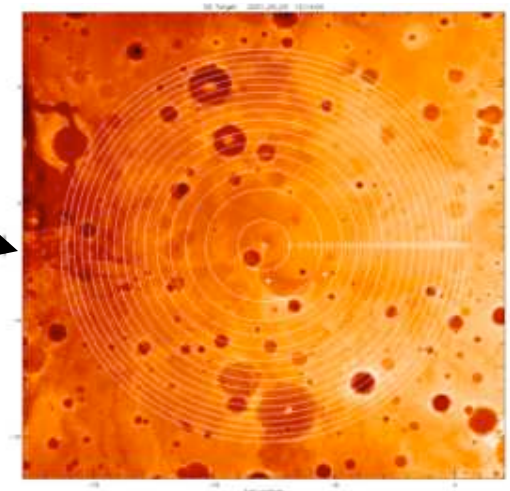
Kristopher Larsen [LASP, CU]

Radar Properties of Candidate MSL Landing Sites from Terrestrial Delay-Doppler Observations.

Terrestrial Radar Derived Measurements

- Measured Radar Backscatter Coefficient
  - Critical for MSL Descent Radar
- Derived Root Mean Square Slopes
  - Critical for Rover Trafficability

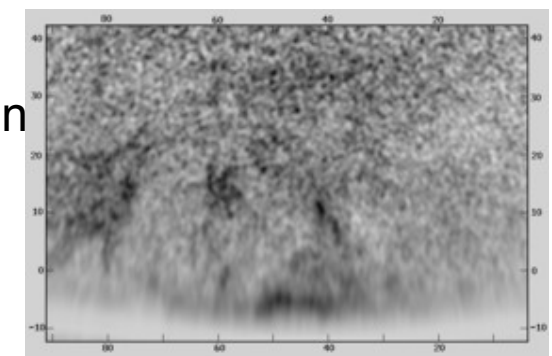




Methods Overview

- X-band (3.5 cm) delay-Doppler Observations
  - Opposite-sense, quasi-specular reflections
  - High spatial resolution (5km)
  - Coverage of Equatorial Landing Sites
    - All except Nili Fossae and Mawrth Vallis

- S-band (12.6 cm) VLA Observations (*Harmon et al. 1999*)
  - Same-sense, diffuse/multiply-scattered reflection
  - Coverage of Mawrth Vallis Only



Results Overview

- Radar Backscatter Coefficient
  - **All landing sites within engineering constraints**
- Root Mean Square Slopes
  - **Initial analyses indicate no roughness concerns**

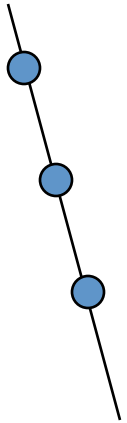
K. Larsen

Topography and Slopes

Most Stringent Constraints

- km Scale - <43 m relief over 1 km
  - Powered Descent
  - Tolerant to 80 m, particularly for low elevation sites
- 100 m Scale - <43 relief over 200 m
  - Powered Descent
- 2-5 m Scale - <15°
  - Tolerant to 20°, 25°

MOLA Data



Orbit Track

300 m Shot Spacing

Spot Size 75 m

Average Elevation of Spot

Footprint Slope & RMS Roughness of Spot

Individual Data Along Track

Evaluated Bidirectional Relief <43 m over 300, 600, 900 m in 20 km Circle for 200-1000 m relief - most stringent constraint

Technique from Anderson et al. [2003]

Evaluated Bidirectional Slope <20° over 2.1, 3.9. 6. 8.1 km in 20 km Circle

Both Can be Easily Modified to Ellipse and Warning Track - Will Provide Definitive Quantitative Comparison to 0.2-10 km Slope; Adirectional Slope

Binned Data 463 m/pixel

In GIS System - Easily Modified for Quick Evaluation

a) 926 m Slope <2.66° over 25 km Circle, equivalent to 43 m constraint

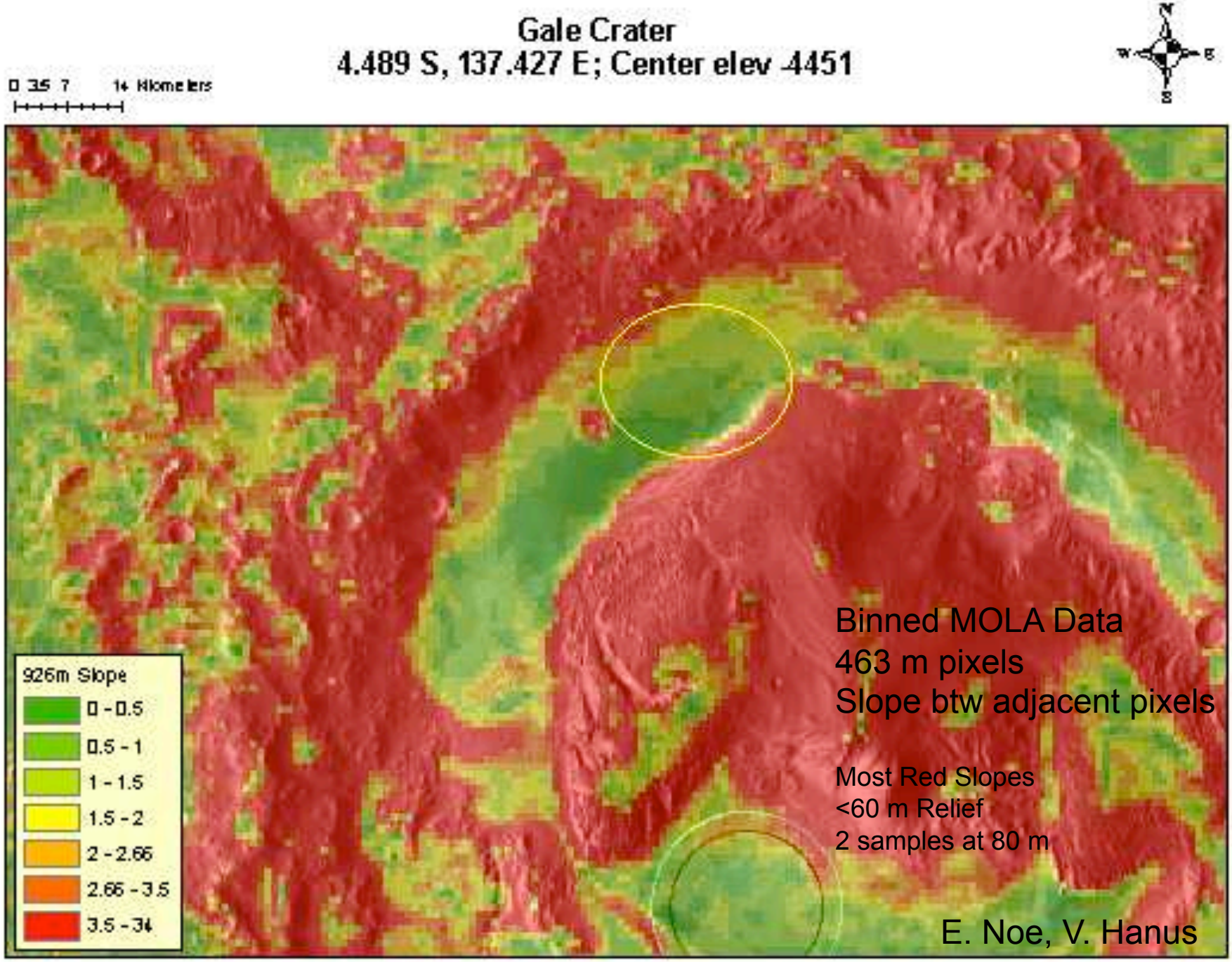
b) 1389 m Slope <12.56° over 25 km Circle, equivalent to 200-1000 m constraint

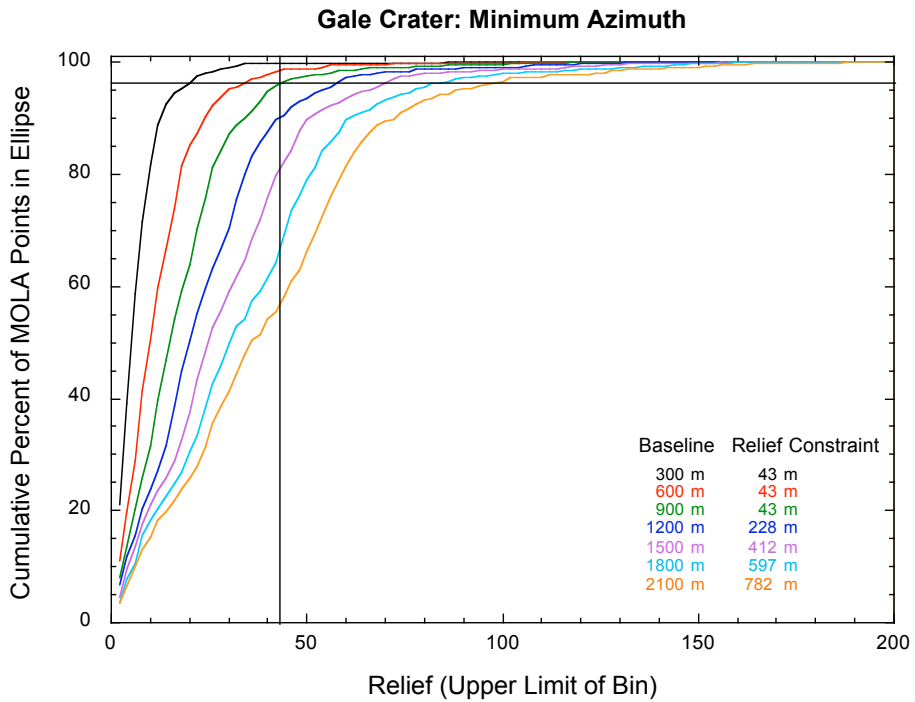
c) 2 km <20° over 25 km Circle and 35 km Circle (warning track)

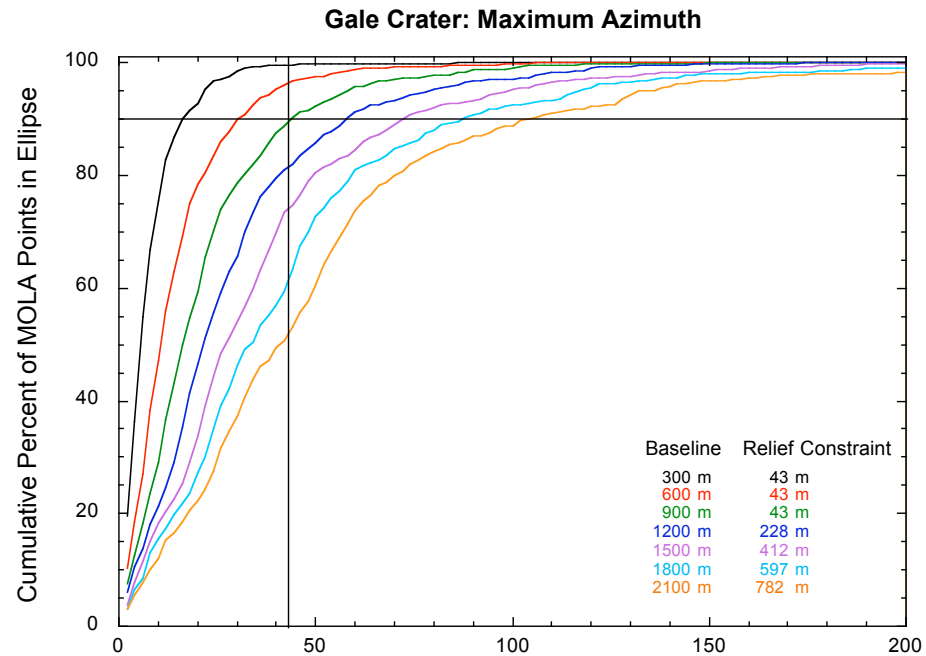
Flexibility in Ellipse Placement (a, b, c above)

Safe Haven Used a and b over 35 km Circle

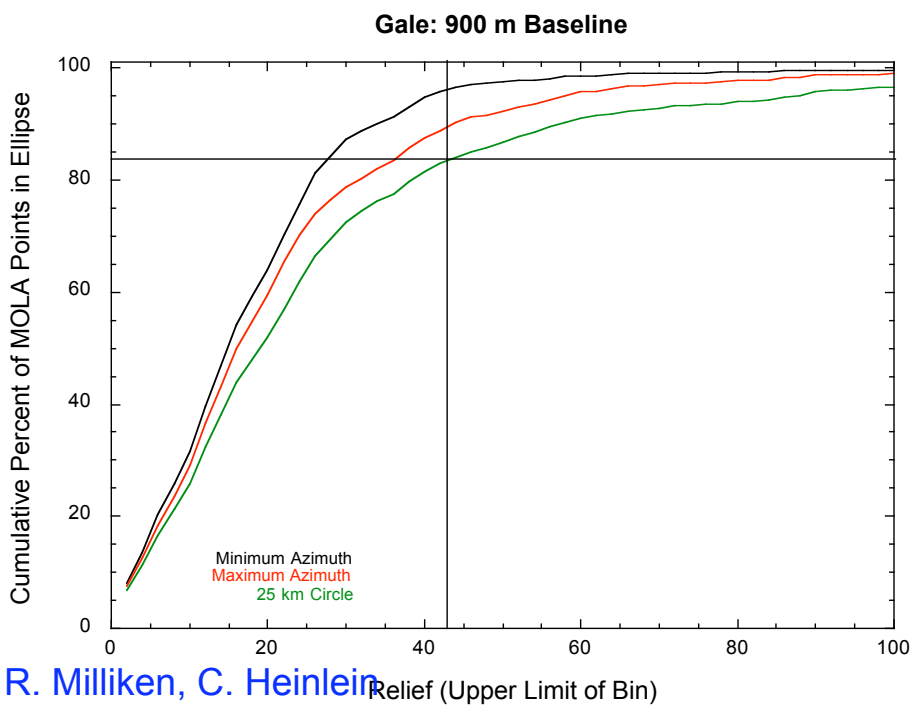
Gale Crater
4.489 S, 137.427 E; Center elev -4451

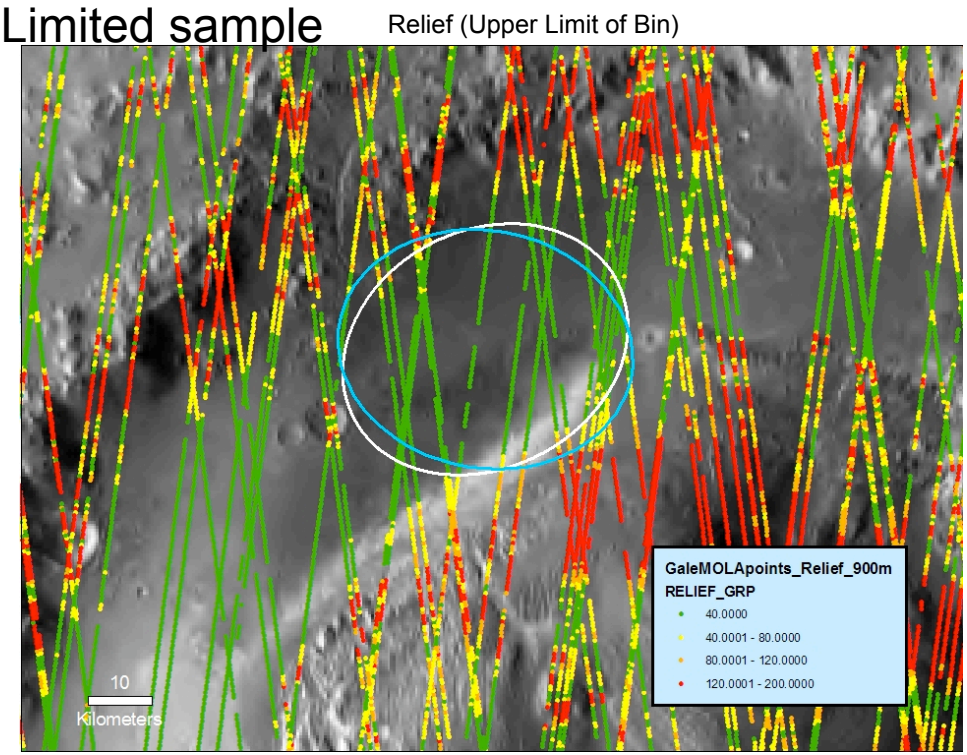






Limited sample





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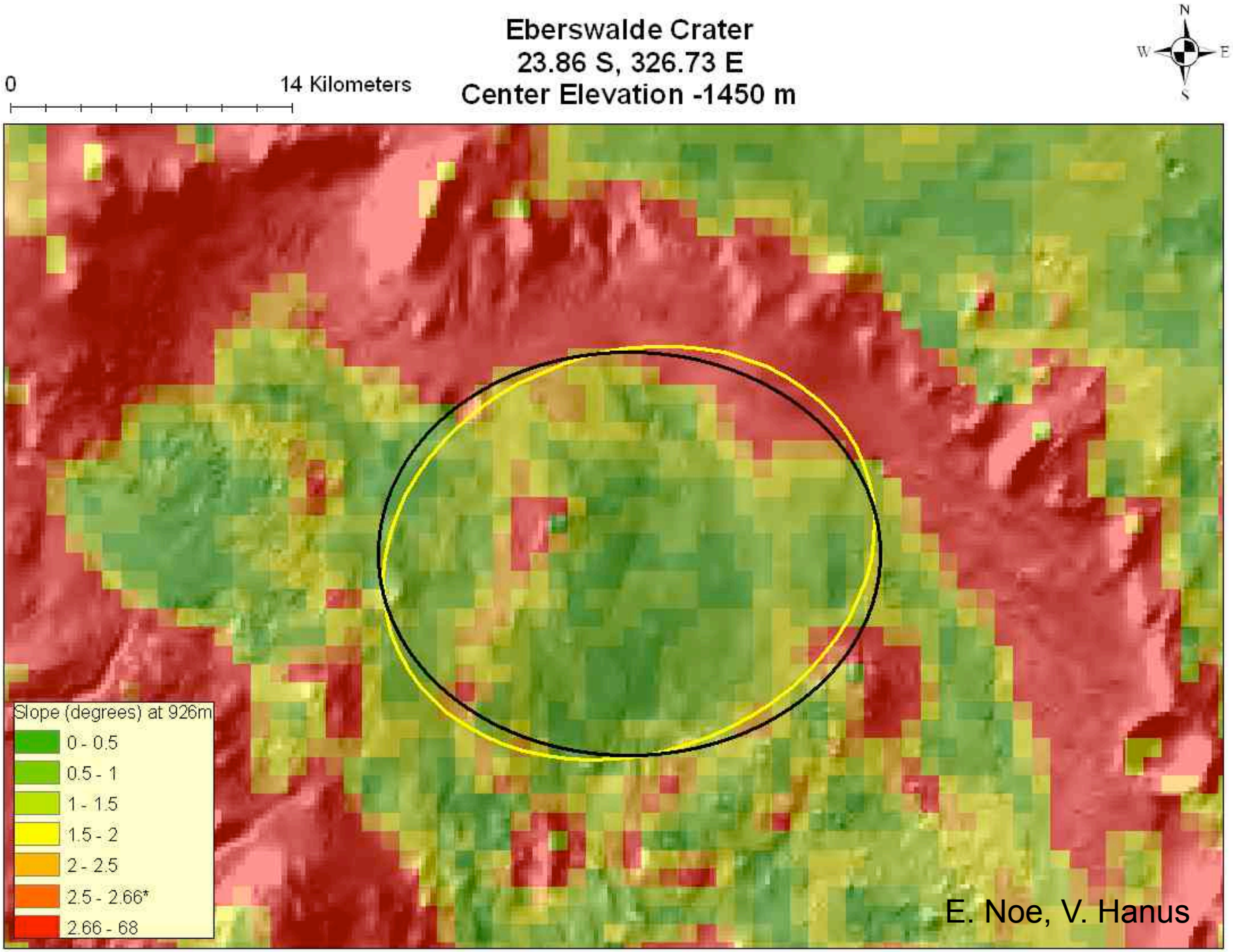
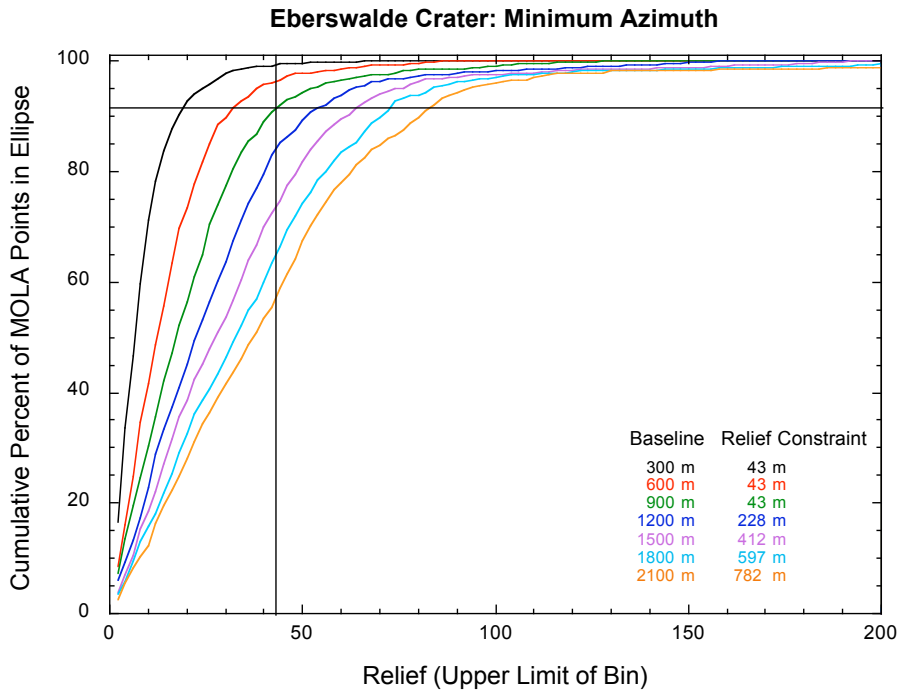
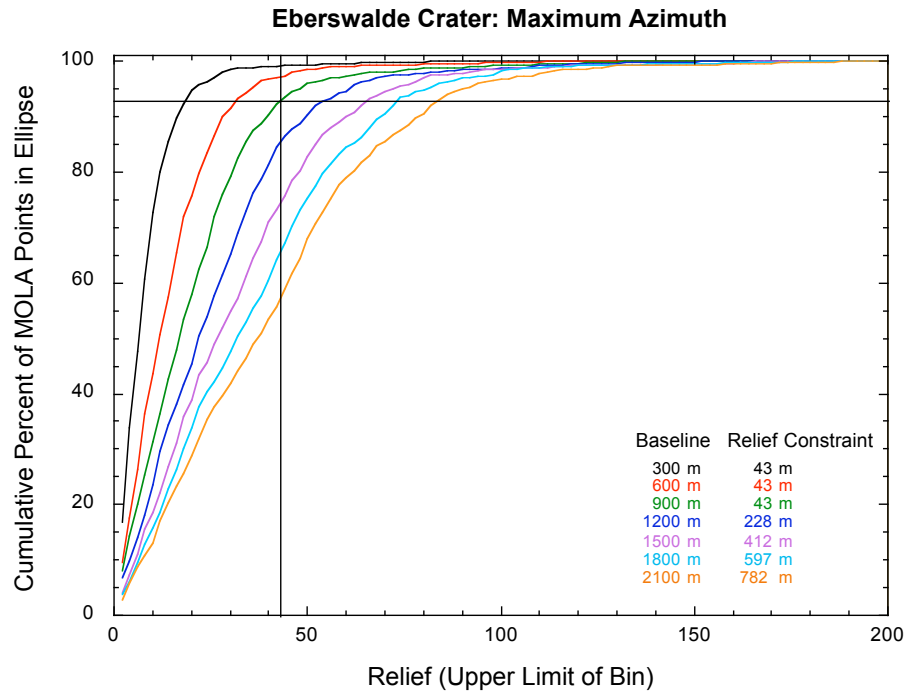
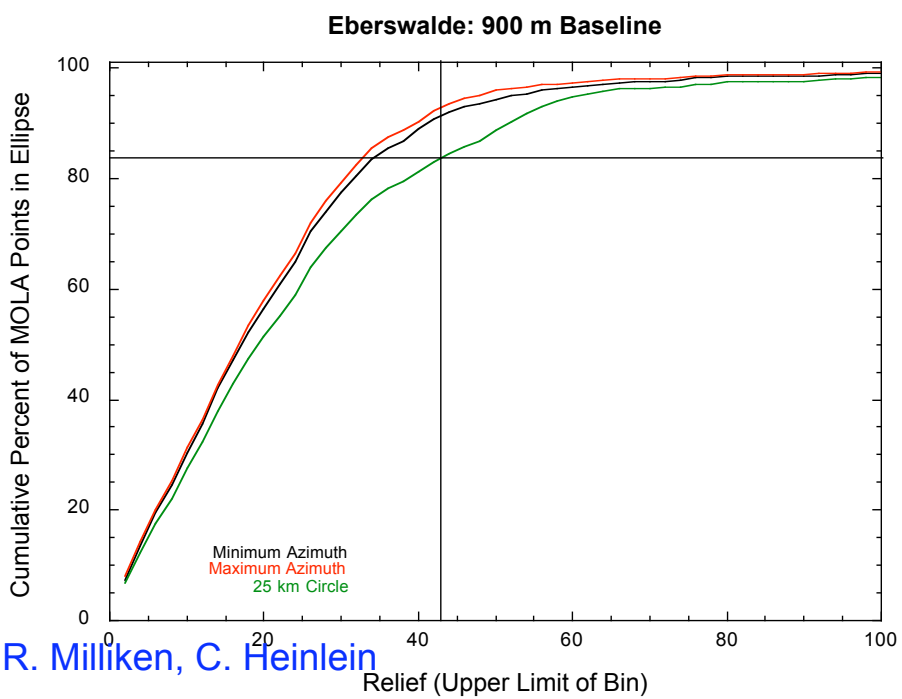
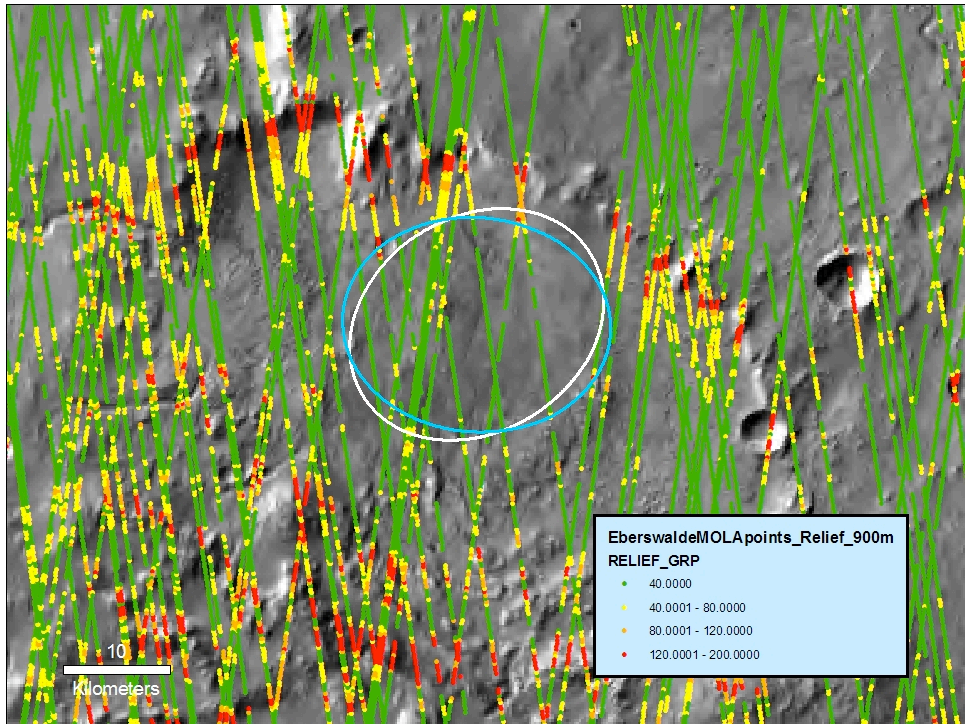

Eberswalde Crater
23.86 S, 326.73 E
Center Elevation -1450 m
0
14 Kilometers
N
W
E
S
Slope (degrees) at 926m
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 2.66*
2.66 - 68
E. Noe, V. Hanus









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% of MOLA shots in each ellipse with >43 m relief at 900 m baseline

	Min. Azimuth	Max. Azimuth	25 km Circle
Gale	4.26	11.13	17.09
Holden	0.00	0.23	0.37
Eberswalde	9.32	7.78	17.08
Nili Trough	4.79	4.46	4.36
Miyamoto	2.68	3.17	3.35
Mawrth 1	5.96	7.89	10.75
Mawrth 2	2.01	1.88	1.98
Mawrth 3	4.46	4.64	6.05
Mawrth 4	1.43	1.65	1.33

All Sites have very small areas with relief >60 m and even less >80 m
Small sample of elevations, so need DTMs to evaluate fully

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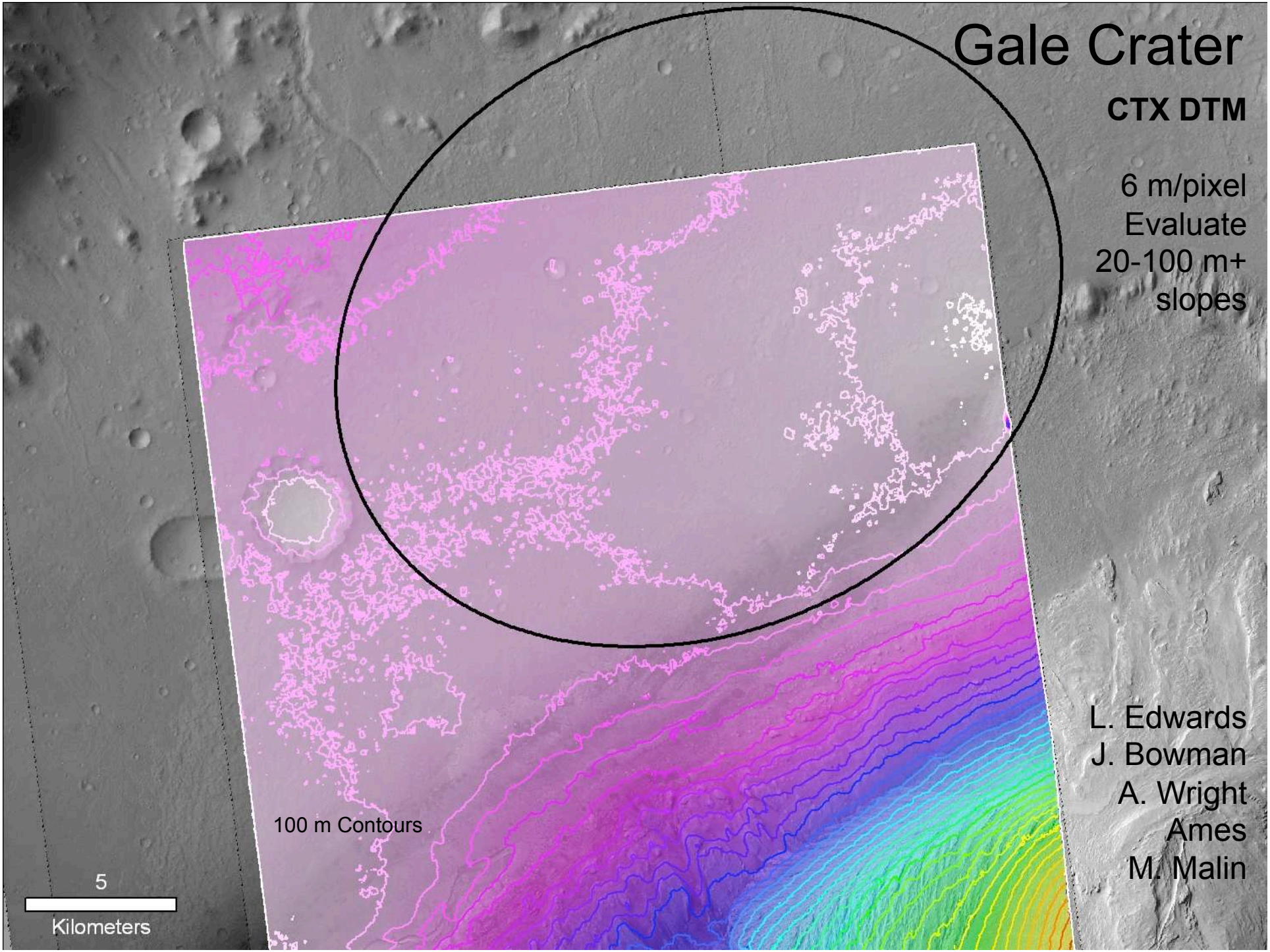
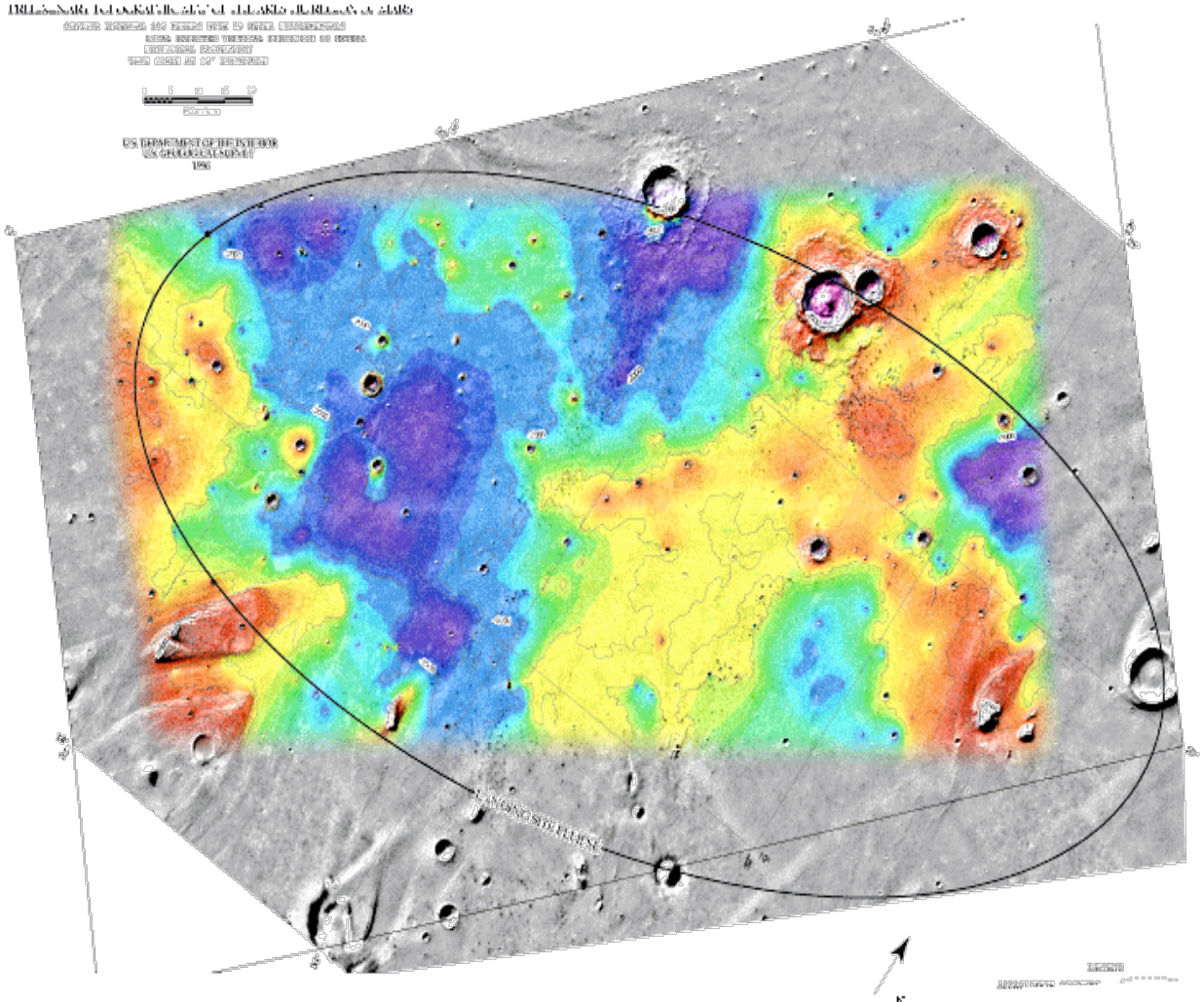

Gale Crater
CTX DTM
6 m/pixel
Evaluate
20-100 m+
slopes
L. Edwards
J. Bowman
A. Wright
Ames
M. Malin
100 m Contours
5
Kilometers

HiRISE Digital Terrain Models

- Randy Kirk, USGS Flagstaff
- Has produced well calibrated DTMs from stereo data for all landed missions
- HiRISE Images at ~0.25 m/pixel
- Stereo posts at 1 m
  - Resolve features few m in extent
- Vertical precision ~0.3 m
- 2°-5° Uncertainty in 2-5 m Length Slopes

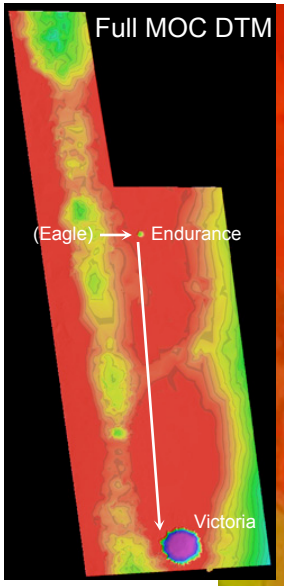


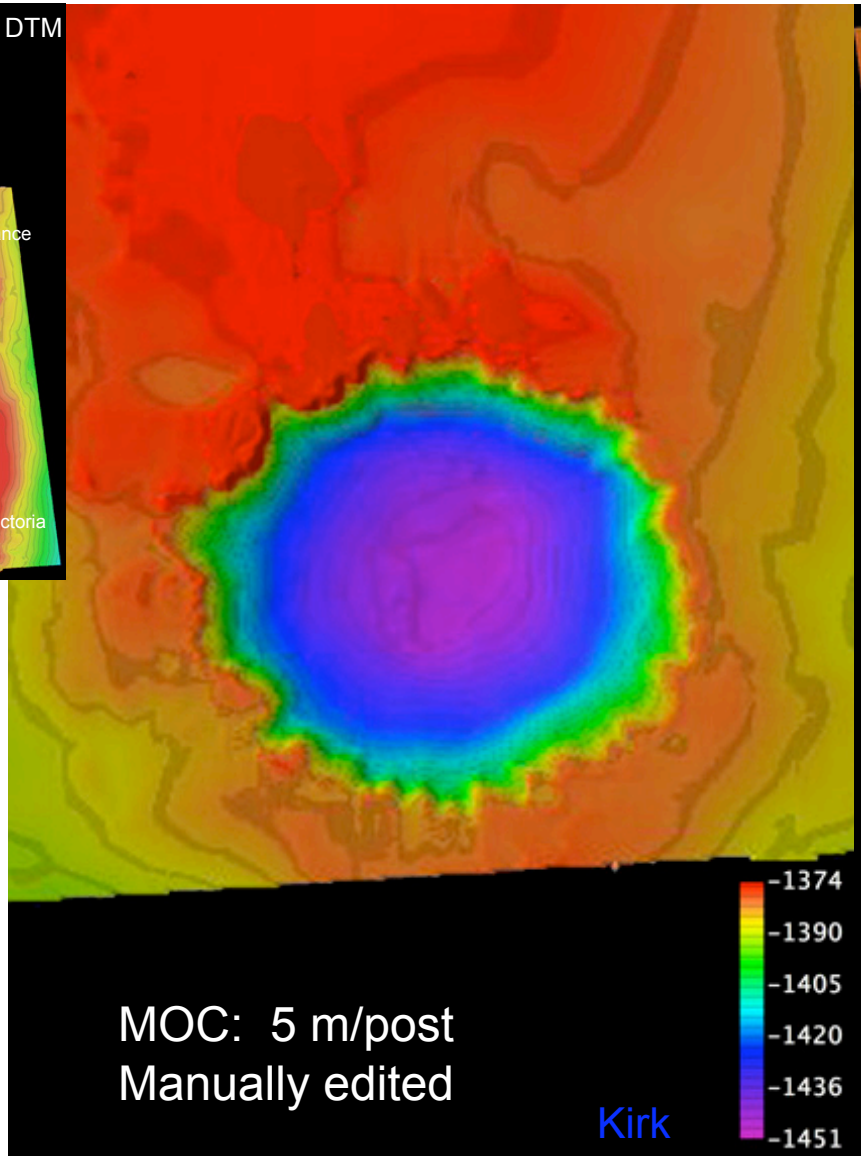
Mars Pathfinder Ares Tiu site
Viking Orbiter 40 m/pix stereo

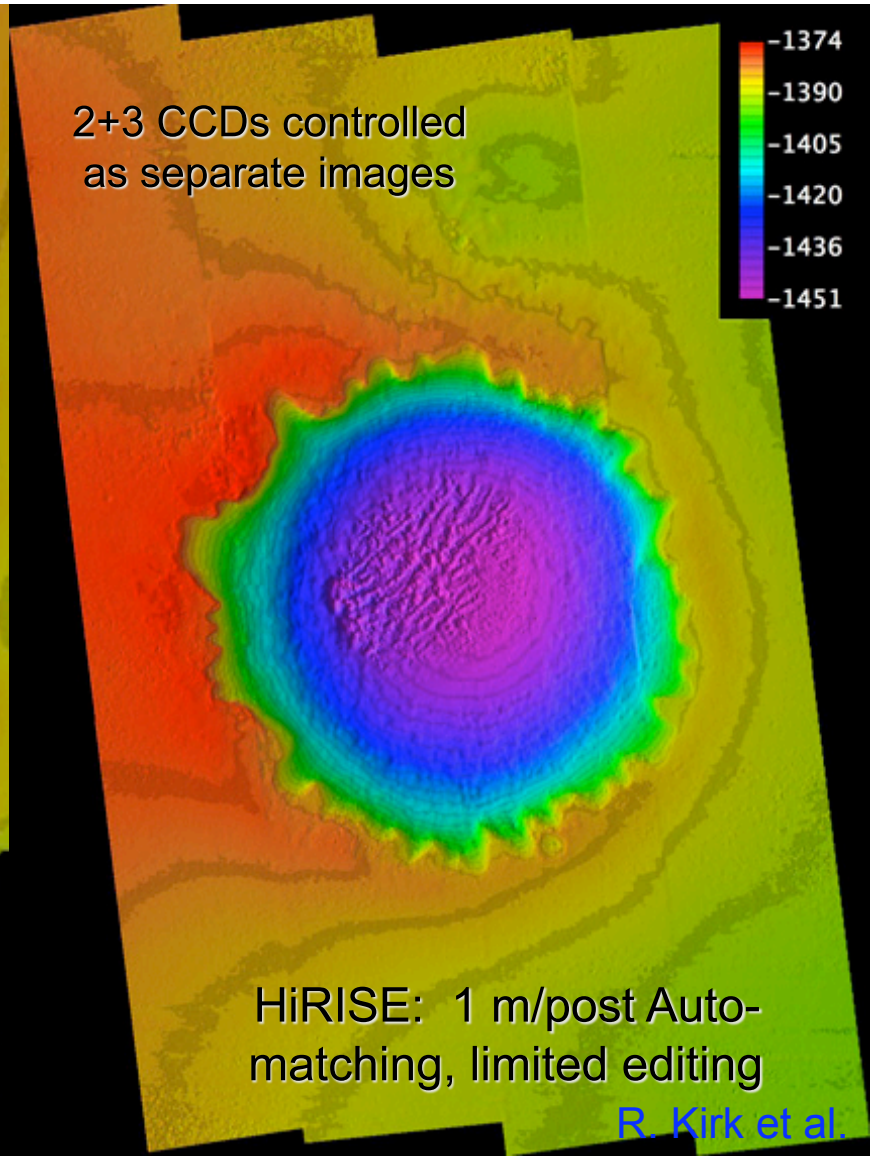
R. Kirk et al.

DTMs of Victoria Crater

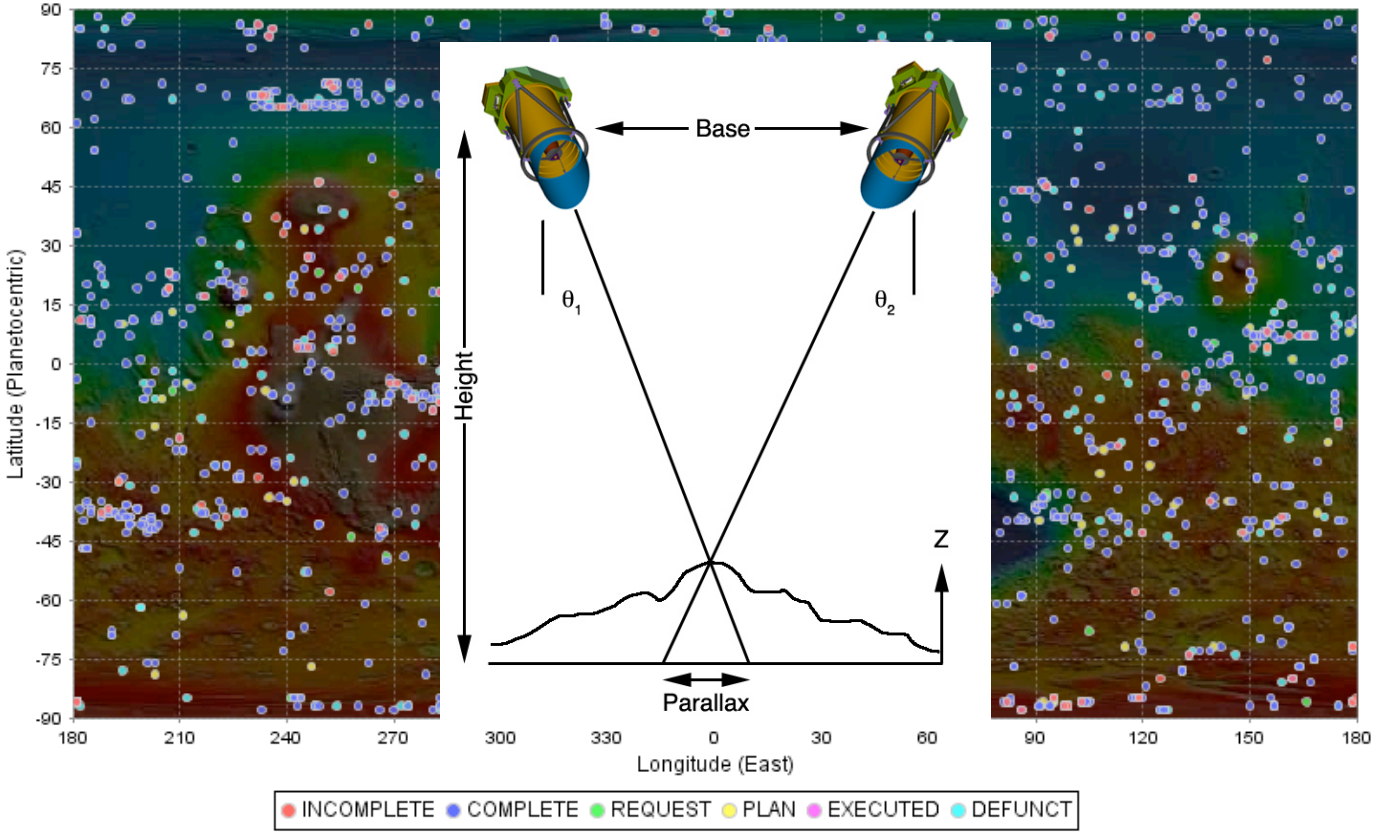
Contour Interval 3 m







HiRISE Coverage



HiRISE Topomapping Program (HiTop)

Goals for prime mission (~1 Mars year):

- ~10,000 images
- ~10 Terabytes
- ~1% of Mars
- 1000 stereopairs
- 10s of DTMs

Mission To Date

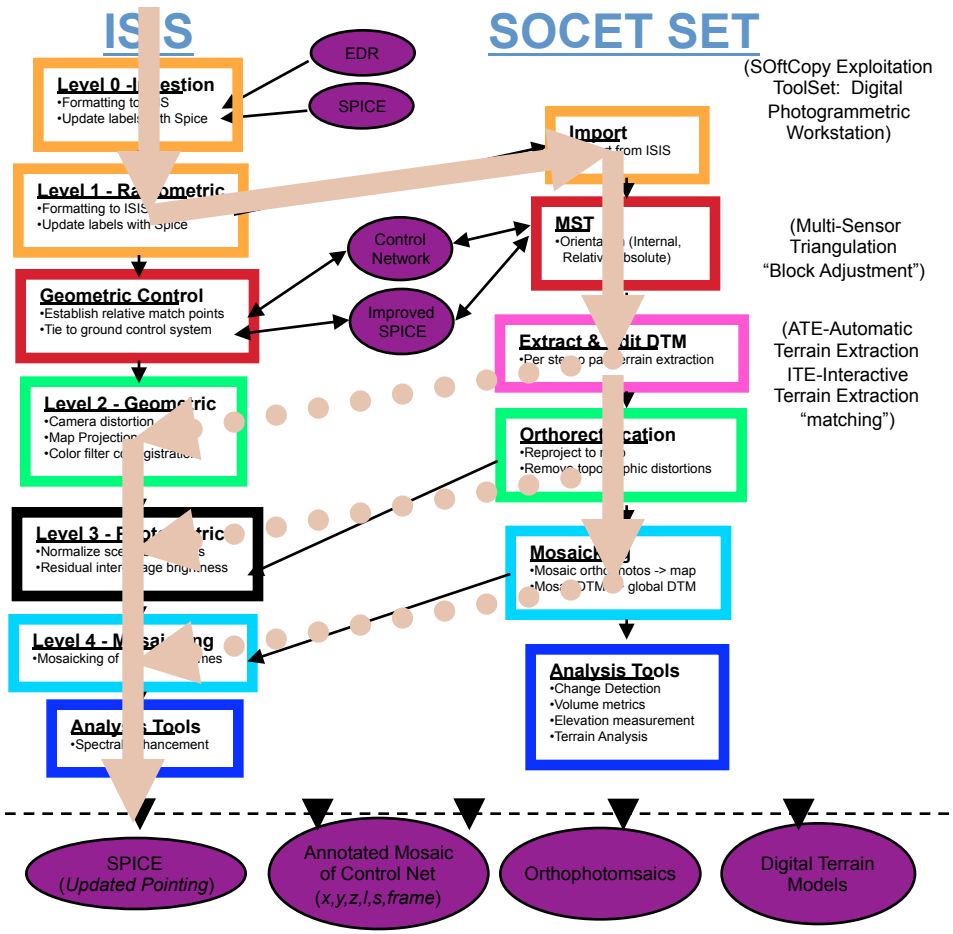
As of 2007 November 8th (DOY 312), HiRISE has completed 4,120 observations of Mars for a total of 3,197 Gigapixels and 3.1 Terabytes. [1]

This covers an area of 484,013 square kilometers, or 0.33% percent of the Martian surface. [2]

1. These figures are based on a daily scan of the EDR Products and Observation Geometry tables.
2. Stereo and other repeated observations are not excluded from this total.

R. Kirk et al.

ISIS/SOCET SET Workflow



ISIS: Integrated Software for Imagers & Spectrometers

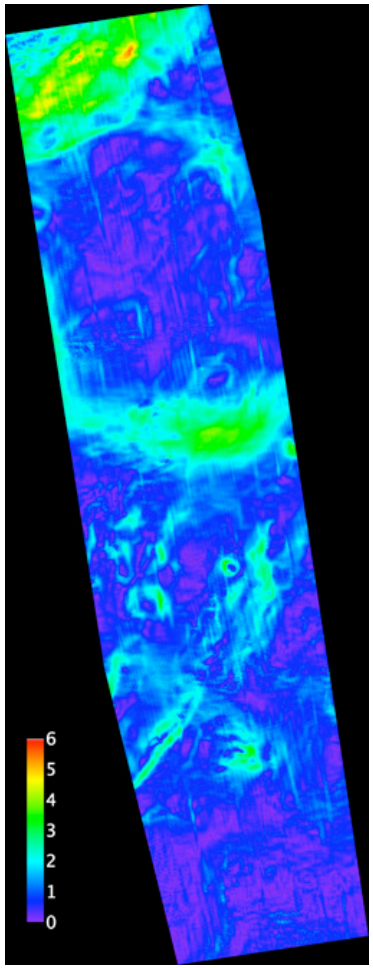
- USGS in house s/w
- Strengths:
  - Ingestion/calibration
  - Planimetric mosaicking
  - Quantitative analysis including photoclinometry
- Use for calibration, 2D proc.

SOCET SET: SOftCopy Exploitation ToolSET

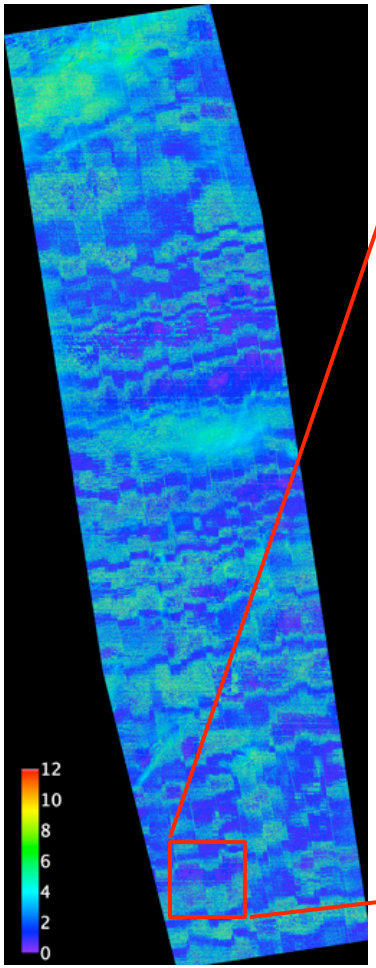
- BAE Systems commercial s/w
- Strengths:
  - Stereo display/input
  - Bundle-block adjustment
  - Automatic DTM matching
- Use for 3D processing
- Write new sensor models

R. Kirk et al.

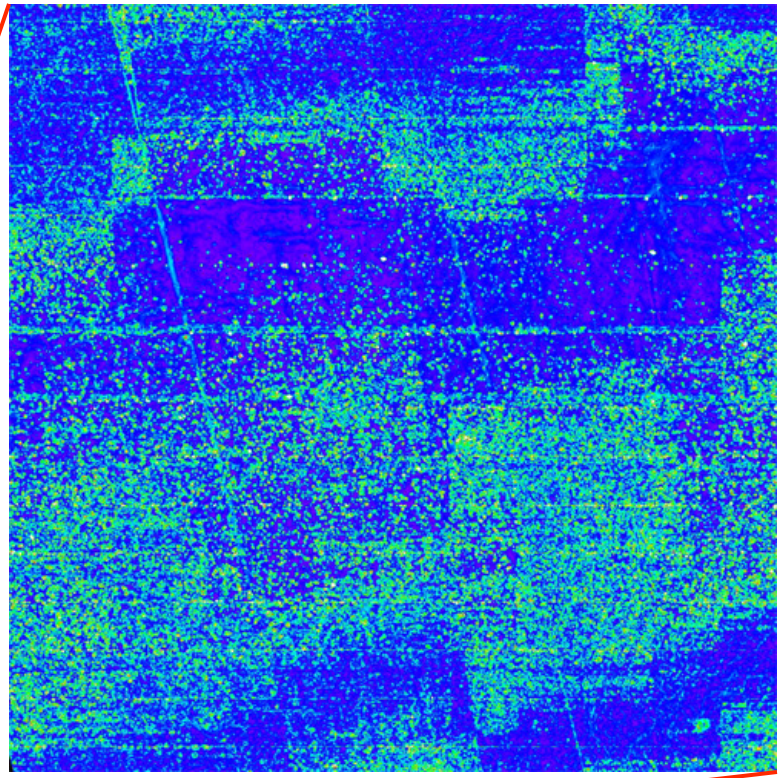
Effect of Mild Jitter on DEM Quality —"Heimdall" Crater



Slopes over
100 m baseline



Slopes over
2 m baseline

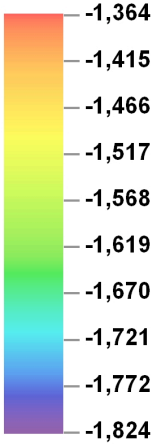


Stereo matching becomes "noisy"
where images are out of alignment
along-track because of jitter
Problem for ≥2 pixels jitter, severe if >3
Solutions devised and being tested

R. Kirk et al.

Holden

Stereopair:
PSP_007191_1535
PSP_007903_1535

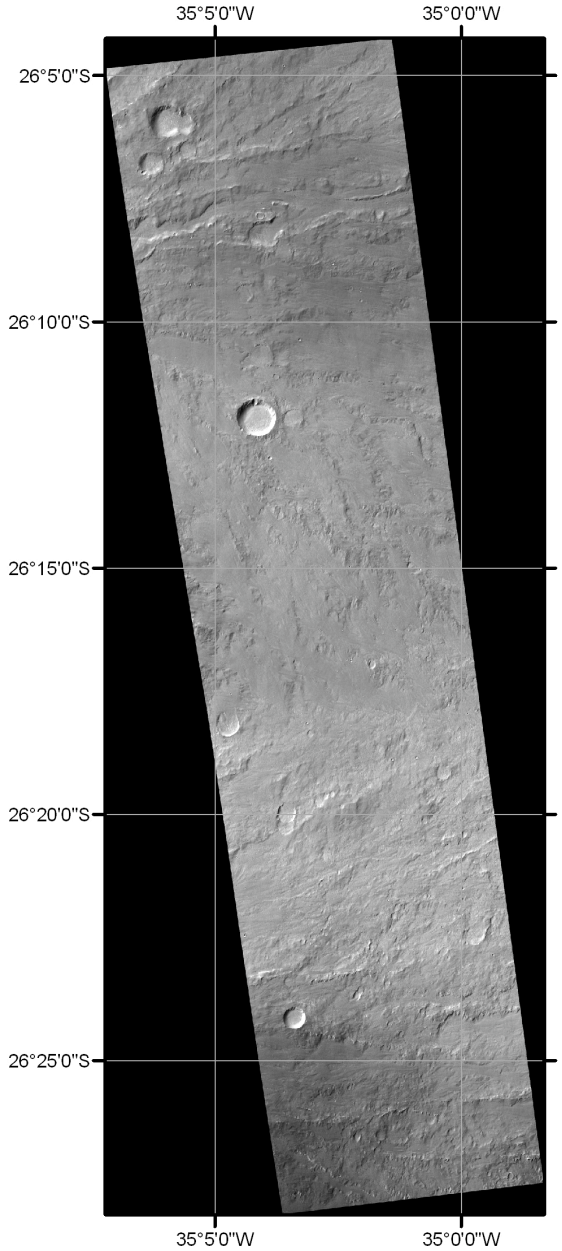


1 0 1 Km

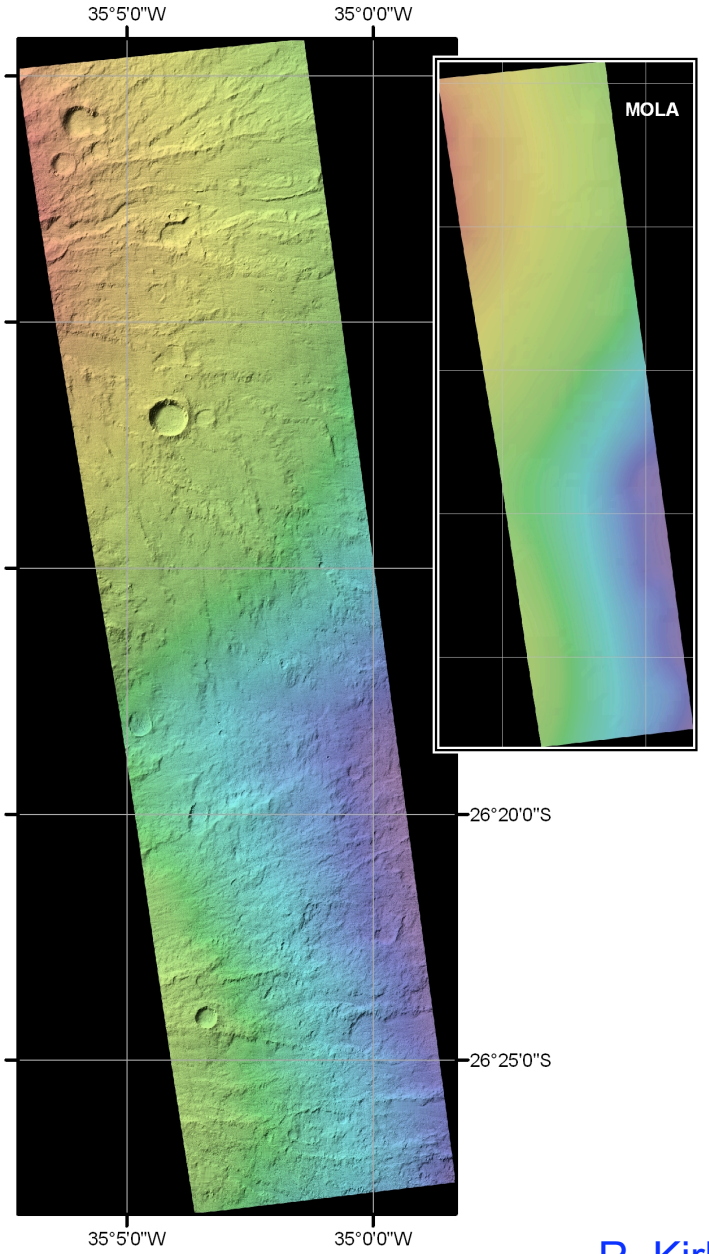
Planetocentric

N

HiRISE Ortho PSP_007191_1535
1 meter/pixel



Stereo DEM
1 meter/pixel



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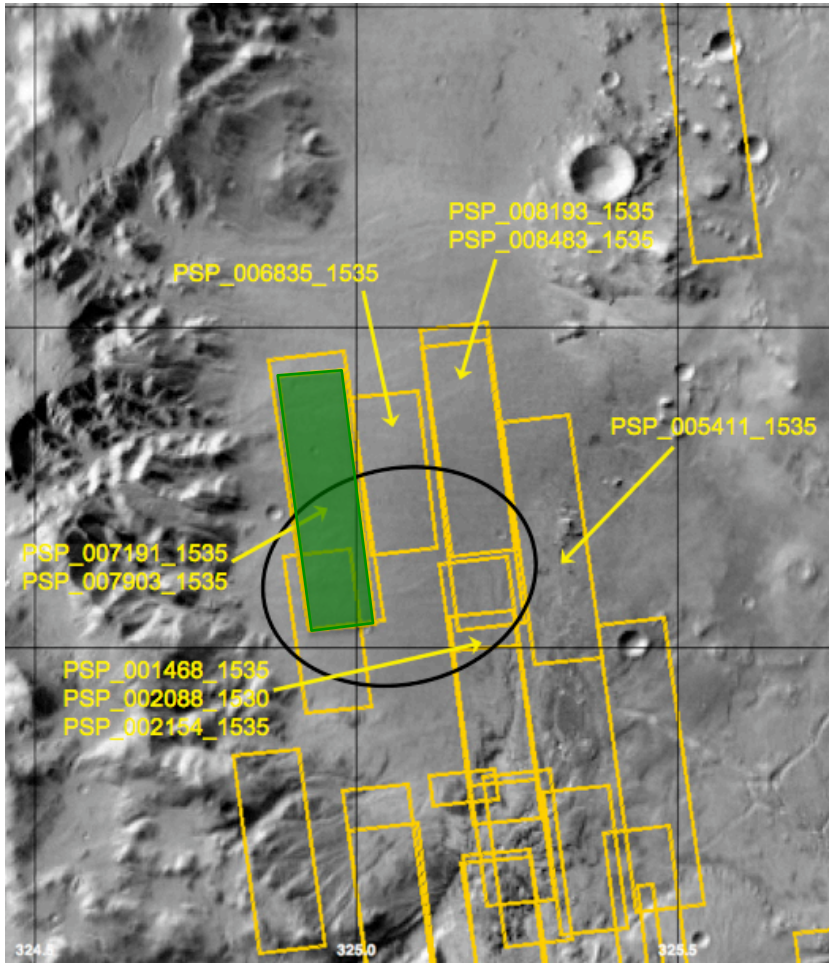
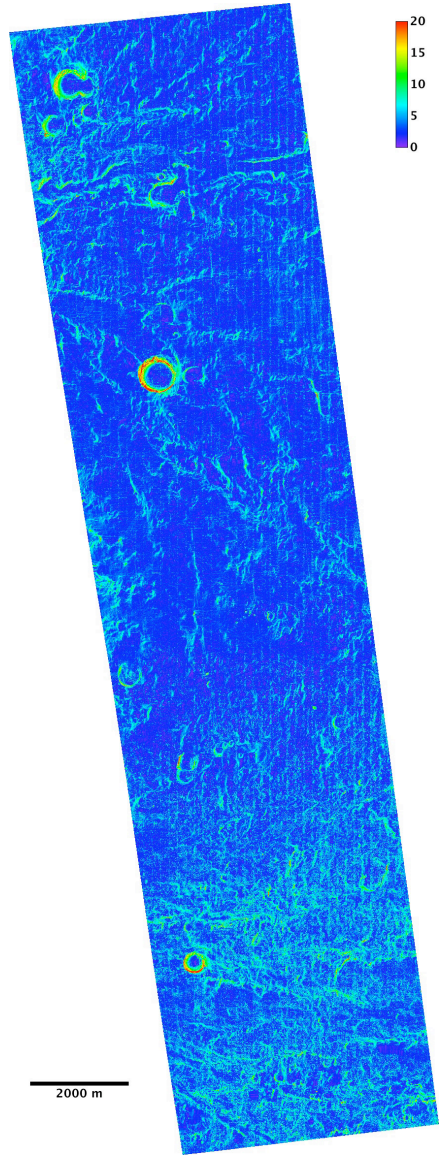
Holden Crater

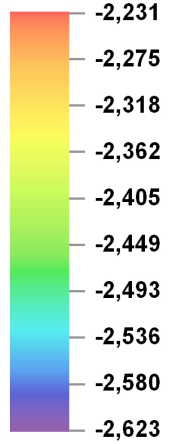


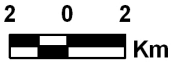


R. Kirk et al.

Mawrth2

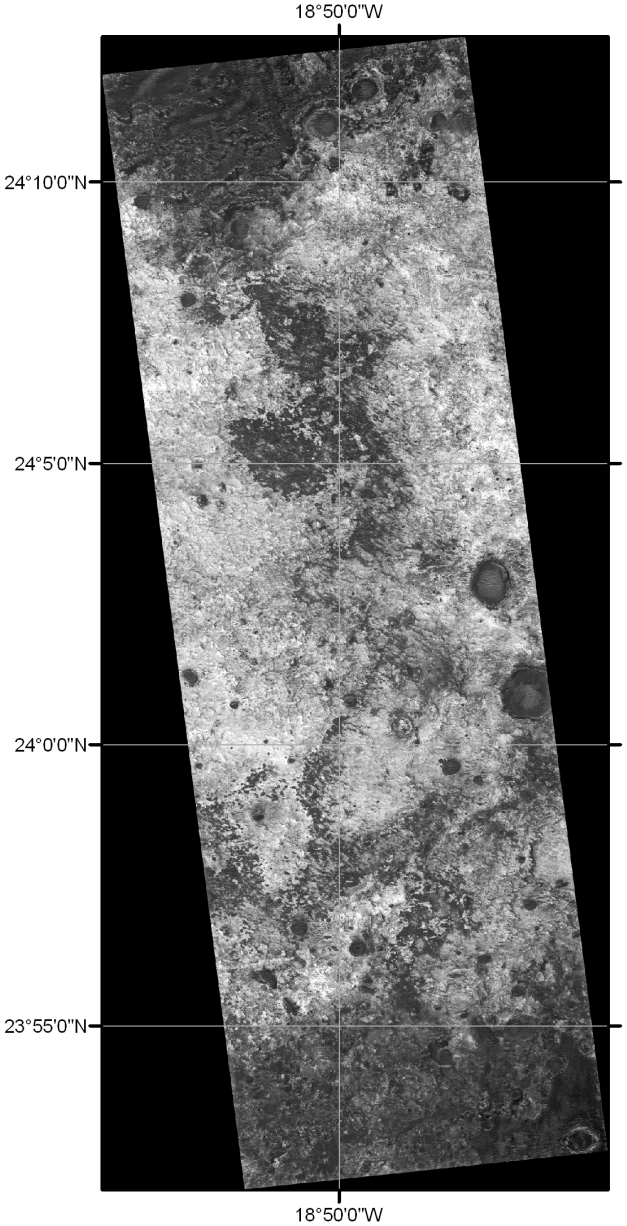
Stereopair:
PSP_006676_2045
PSP_007612_2045



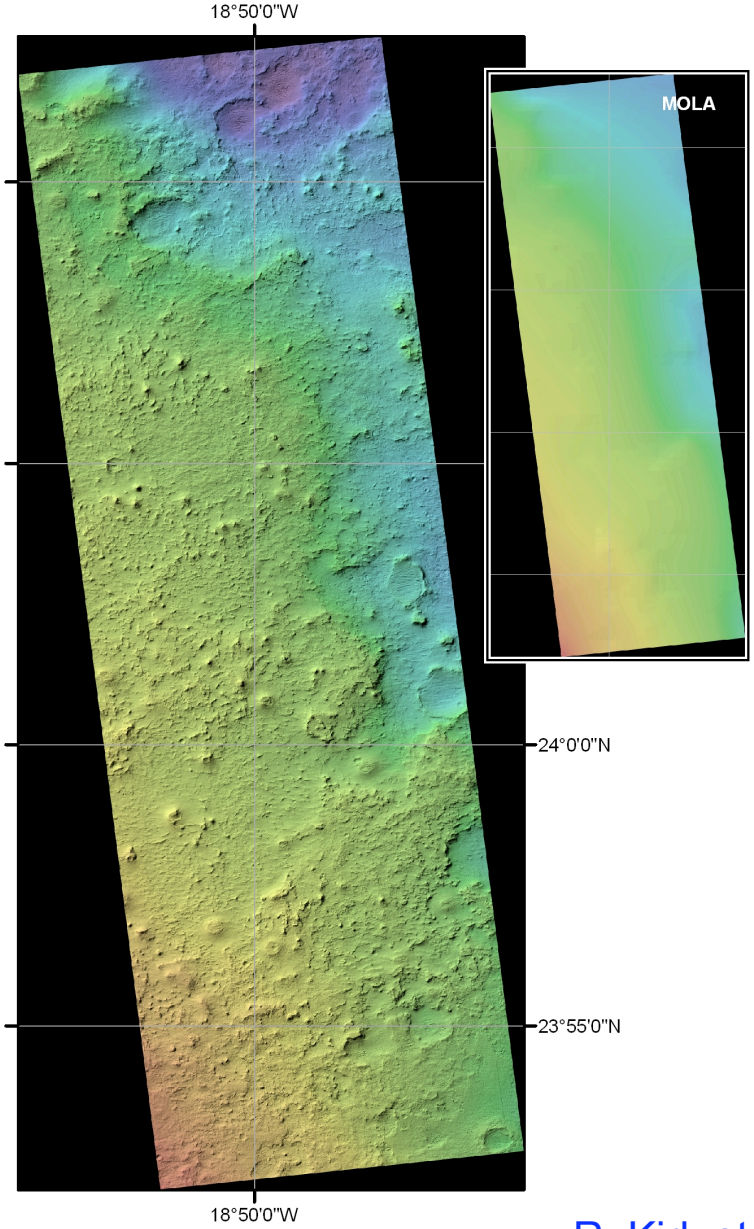


Planetocentric

HiRISE Ortho PSP_006676_2045
1 meter/pixel

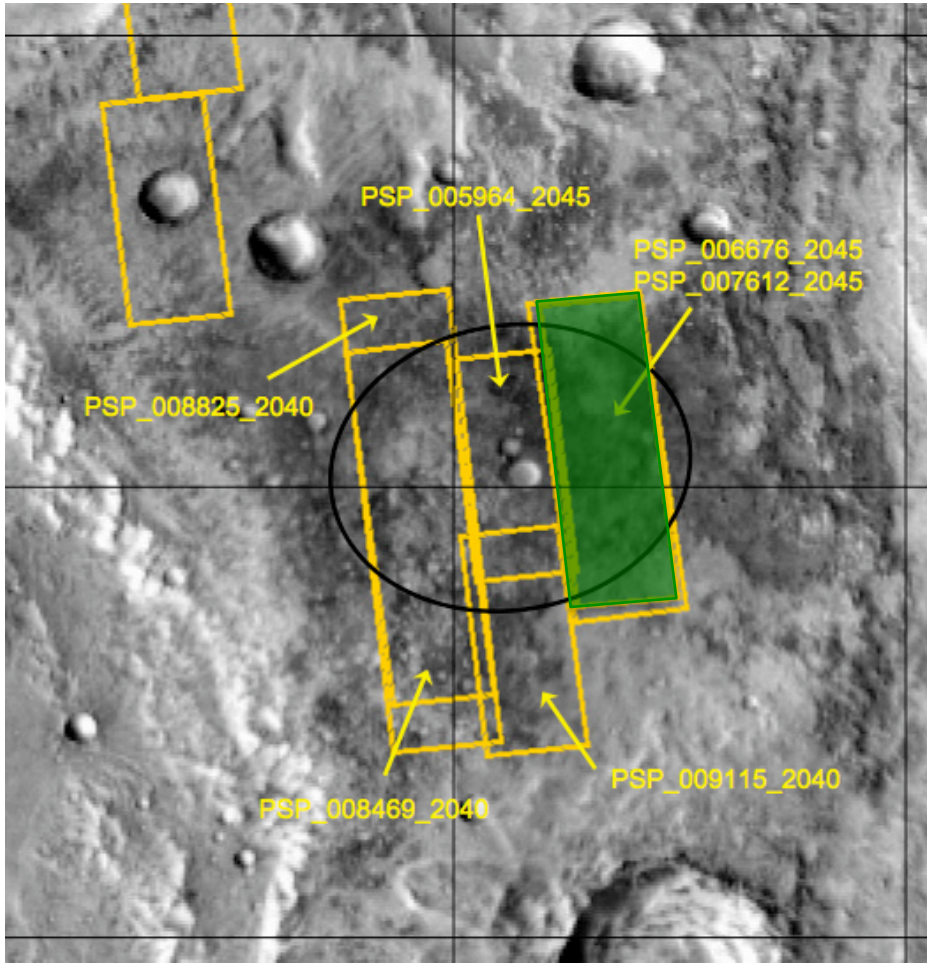


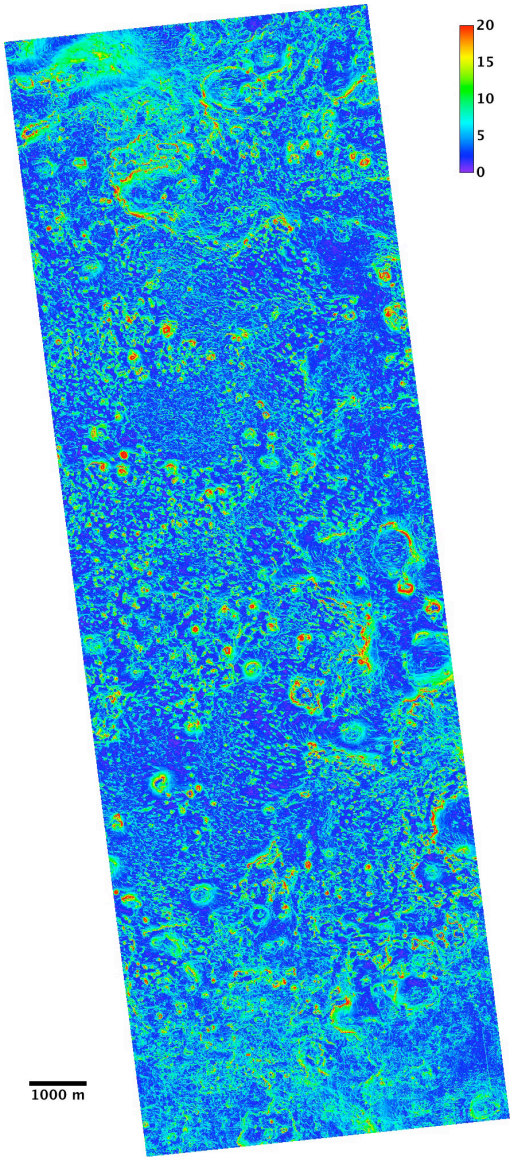
Stereo DEM
1 meter/pixel



R. Kirk et al.

Mawrth 2





R. Kirk et al.

DTM Slopes Summary

Site	RMS Slope (°) at 2m	% 15° Slopes at 2m	RMS Slope (°) at 5m	% 15° Slopes at 5m
Holden Crater	4.41	0.59	3.85	0.25
Mawrth 2	6.73	3.30	6.30	2.60
Mawrth 4	5.47	1.52	4.87	0.98
Eberswalde*	10.89	13.90	9.22	9.43
Gale Crater	6.66	2.98	6.19	2.47
Mawrth 3				
Nili Fossae				
Mawrth 1				
Miyamoto				
S. Meridiani				

*Contains both real features with steep slopes and extremely bland areas in which matching fails, leading to high apparent slopes at short distances

Photoclinometry result (next) smoother

Small Areas with Slopes >15°, even smaller areas >20° or 25°

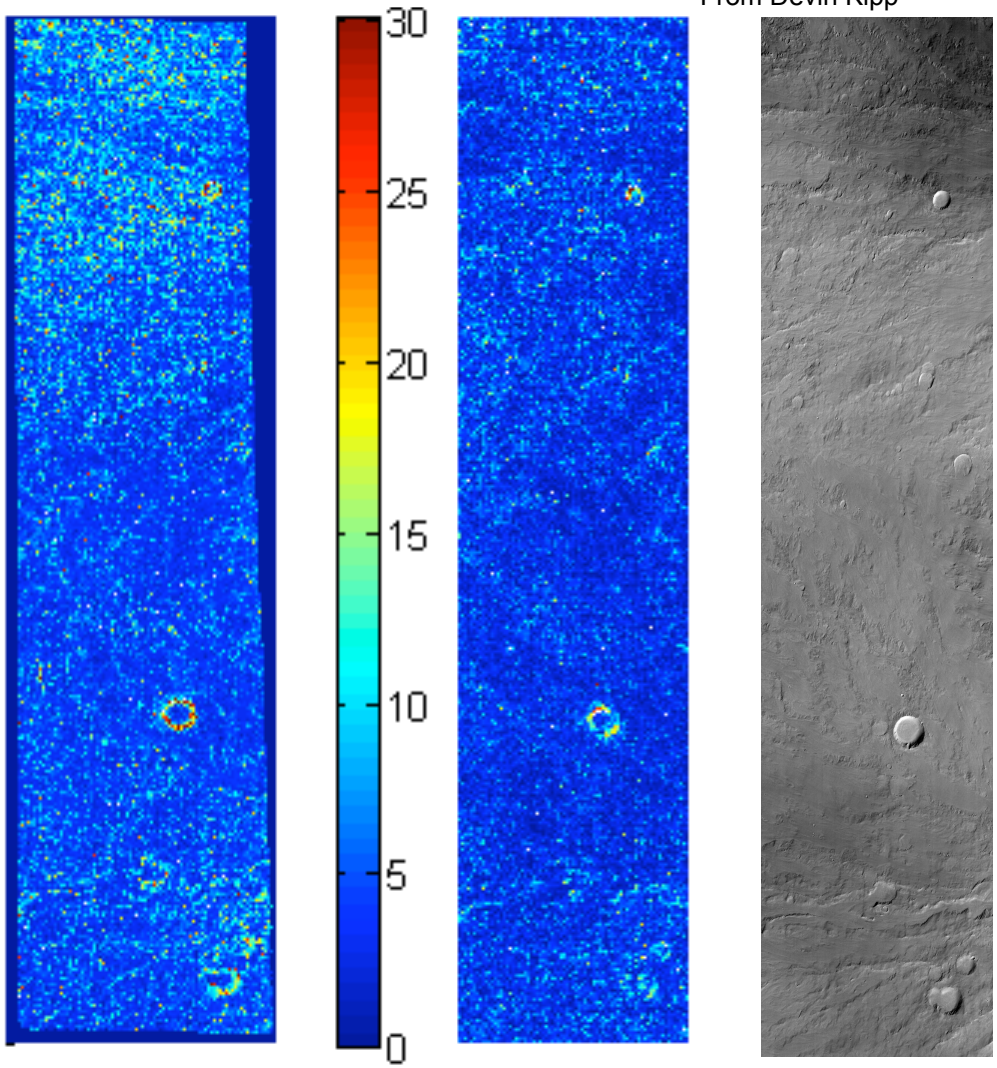
R. Kirk et al.

Meter-scale slopes from Point Photoclinometry

- Technique converts image DN values to slopes in the down-Sun direction (bi-directional)
- Cannot apply to images with severe haze or albedo variations
- Verified against Viking and Pathfinder, as well as against simulated fractal topography and stereo models

Holden Crater, PSP_007191_1535

Comparison figure
From Devin Kipp



USGS DTM slopes

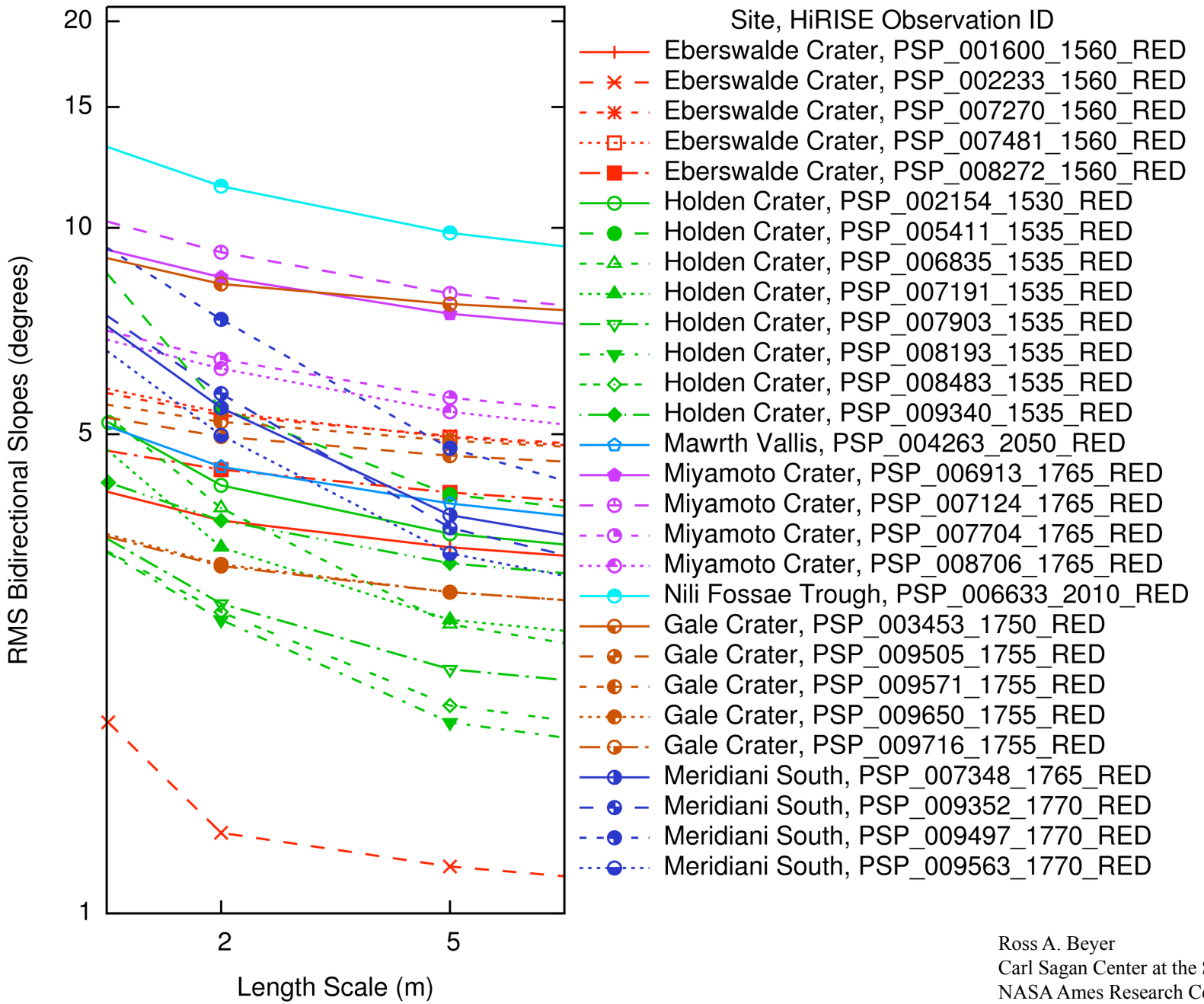
Point Photoclinometry Slopes

Original image

Ross Beyer

Ross A. Beyer
Carl Sagan Center at the SETI Institute
NASA Ames Research Center

MSL Landing Site Roughnesses from Point Photoclinometry

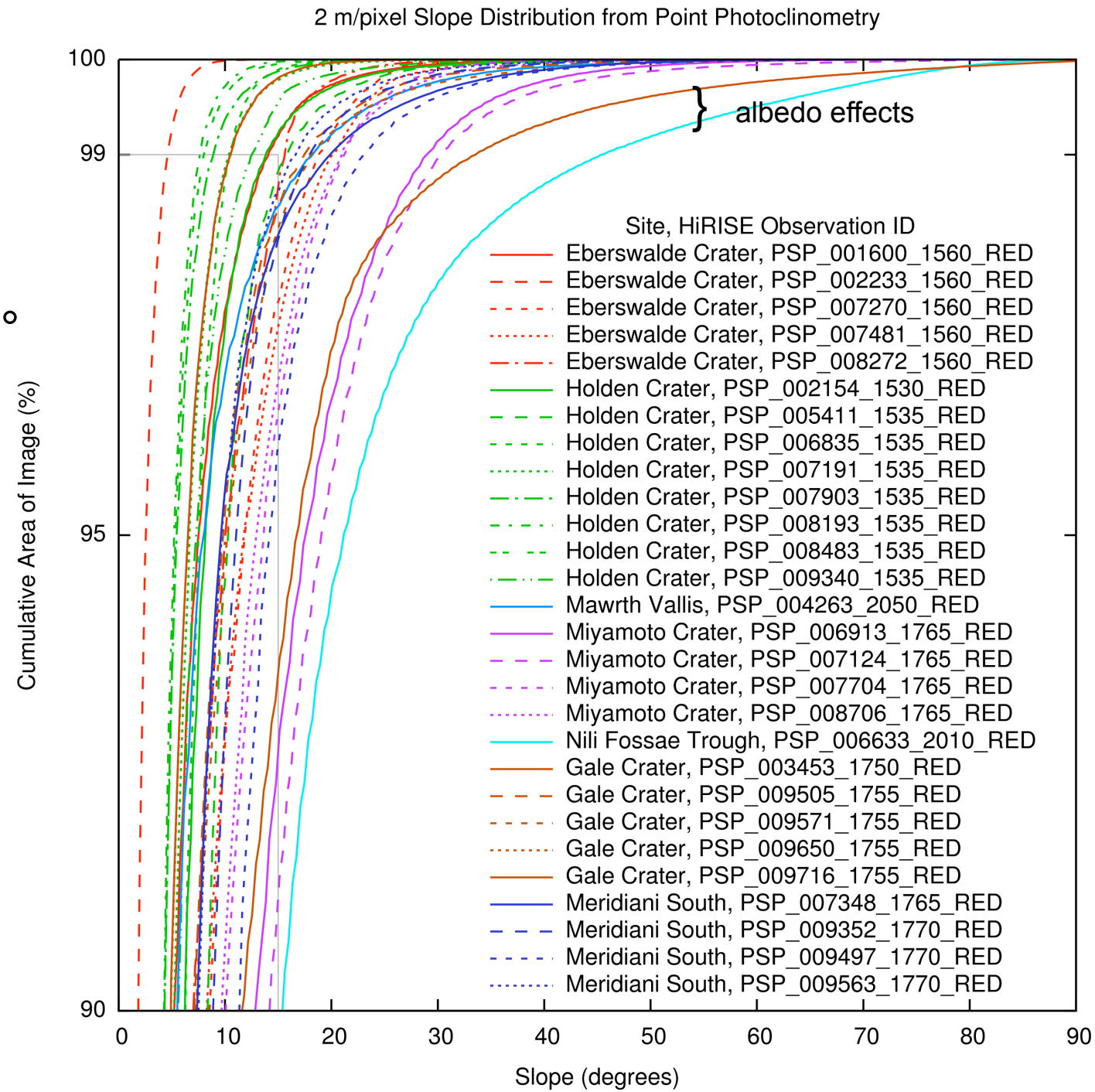


Ross A. Beyer
Carl Sagan Center at the SETI Institute
NASA Ames Research Center

<4% Area >15°

<1% Area >20°

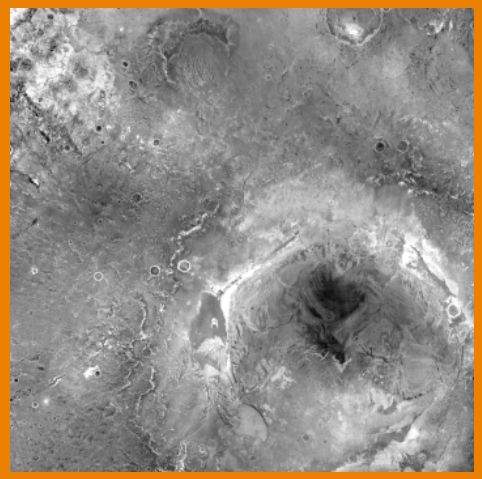
<0.5% Area >25°



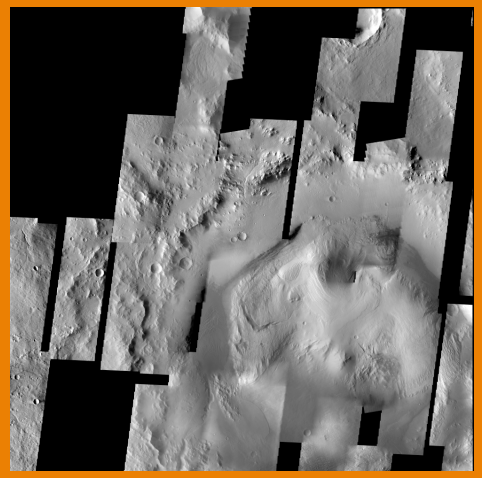
Ross A. Beyer
Carl Sagan Center at the SETI Institute
NASA Ames Research Center

THEMIS Mosaics/Thermal Inertia

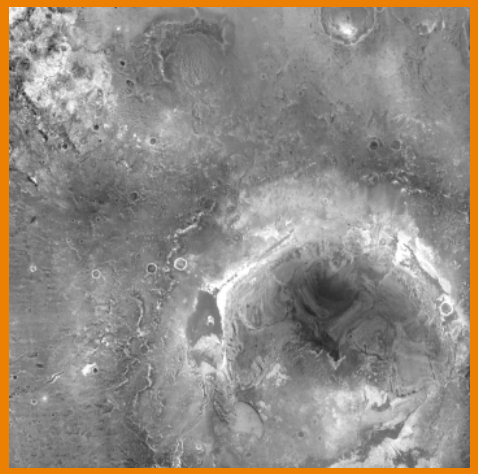
Day IR



Night IR



Visible



Thermal Inertia

Full-resolution THEMIS mosaics of all candidate landing sites are provided by the Mars Odyssey THEMIS Science Team and Arizona State University, and available to download at:

http://themis.asu.edu/landingsites

For scientific or technical questions regarding these mosaics contact:
Dr. Robin L. Fergason
rfergason@usgs.gov

***R. L. Fergason*, USGS**

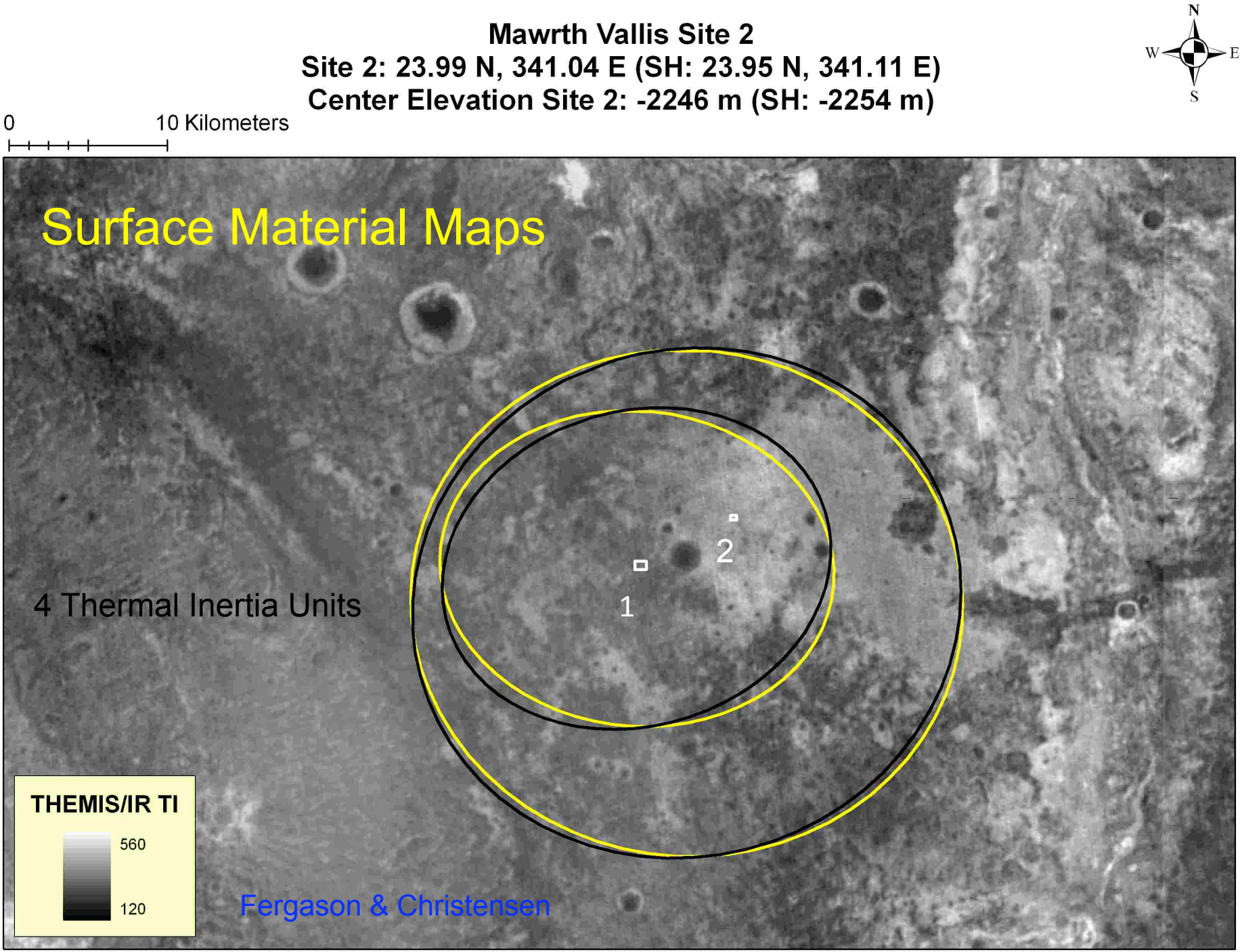
Thermal Inertia Results

- Majority of the candidate landing sites have moderate thermal inertia
  - Suggests a mixture of exposed bedrock, indurated surfaces, crater rims and ejecta, rocks, and unconsolidated material on the surface.
- None of the landing sites have a significant amount of dust (very low thermal inertia <100 J m-2 K-1 s-1/2)
- Rocky Material, Bedrock Indicated by High Thermal Inertia
  - Nili Fossae Trough – thermal inertia in excess of 530 J m-2 K-1 s-1/2,
  - Holden crater – thermal inertia in excess of 600 J m-2 K-1 s-1/2
  - Mawrth Vallis – Site 4 thermal inertia in excess of 400 J m-2 K-1 s-1/2
  - Gale crater – thermal inertia in excess of 780 J m-2 K-1 s-1/2,
- On the Horizon
- Detailed analysis of thermal inertia and visible images of the remaining candidate sites and the surrounding terrain – surface material maps
- Predicted temperature maps of the remaining candidate landing sites

See R. L. Fergason poster for addition discussion and to view the thermal inertia mosaics.

***R. L. Fergason*, USGS**

Mawrth Vallis Site 2
Site 2: 23.99 N, 341.04 E (SH: 23.95 N, 341.11 E)
Center Elevation Site 2: -2246 m (SH: -2254 m)



Mawrth Vallis
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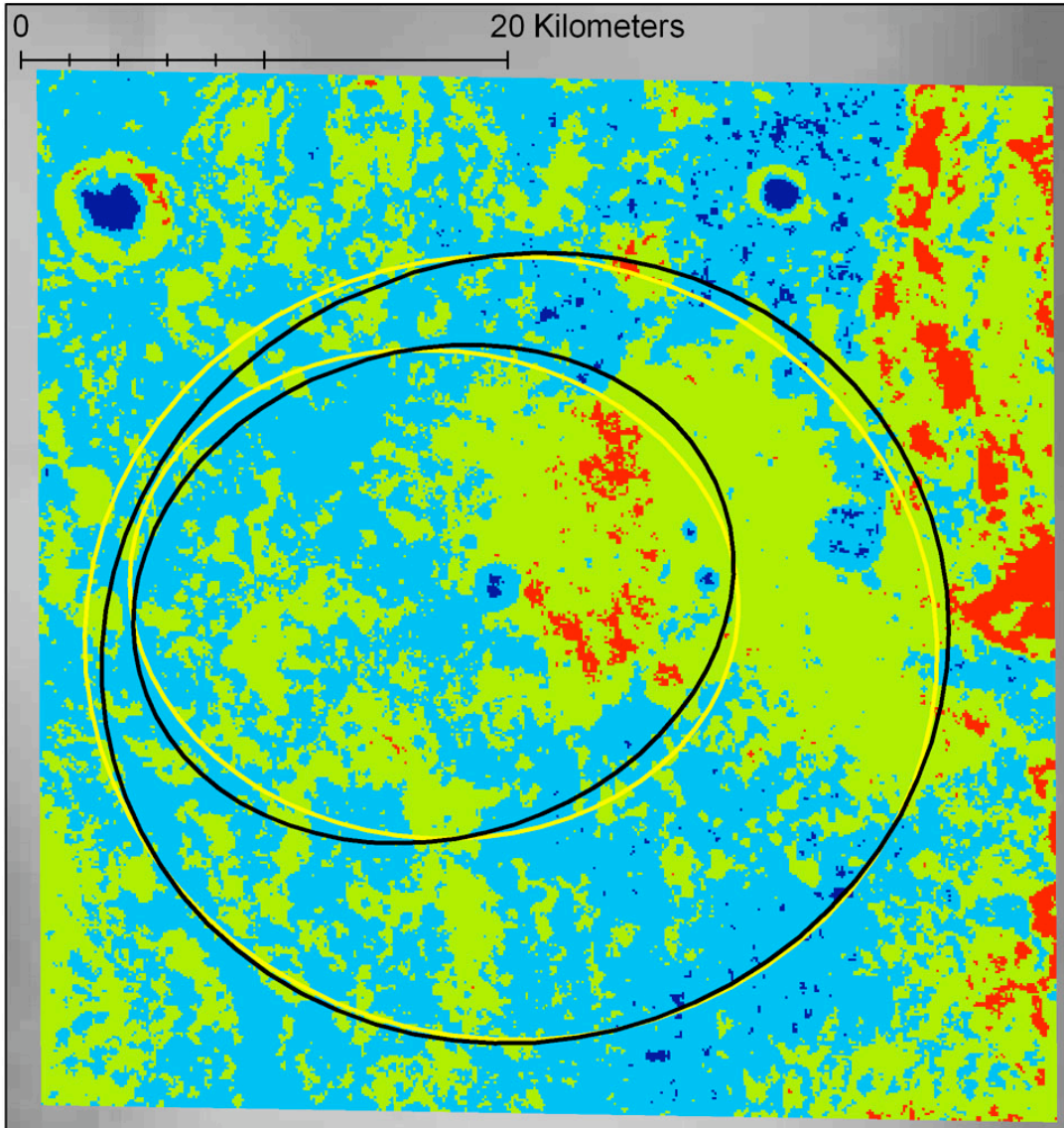


Dark Blue:
90% or more poorly consolidated sediment (e.g., ripples, sand sheets)

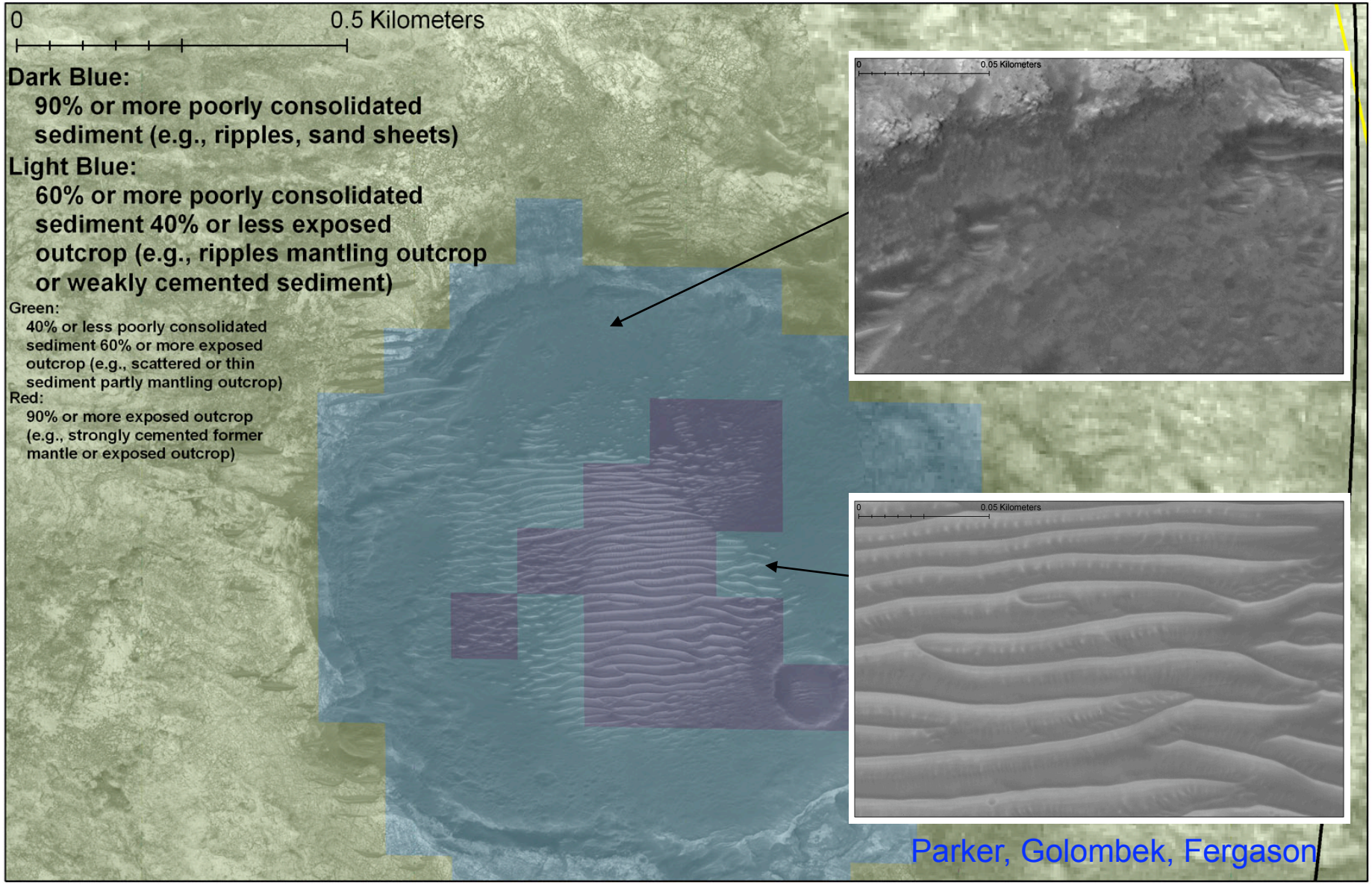
Light Blue:
60% or more poorly consolidated sediment 40% or less exposed outcrop (e.g., ripples mantling outcrop or weakly cemented sediment)

Green:
40% or less poorly consolidated sediment 60% or more exposed outcrop (e.g., scattered or thin sediment partly mantling outcrop)

Red:
90% or more exposed outcrop (e.g., strongly cemented former mantle or exposed outcrop)

Parker, Golombek, Fergason

Mawrth Vallis
Site 2: 23.99 N, 341.04 E (SH: 23.95 N, 341.11 E)
Center Elevation Site 2: -2246 m (SH: -2254 m)



Mawrth Vallis
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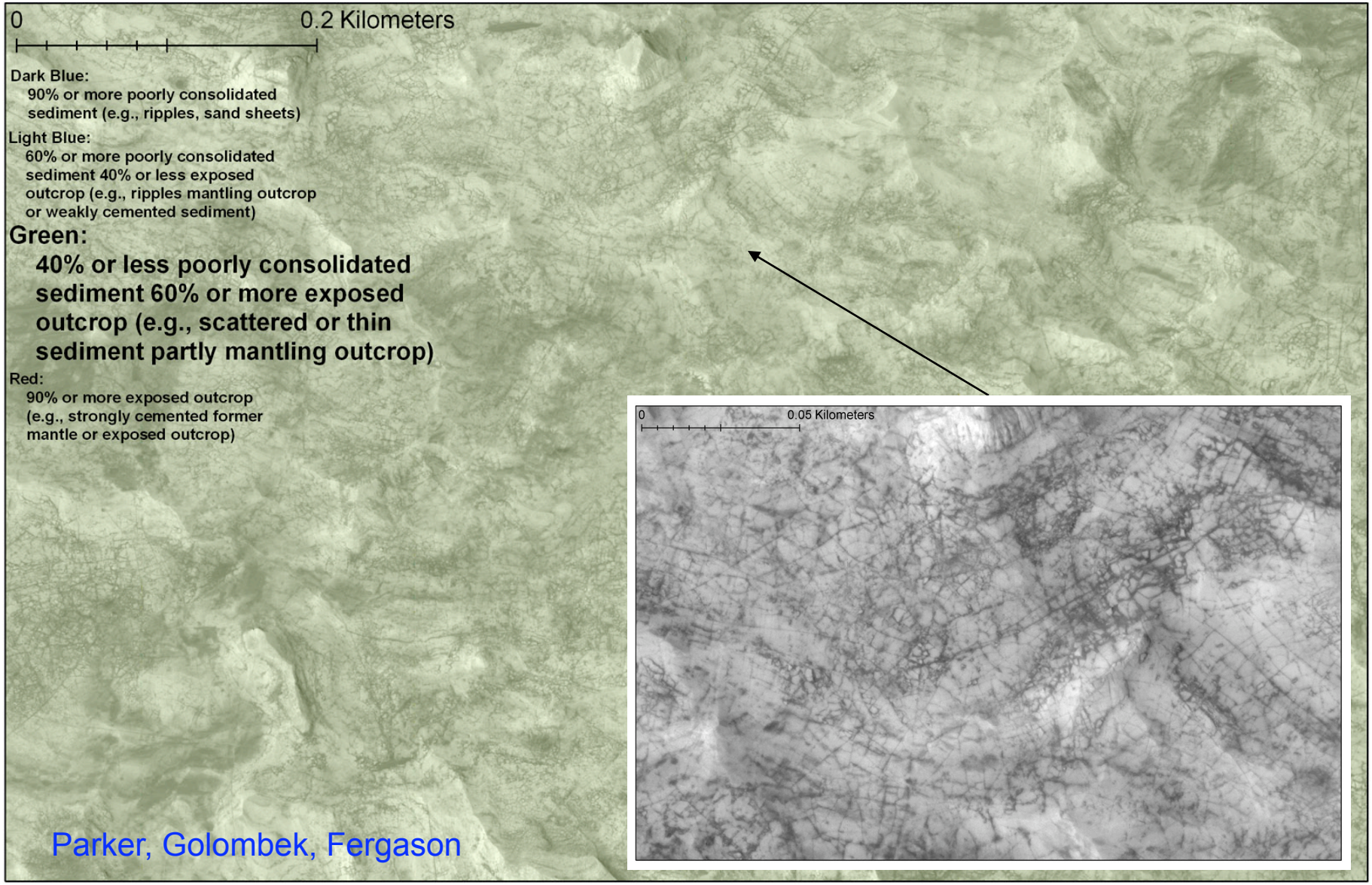

Parker, Golombek, Fergason

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Site 2: 23.99 N, 341.04 E (SH: 23.95 N, 341.11 E)
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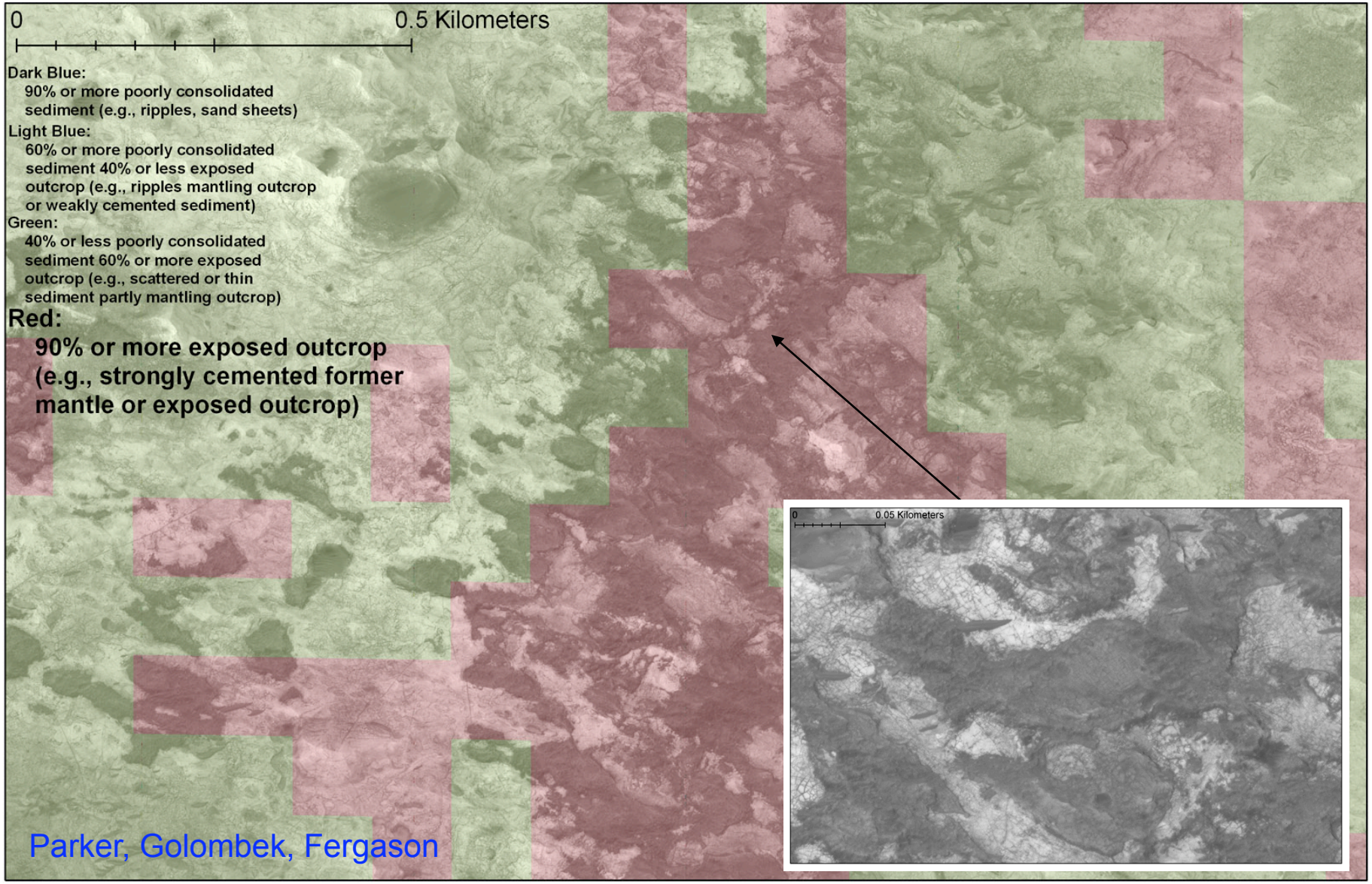
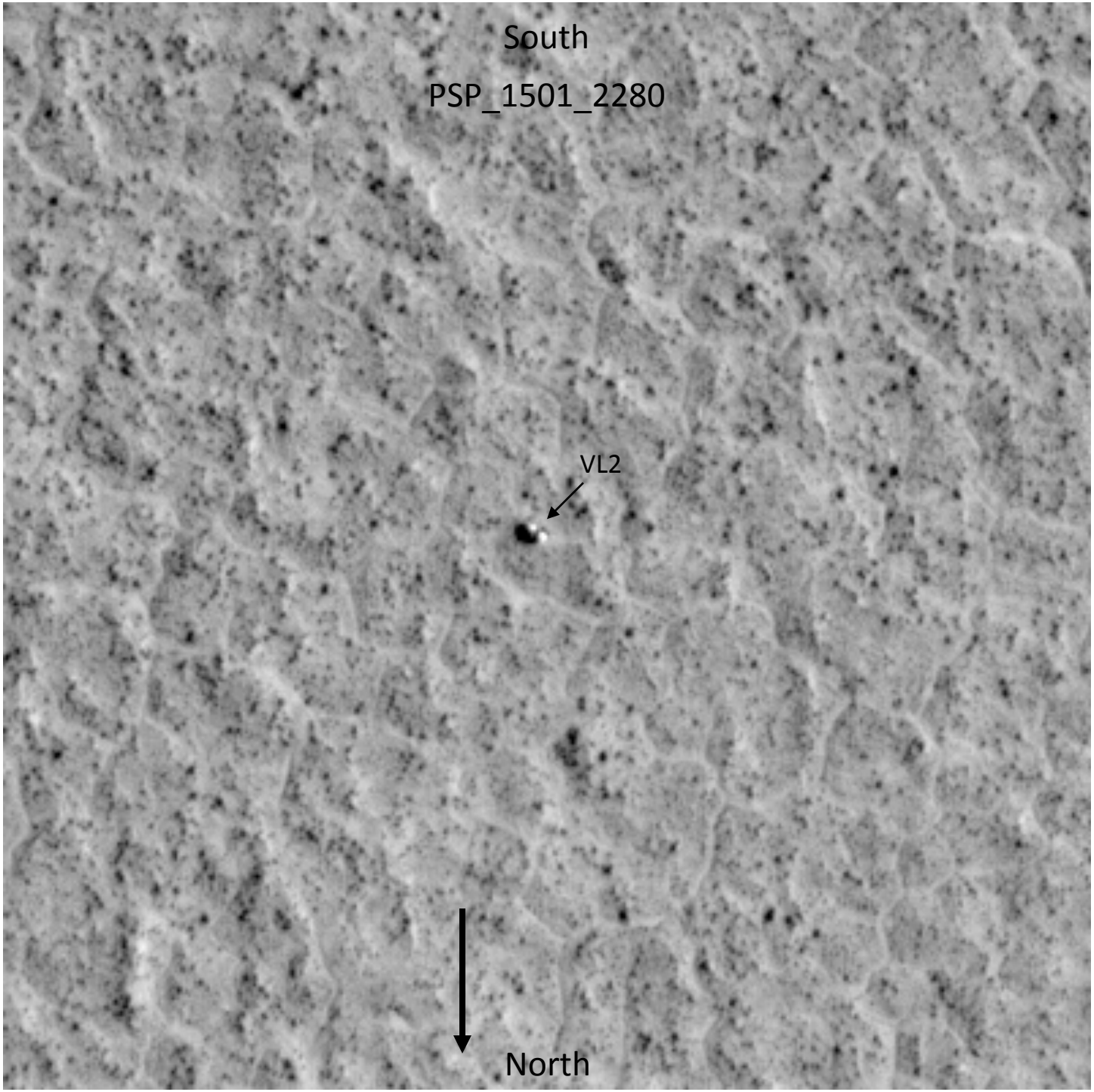




VL2

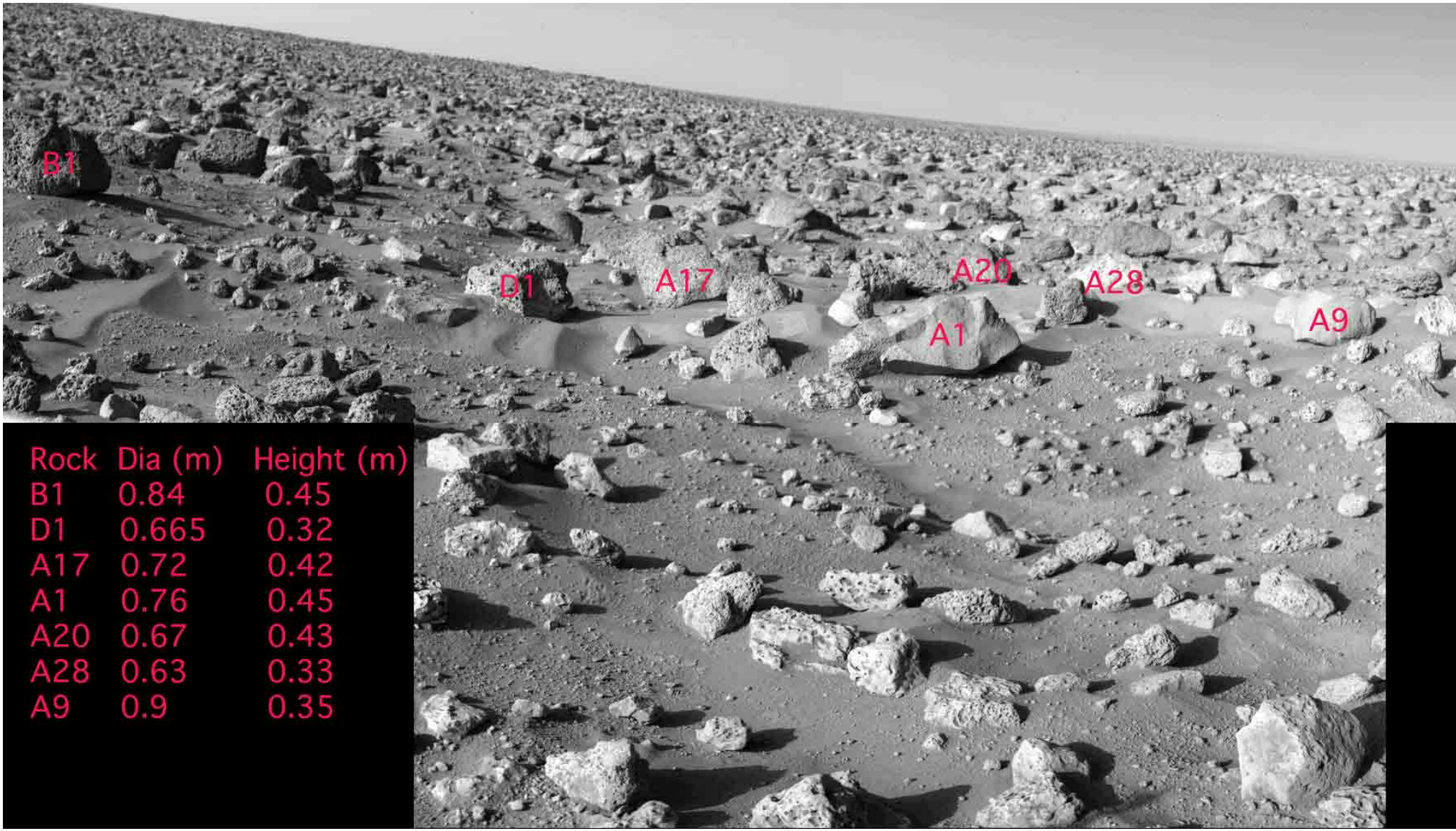
Can See Rocks Directly in HiRISE

Correlate Large Rocks in HiRISE with those Seen from Lander at All Landing Sites

400x400 pixels
124x124 meters
1.5 hectares

Golombek et al. [2008]

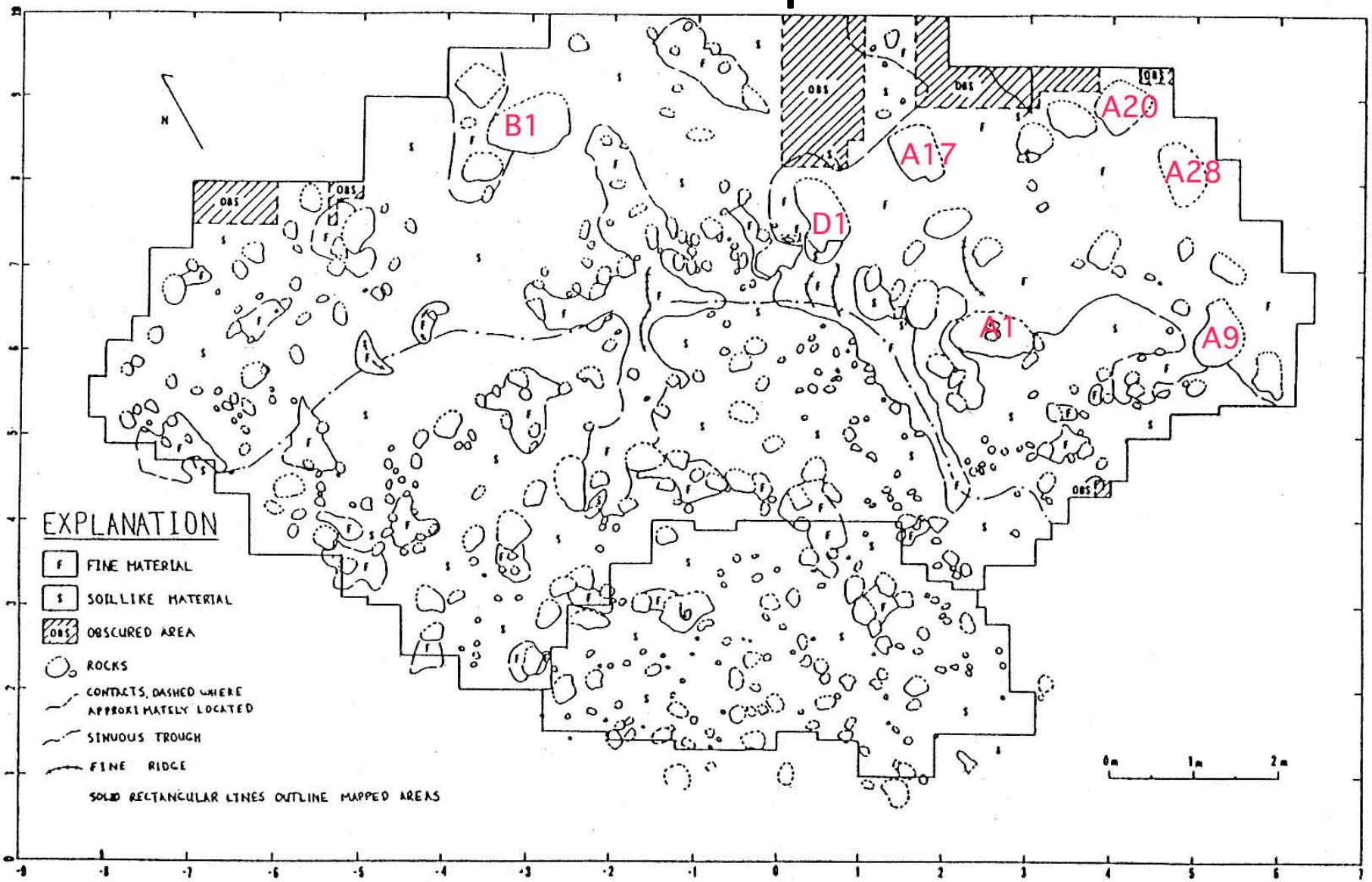
VL2 Large Rocks



Rock	Dia (m)	Height (m)
B1	0.84	0.45
D1	0.665	0.32
A17	0.72	0.42
A1	0.76	0.45
A20	0.67	0.43
A28	0.63	0.33
A9	0.9	0.35

Golombek et al. [2008]

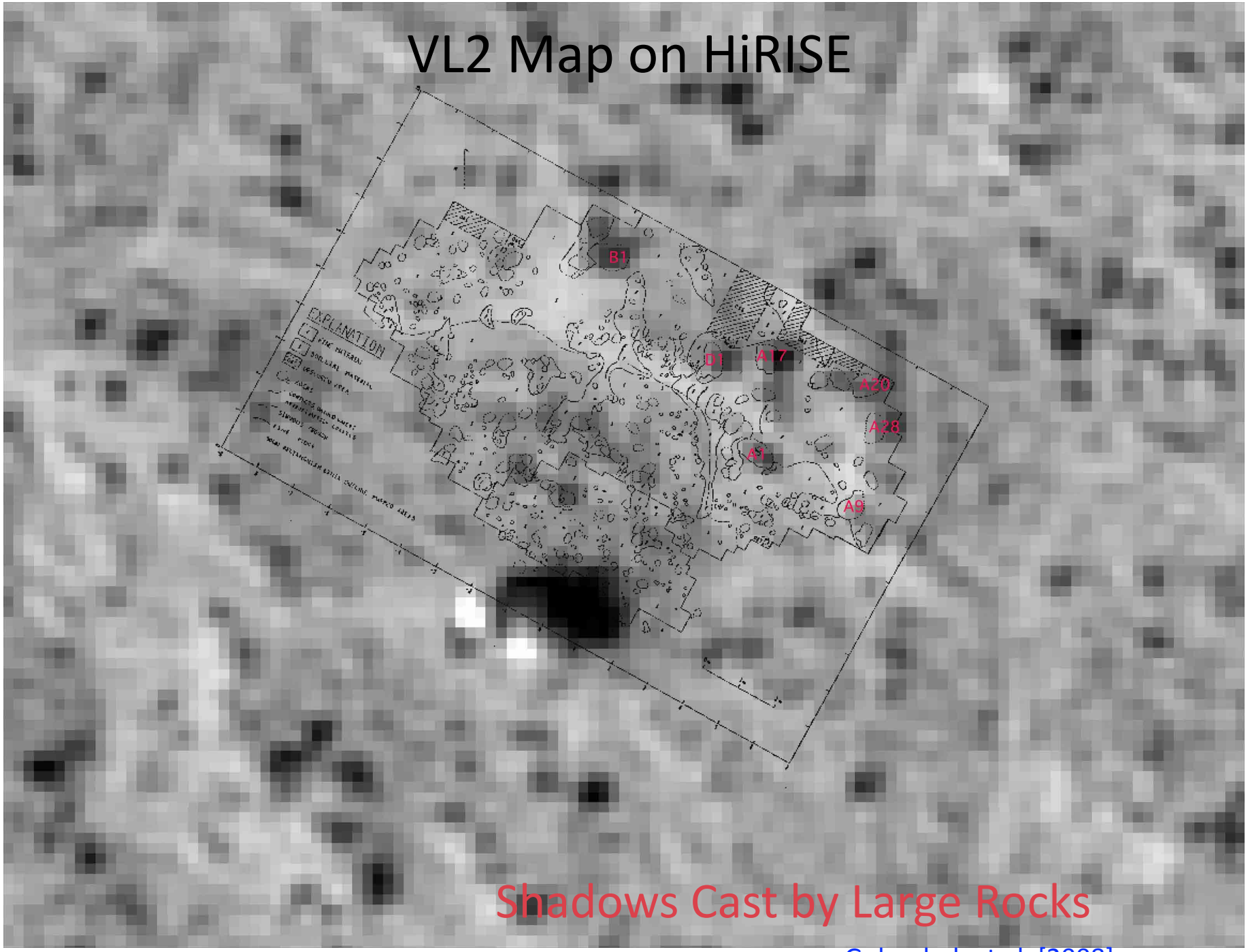
VL2 Map



7 Largest Rocks

Moore & Keller

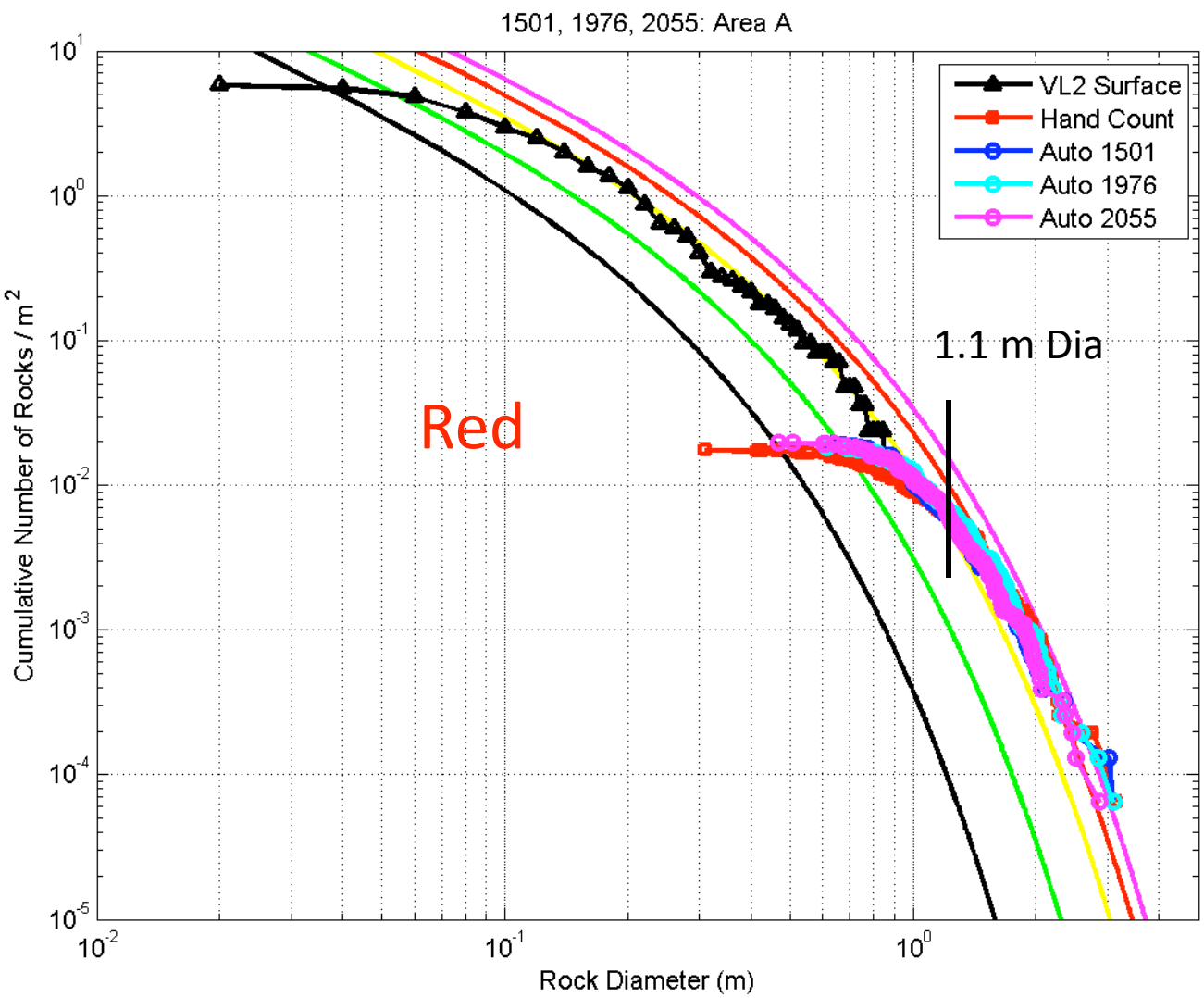
VL2 Map on HiRISE



Shadows Cast by Large Rocks

Golombek et al. [2008]

VL2 Surface to HiRISE Comparison



Automated Counting Routine Fits Ellipse to Shadow and Cylinder to Rock - Get Rock Diameter and Height

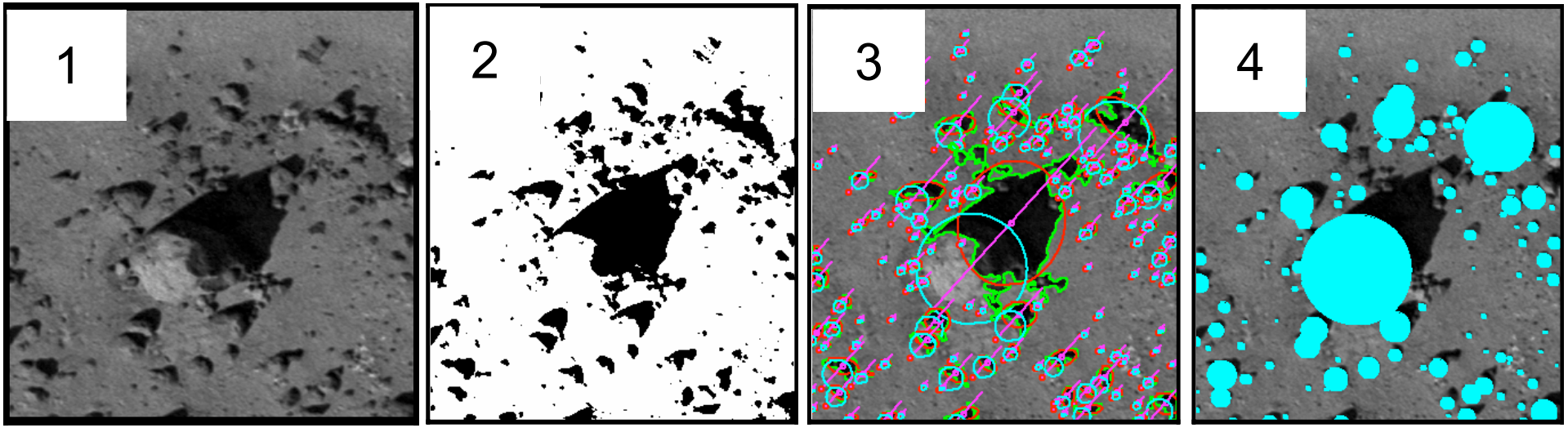
Validated on Landers/ Rovers and Matches Hand Counts

Size-Frequency Distribution Measured in HiRISE Matches Model Distribution at Smaller Diameter from Lander

Can Count Rocks in HiRISE and Extrapolate to Size Range of Interest along Model Curve

Golombek et al. [2008]

Automated Rock Counting



1) Image
2) Software Segments Shadow
3) Fits Ellipse to Shadow - Width is Rock Width
4) Fits Cylinder to Rock - Diameter is Rock Diameter
   Height is Rock Height from Shadow Length

Huertas et al.

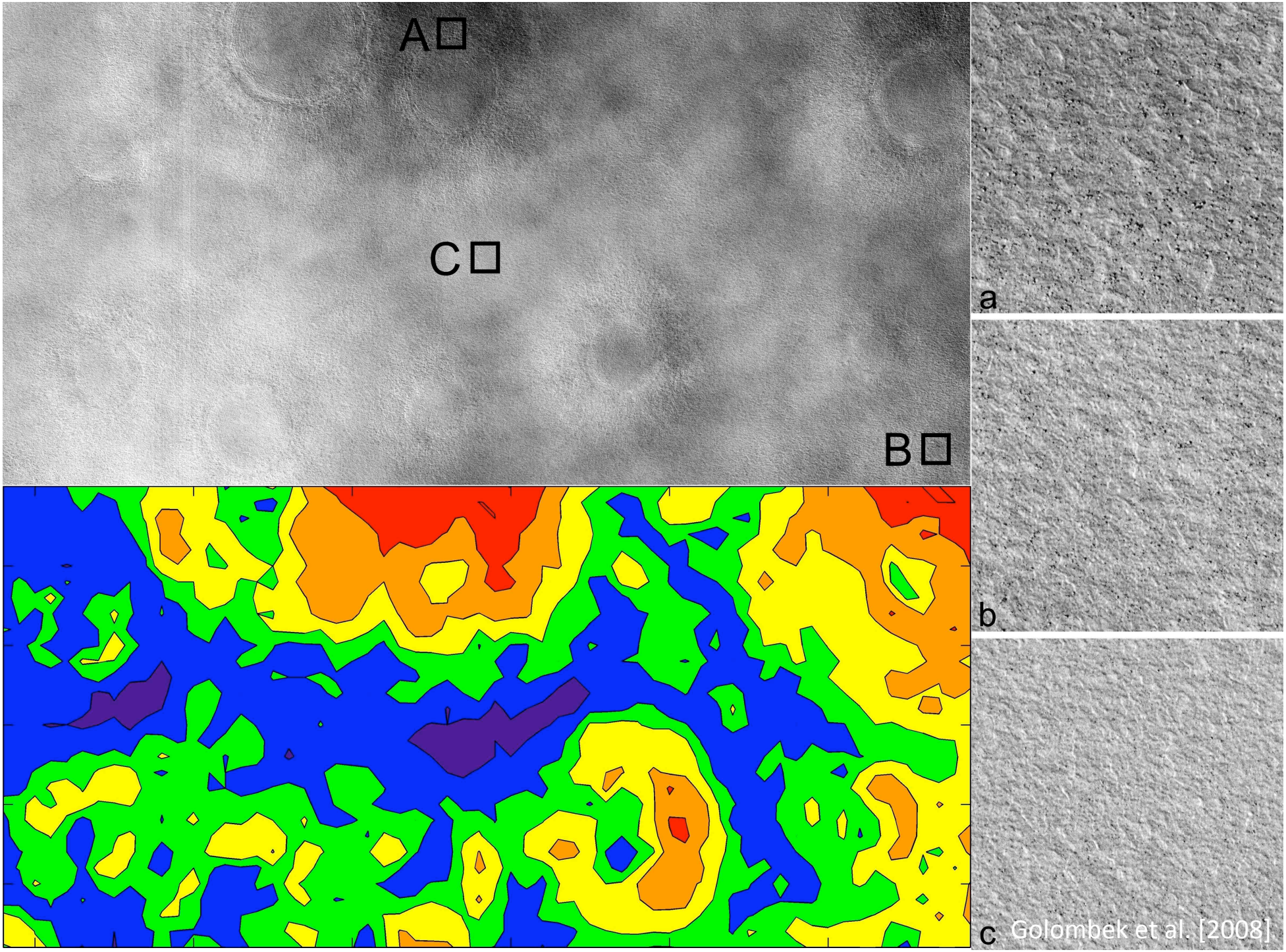
Results Match Hand Counts

Golombek et al. [2008]

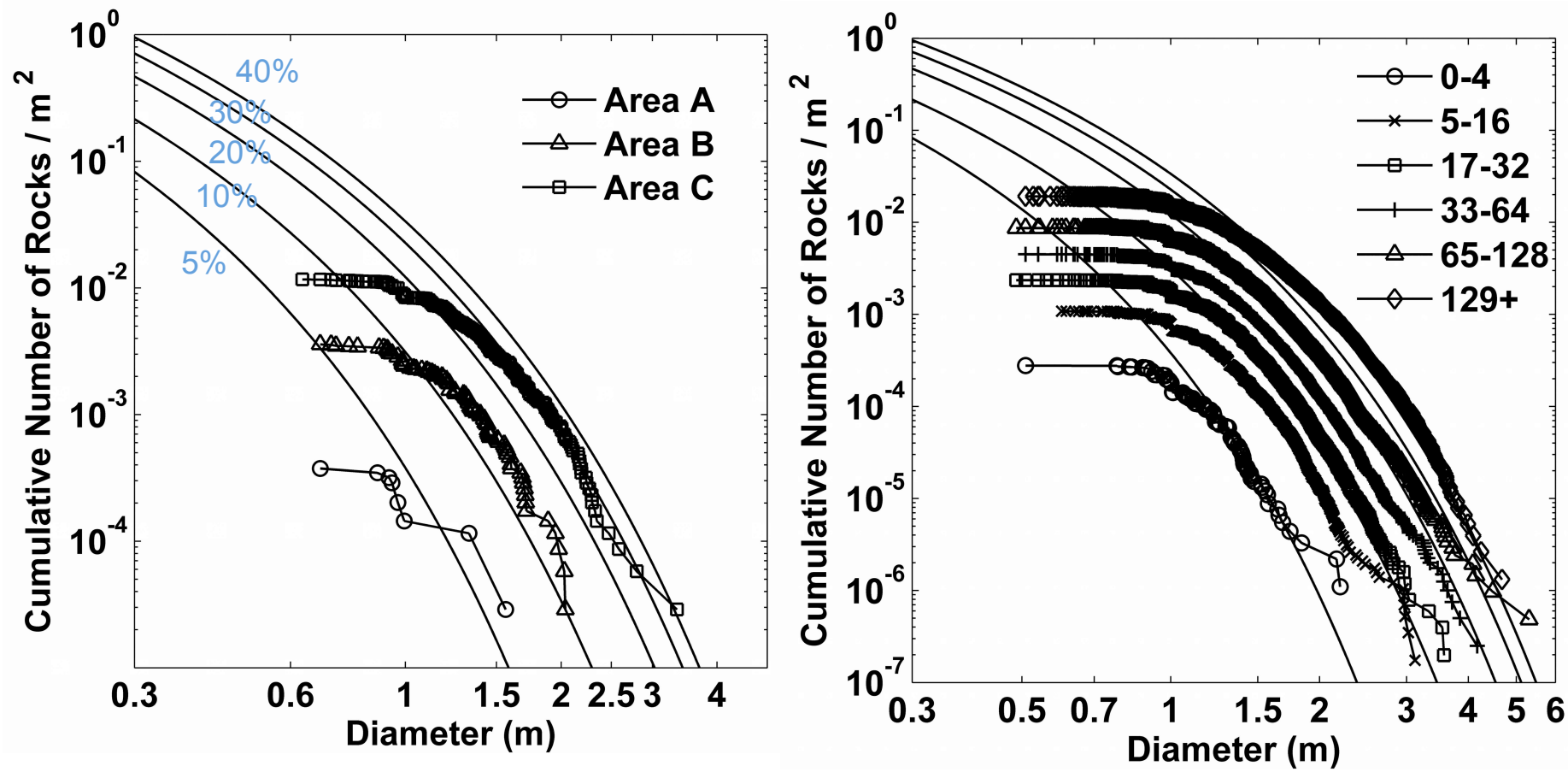
Results for Lander and Rovers of Known Size Generally ±1 pixel

Used to Map ~10 million rocks >1500 km^2 of the Northern Plains

Certified Phoenix Landing Site, Accurately predicted surface rocks


A
C
B
a
b
c
Golombek et al. [2008]

Cumulative Number Rocks/m^2



Match Cumulative Number >1.5 m Diameter to Model CFA 5%, 10%, 20%, 30%, 40%
Extrapolate to any smaller size

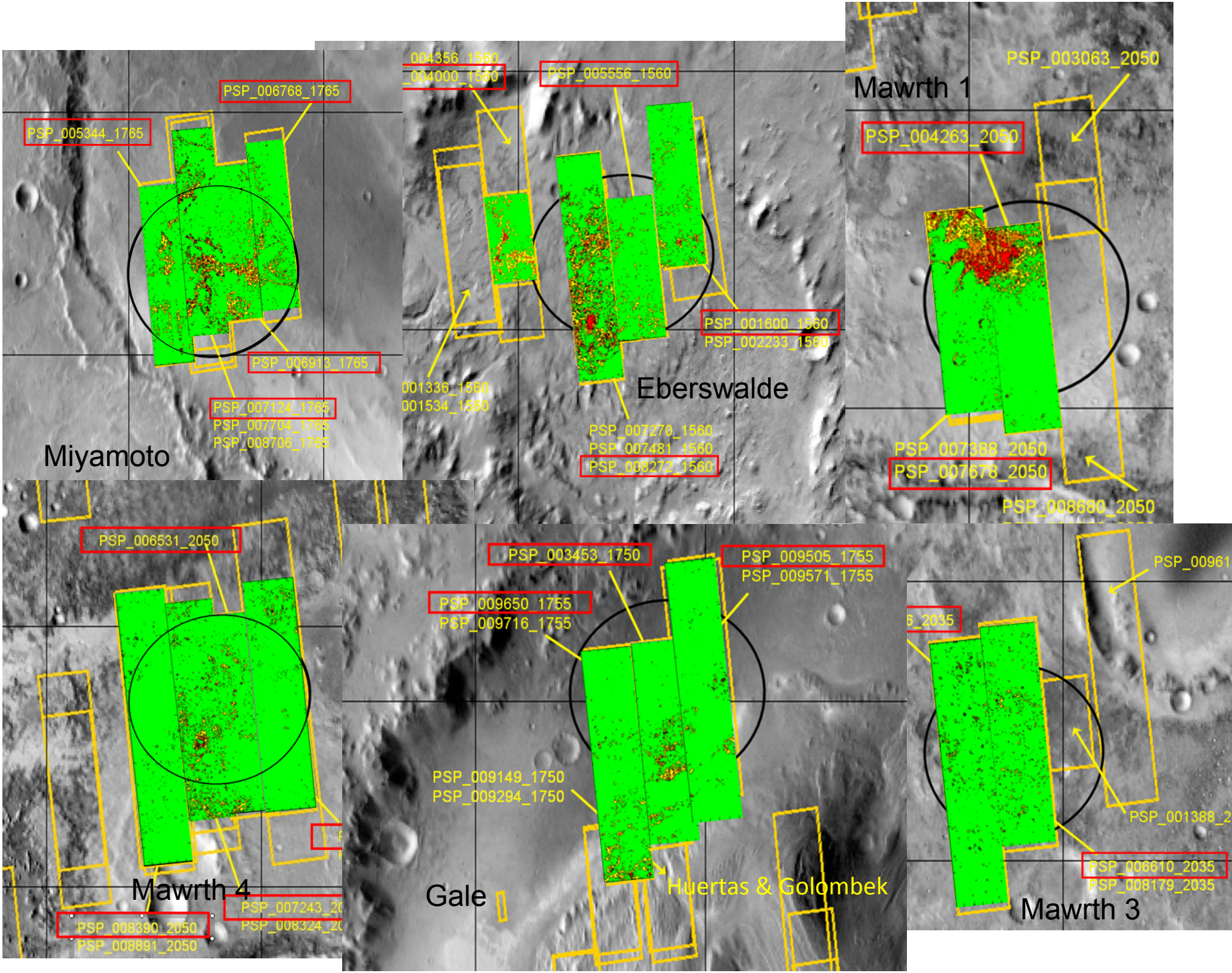
Golombek et al. [2008]

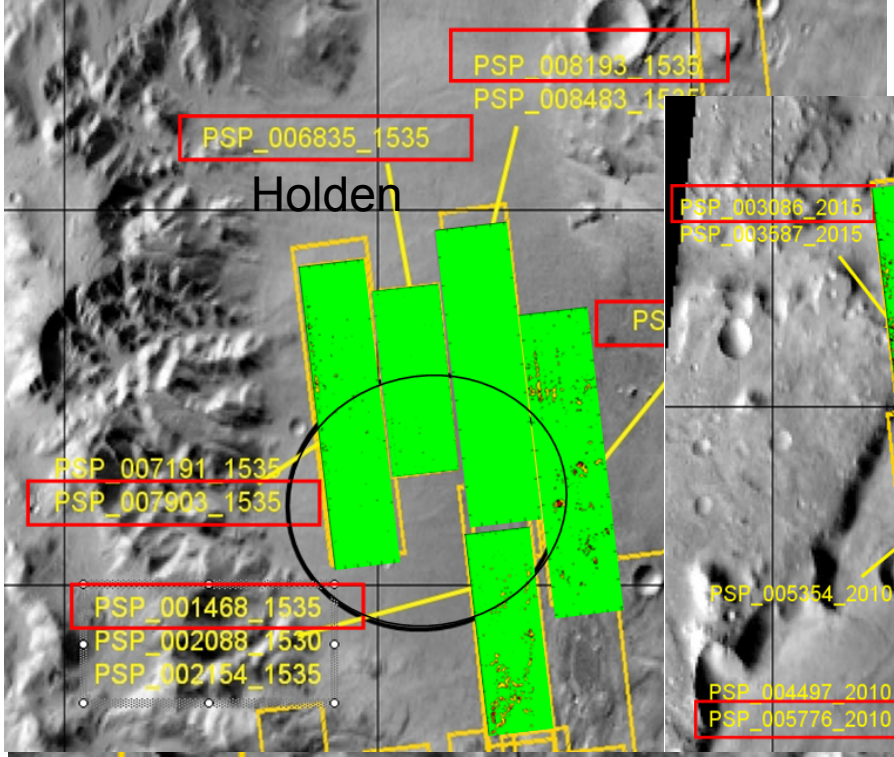
Cumulative Number of Rocks

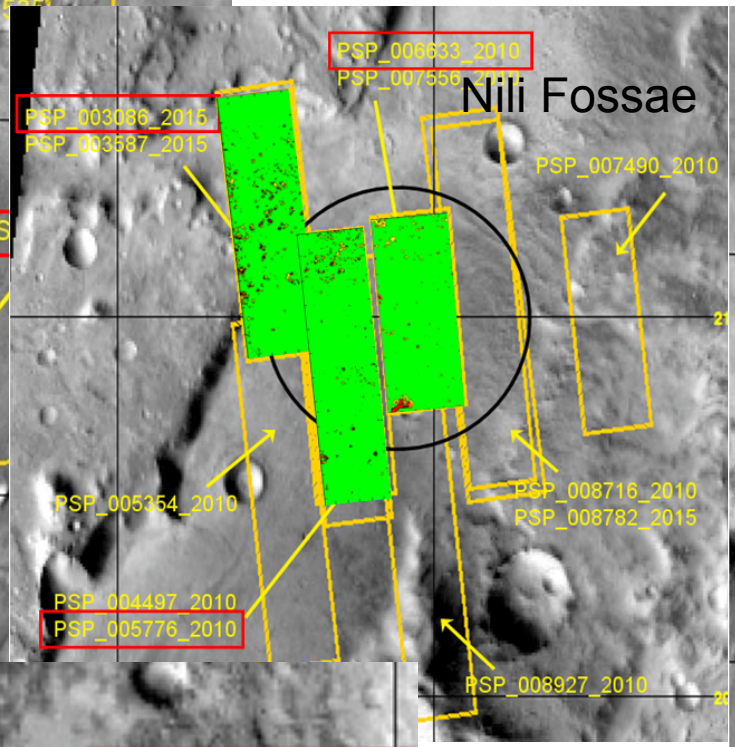
Rock Density	Cum # Rocks >1.5 m Dia/sq hectare from Map and count	Equivalent CFA %
High Rock Density	30 >20	37 >21
Medium-high rock density	9-19	<20
Medium-low rock density	4-8	<15
Low Rock Density	2-3	<10

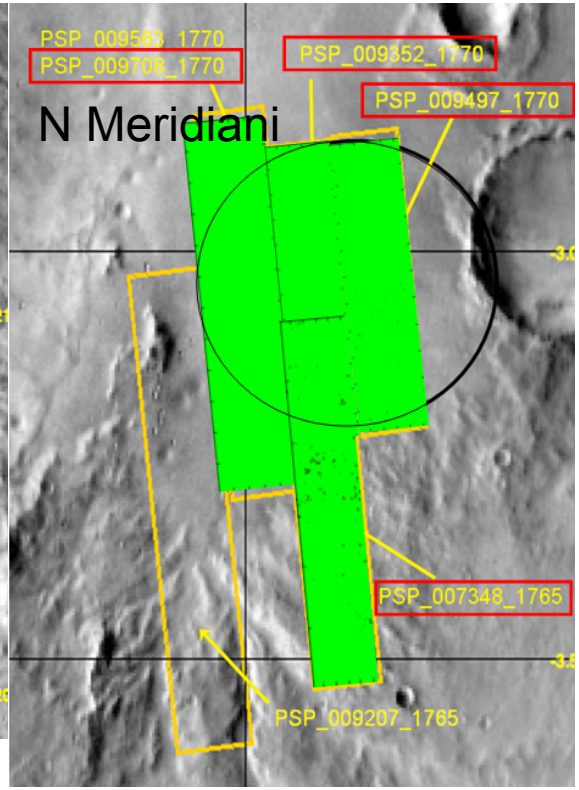
Golombek et al. [2008]

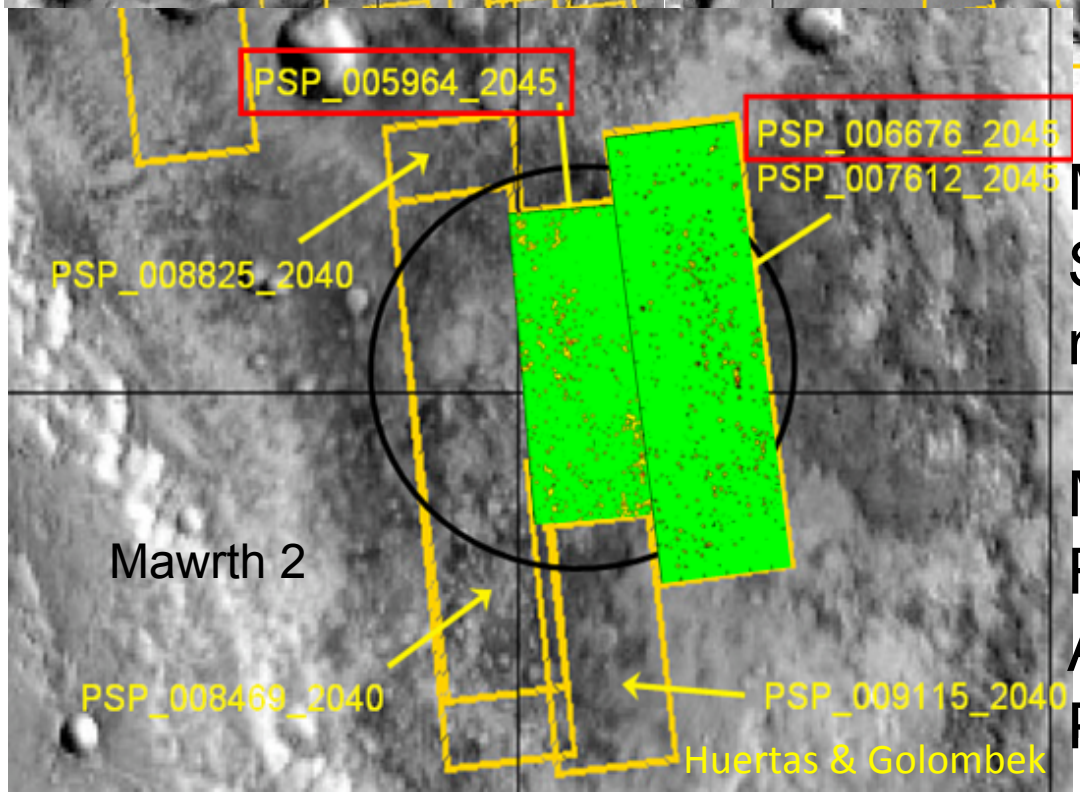
Color codes Refer to Map Units


PSP_006768_1765
PSP_005344_1765
PSP_006913_1765
PSP_007124_1765
PSP_007704_1765
PSP_008706_1765
Miyamoto
004356_1560
_004000_1560
PSP_005556_1560
PSP_001600_1560
PSP_002233_1560
001336_1560
001534_1560
Eberswalde
PSP_007270_1560
PSP_007481_1560
PSP_008272_1560
Mawrth 1
PSP_003063_2050
PSP_004263_2050
PSP_007388_2050
PSP_007676_2050
PSP_008680_2050
PSP_006531_2050
Mawrth 4
PSP_008390_2050
PSP_008891_2050
PSP_007243_20
PSP_008324_20
PSP_003453_1750
PSP_009505_1755
PSP_009571_1755
PSP_009650_1755
PSP_009716_1755
PSP_009149_1750
PSP_009294_1750
Gale
Huertas & Golombek
PSP_00961
6_2035
PSP_001388_2
PSP_006610_2035
PSP_008179_2035
Mawrth 3









Maps Still Preliminary
Some scarps recorded as rocks (Eberswalde, Mawrth 1)

Most of Ellipses Relatively Rock Free
Areas with Rocks Cover Small Portion of Ellipse

Summary

- Extensive Surface and Atmospheric Characterization Studies being Carried Out
- Data Products and Models Appear Capable of Addressing All of the Engineering Criteria and Providing Input for Landing Safety Evaluations
- Comparison of Characteristics to Engineering Criteria and Engineering Team Assessment …
- **None of the Landing Sites Violate the Safety Criteria Such that they Should Not be Considered at this Time**
- **So … Let's Talk Science**