Overview of Mars Science Laboratory Landing Sites: Data Products for Engineering Analysis

M. Golombek
E. Noe Dobrea, D. Kipp, T. Parker, Y. Sun, H. Sladek, A. Huang, F. Calef
Jet Propulsion Laboratory, California Institute of Technology

Including work by:
R. Kirk, E. Howington-Kraus et al.: USGS Flagstaff – HiRISE Digital Elevation Models
A. Huertas, M. Golombek: JPL – HiRISE Rock Maps
R. Ferguson: USGS Flagstaff; Phil Christensen: ASU – THEMIS Thermal Inertia
R. Beyer: SETI NASA Ames – HiRISE Photoclinometry
K. Larsen: CU Boulder – Earth-based Radar
Y. Sun – MOLA Analysis
J. Griffes, J. Grant - HiRISE

Fourth Mars Science Laboratory
Landing Site Workshop
September 29, 2010
DoubleTree Hotel
Monrovia, CA

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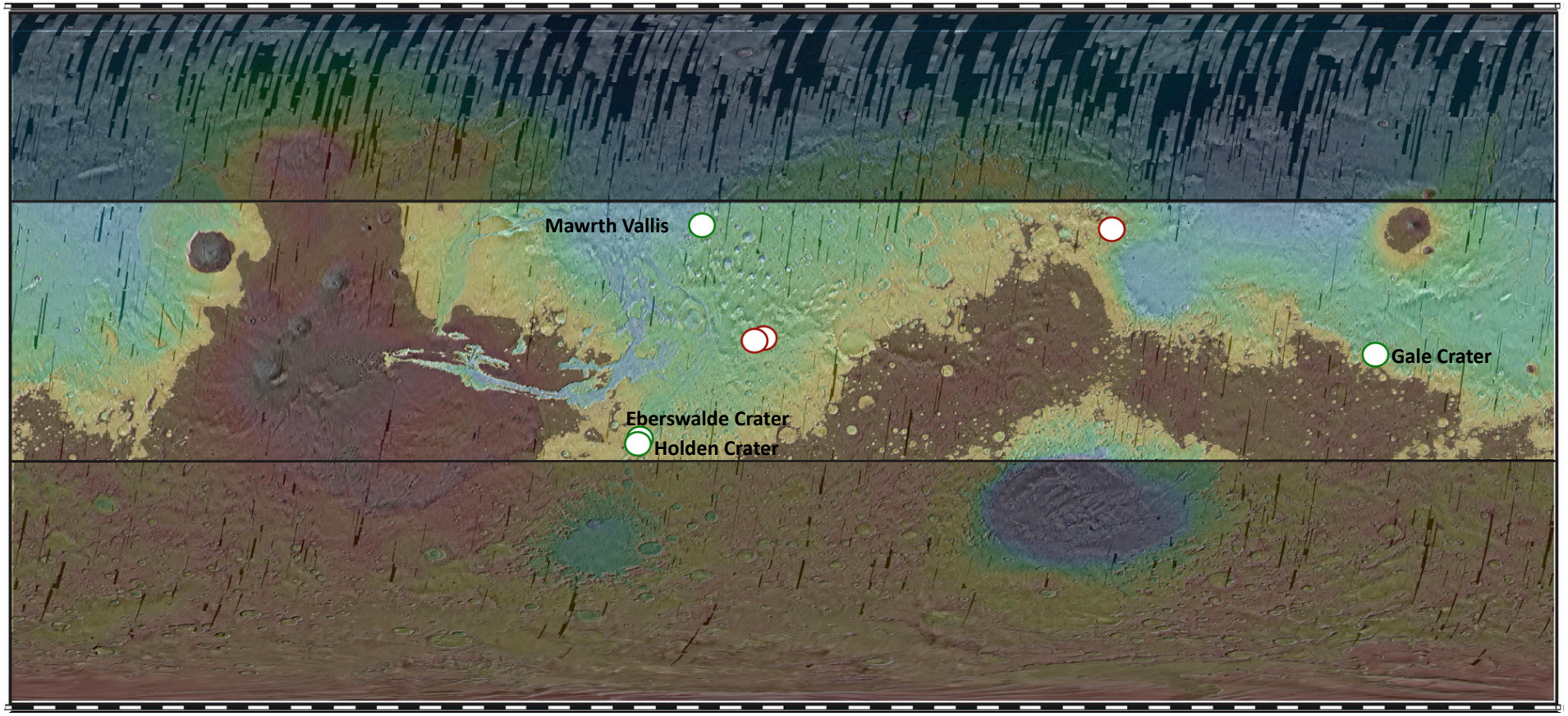
Outline

- 1) Define 4 Landing Site Ellipses
  - Previous Ellipses Defined for 2009 Launch
    - Azimuth Change
    - New Data Products Available
- 2) Summarize Data Products & Coverage for Engineering Analysis
  - HiRISE Coverage & Registration
  - Topography HiRISE DTMs (1 m Elevation Postings) and Slopes & Coverage
  - Slopes from Photoclinometry
  - km Slopes MOLA
  - Rocks
  - Thermal Inertia
  - Surface Material Properties
- 3) Summarize Surface Characteristics
  - Comparison to Previous Landing Sites and Ground Truth
    - Thermal Inertia, Albedo, Dust Cover
    - 5 m Slopes
    - km Slopes; 100 m Roughness
    - Rock Abundance
    - Radar
- 4) Potential Additional Hazards
  - Inescapable Hazards
  - Inescapable Eolian Bedforms

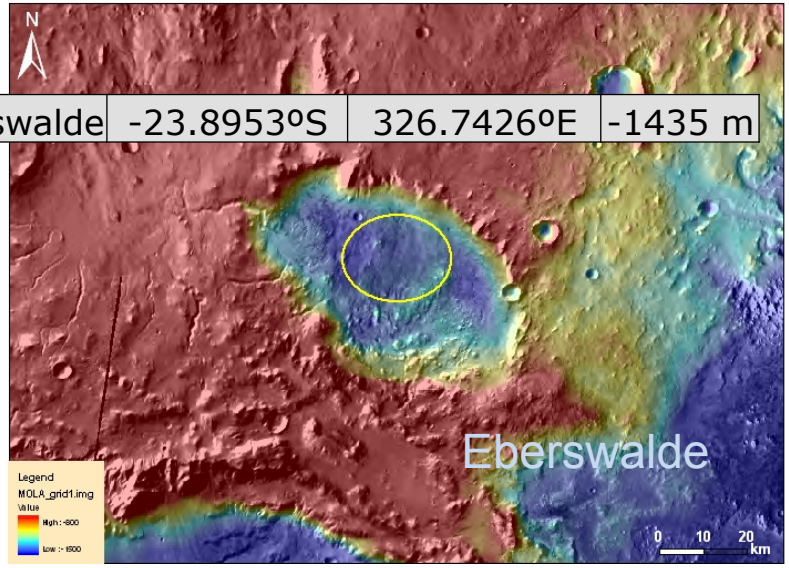
Final 4 MSL Landing Sites



J. Griffes, Caltech

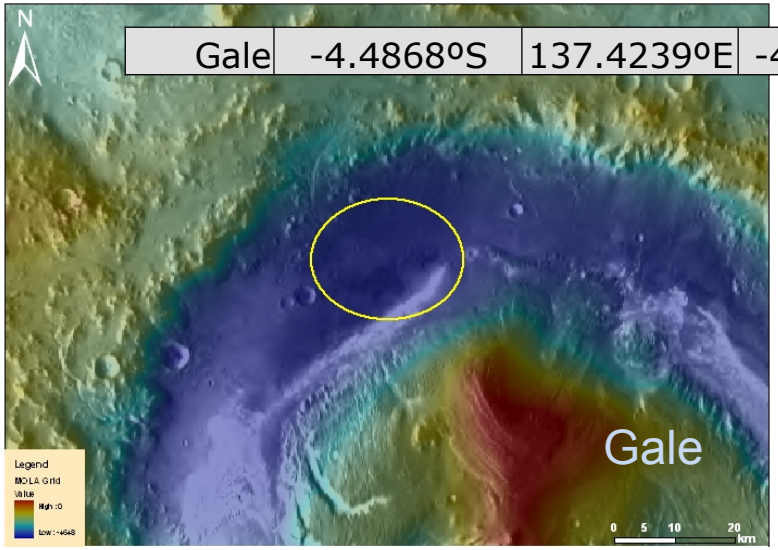
Final Four MSL Landing Ellipses

Eberswalde Crater: MOLA



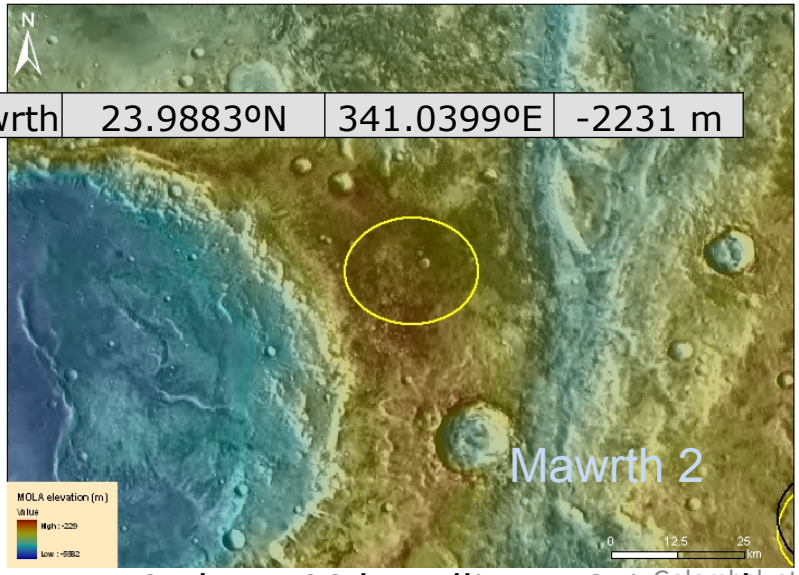
Eberswalde	-23.8953ºS	326.7426ºE	-1435 m

Gale Crater: MOLA



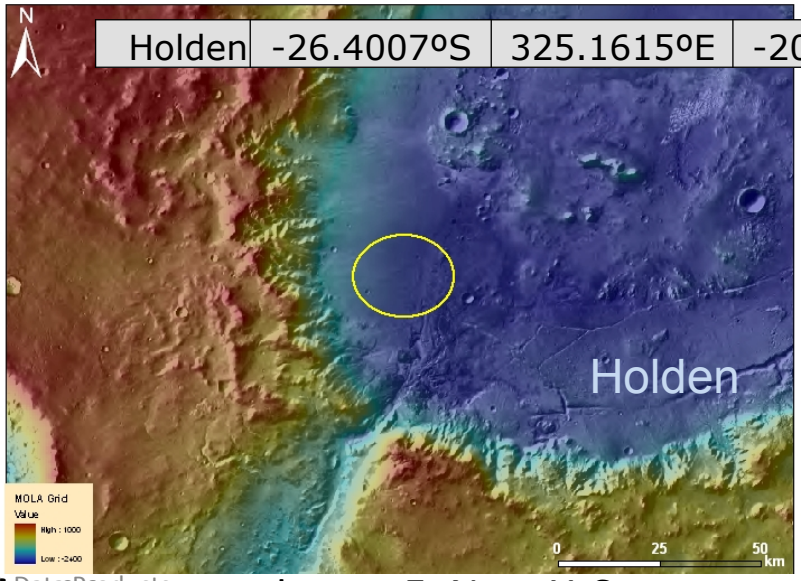
Gale	-4.4868ºS	137.4239ºE	-4449 m

Mawrth Vallis Site 2: MOLA



Mawrth	23.9883ºN	341.0399ºE	-2231 m

Holden Crater: MOLA



Holden	-26.4007ºS	325.1615ºE	-2088 m

25 km x 20 km Ellipses Oriented ~E-W for 2011 Launch

Golombek et al., MSL Data Products

E. Noe, Y. Sun

Coordinates of 2011 MSL Landing Sites

Ellipse Center Coordinates and Elevation 8/2010			
E-W Azimuth (25 x 20 km)			
Landing Site	**Latitude (Deg)**	**Longitude (Deg)**	**Elevation (m)**
Eberswalde	-23.8953ºS	326.7426ºE	-1435
Gale	-4.4868ºS	137.4239ºE	-4449
Holden	-26.4007ºS	325.1615ºE	-2088
Mawrth	23.9883ºN	341.0399ºE	-2231

Old Ellipses were for 2009 Launch
New Ellipses Assume E-W Azimuth Appropriate for 2011
Based on MOLA topography, Hazards in Images and HiRISE DTMs and Rock Maps

HiRISE Images & Coverage

Thanks to A. McEwen & HiRISE Team

HiRISE Images are ~0.25 m/pixel; 6 km wide

Camera on MRO,

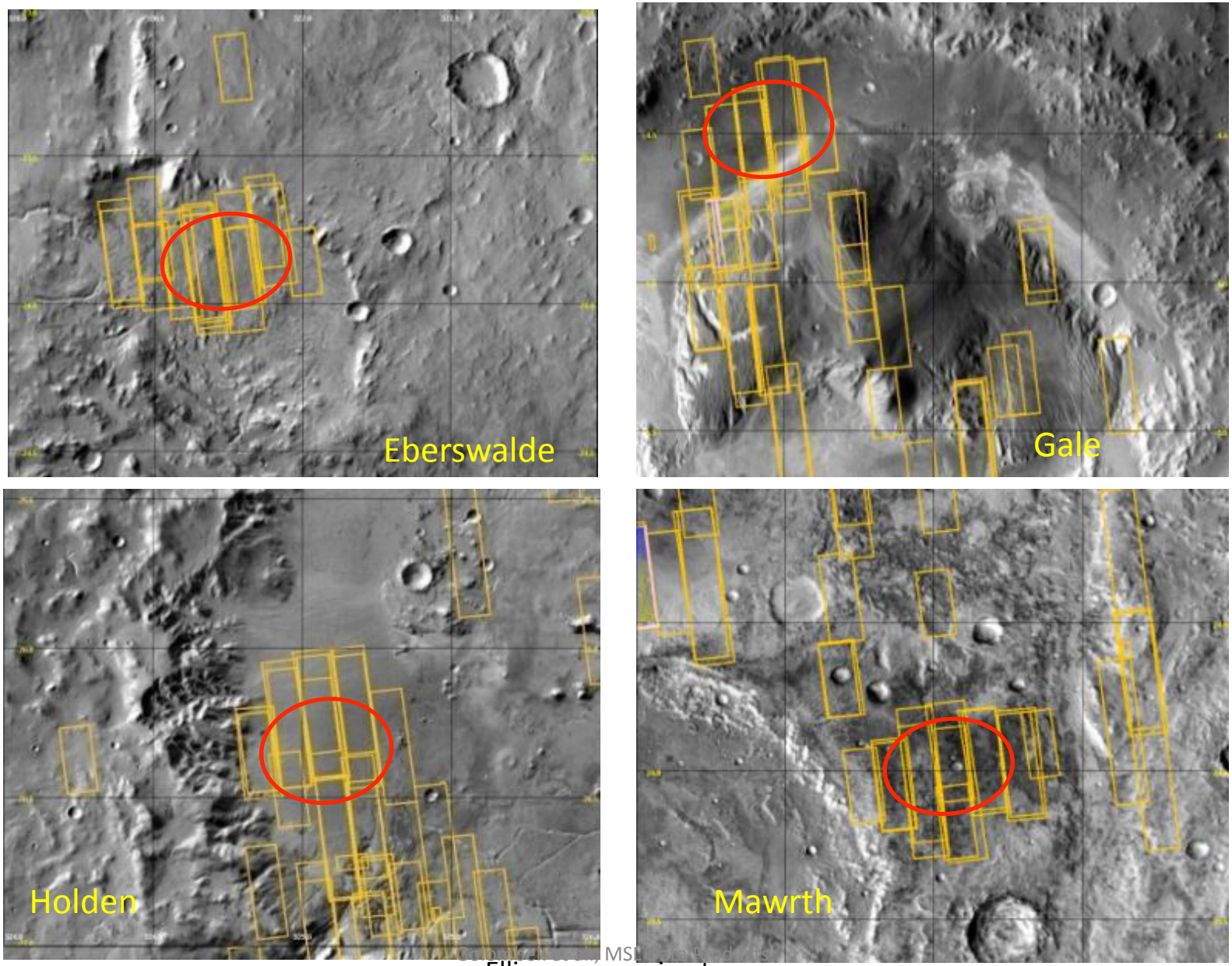
Images Targeted via Mars Program Must Haves Each Cycle [2 weeks]

Most Have Co-Located CTX, 6 m/pixel, 30 km wide

and CRISM, 20 m/pixel, 11 km wide (512 bands 0.4-4 microns)

These are the Best Imaged Best Characterized Landing Sites in History Mars Exploration

HiRISE Image Coverage in Vicinity of Sites

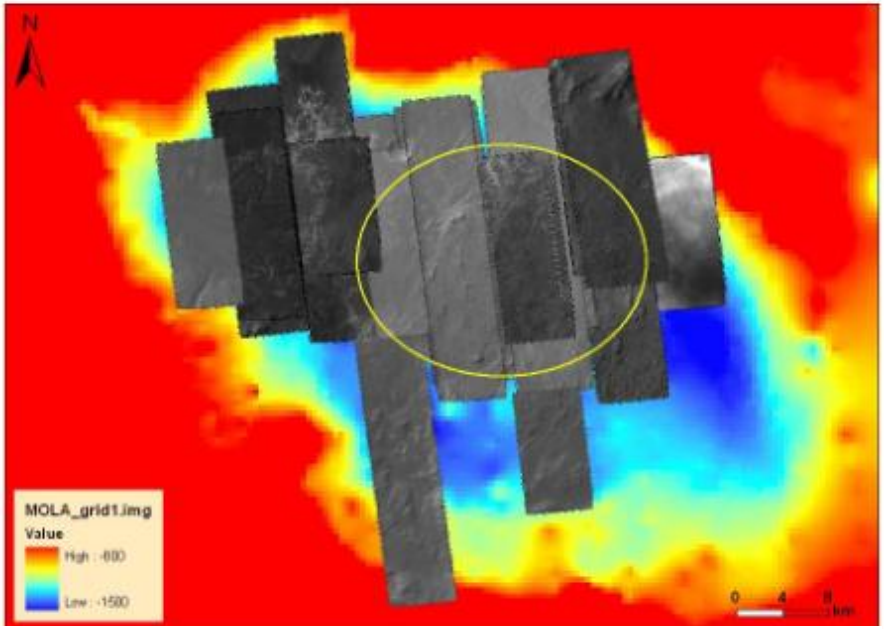


Ellipses approximate

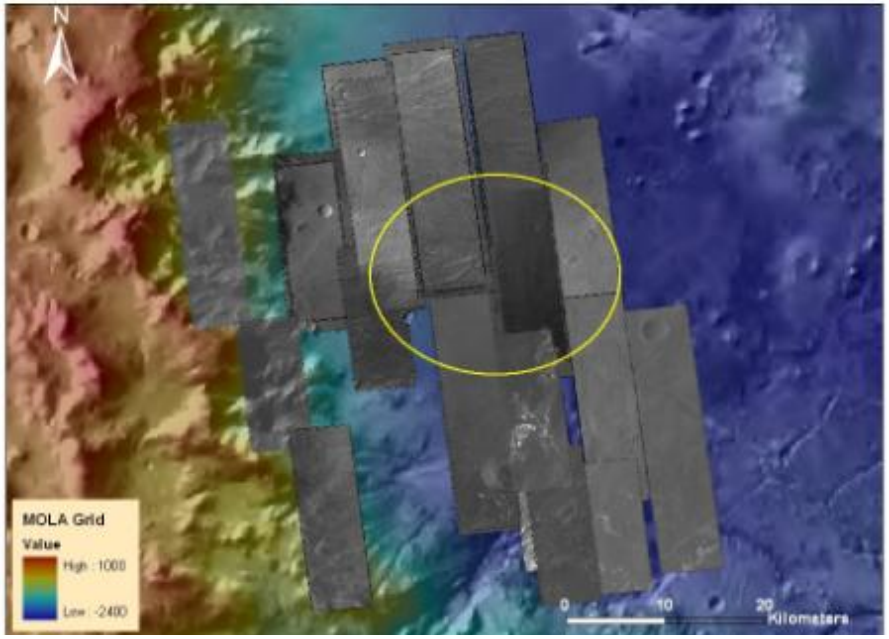
HiRISE Image Coverage in Ellipse

Ellipses Exact
Images Georeferenced

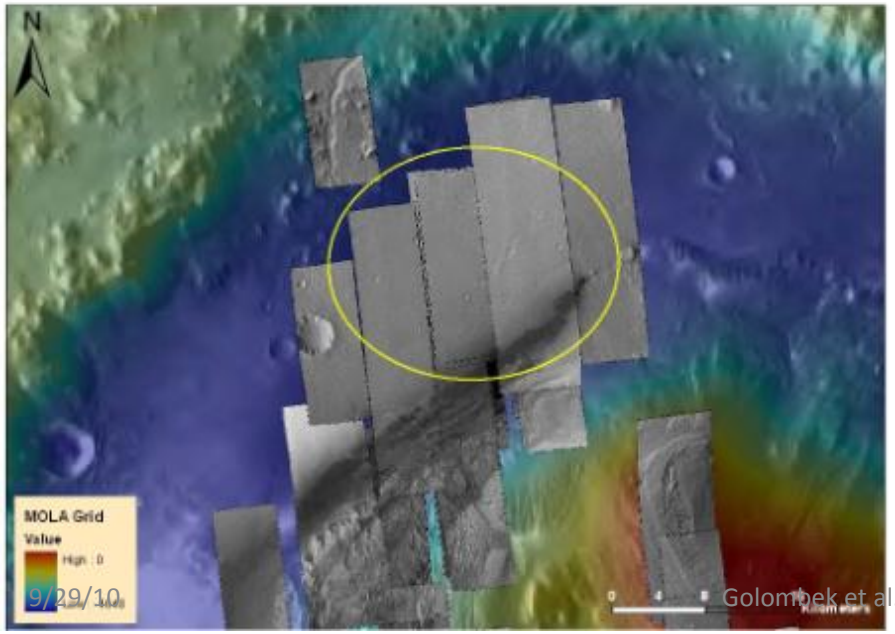
Eberswalde Crater HiRISE



Holden Crater HiRISE

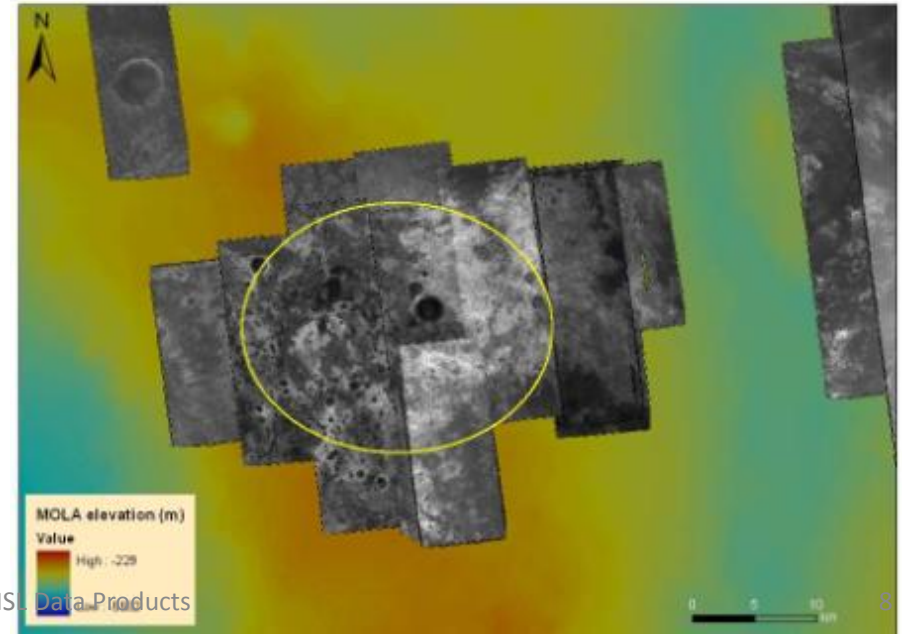


Gale Crater HiRISE



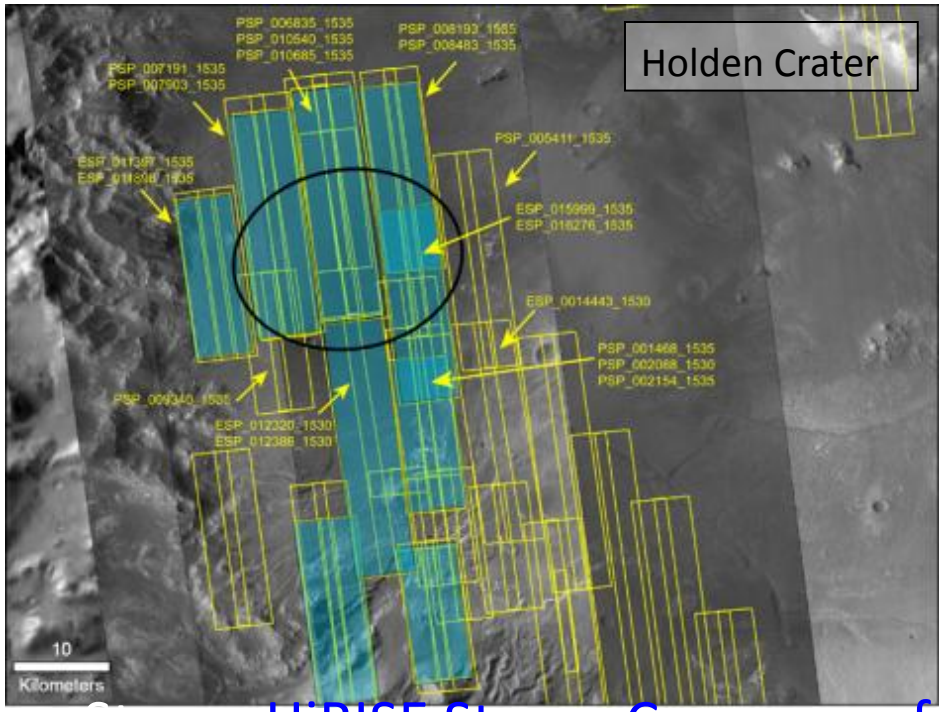
Mawrth Vallis HiRISE

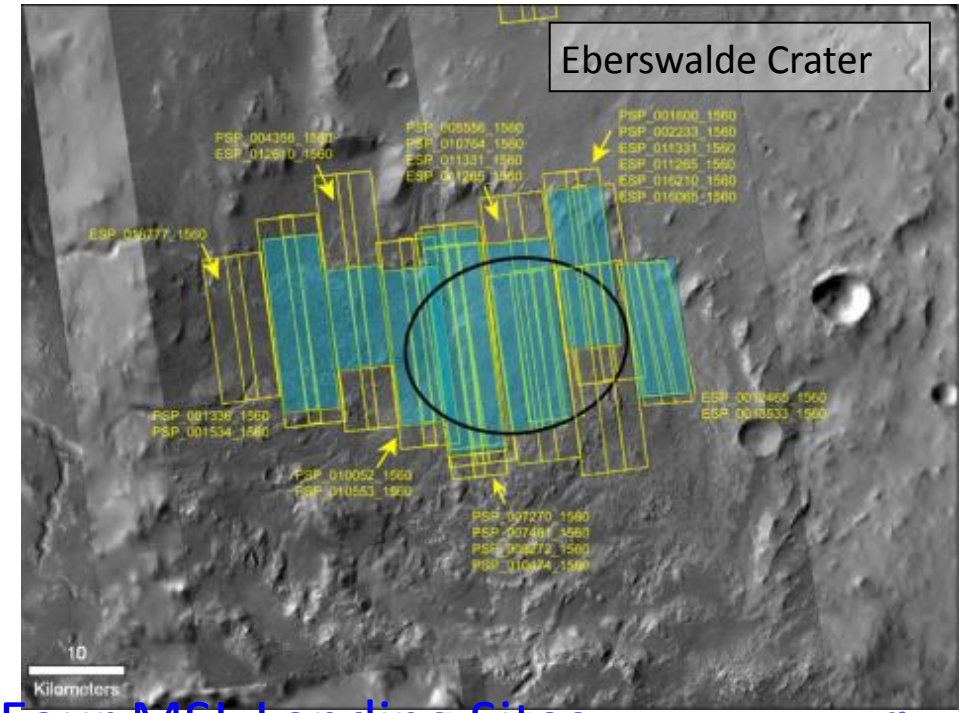
Sun & Sladek

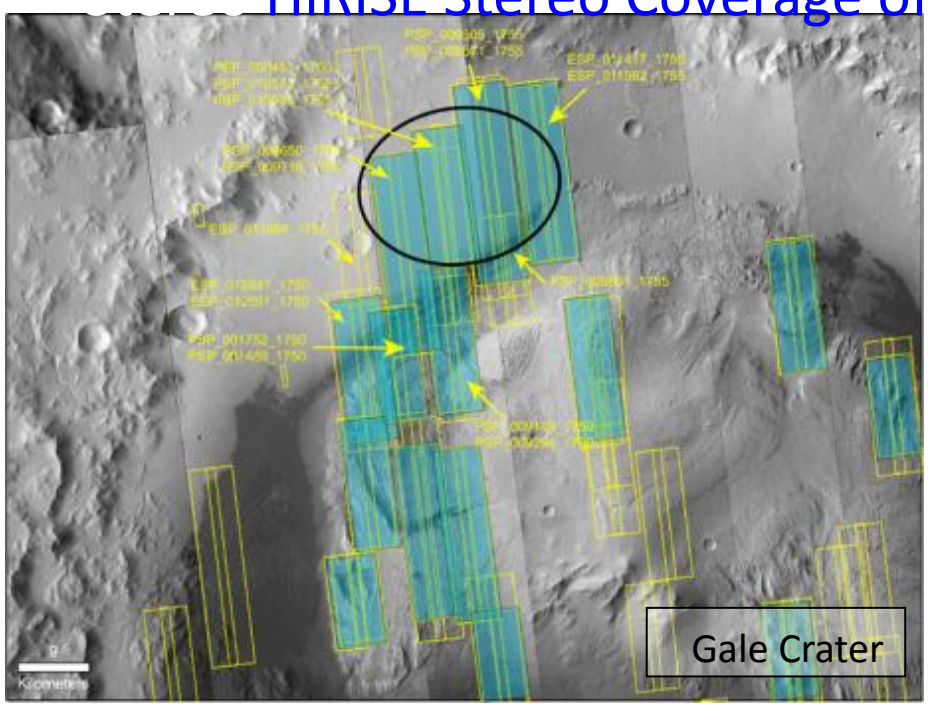


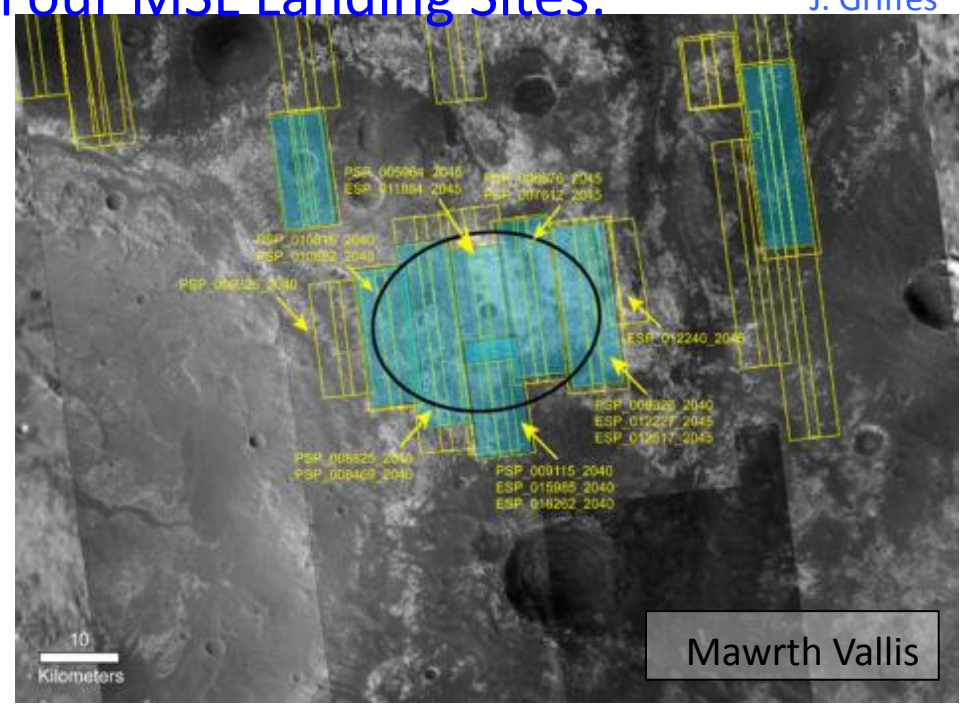
HiRISE Stereo Coverage of Four MSL Landing Sites:

J. Griffes









Registration and Maps of Data Products

by T. Parker, E. Noe Dobrea, Y. Sun,
H. Sladek & M. Golombek, JPL

MOLA Topo Shaded Relief [~0.5 km]

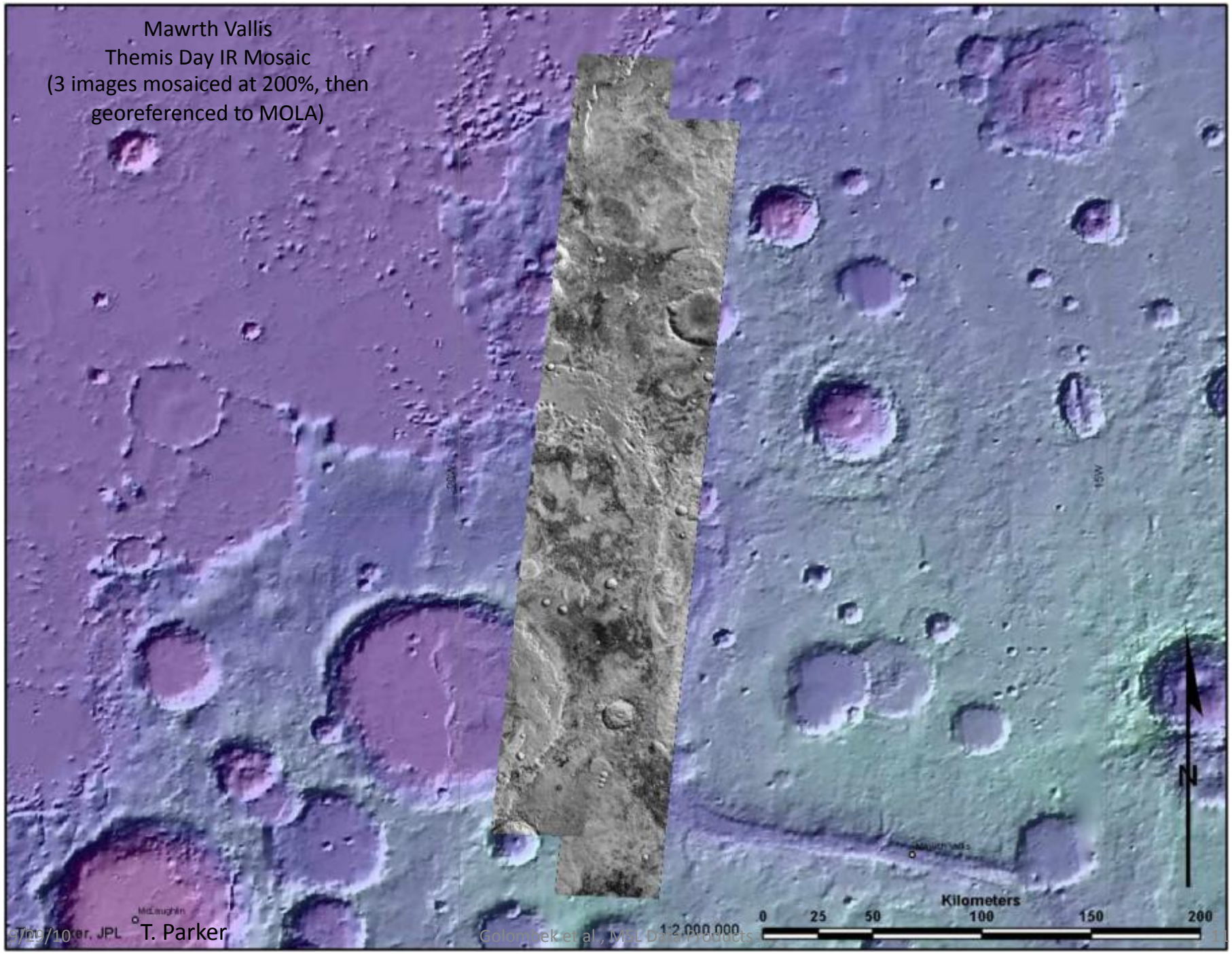
Cartographic Net Based on MOLA

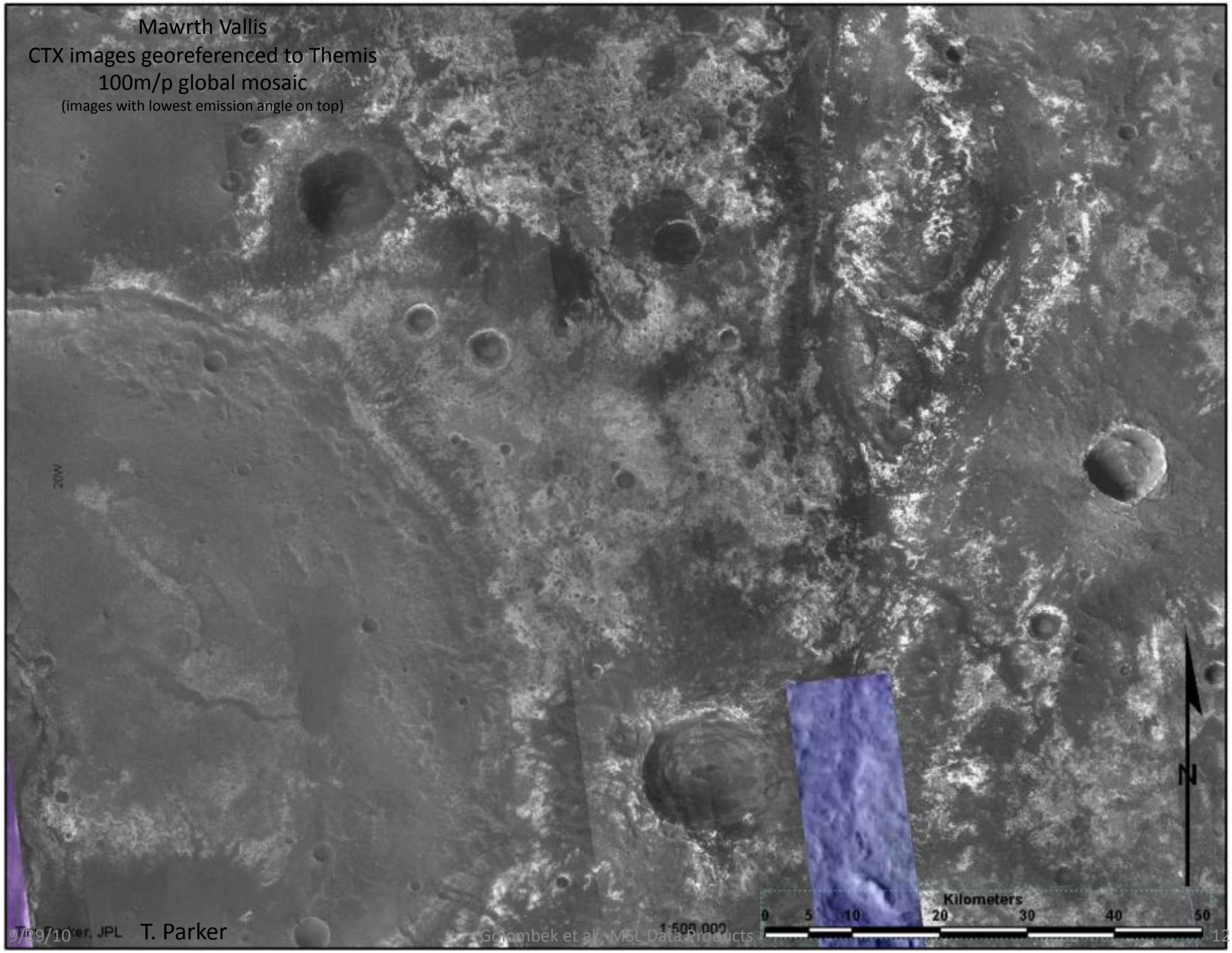
Inertial – Cartographic Tie [±300 m]

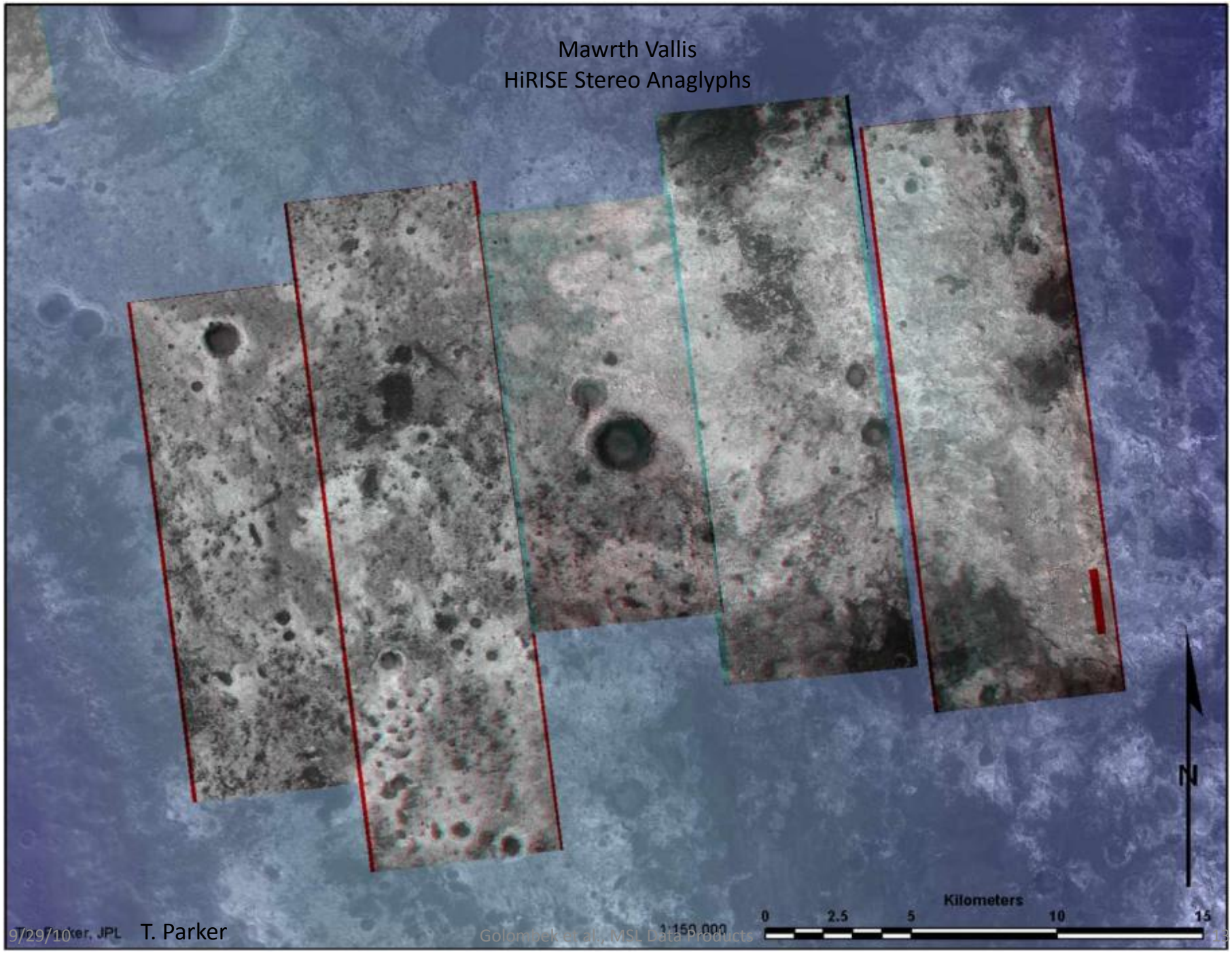
THEMIS Thermal Image Mosaic [100 m/pixel]

CTX Images [6 m/pixel]

HiRISE Images [0.25 m/pixel]


Mawrth Vallis
Themis Day IR Mosaic
(3 images mosaiced at 200%, then
georeferenced to MOLA)
Kilometers
0 25 50 100 150 200
1:2,000,000
N
T. Parker


Mawrth Vallis
CTX images georeferenced to Themis
100m/p global mosaic
(images with lowest emission angle on top)
20W
1:500,000
Kilometers
0 5 10 20 30 40 50
N
T. Parker


Mawrth Vallis
HiRISE Stereo Anaglyphs
N
Kilometers
0
2.5
5
10
15
1:150,000
T. Parker, JPL

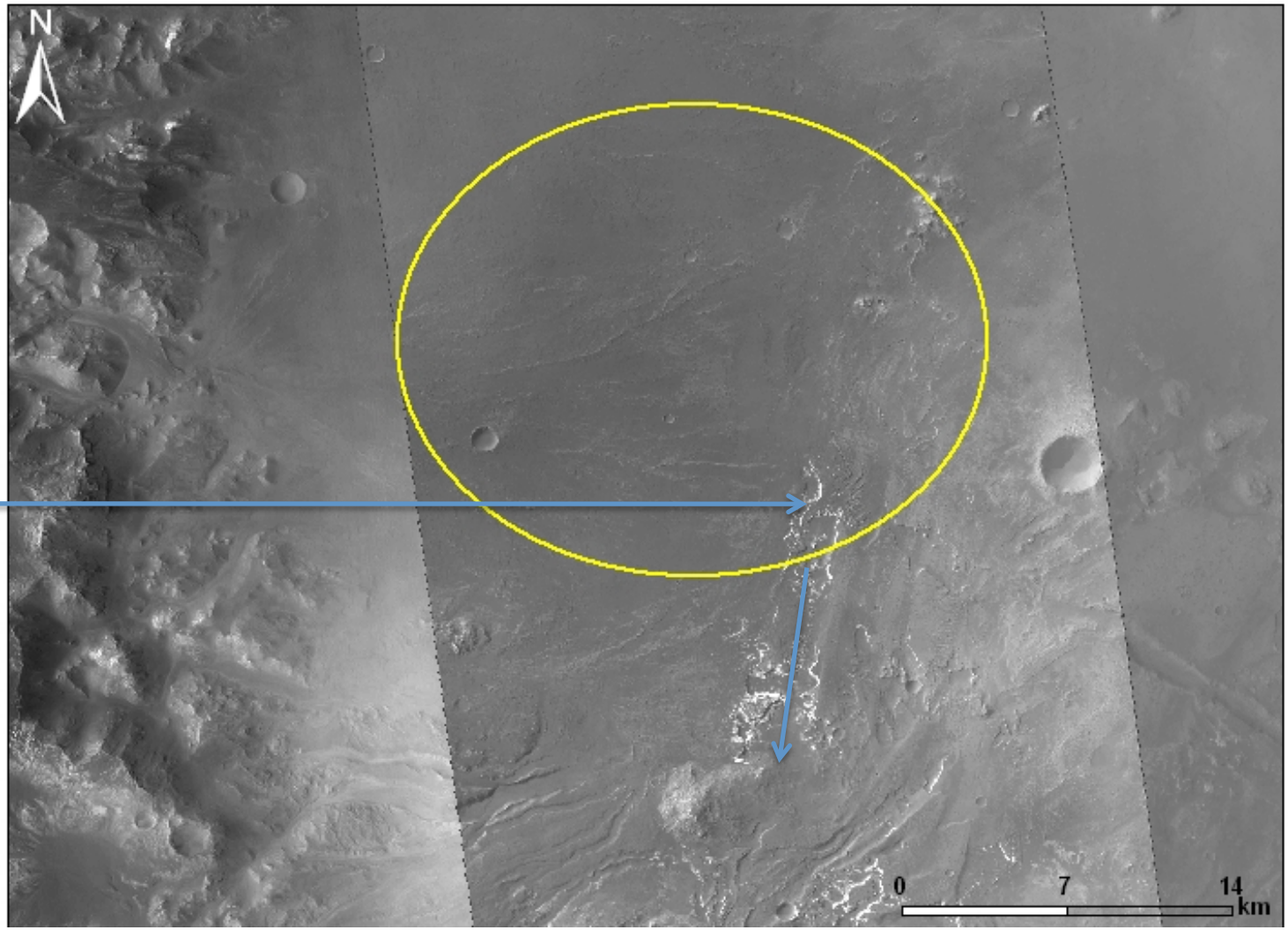
T. Parker

Holden Crater

Ellipse:
Smooth, Flat

Hills to NE
Crater to SW
Go to Target to SE

Go To Here



Golombek et al., MSL Data Products

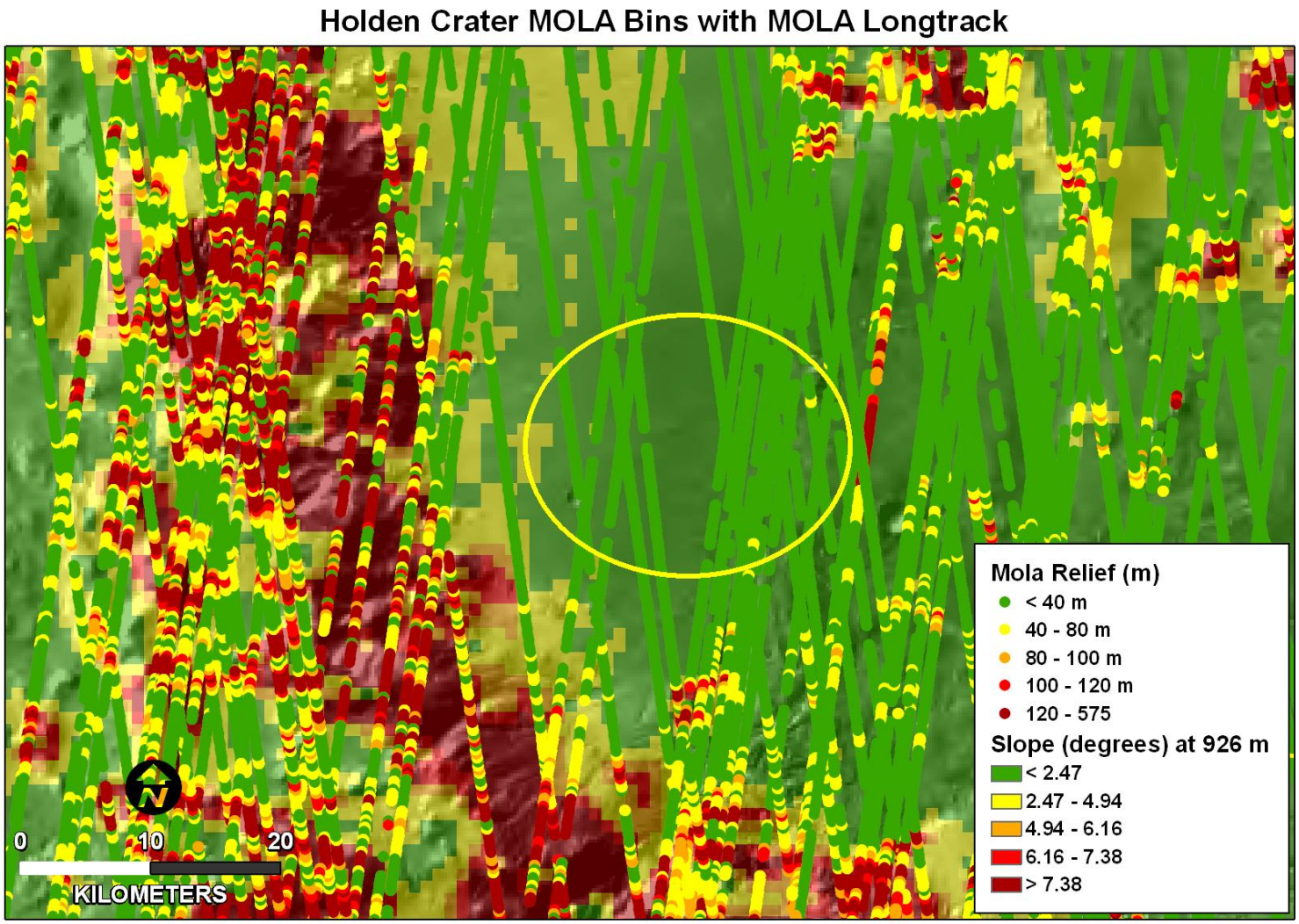
Holden Crater

Siting of Ellipse

1 km Relief Most Restrictive Constraint at this Scale

Used MOLA Along Track Relief at ~900 m

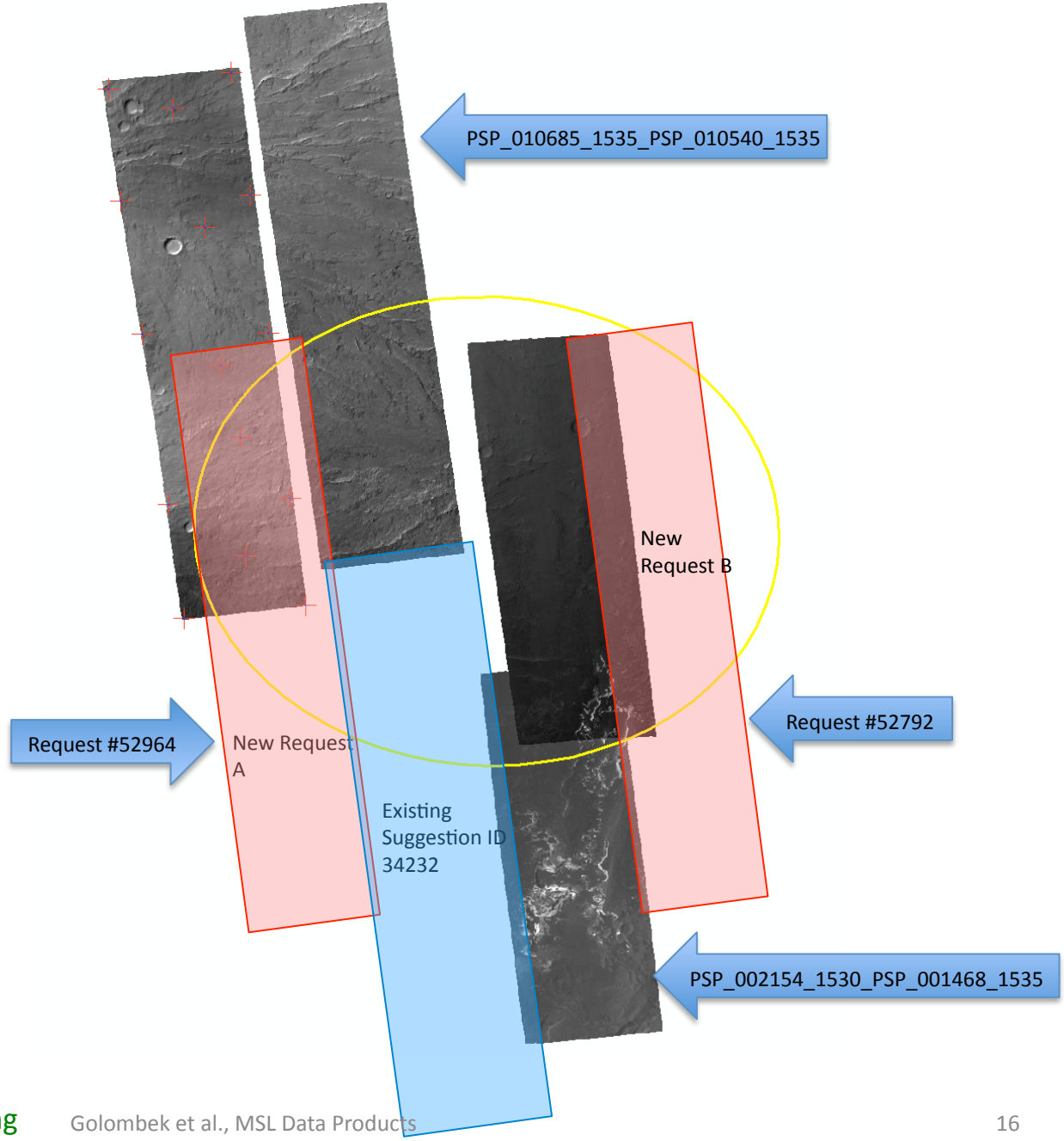
Used binned MOLA data at 463 m/pixel to calculate equivalent relief at 926 m



Golombek et al., MSL Data Products

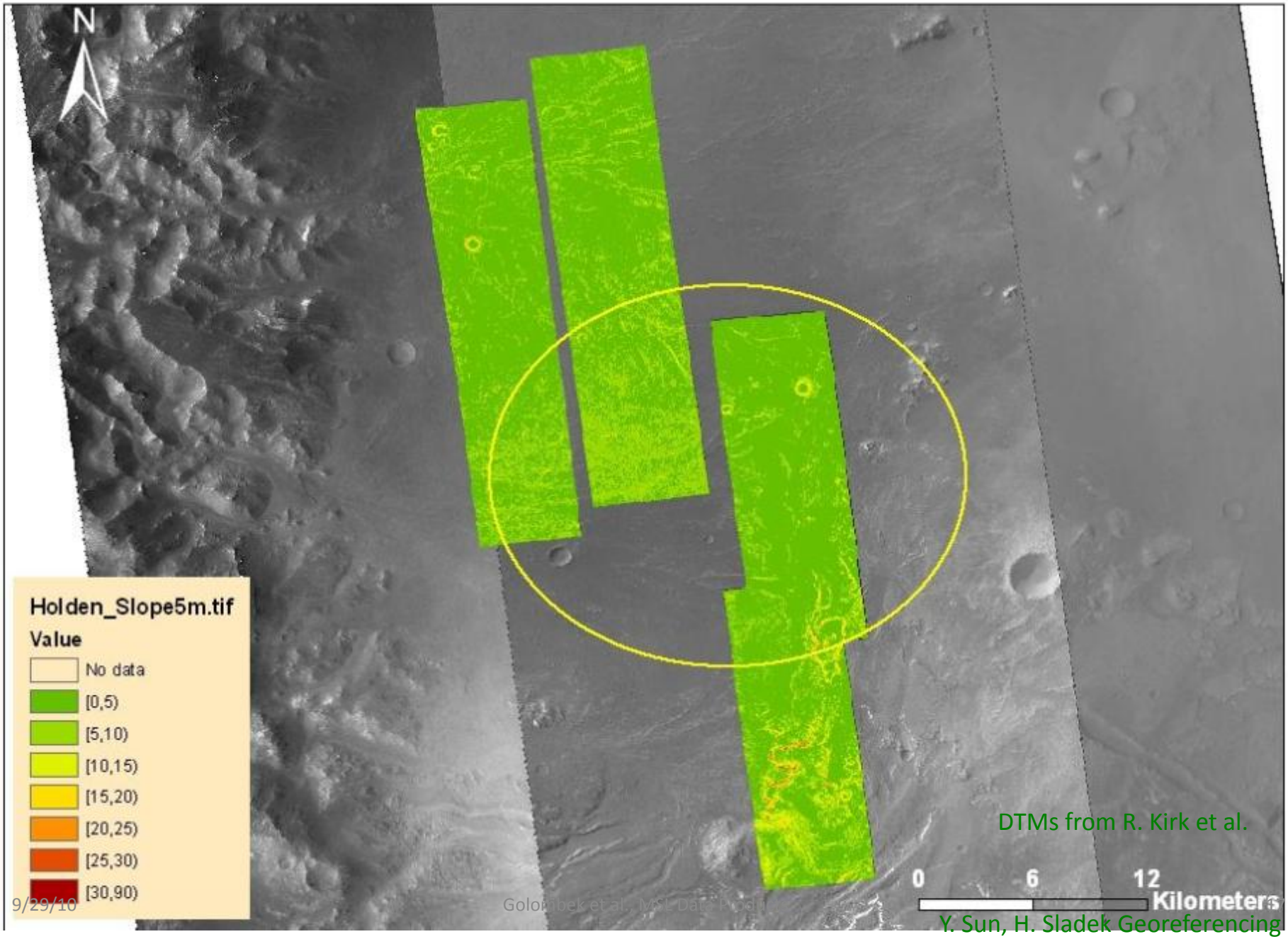
Y. Sun, E. Noe

Holden DTMs



DTMs from R. Kirk et al.

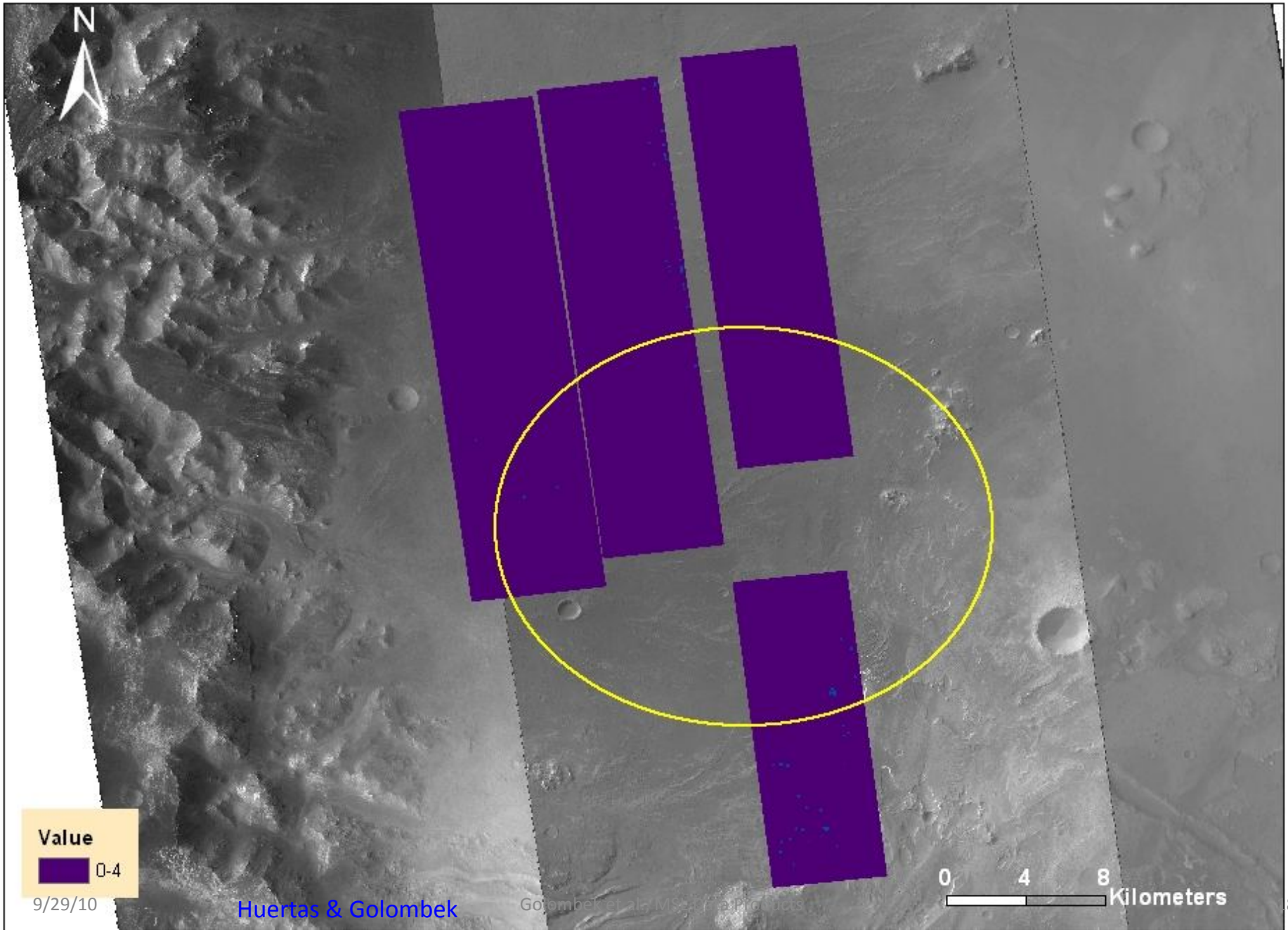
Holden Crater: 5m Slopes



DTMs from R. Kirk et al.

Y. Sun, H. Sladek Georeferencing

Holden Crater Rock Density



Huertas & Golombek

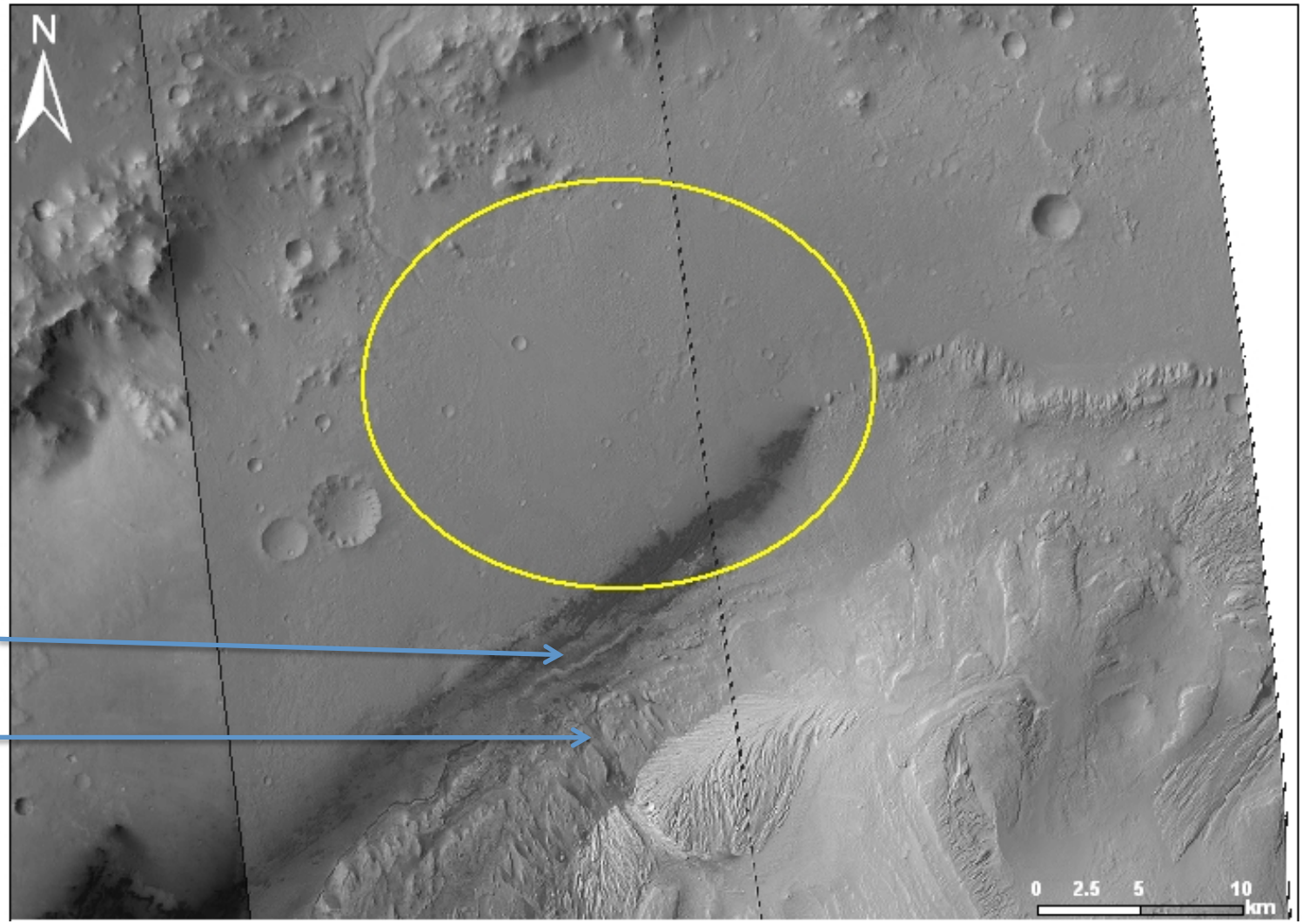
Gale Crater

Land on Cratered Plains

Smooth, Flat, Cratered Plains

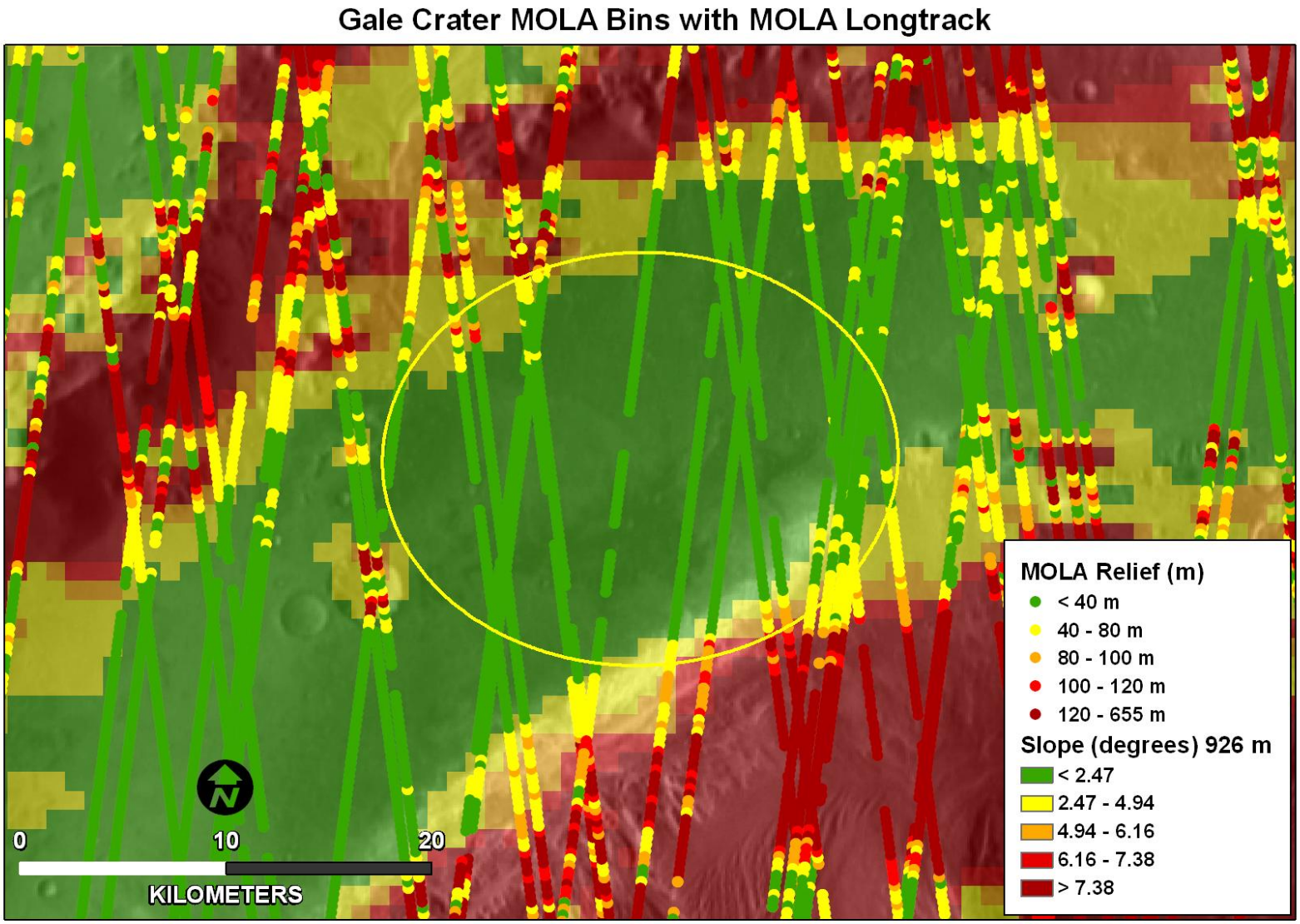
Sample Strata Here

Drive up Canyon Here



Golombek et al., MSL Data Products

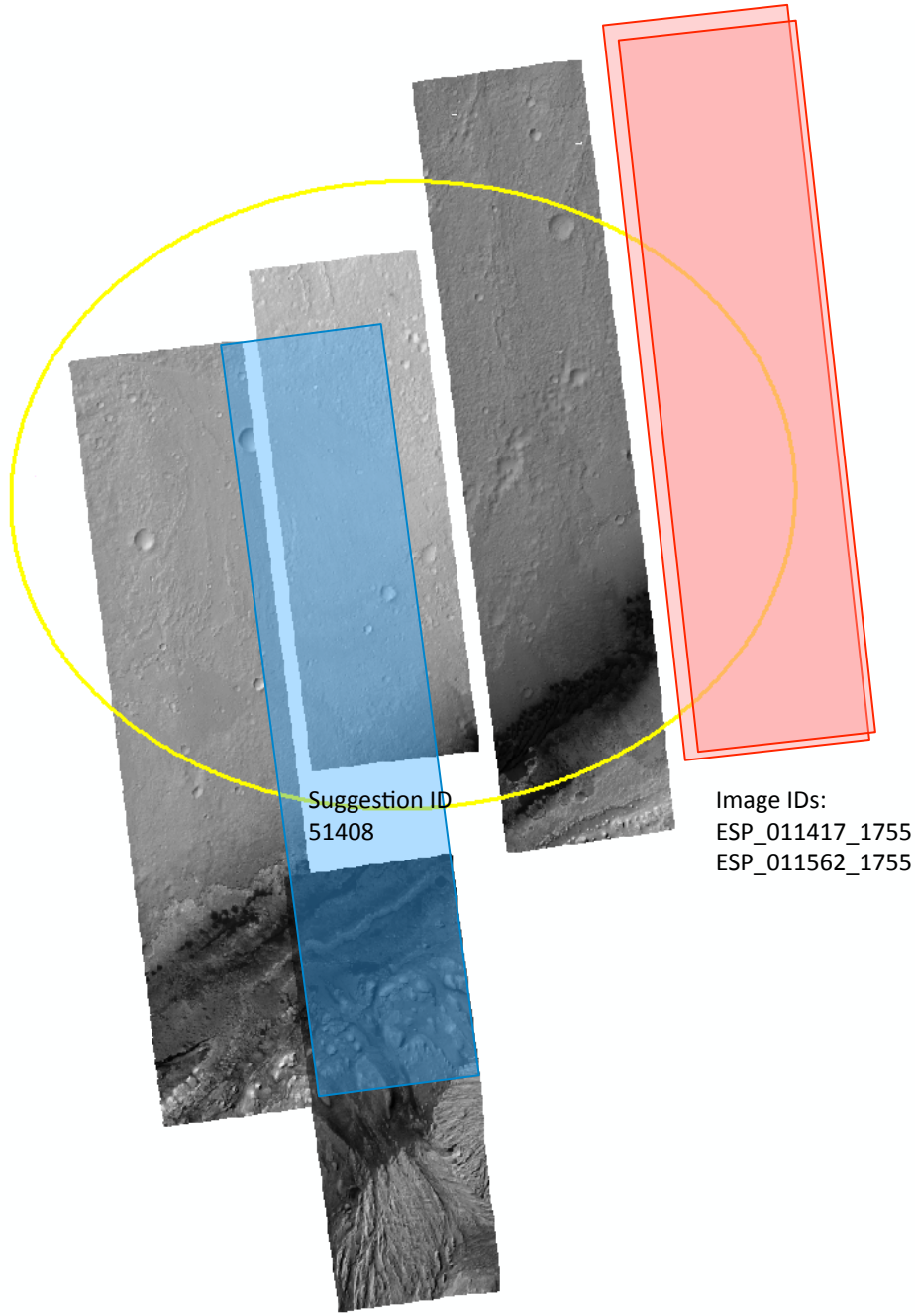
Gale Crater



Golombek et al., MSL Data Products

Y. Sun, E. Noe

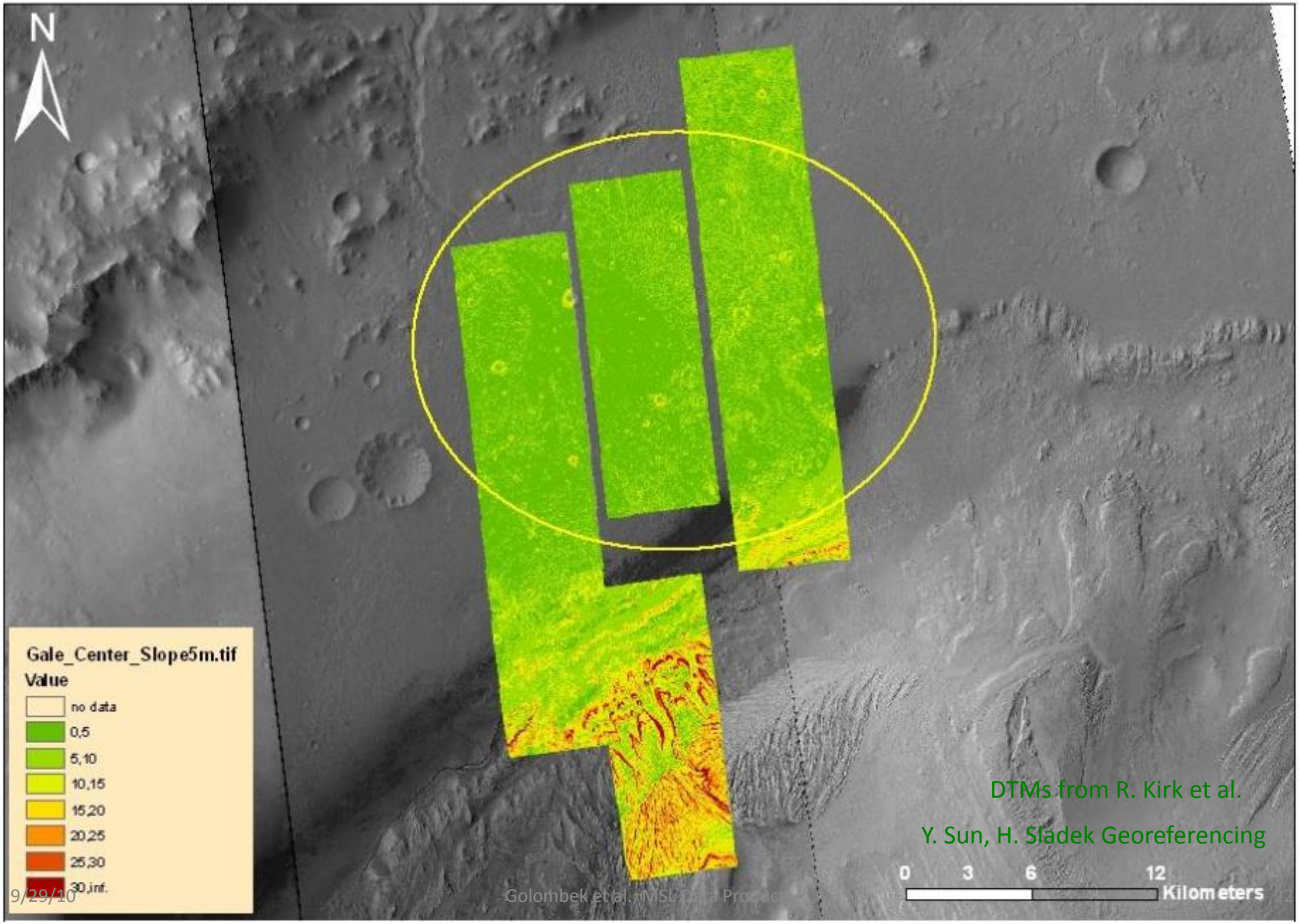
Gale DTMs



DTMs from R. Kirk et al.

Y. Sun, H. Sladek Georeferencing

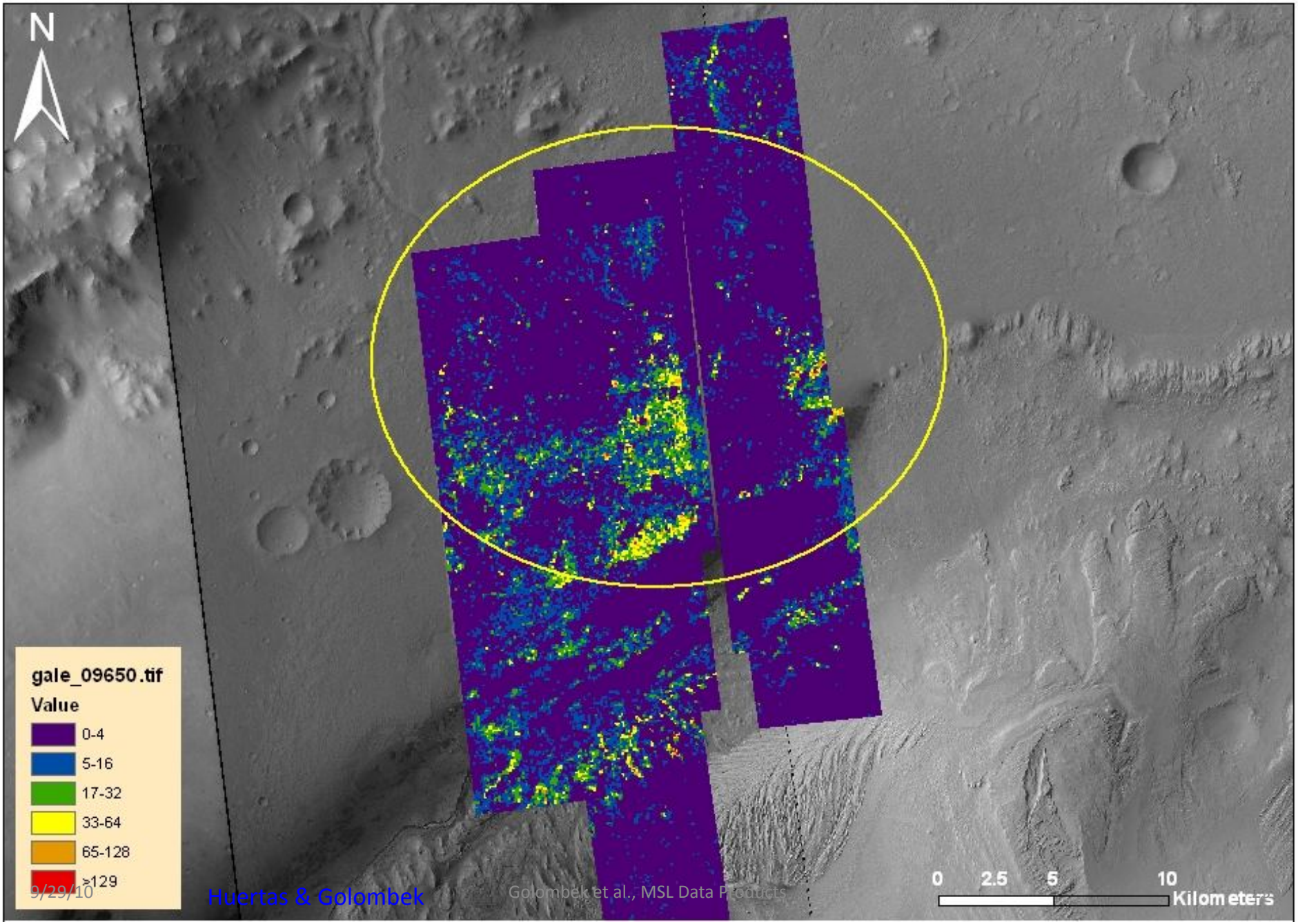
Gale Crater: 5m Slopes



DTMs from R. Kirk et al.

Y. Sun, H. Sladek Georeferencing

Gale Crater Rock Density



Huertas & Golombek

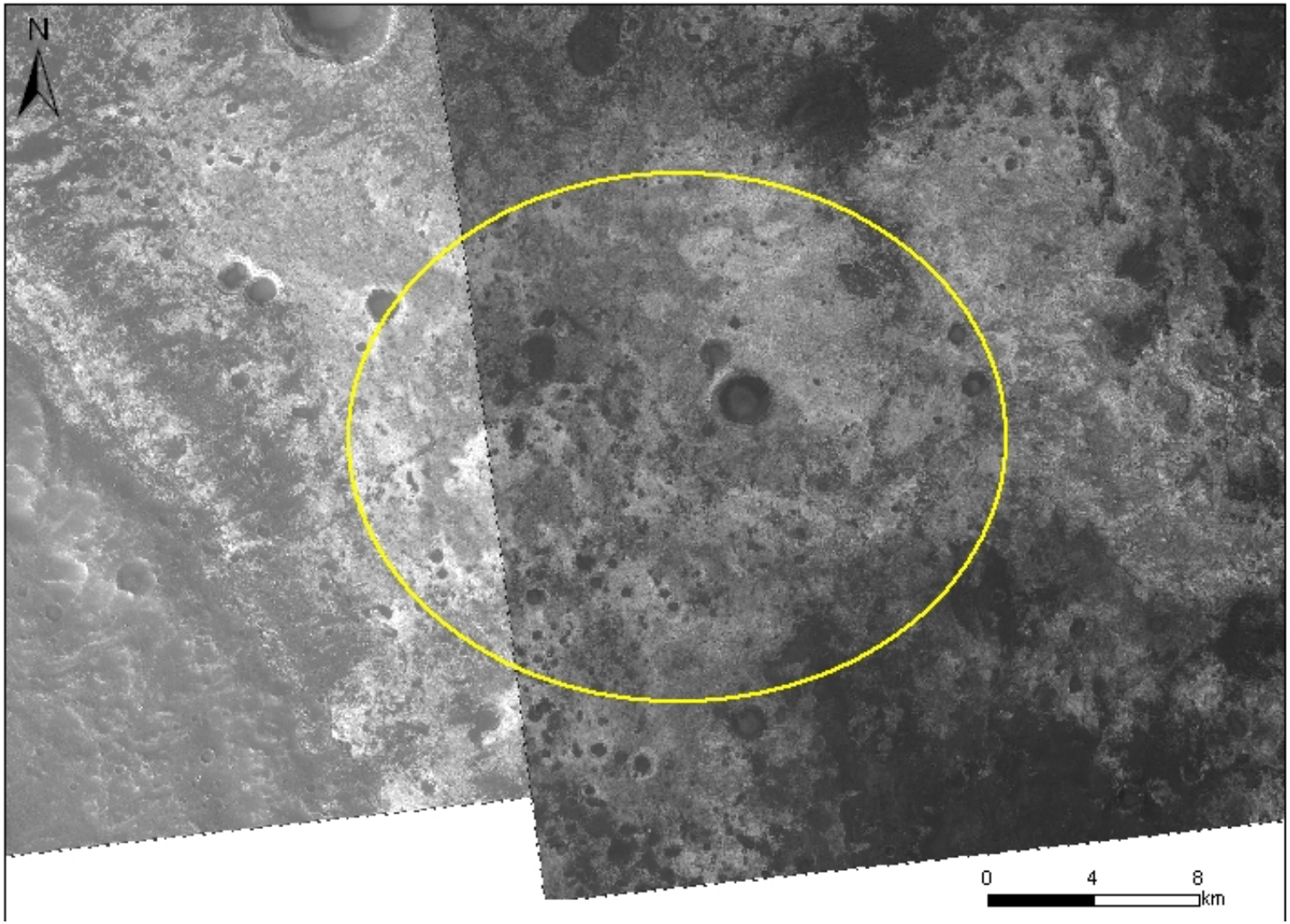
Golombek et al., MSL Data Products

Mawrth Vallis

Land Here
Stay Here
Non Go To

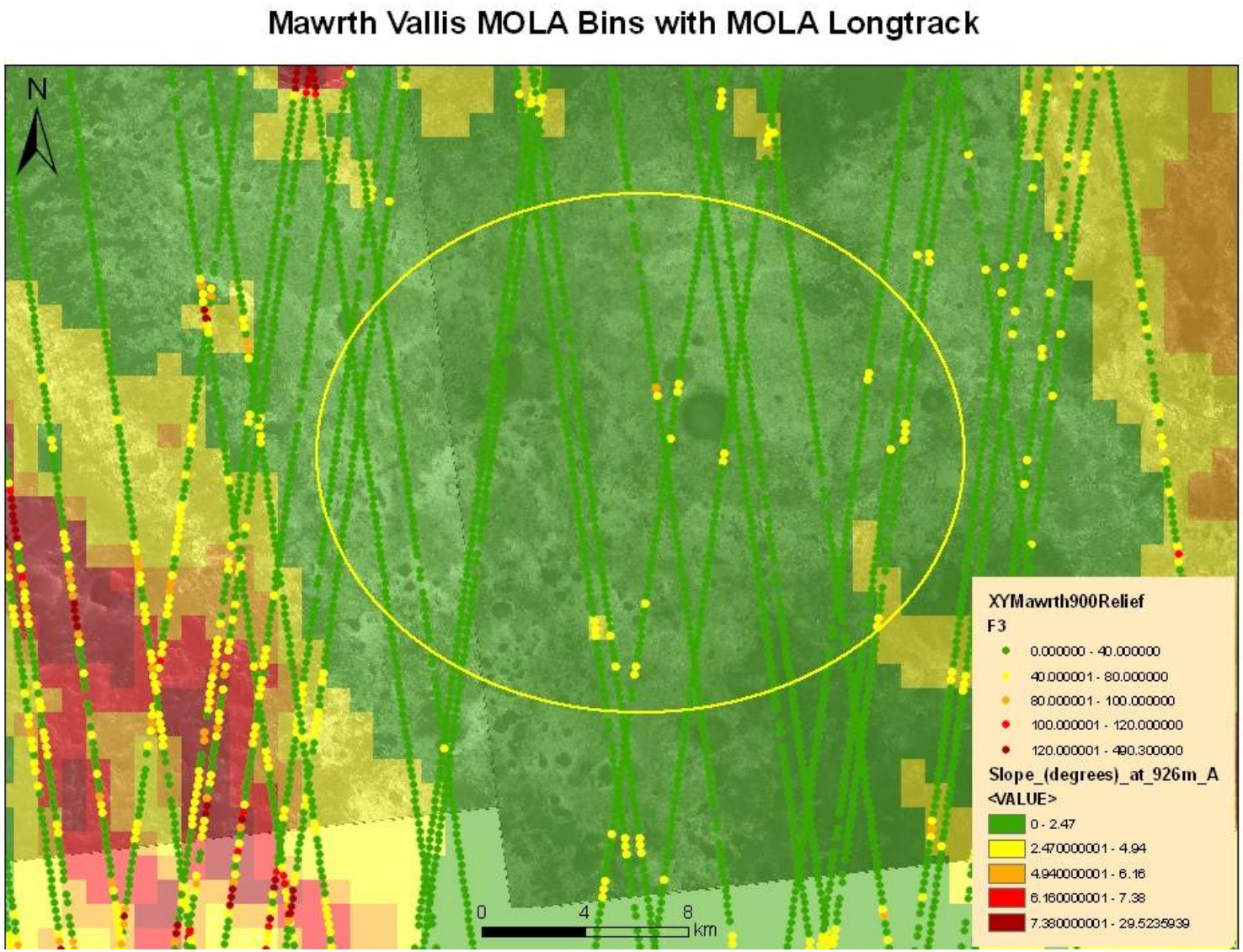
Rugged mesas

Contact between
Fe-Mg & Al
Phyllosilicates
Runs Through
Ellipse



Golombek et al., MSL Data Products

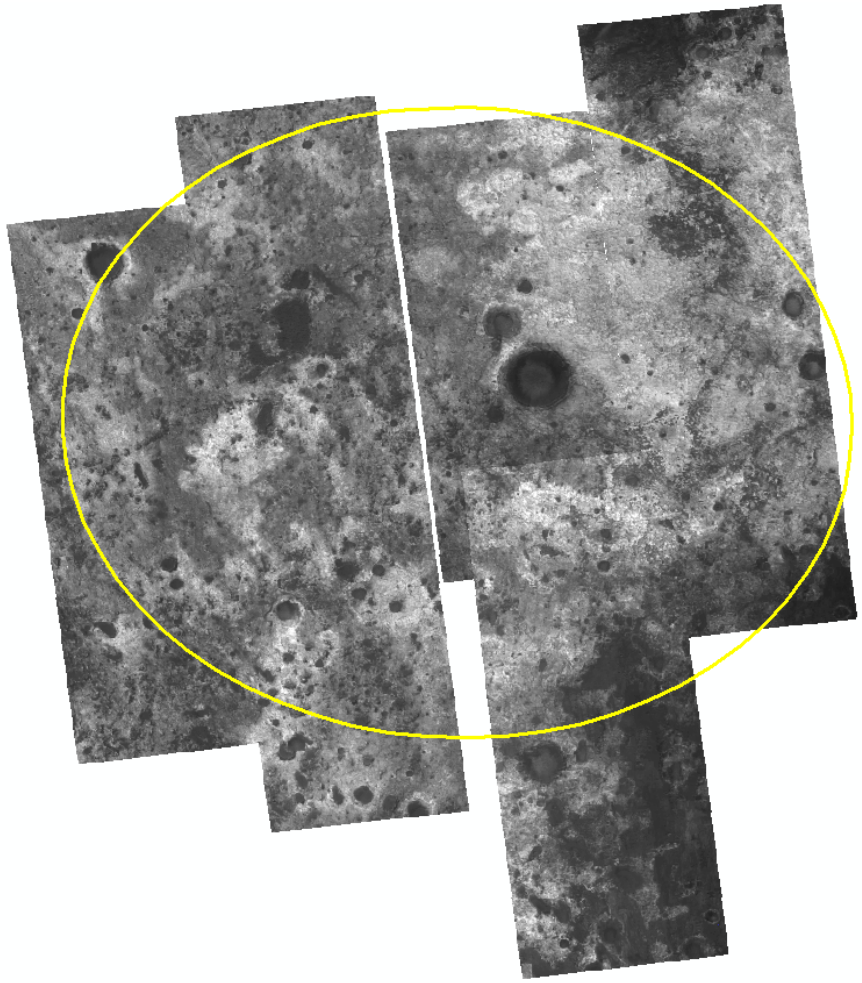
Mawrth Vallis



Golombek et al., MSL Data Products

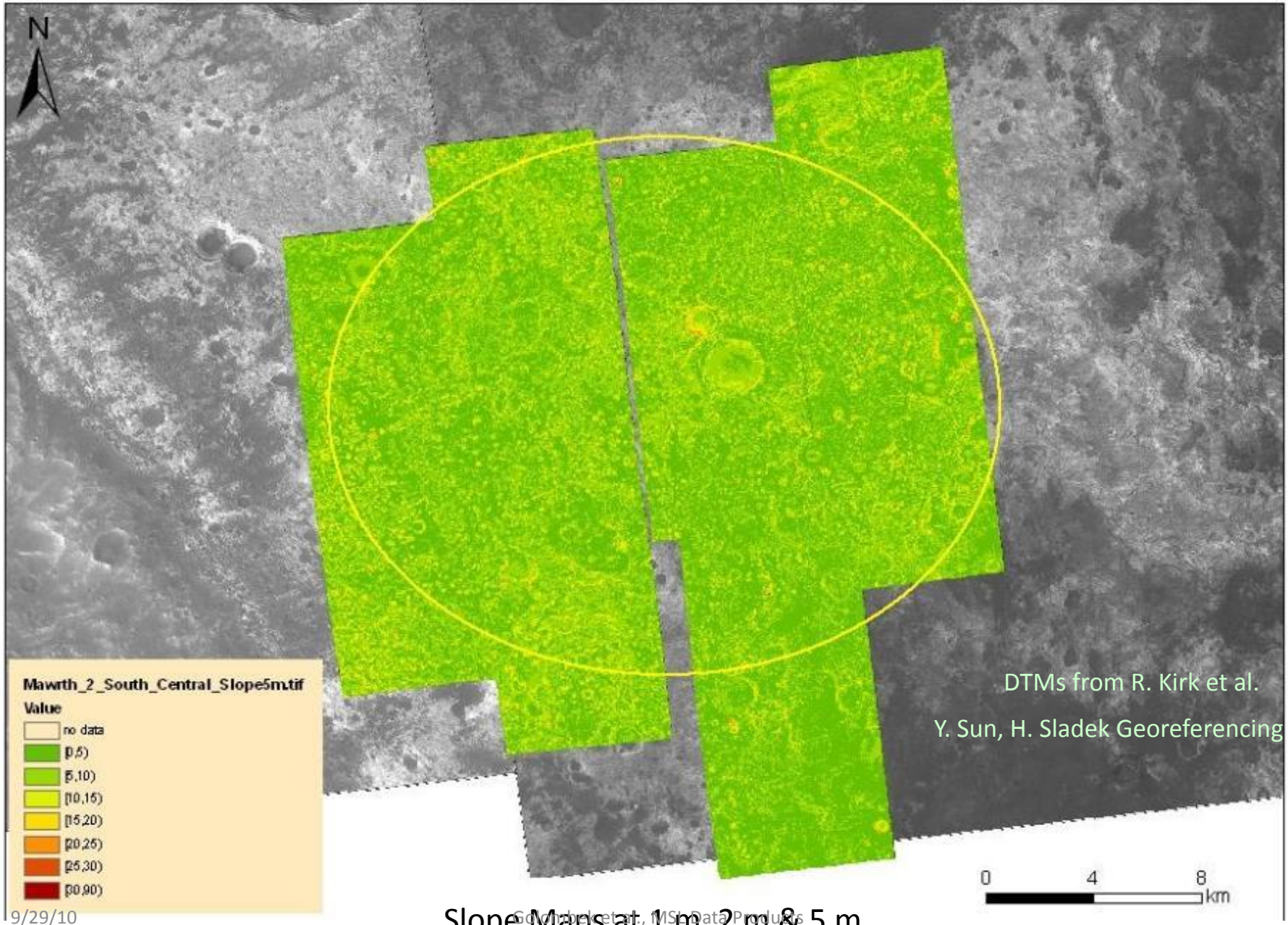
Y. Sun, E. Noe

Mawrth DTMs



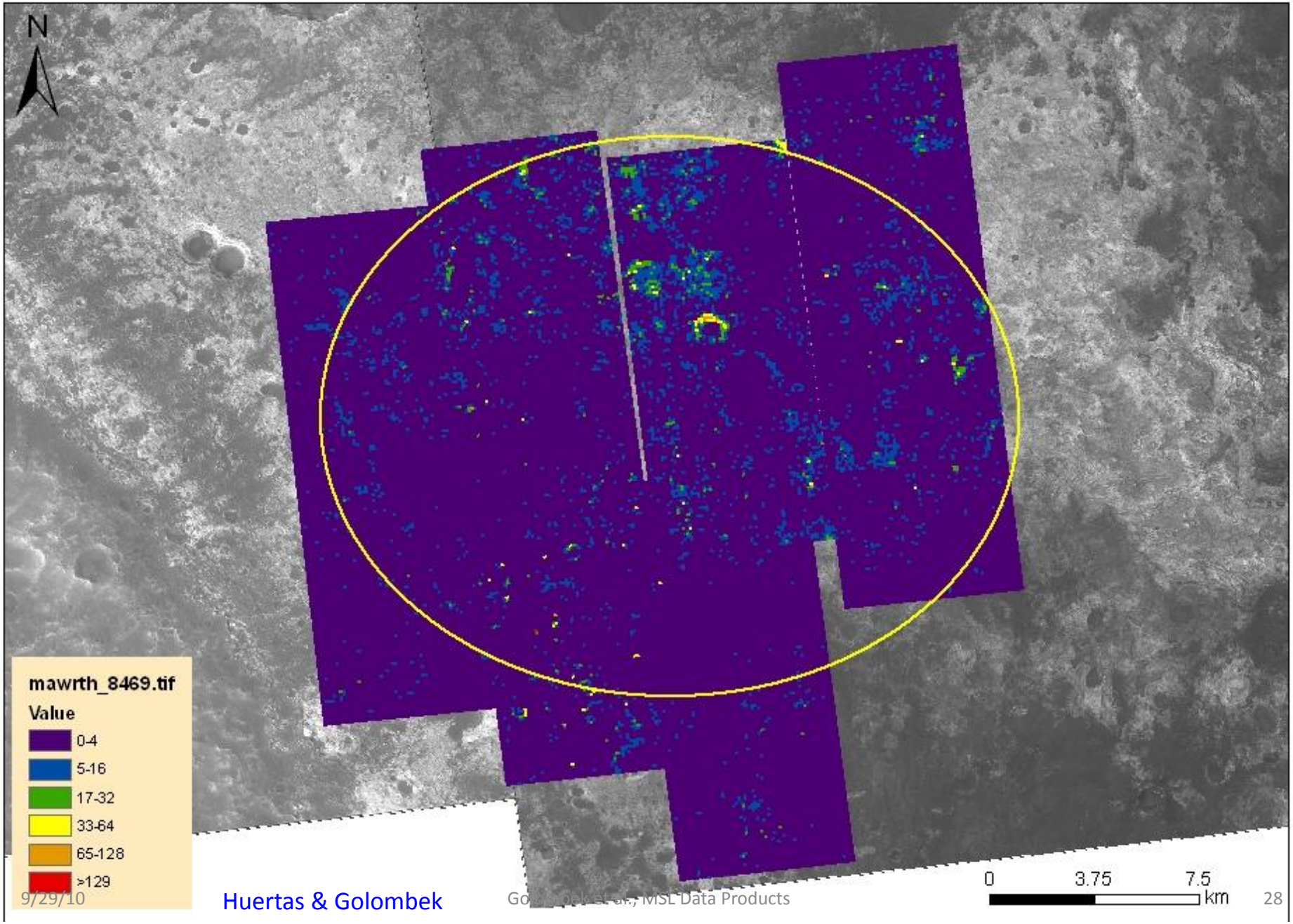
DTMs from R. Kirk et al.

Mawrth Vallis: 5m Slopes



Slope Maps at 1 m, 2 m & 5 m

Mawrth Vallis Rock Density



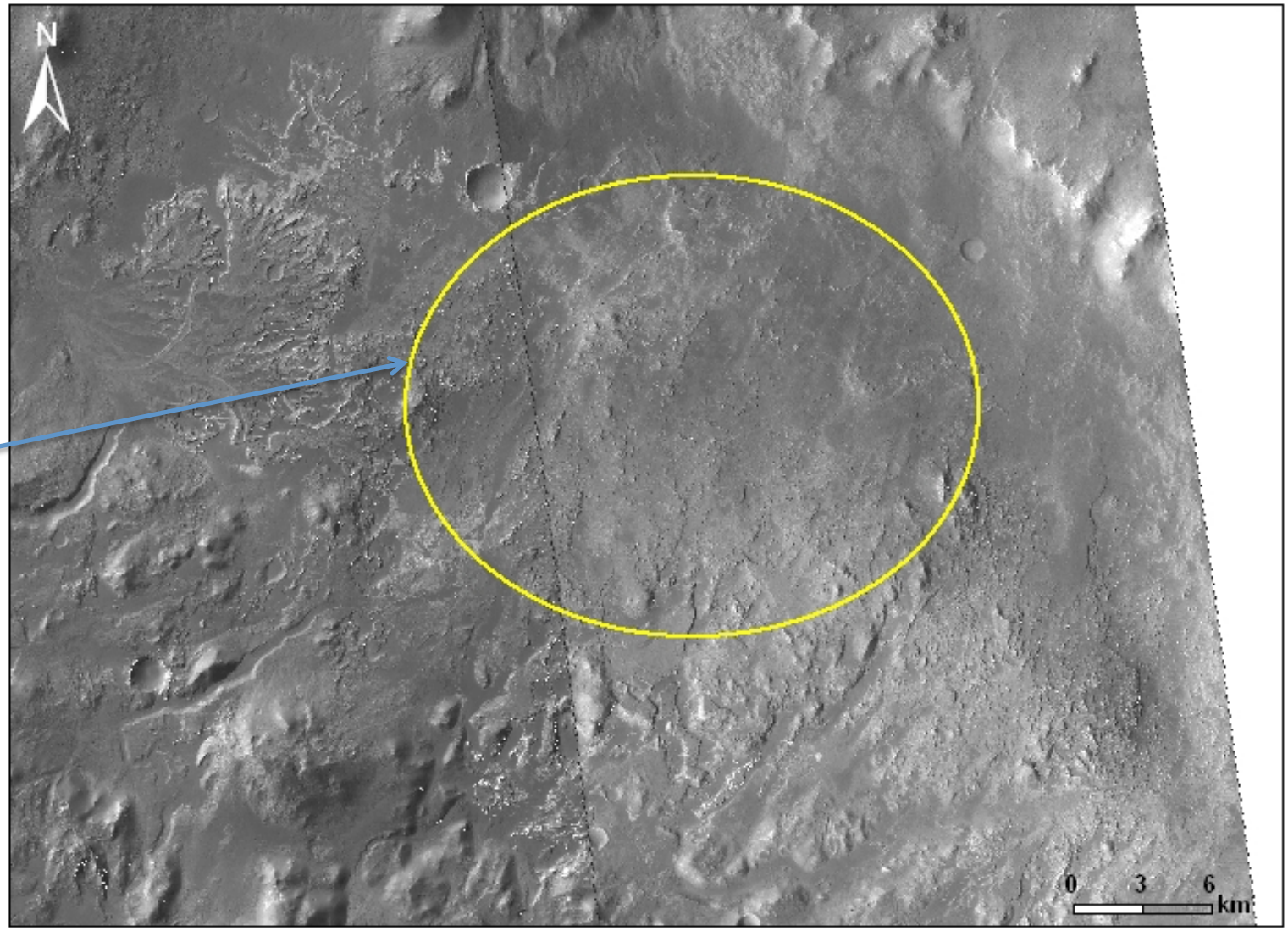
Huertas & Golombek

Eberswalde Crater

Land in Ellipse

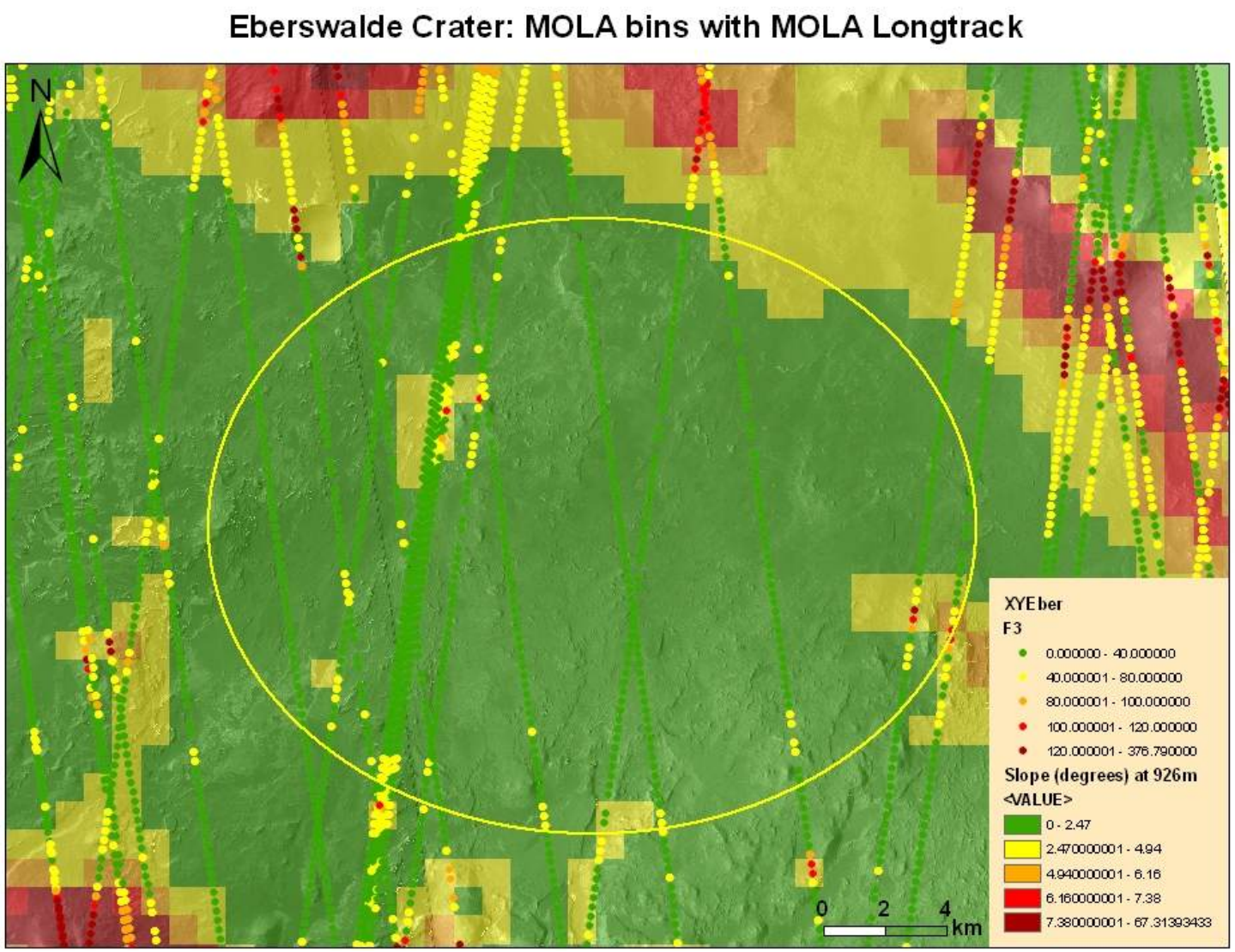
Rough terrain all around

Drive to Delta and Bottomset Beds



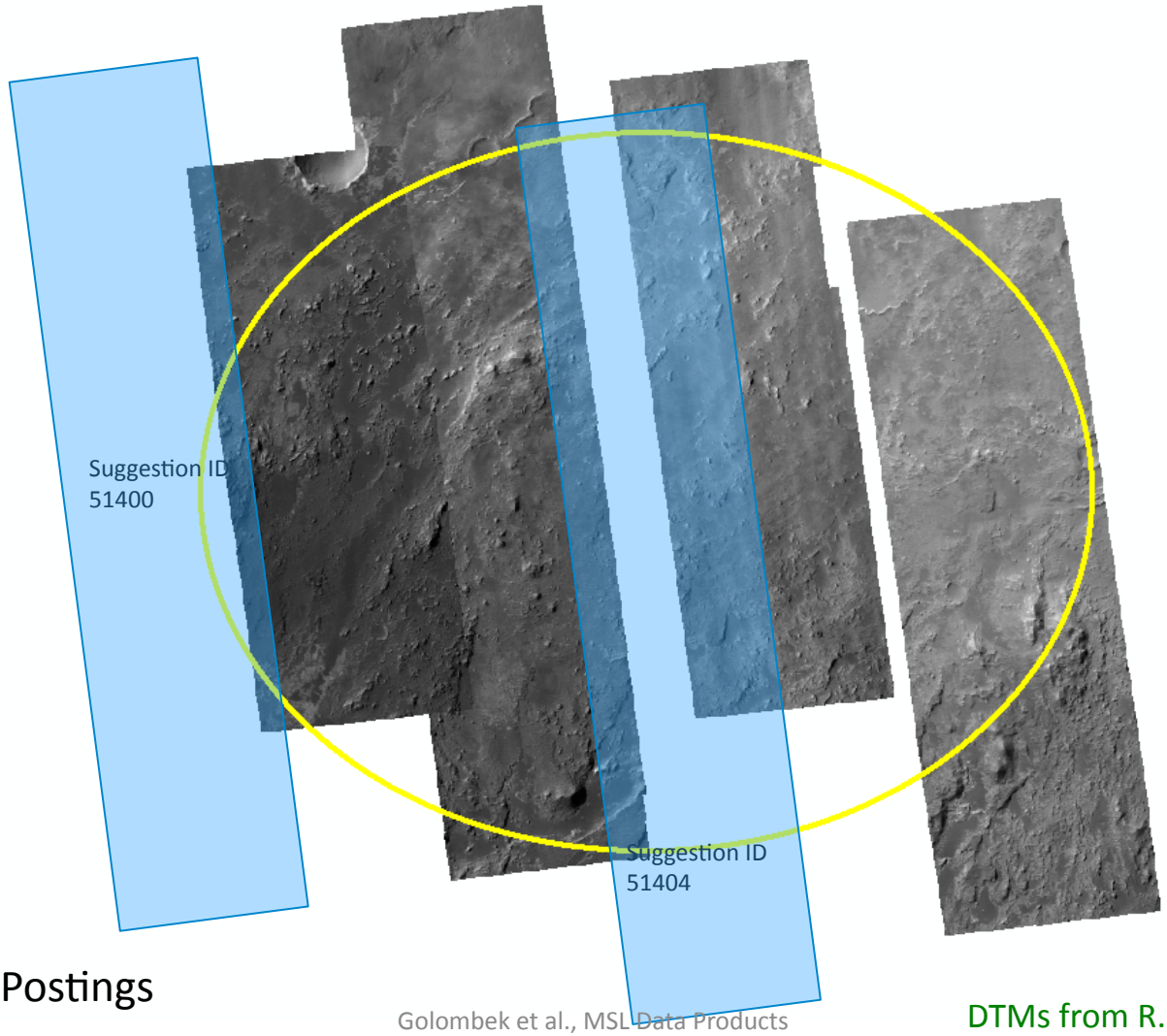
Golombek et al., MSL Data Products

Eberswalde Crater



Y. Sun, E. Noe

Eberswalde DTMs



Ellipses and DTMs Exact

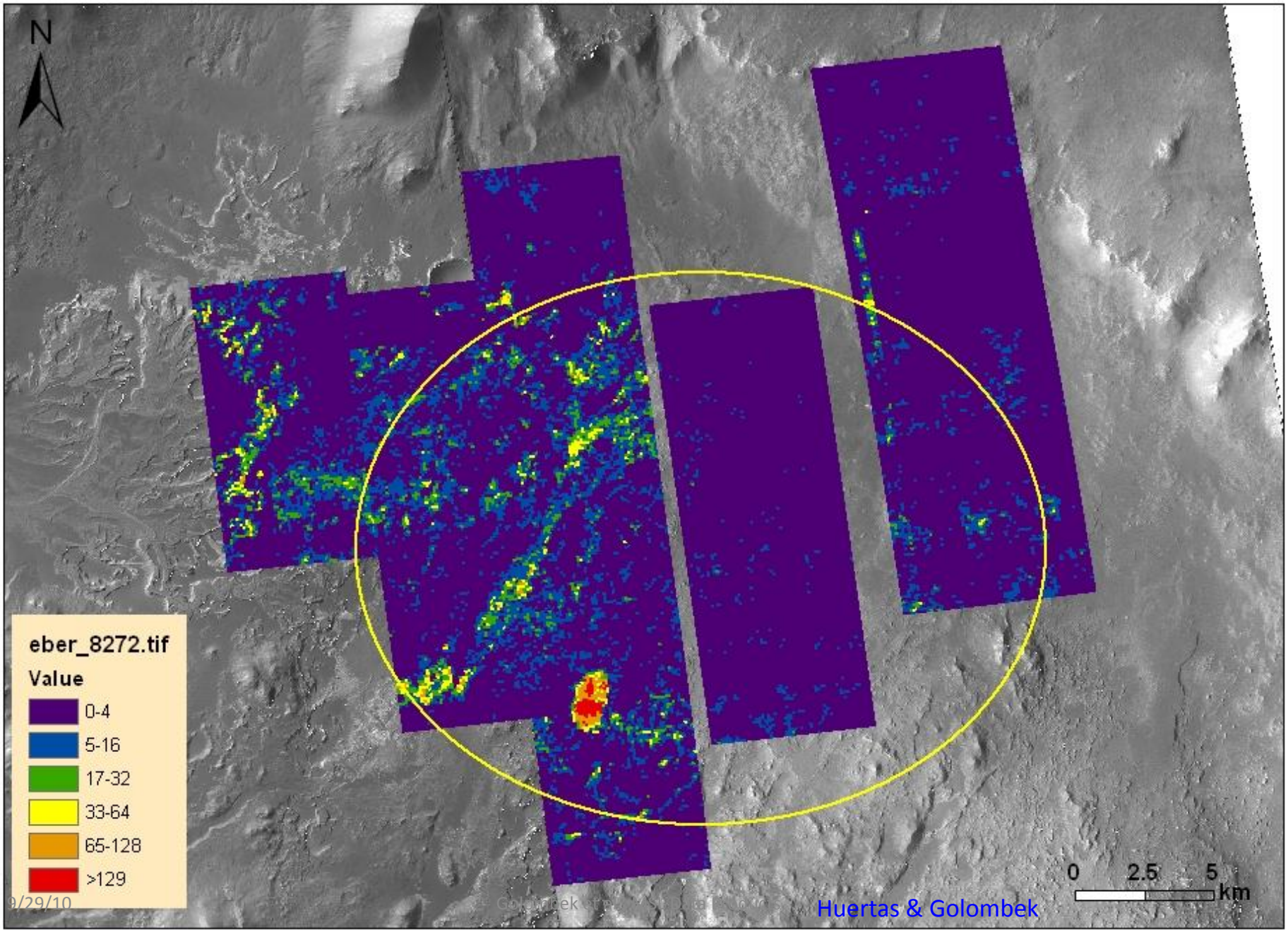
1 m Elevation Postings

DTMs from R. Kirk et al.

Eberswalde Crater: 5m Slopes

DTMs from R. Kirk et al.

Eberswalde Crater Rock Density

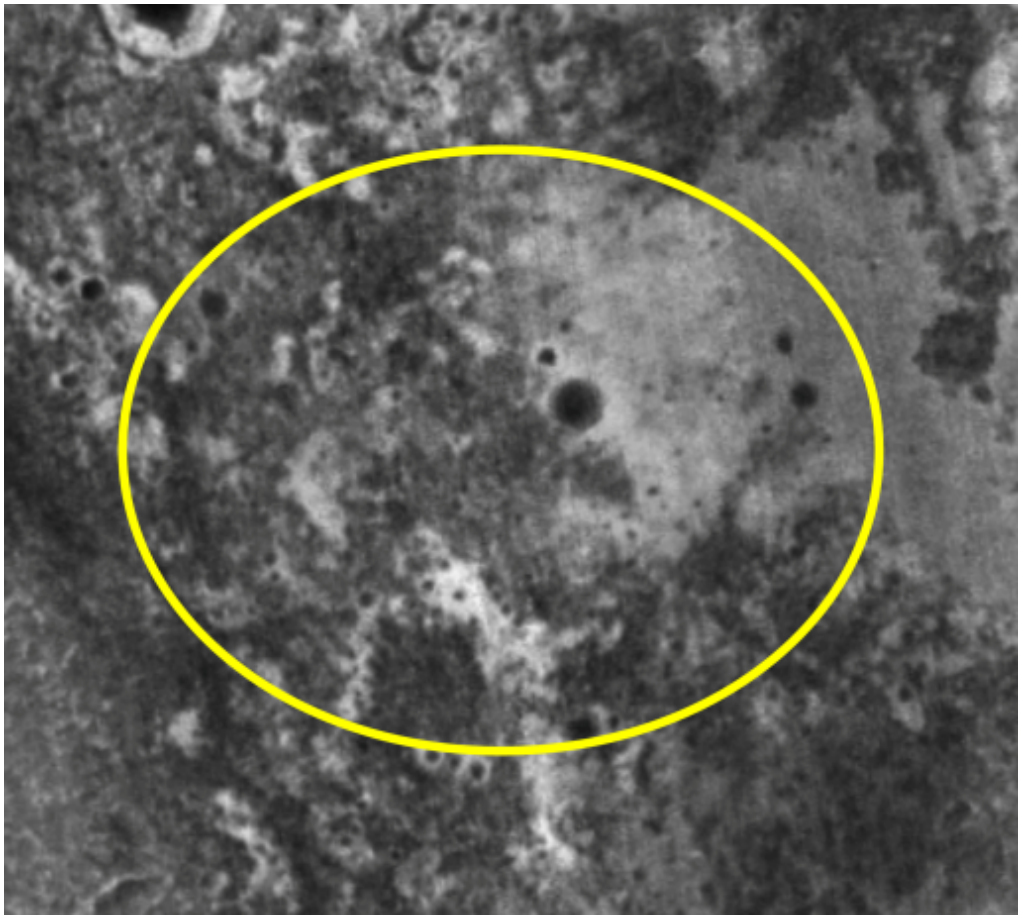


Huertas & Golombek

Thermal Inertia
THEMIS (100 m/pixel)

by
R. Fergason, USGS &
P. Christensen, ASU

Mawrth Vallis



240 495

Thermal Inertia

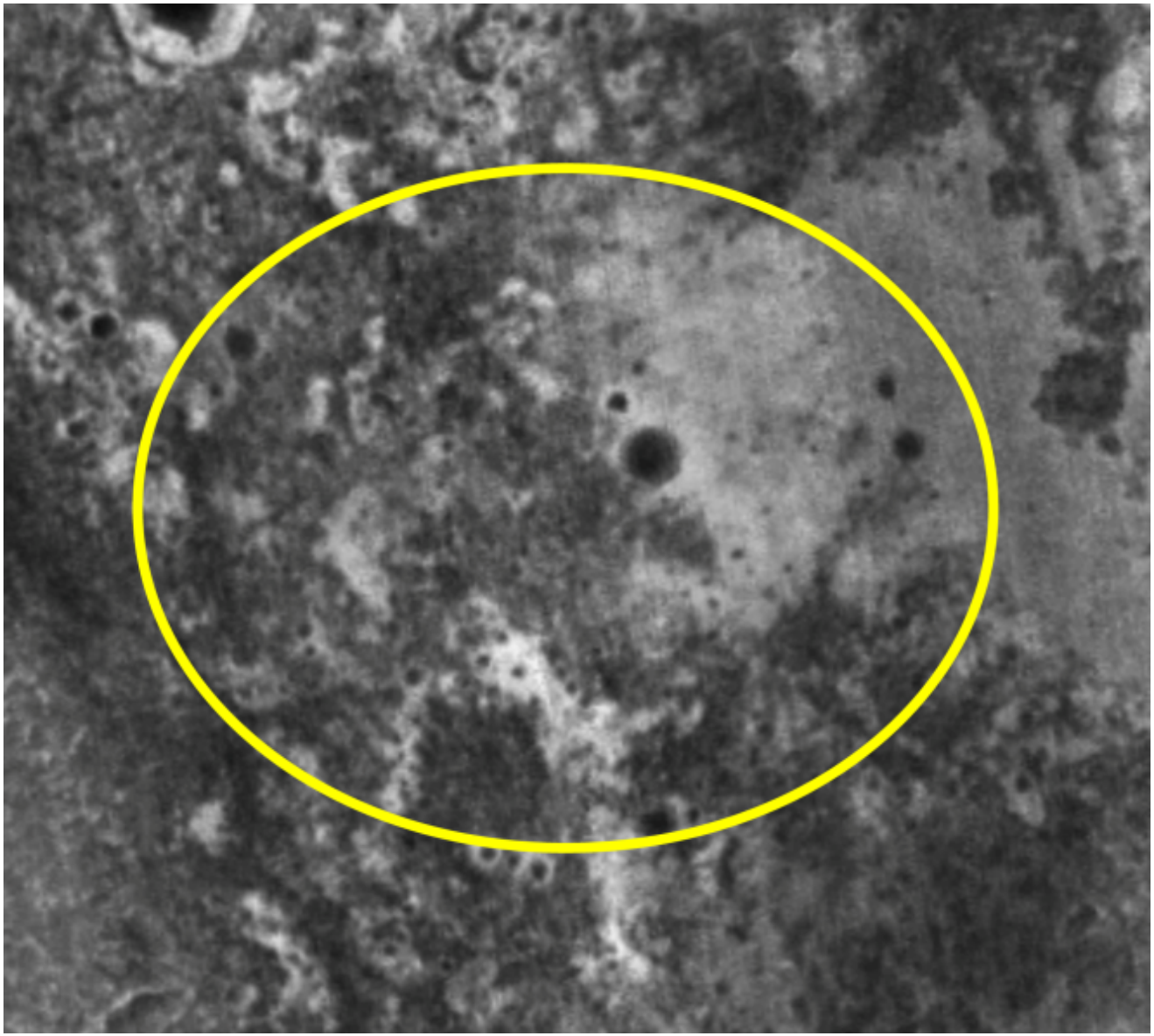
J m^{-2} K^{-1} $s^{-1/2}$

- Surface is likely a mixture of exposed bedrock, indurated material, and crater rims and unconsolidated material

Surface Material Properties

by T. Parker & M. Golombek, JPL;
Thermal Inertia from
R. Fergason, USGS & P. Christensen, ASU

Mawrth Vallis



High Inertia Outcrop

Low Inertia Sediment

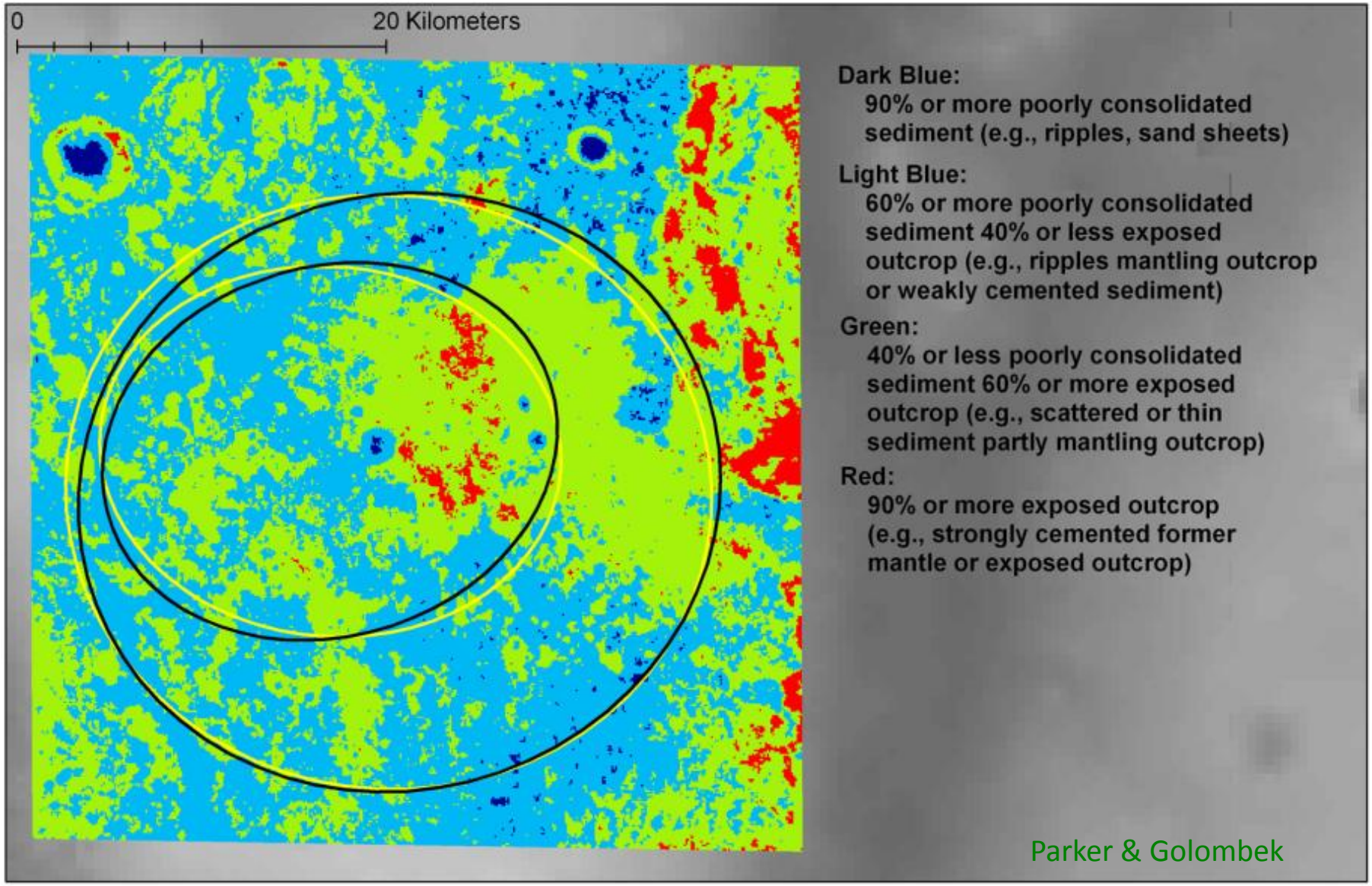
Intermediate-Mixes

Thermal Inertia
J m^{-2} K^{-1} $s^{-1/2}$

240 495

R. 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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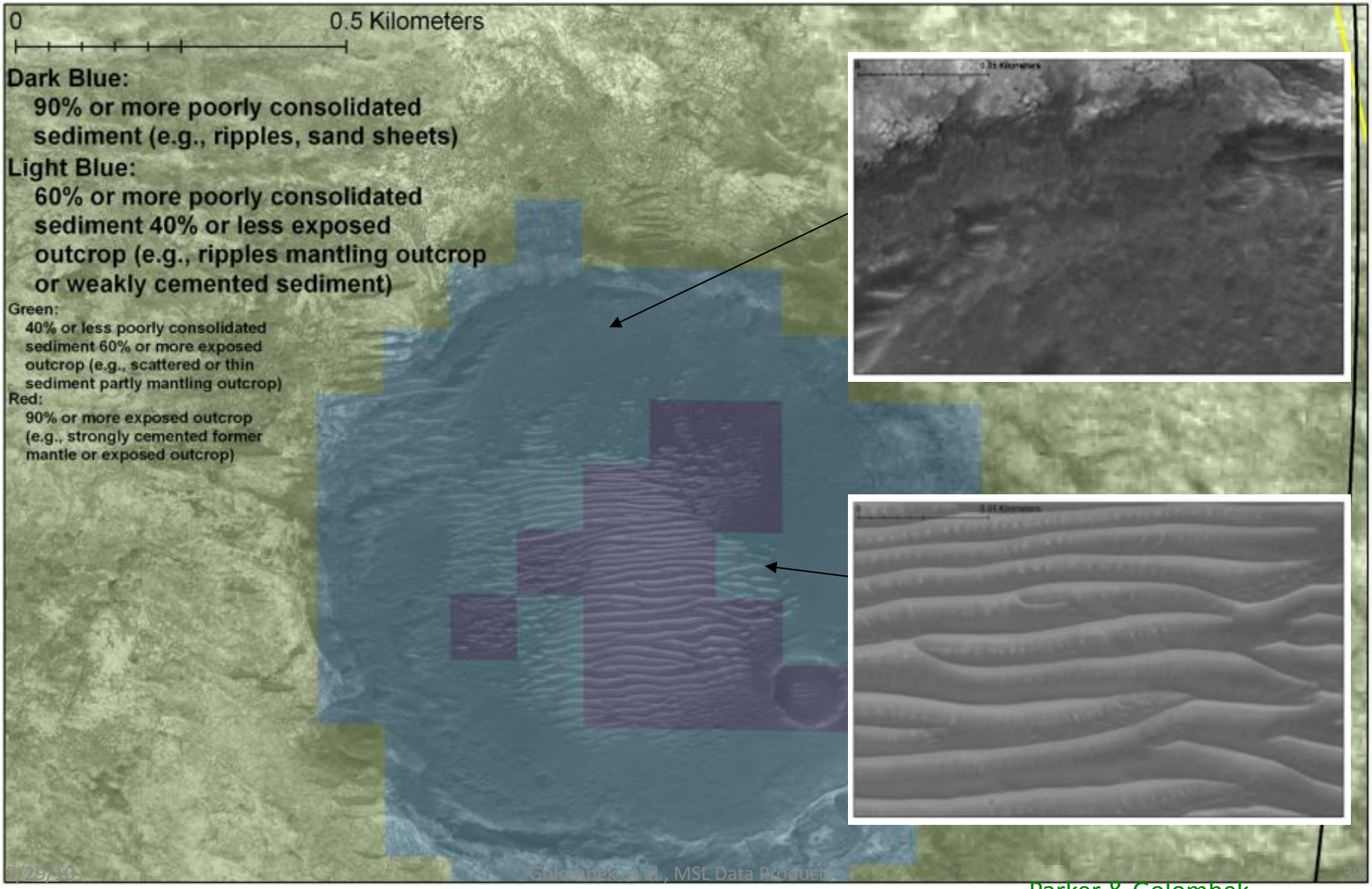

Parker & Golombek

Mawrth Vallis
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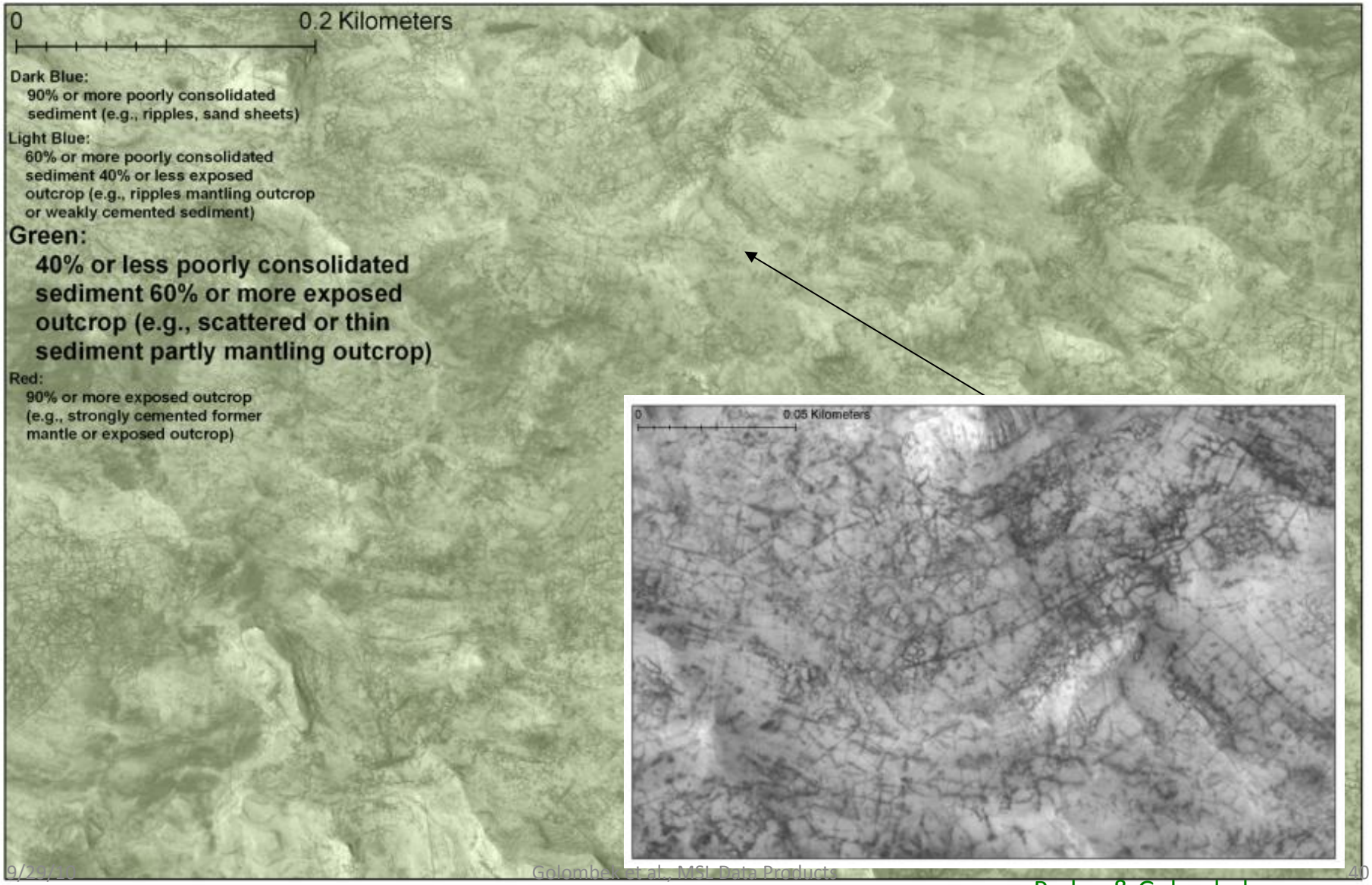

Parker & Golombek

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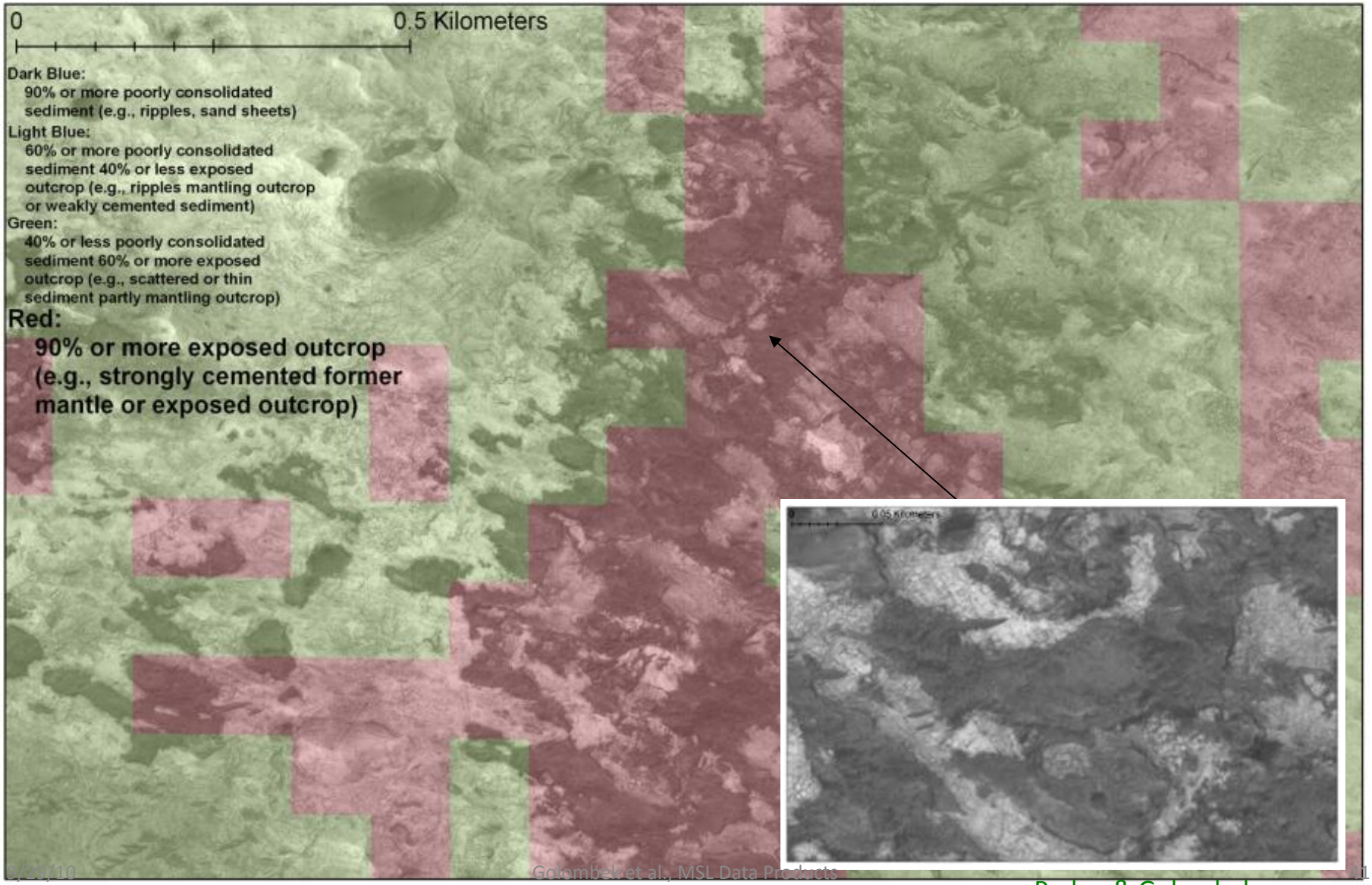
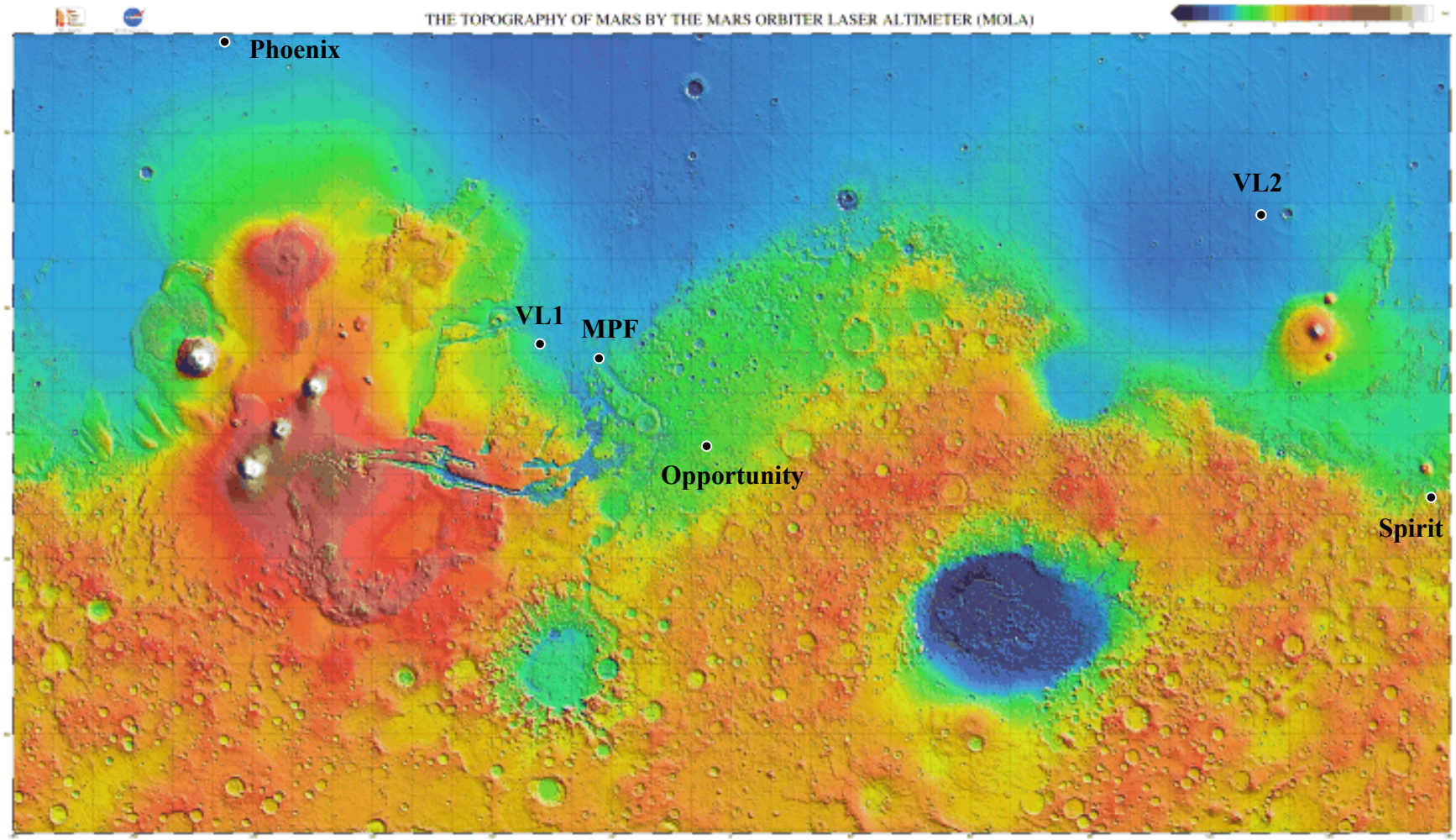


Parker & Golombek

Landing Sites on Mars



21

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.
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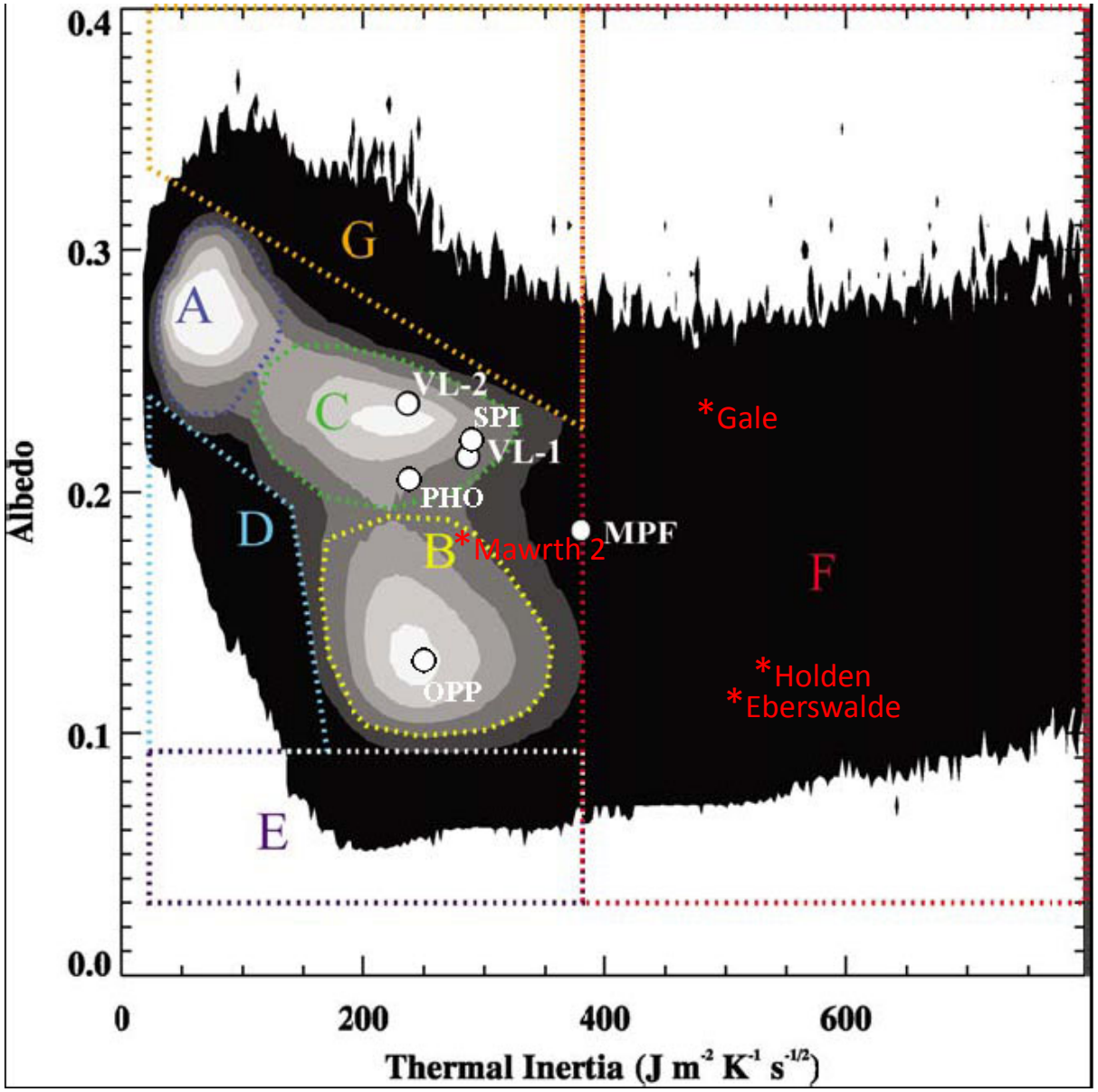
- Chapter from Mars Book [The Martian Surface, J. Bell ed.]
- Direct Relationship between Surface Characteristics at Landing Sites & Remote Sensing from Orbit
- Surface - Cohesion, Particle Size of Fine Component and Rocks, topo maps
- Orbit - Thermal Inertia, Albedo, Dust Index, Rock Abundance, Rocks, Topo maps
- Materials at Landing Sites can be used as Ground Truth for Materials that Make Up Mars
- Remote Sensing Data can be used to infer surface materials and characteristics at other locations
- Successful Predictions MPF, MER, PHX

Mars Thermal Inertia versus Albedo



A – Dust: v. low Thermal Inertia, v. high albedo

B - Dust Free: v. Low albedo

C – Duricrust: Moderate Thermal Inertia, Int. albedo

80% of Mars

VL1, 2, MPF, Spirit, PHX in Unit C; MPF similar but higher thermal inertia

Opportunity in Unit B

MSL Landing Sites - Moderate-High Thermal Inertia; 3 Low Albedo - Relatively Dust Free; Competent Load Bearing Surface-Sand to Outcrop CRISM Spectra Also Indicate Dust Free; Incl. Gale Targets

Putzig et al.

Opportunity – Meridiani Planum

Dark Surface, Albedo ~0.1, unit B
Dust Free
Rock Free
Sand and Granule Surface
Thermal inertia expected from these particles

Smooth, flat plain at all length scales: 1 km, 100 m, 5 m

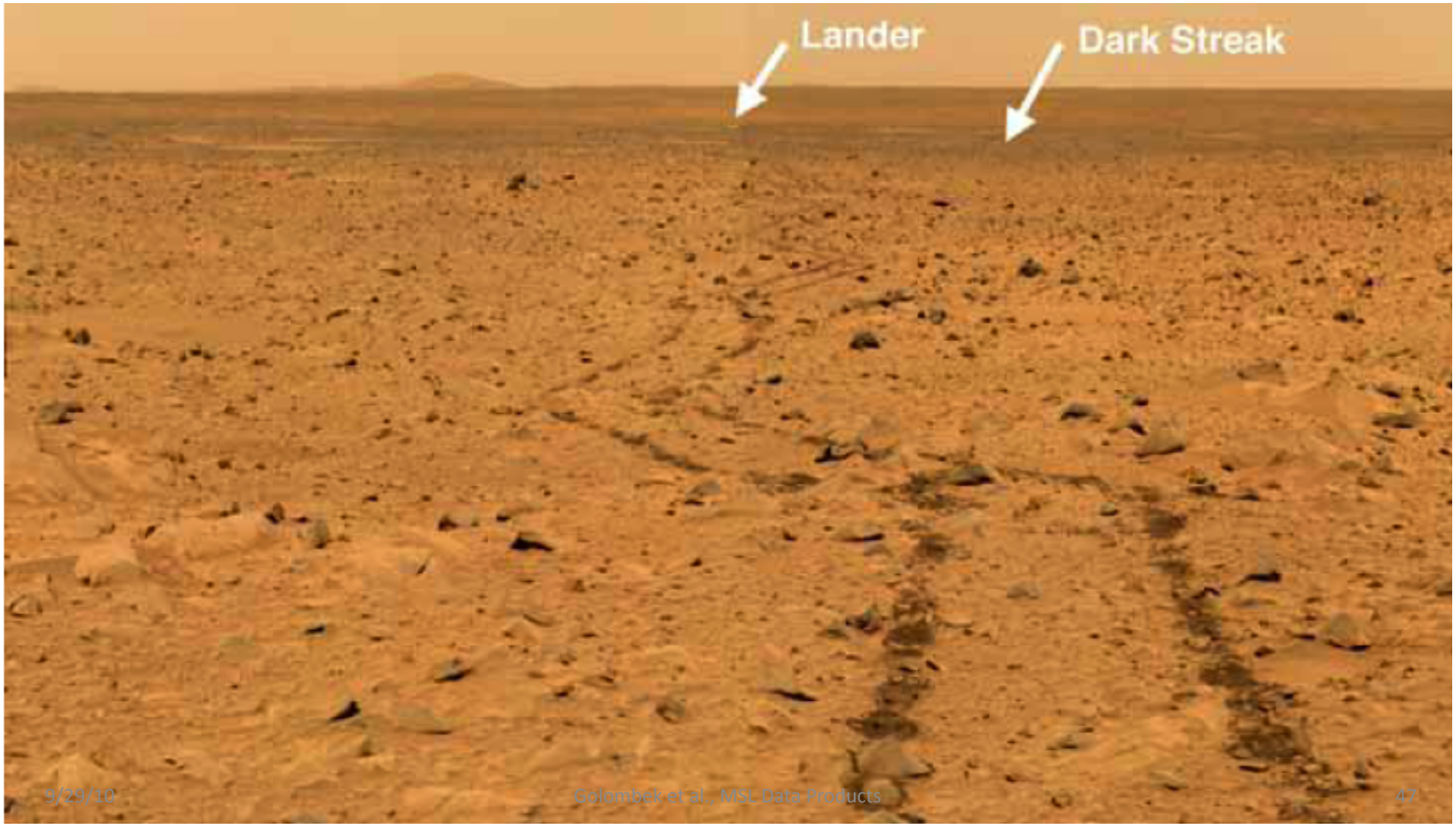
Backshell
450 m Away; 1 m High

Spirit Landing Site - Gusev Crater

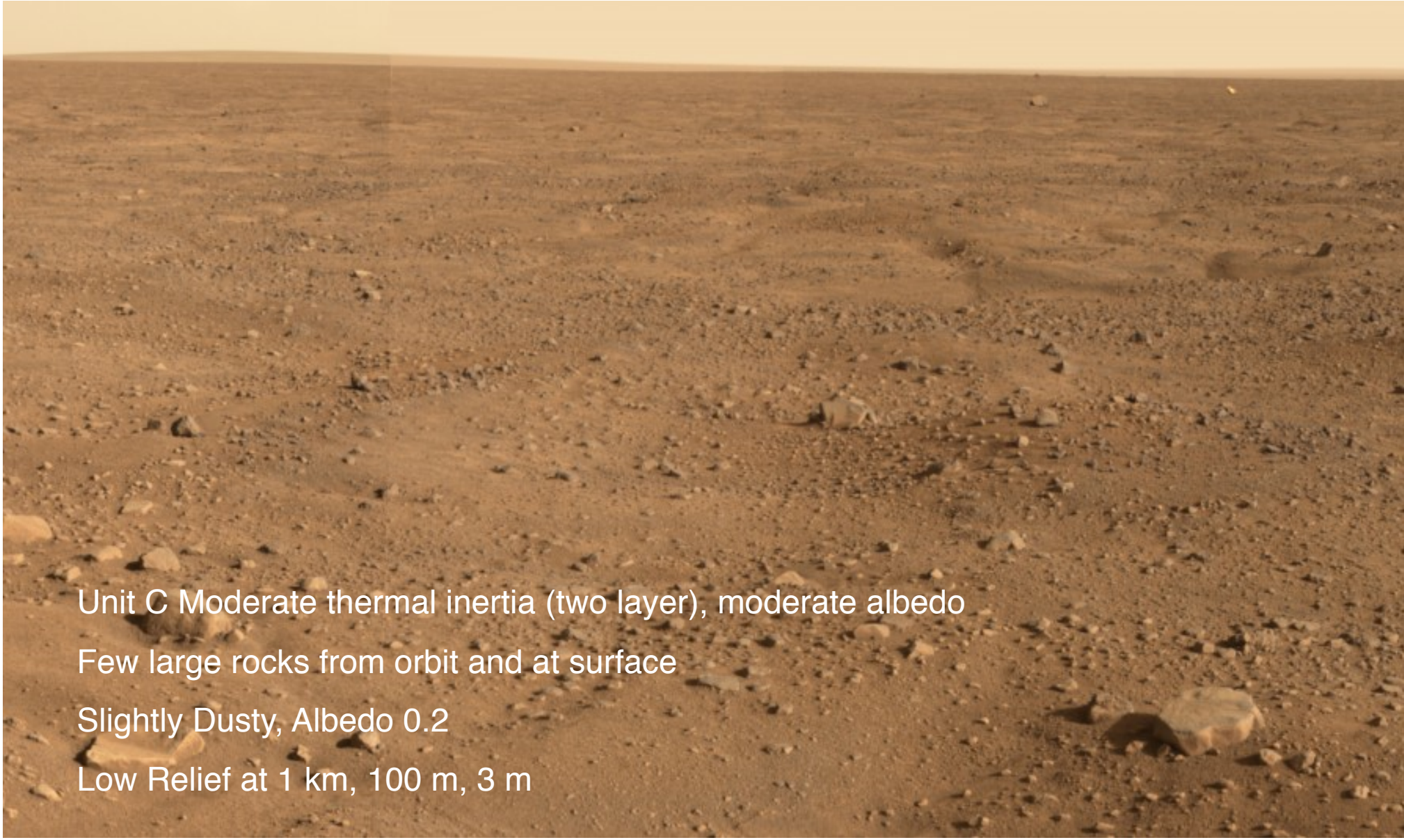
Unit C Moderate Thermal Inertia, Moderate Albedo
Relatively low rock abundance; pebble rich – higher thermal inertia
Relatively Dust Free Portion; Albedo 0.195 in dust devil track
Very Low Relief at 1 km, 100 m, Moderate relief at 10 m

Spirit- Gusev Dust Devil Tracks

Albedo Difference between Bright (0.26) and Dark Areas (0.19)
Pancam Albedo Matches Orbital Albedo



Phoenix –Northern Plains



Mars Pathfinder Landing Site

Similar to unit C but with higher thermal inertia – more extensive duricrust

Slightly Dusty, Albedo 0.19

Rocky at surface (~20%) and estimated from orbit

Relatively High Relief at 1 km, 100 m, 10 m

Viking Lander 2

Unit C Moderate thermal inertia, moderate to high albedo
Rocky from orbit and at surface; diffuse scattering from rocks
Relatively Dusty, Albedo 0.24 – bright drift deposits at surface
Low Relief at 1 km, 100 m, 10 m

Viking Lander 1

Unit C Moderate thermal inertia, moderate albedo

Rocky from orbit and at surface (with outcrops)

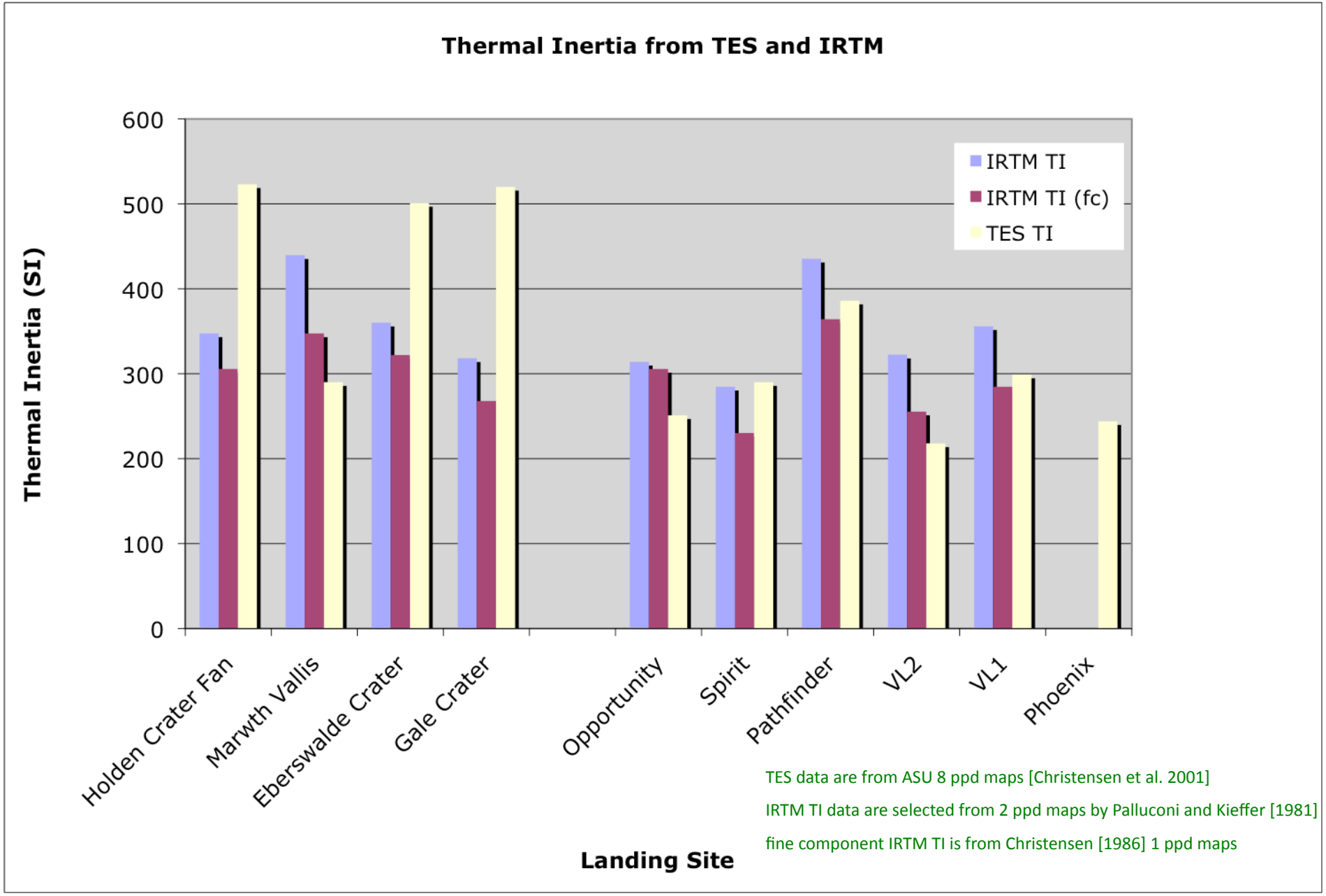
Relatively Dusty, Albedo 0.22

Relatively Higher Relief at 1 km, 100 m, 10 m

Columbia Hills

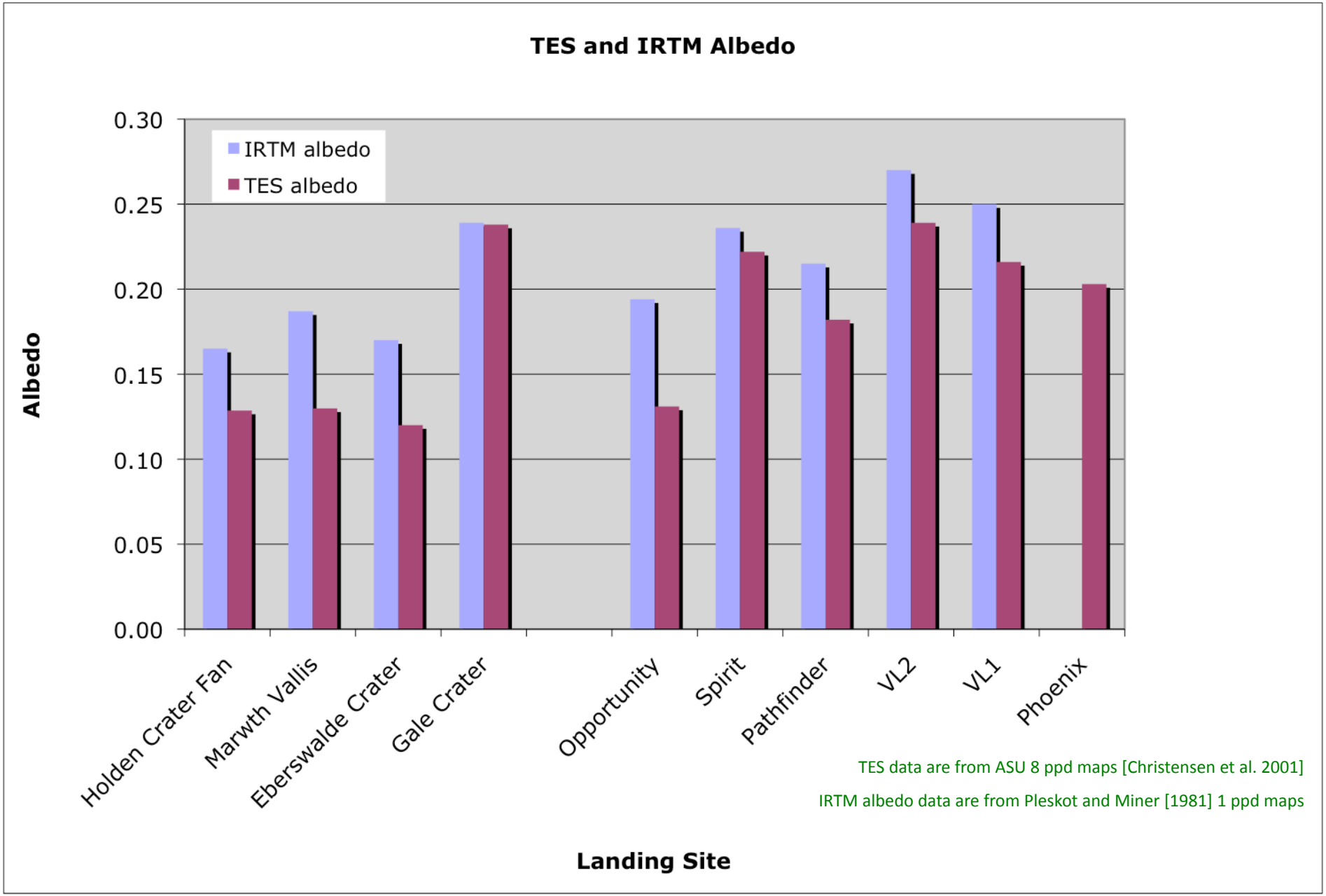
Unit C

Example of Surface with Much Higher Relief
at All Length Scales [km, 100 m, 5 m]
9.5° RMS; 7.6° Mean at 3-10 m Length Scale



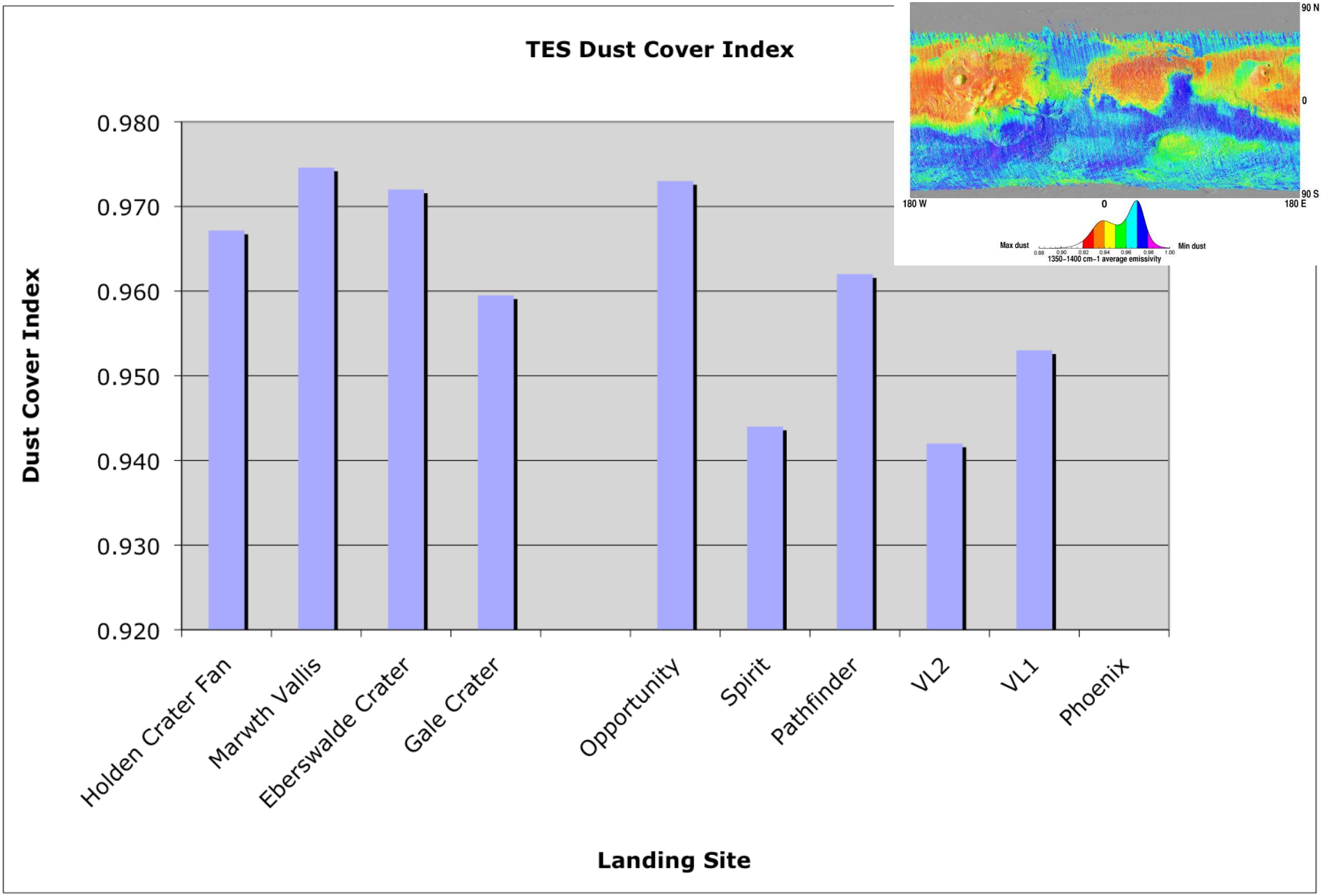
Thermal Inertias Comparable or Higher than Previous Landing Sites

No Significant Dust Deposits



Holden, Mawrth, Eberswalde Low Albedo (Unit B Like Meridiani Planum) Expect Dust Free

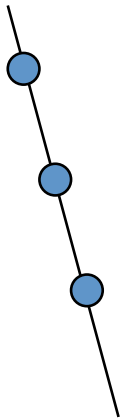
Gale Dustier – Comparable to Dusty Gusev Plains or VL1



Mawrth, Eberswalde, Holden Relatively Dust Free; Gale Dustier – Similar to MPF

Ruff and Christensen, 2002

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 <100 m over 300, 600, 900 m in 20 km Circle for 200-1000 m relief - most stringent constraint

Technique from Anderson et al. [2003]

Constraint from Relief that can be Tolerated During Powered Descent

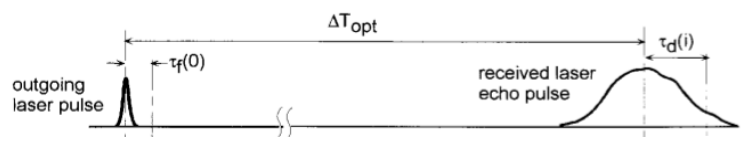
Concern when Relief over 100 m over Length Scales of 200-1000 m Length Scales

Most Stringent Constraint is at 1 km

Pulse Spread

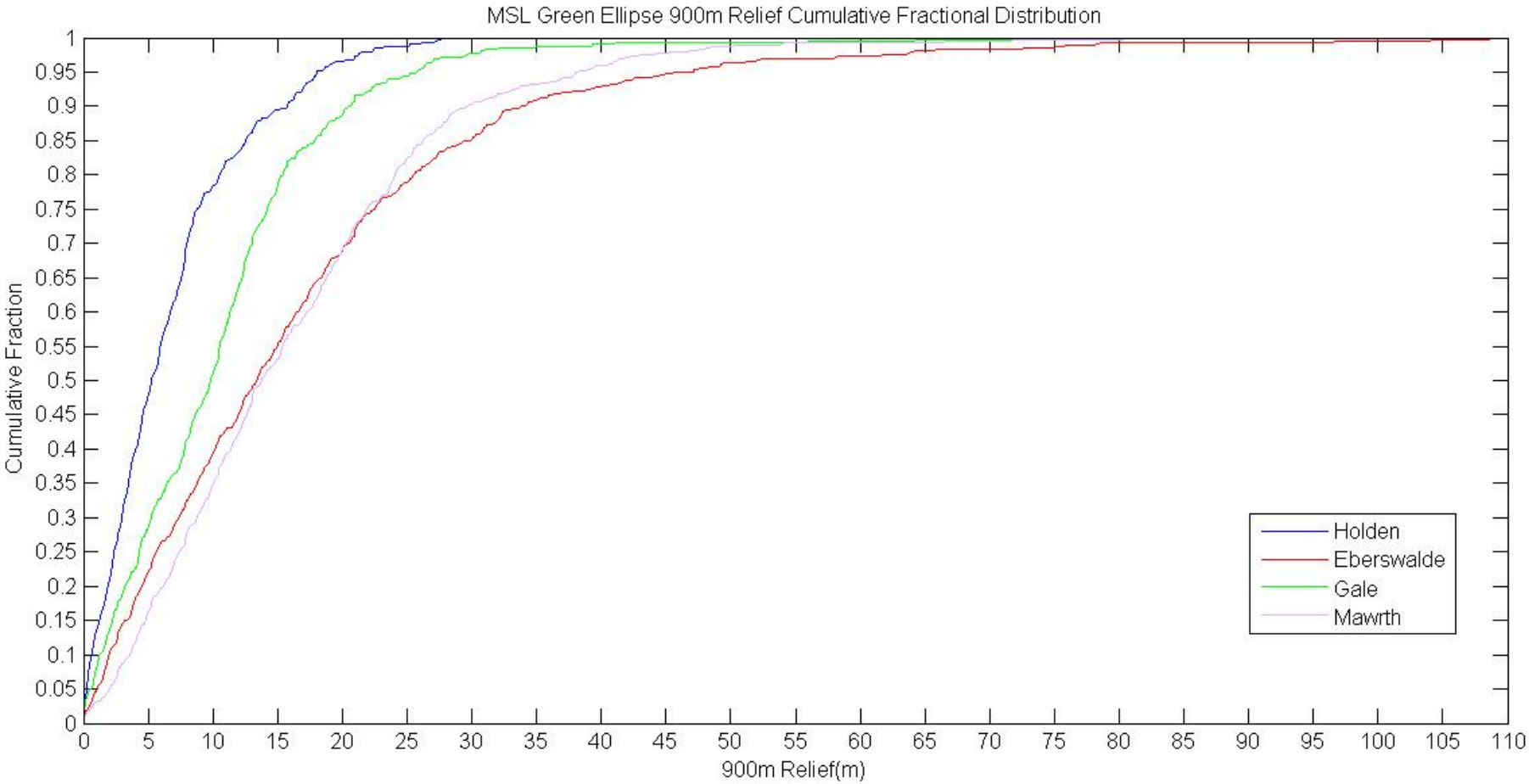
Measure of Relief, Roughness

Over 75 m Diameter Shot Point



Neumann et al. [2003]

MOLA 900 m Relief



Bidirectional Relief at 1 km Length Scale Most Stringent Constraint
Engineering Concern >100 m
Can accommodate 130 m

MOLA 900 m Relief

Site	Mean (m)	±SD (m)	# Data	# >40 m	# >80 m	# >100 m
Holden	6.7	11.5	538	0	0	0
Gale	10.7	5.8	416	4	0	0
Mawrth	16.1	8.7	503	20	1	0
Eberswalde	16.9	15.6	488	35	3	2

Bidirectional Relief

All can be accommodated – D. Kipp Presentation

1 km and 100 m Statistics

Site	Oppy	Spirit	VL1	VL2	MPF	Holden	Gale	Mawrth	Eberswalde
1.2 km Bi-Dir. Slope°, Mean ±s.d., RMS, n	0.15± 0.18 0.26 680	0.20± 0.44 0.49 679	0.26± 0.96	0.29± 0.29	0.25± 0.66	0.38± 0.85 0.5 522	0.62± 0.48 0.78 406	0.97± 0.63 1.2 488	0.98± 0.85 1.3 475
Pulse Width, m Mean ±s.d., n	0.84± 0.46	1.34± 1.11	1.54± 2.4 19848	1.22± 0.55 10560	1.52± 1.81 25853	1.40± 0.99	1.78± 1.2	1.99± 1.27	2.04± 2.73
Self affine 100 m Allen dev, m RMS slope°	3.4 1.9	5.8 3.3	1.8 1.0		5.0 2.9				

1.2 km Bidirectional Slope from MOLA Along Track Data

MOLA Pulse Spread from Neumann et al. [2003]; Slope Corrected; Measured 0-20 m on Mars

At 1 km and 100 m Length Scale

Smoothest to Roughest: Holden, Gale, Mawrth, Eberswalde

Holden Slightly Rougher than 6 Previous Landing Sites

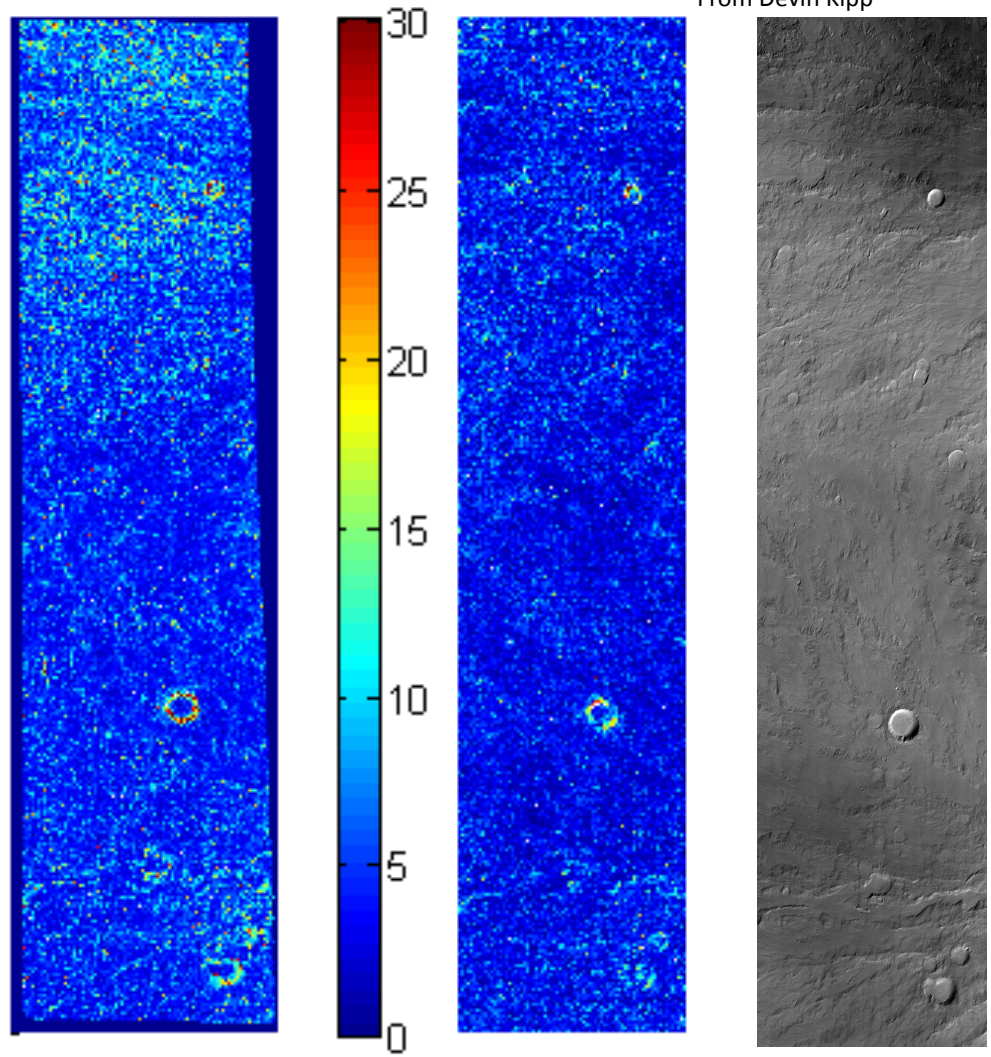
Gale, Mawrth, Eberswalde Much Rougher

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

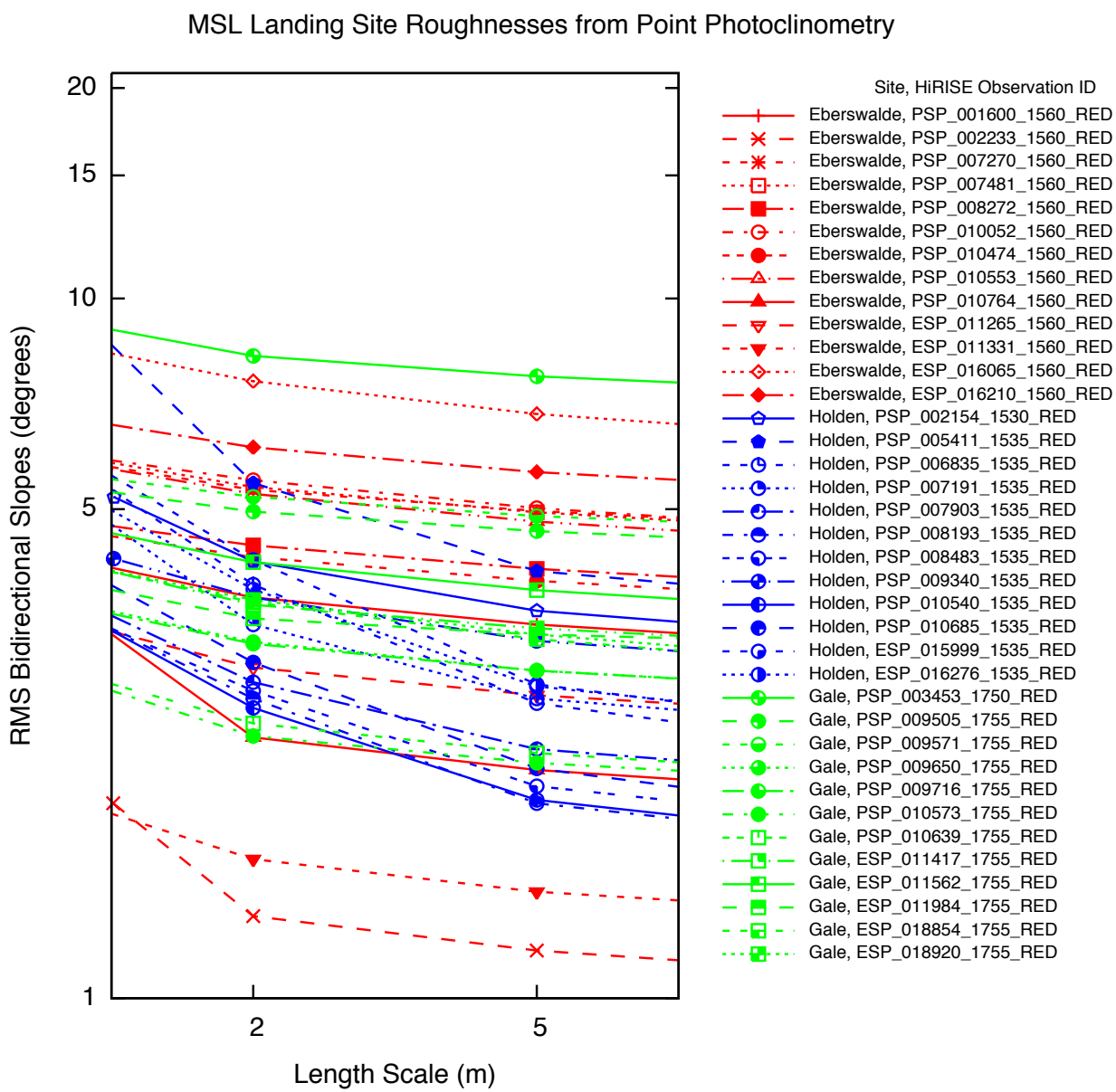
Point Photoclinometry Slopes

Original image

Ross Beyer

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

RMS Slope



RMS Slope vs Baseline

HiRISE Photoclinometry

R. Beyer SETI Ames

Slope at 5 m Length Scale

Site	RMS Slope DTMs *	RMS Slope Pcl	% Slopes >20°	% Slopes >25°
Opportunity	1.2° (3.3°)		0	0
Phoenix	1.8°		0	0
VL2		1.6°		
Spirit (Columbia Hills)	3.7° (10°)	3.4° (10°)	0.05	0.01
Holden	4.1°	2.6°	0.08	0.02
Gale	4.5°	4.3°	0.12	0.04
VL1		5.1°		
Pathfinder	4.9°	5.1°		
Mawrth	6.0°		0.57	0.15
Eberswalde	7.0°	4.5°	2.45	0.94

At 5 m Length Scale:
Holden & Gale Similar to Rougher Previous Landing Sites (Rougher Parts of Gusev Cratered Plains & MPF)

Mawrth & Eberswalde are Rougher (Comparable to parts of Columbia Hills)

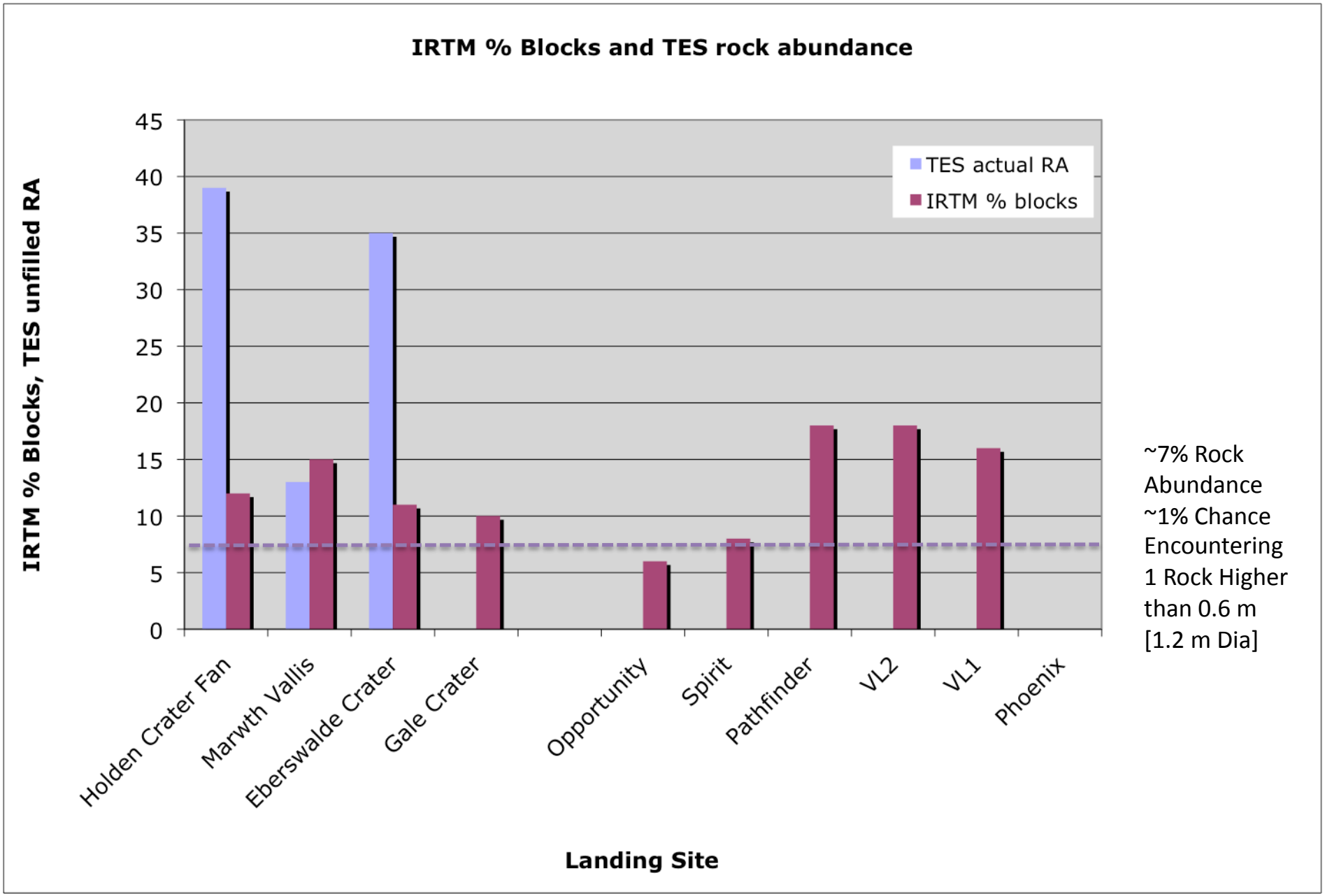
Area Covered by Slopes >25° <1%

*Sources from HiRISE & MOC Stereogrammetry & Photoclinometry Kirk et al. [2003, 2008, 2010]
** Photoclinometry Beyer et al. [2003, 2010]

Columbia Hills

Unit C

Example of Surface with Much Higher Relief
at All Length Scales [km, 100 m, 5 m]
9.5° RMS; 7.6° Mean at 3-10 m Length Scale



~7% Rock Abundance
~1% Chance Encountering 1 Rock Higher than 0.6 m [1.2 m Dia]

High "Rock Abundance" at MSL Sites from Thermal Differencing Techniques Probably due to Outcrop

Rock Abundance

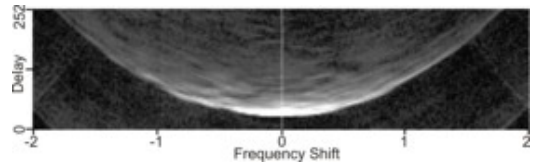
- But See Rocks Directly in HiRISE
  - Took Measured Total % Area Covered by Rocks at Each Site
  - Holden 0.014%
  - Mawrth 0.015%
  - Gale 0.047%
  - Eberswalde 0.054%
  - Assume Roughly = % Area Covered by >1.5 m Diameter Rocks
    - Overestimate as some area covered by smaller rocks
    - Area is rough measure of risk of encountering rock >1.5 m;
    - Obviously very small area
  - Extrapolate to % Area Covered by >0.1-0.15 m Diameter Using Model
- Equivalent IRTM or TES Rock Abundance
  - Gale & Eberswalde Roughly <5% CFA
  - Holden & Mawrth Roughly <7% CFA
  - Can Compare with Previous Landing Sites –
    - Similar to Gusev Cratered Plains
- Even at this Level, All Sites Meet Guideline of <7% CFA

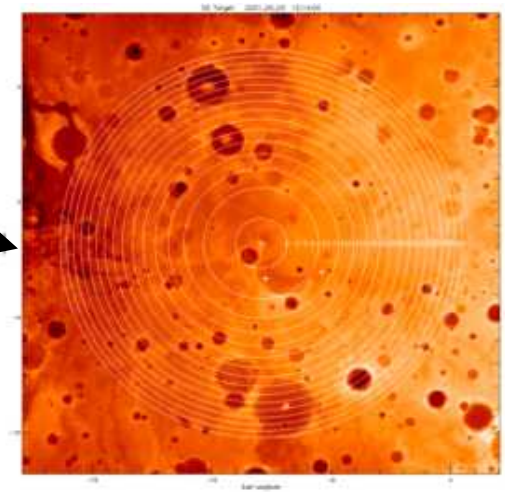
Kristopher Larsen [LASP, CU]

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

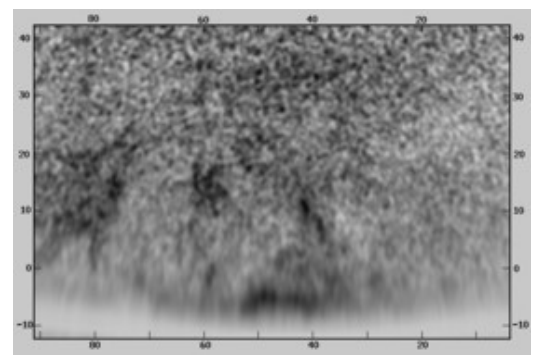




Methods Overview

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

- S-band (12.6 cm) VLA Observations (*Harmon et al. 1999*)
  - Same-sense, diffuse/multiply-scattered reflections
  - 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**

Inescapable Hazard Assessment

- Areas that can trap the rover from traversing after successfully landing
  - Craters or mesas
  - Circular patterns of high slope
- Look at slope maps and HiRISE to determine surface material
  - Lighter, probably outcrop
  - Darker, probably sand
  - Aeolian bedforms – sand
  - Stratigraphy- rock

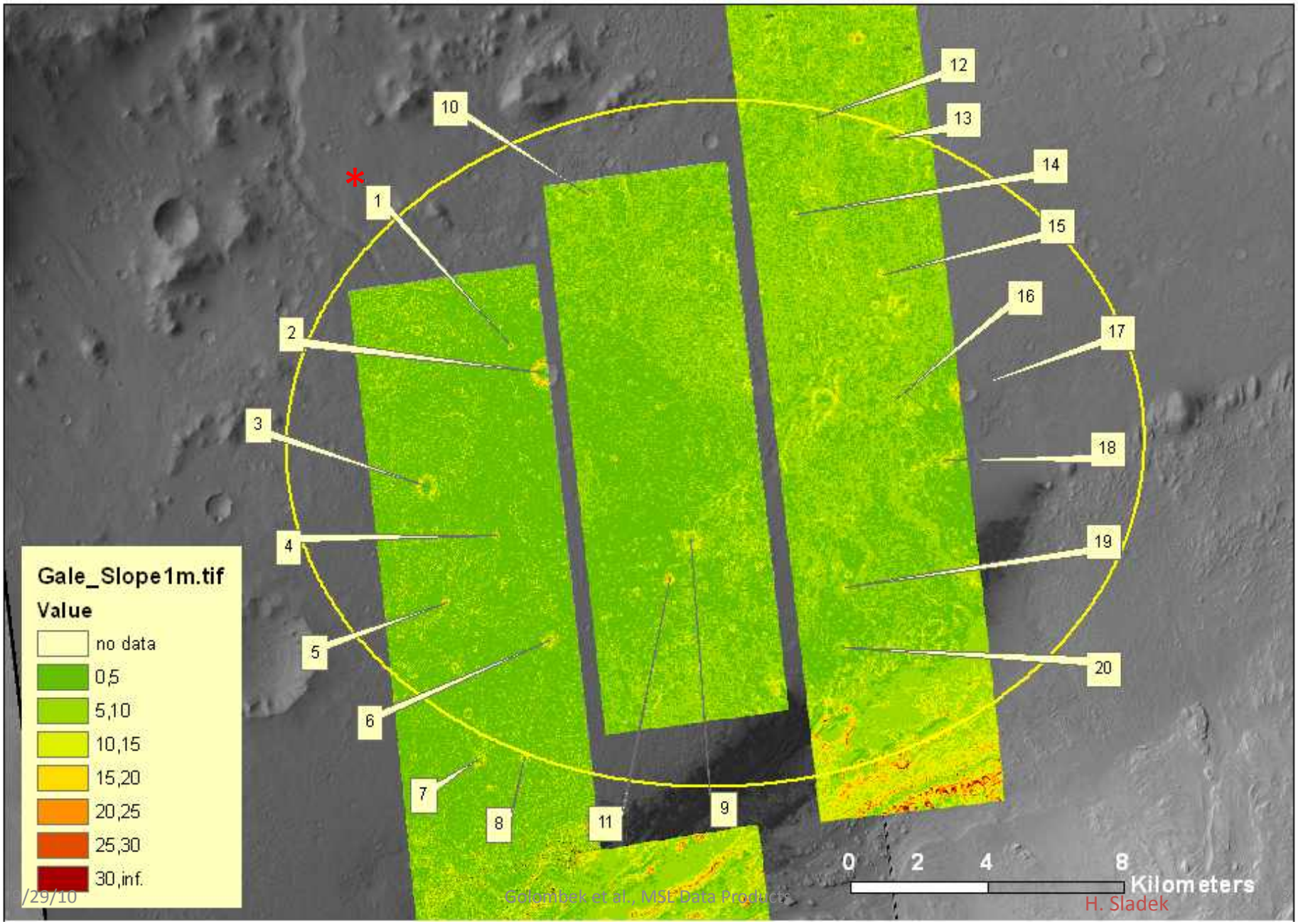
- MSL could drive down >30 deg. slope if it had to

Slopes	*MSL Driving*
>30 deg.	Not traversable
15 - 30 deg.	Traversable on rock, not sand
< or = 15 deg	Traversable in sand or outcrop

➢Shadowed areas $\geq 36°$
➢Sun elevation above the horizon of images

- Approach
  - Inspect 1m slope maps for circles of high slope with low slope in the middle
  - Identify all such circles
  - Evaluate trafficablity using slope and material [Outcrop vs. Sand]
  - Classify as Inescapable Hazard, Probable, or Not Inescapable Hazard

Gale Crater



Golombek et al., MSL Data Products

H. Sladek

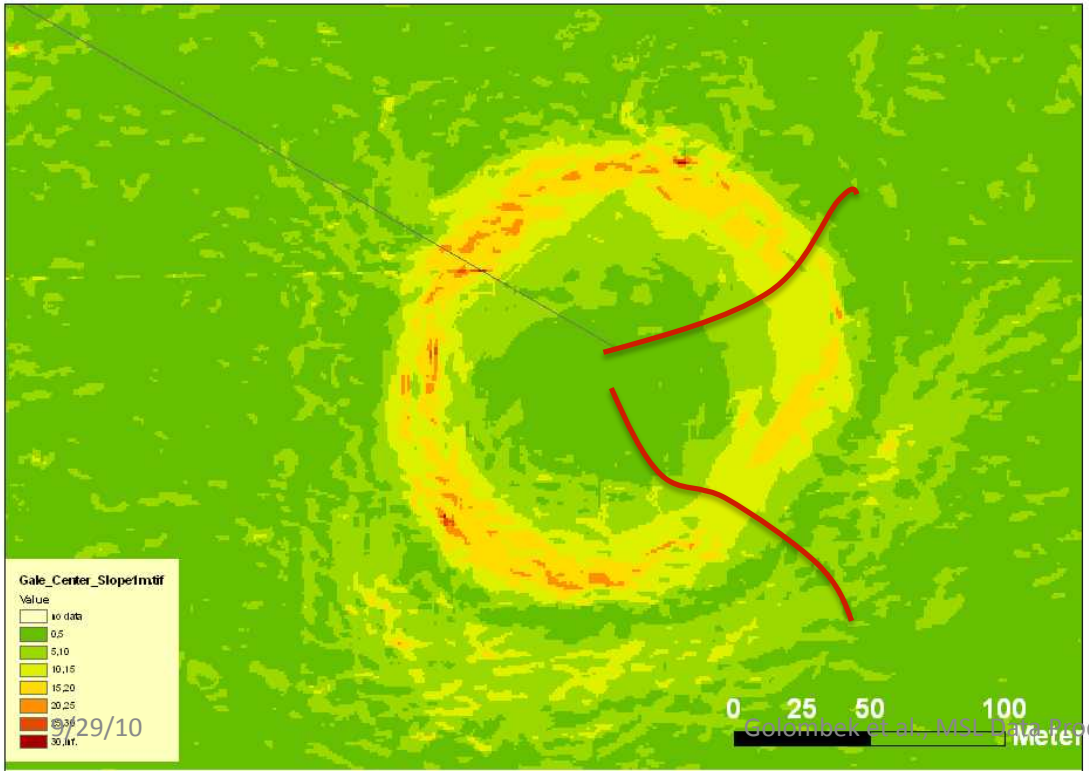
/29/10

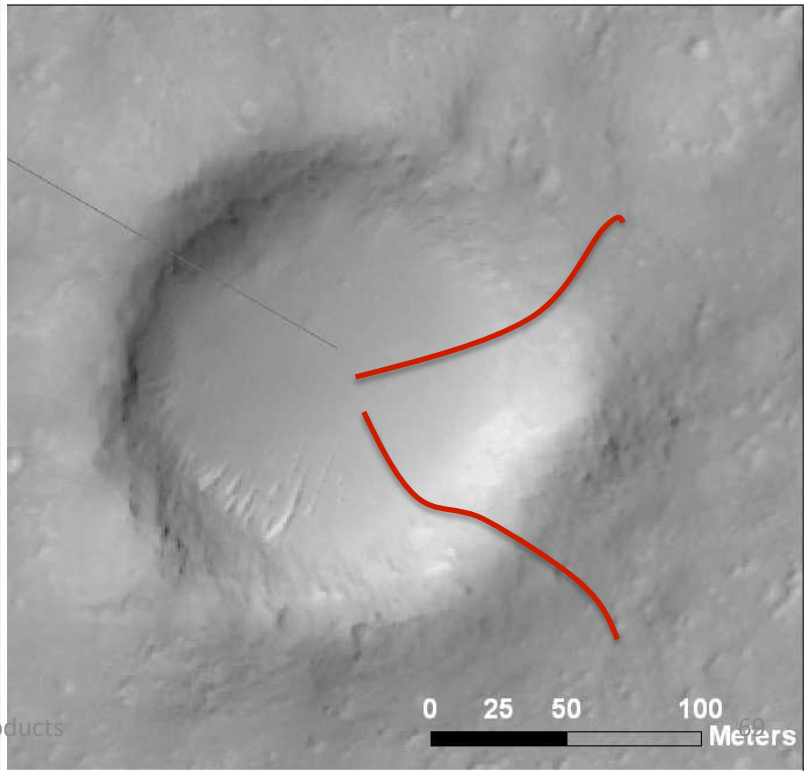
ID. 1

- Crater, 160 m diameter
- Sandy
- 0.025099 km^2
- 137.3229 E, -4.4385 S

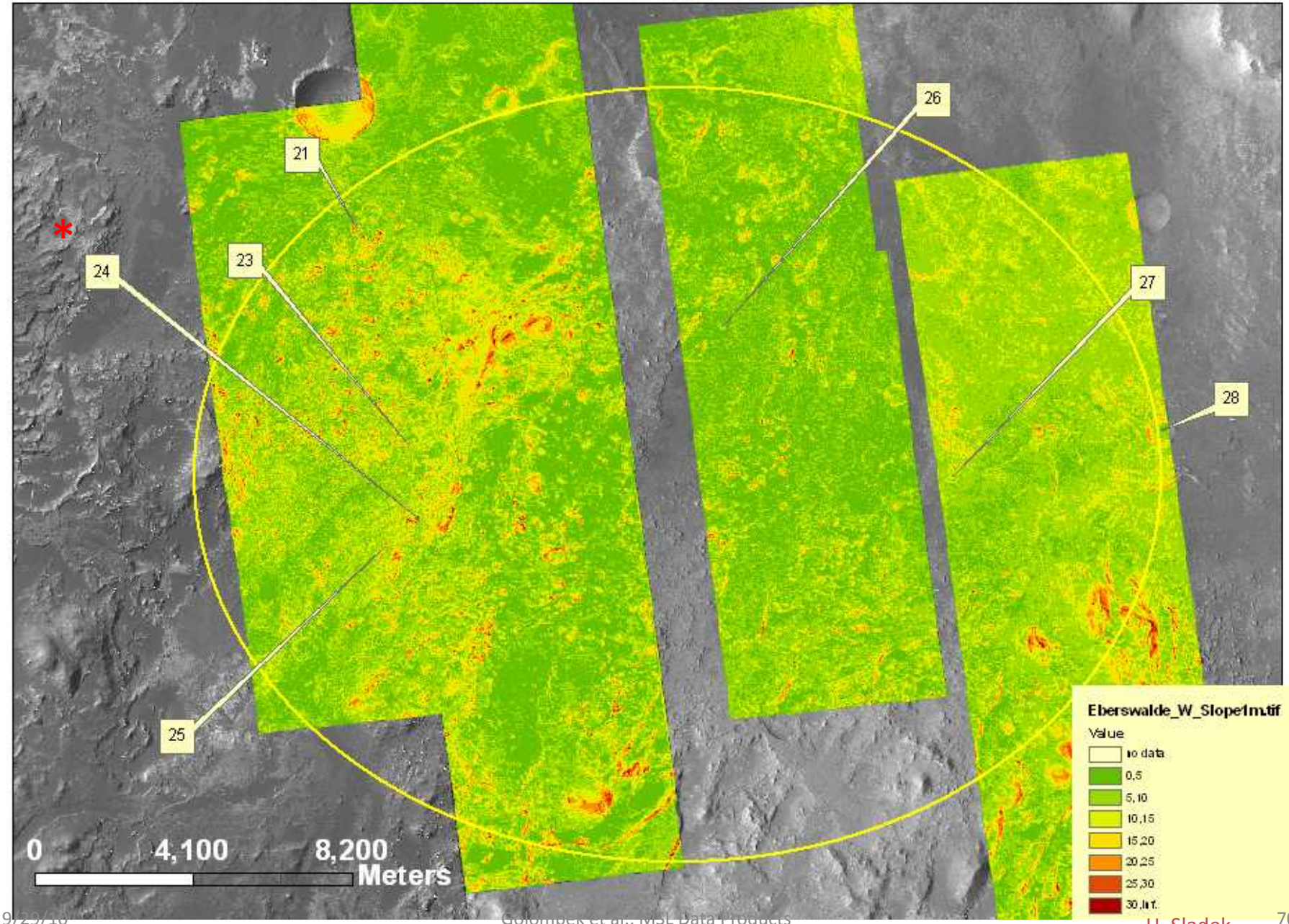
- Escapable
- Egress routes 10 - 15° slopes in sandy material (note red lines)

H. Sladek





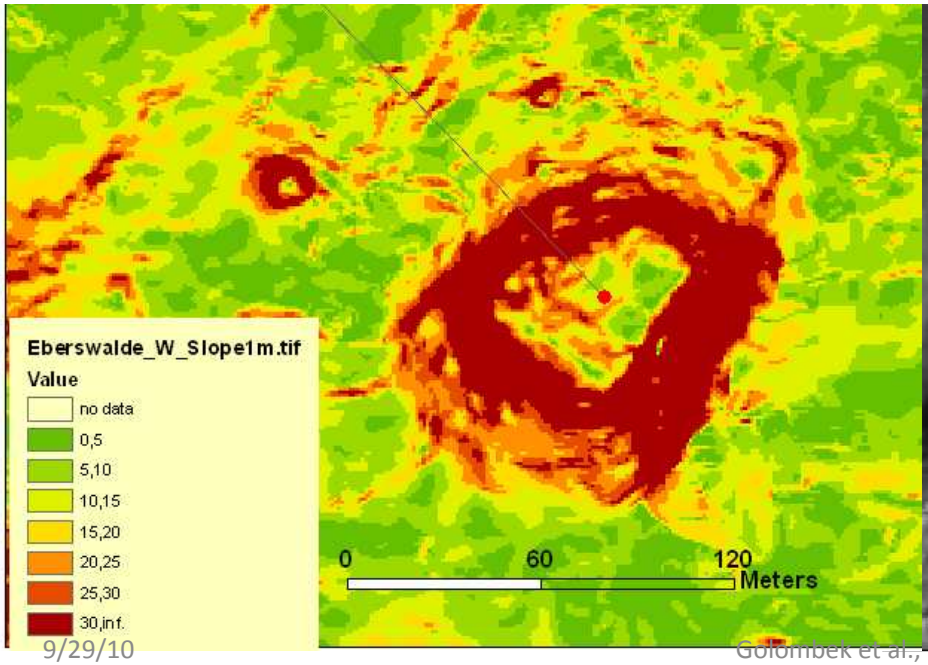
Eberswalde Crater

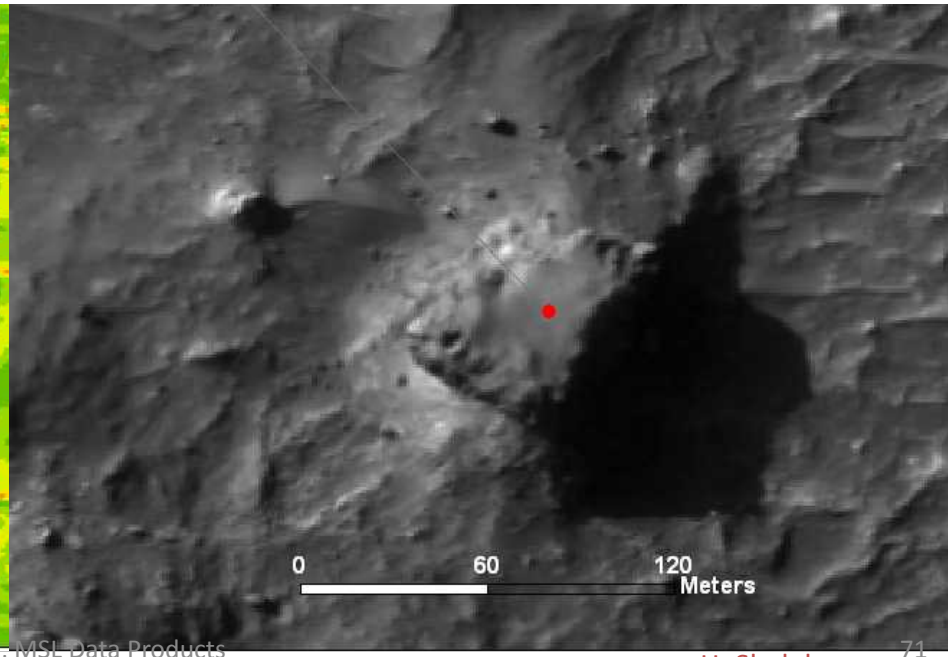


ID. 24

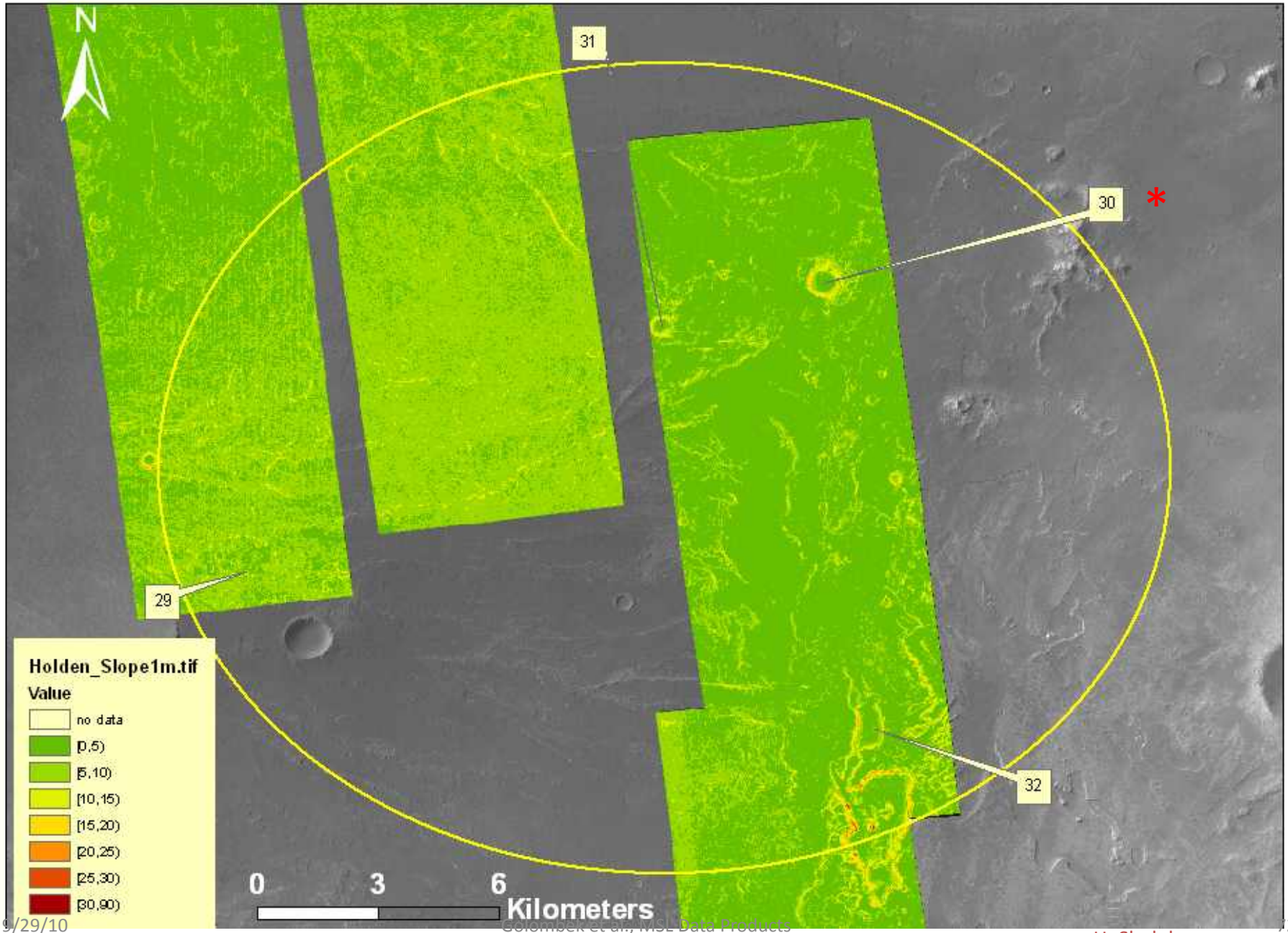
- Mesa, 95m diameter
- >30° slopes
- outcrop
- 0.00748 km^2
- 326.6293 E, -23.9139 S

- Inescapable
- Slopes are >30°





Holden Crater

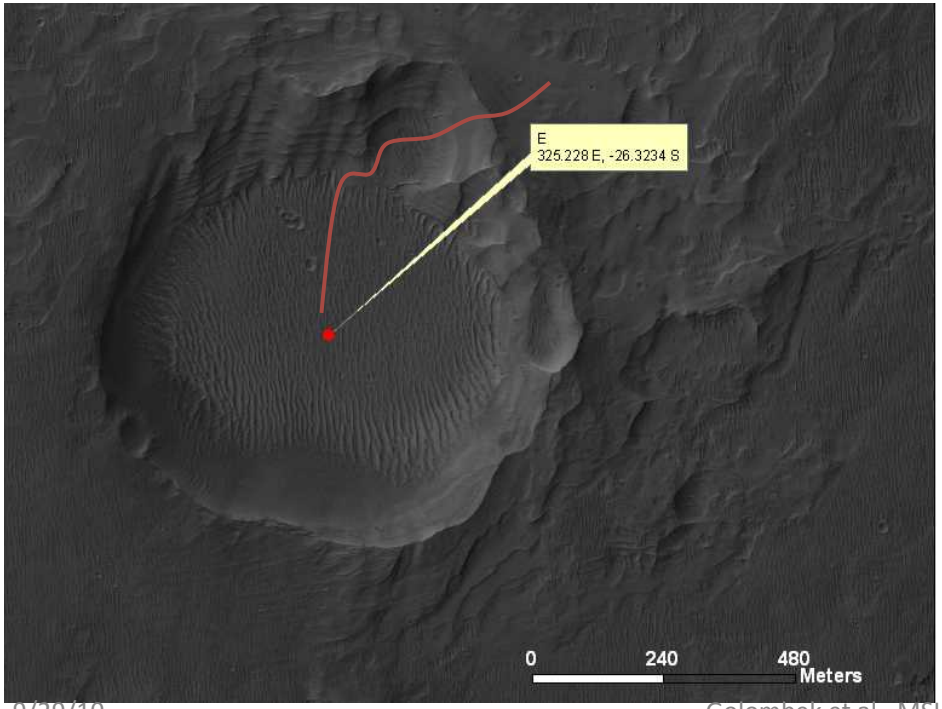


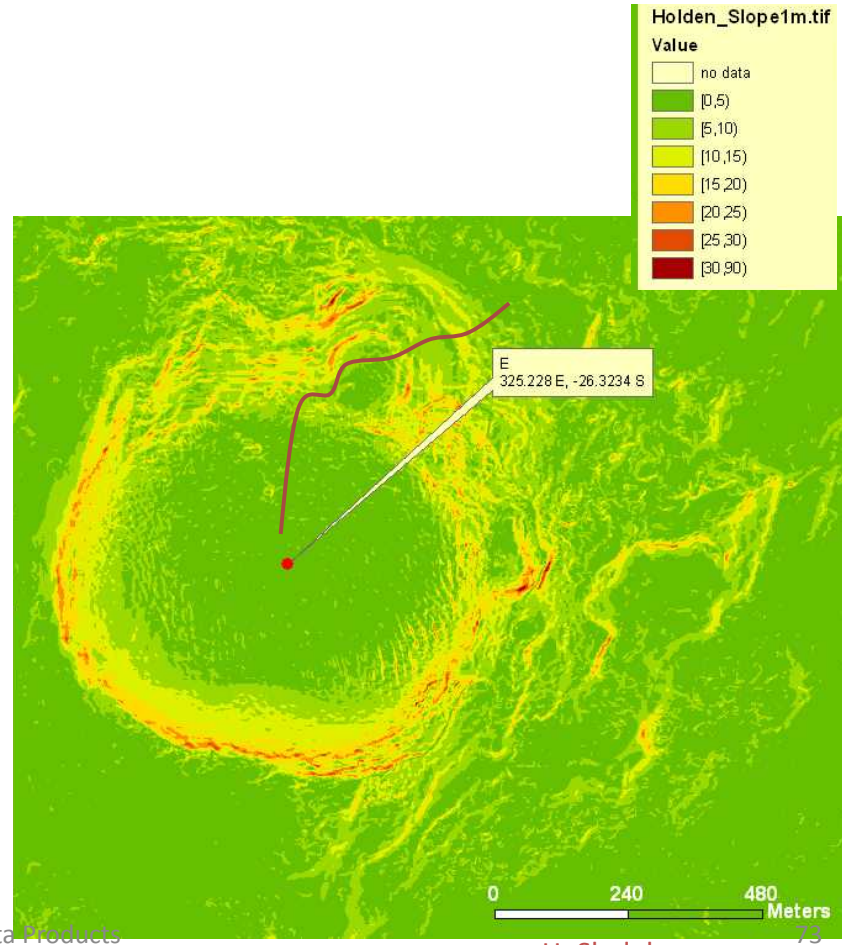
H. Sladek

ID. 30

- Crater, 840m diameter
- 10 to 30 deg. Slope
- Outcrop rims with sandy bottom
- 0.53978 km^2
- 325.228 E, -26.33237 S

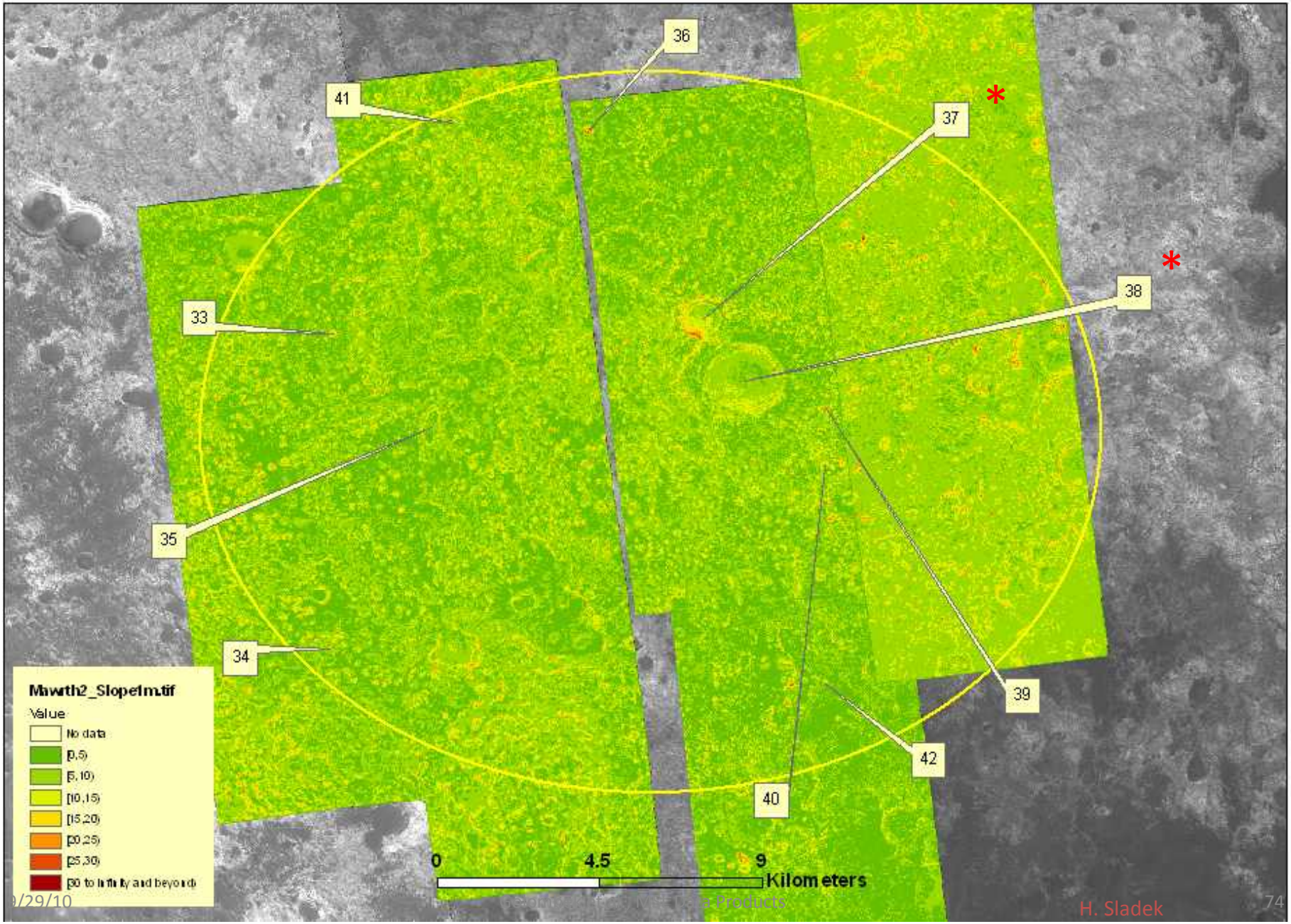
- Escapable
- Egress route 5 to 15° Slope (note red line)





H. Sladek

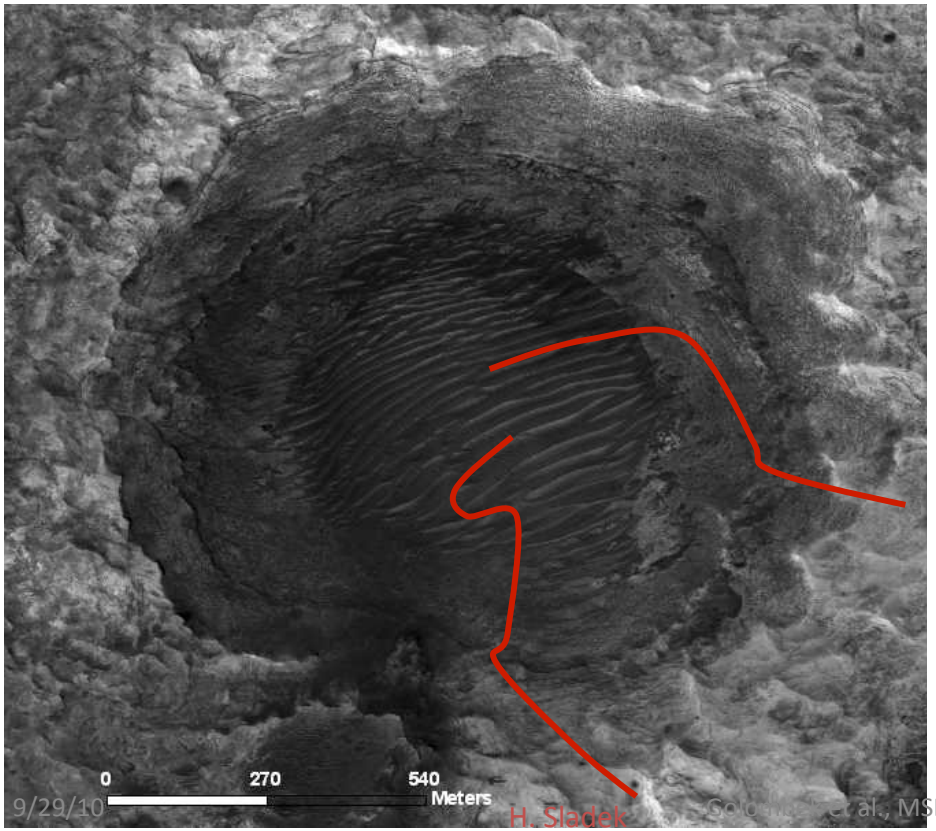
Mawrth Vallis

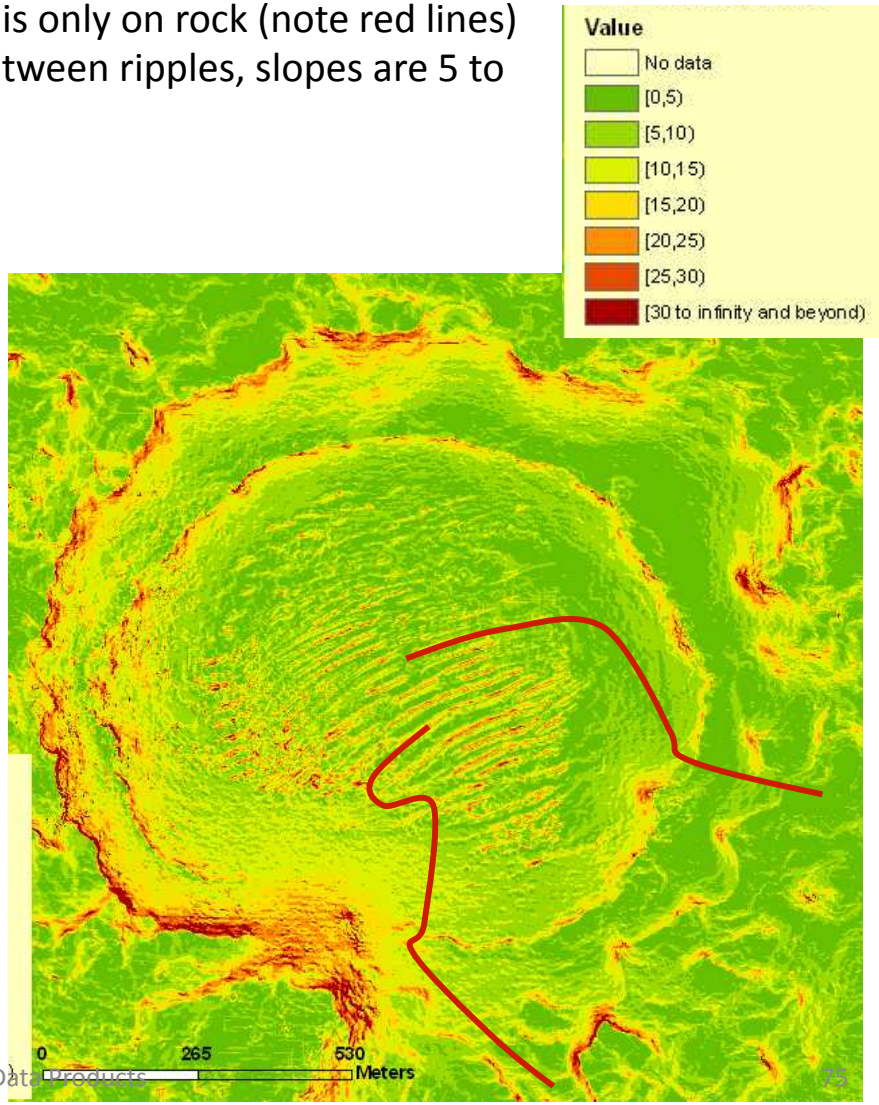


ID. 37

- Crater, 1000m diameter
- 10 to >30° slopes
- Outcrop with sandy bottom
- 0.007308244 km^2
- 341.0648 E, 24.0416 N

- Escapable, and a nice "go to" location
- Egress routes are 10 to 15° with a little 15 to 20° slope that is only on rock (note red lines)
- Traversable between ripples, slopes are 5 to 10°

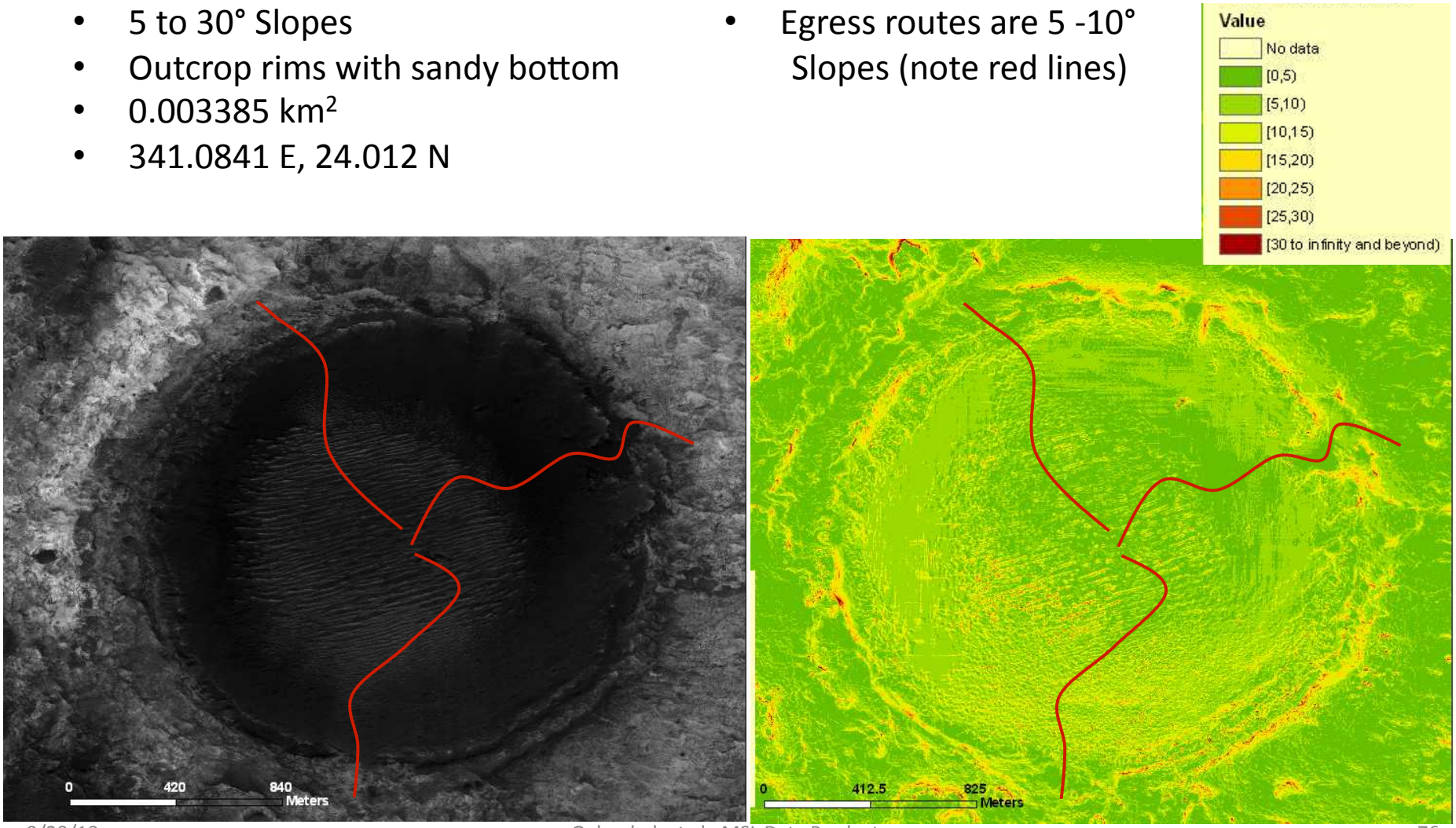




ID. 38

- Crater, 2000m diameter
- 5 to 30° Slopes
- Outcrop rims with sandy bottom
- 0.003385 km^2
- 341.0841 E, 24.012 N

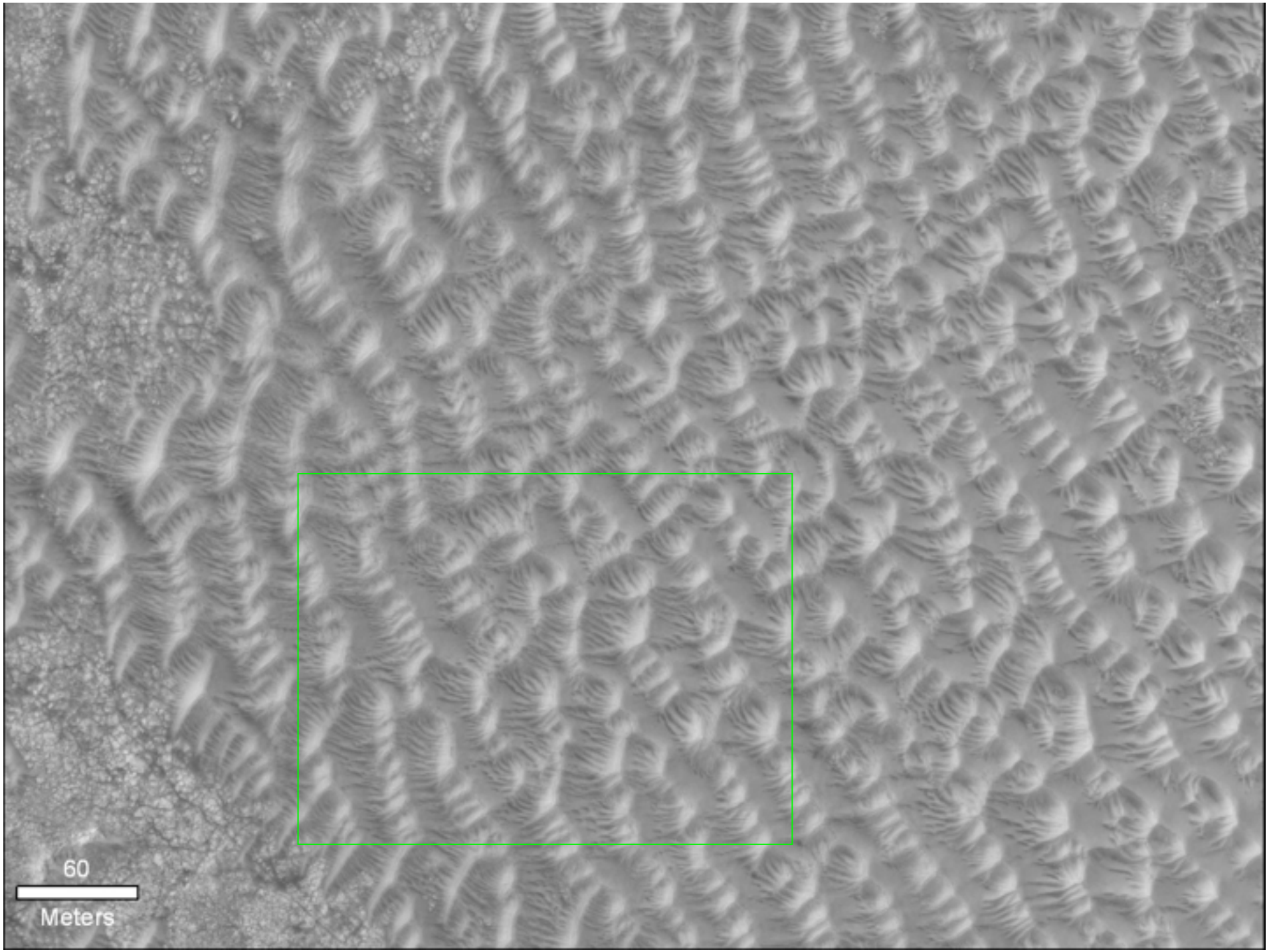
- Escapable
- Egress routes are 5 -10° Slopes (note red lines)

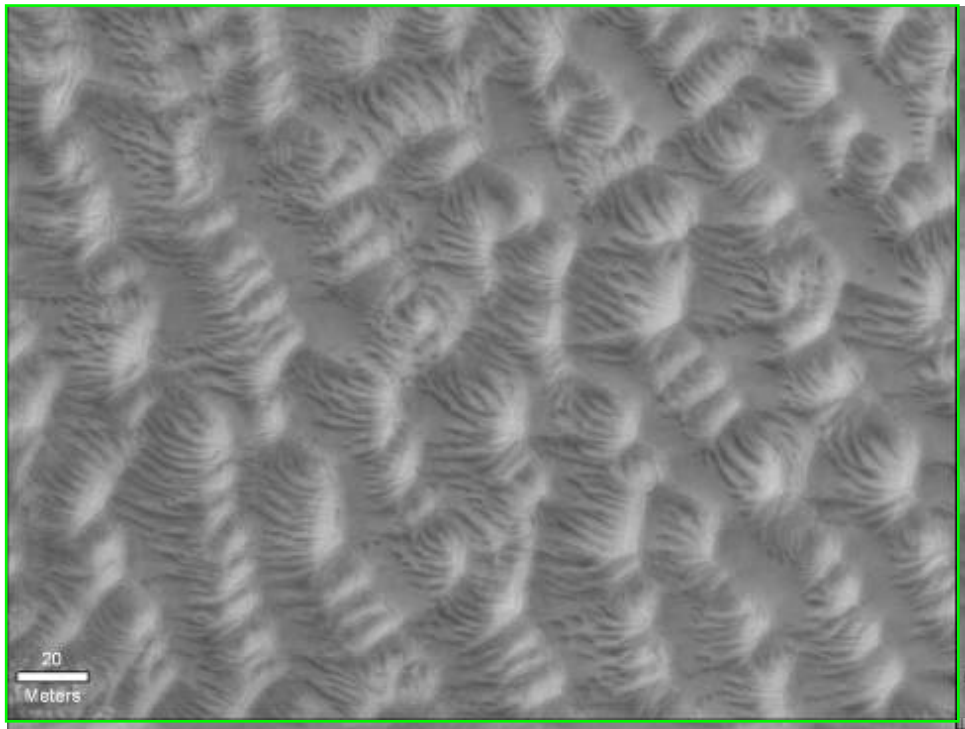


Summary of Inescapable Hazards

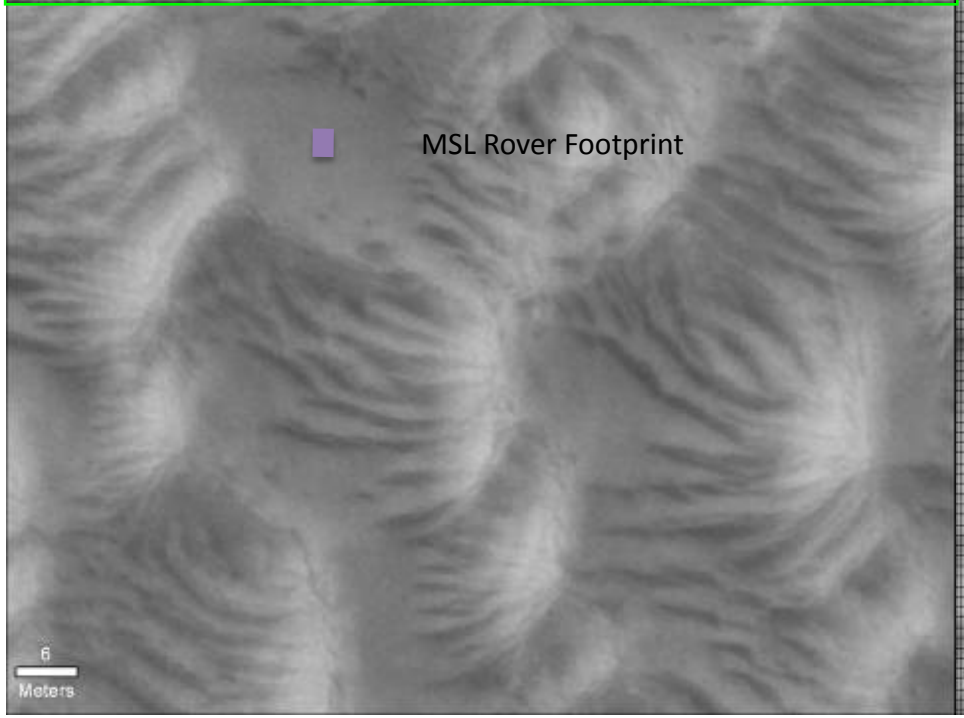
- 39 Potential Inescapable Hazards Assessed; Most 10s to 100s m Diameter
  - 18 Gale, 10 Mawrth, 7 Eberswalde, 4 Holden
- 6 Found; 6 Probably Inescapable; Rest Escapable
  - None in Holden
  - 0.0001% Area of Ellipse in Eberswalde
  - 0.0002% Area of Ellipse in Mawrth
  - 0.002% Area of Ellipse in Gale
- The Inescapable Hazards are *<0.0003%* in each landing site and the Probable Inescapable Hazards are *<0.002%* in each landing site.
- Inescapable Hazards are not considered an additional concern for the landing site selection because the number of inescapable hazards are few and they cover a very small area.
- If the mission depended on it, MSL probably could traverse down a mesa with >30° slopes
  - Decreases concern for inescapable hazards further

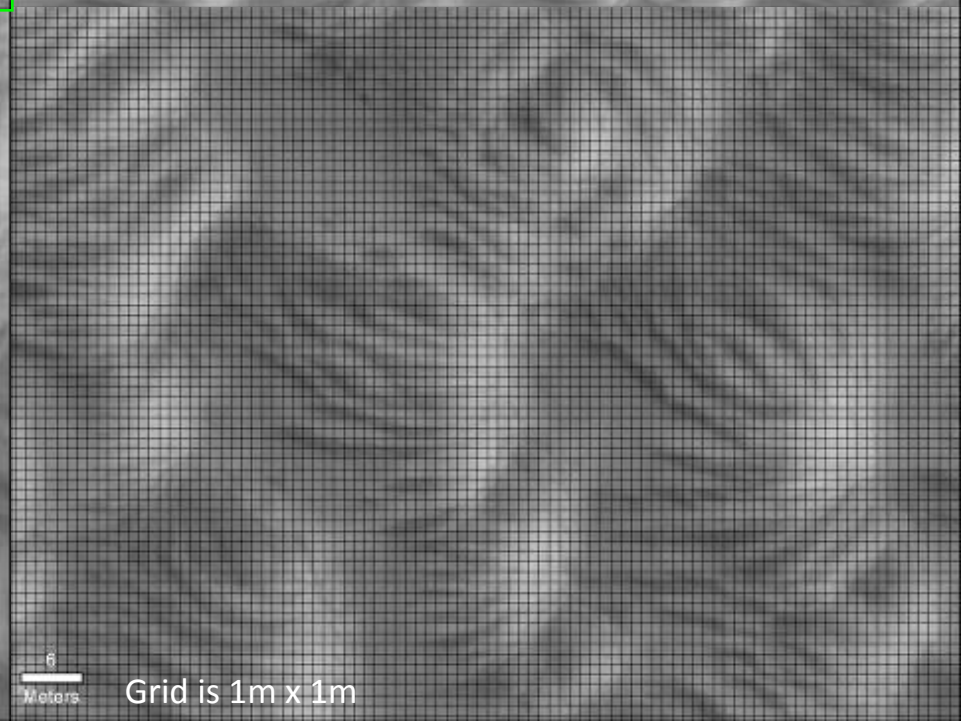
No Inescapable Eolian Bedforms Found in the 4 Sites


60
Meters

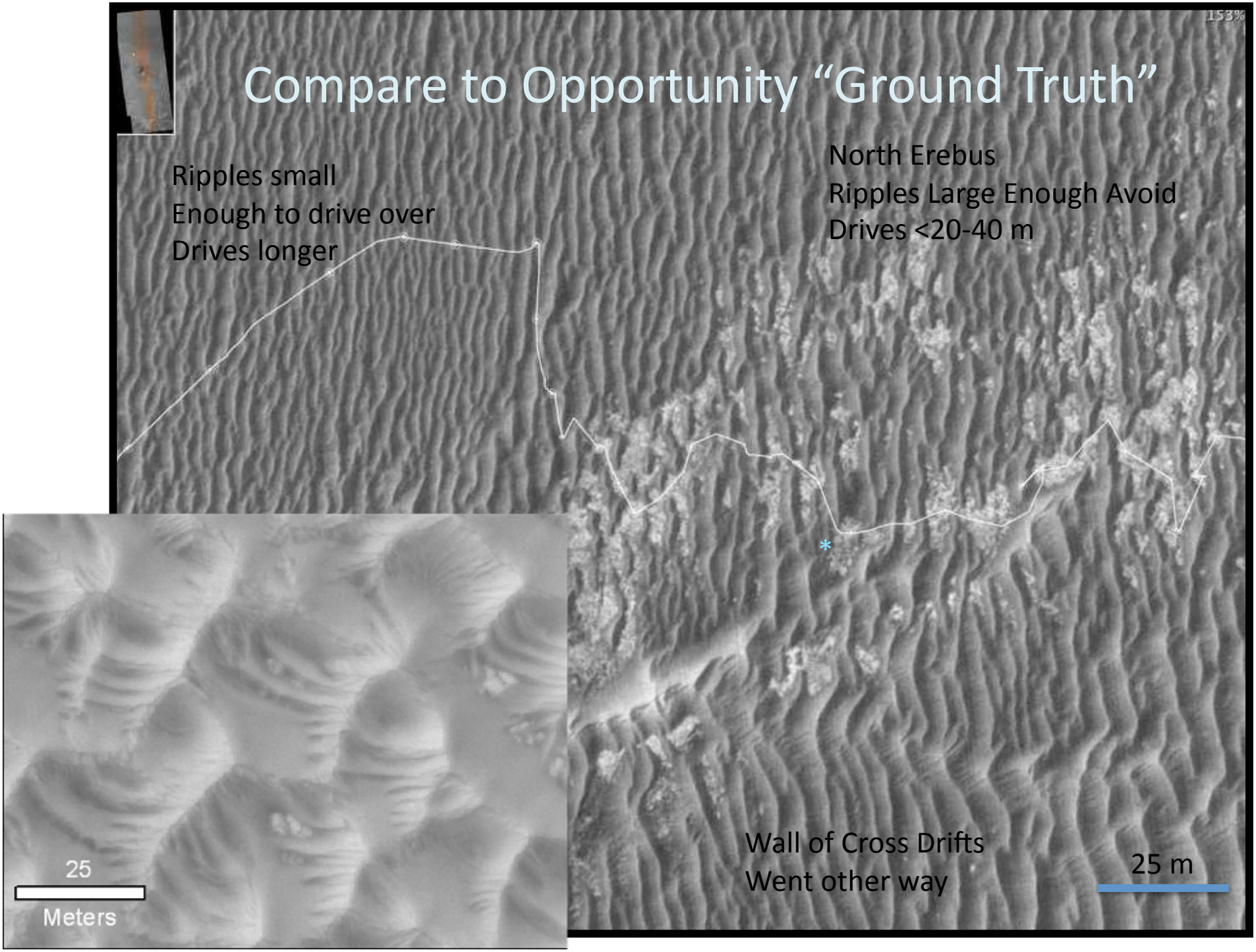


20 m “red” dunes; Easy to Imagine they are 6 m high; If so slopes ~30˚, not only mobility trap, also landing hazard



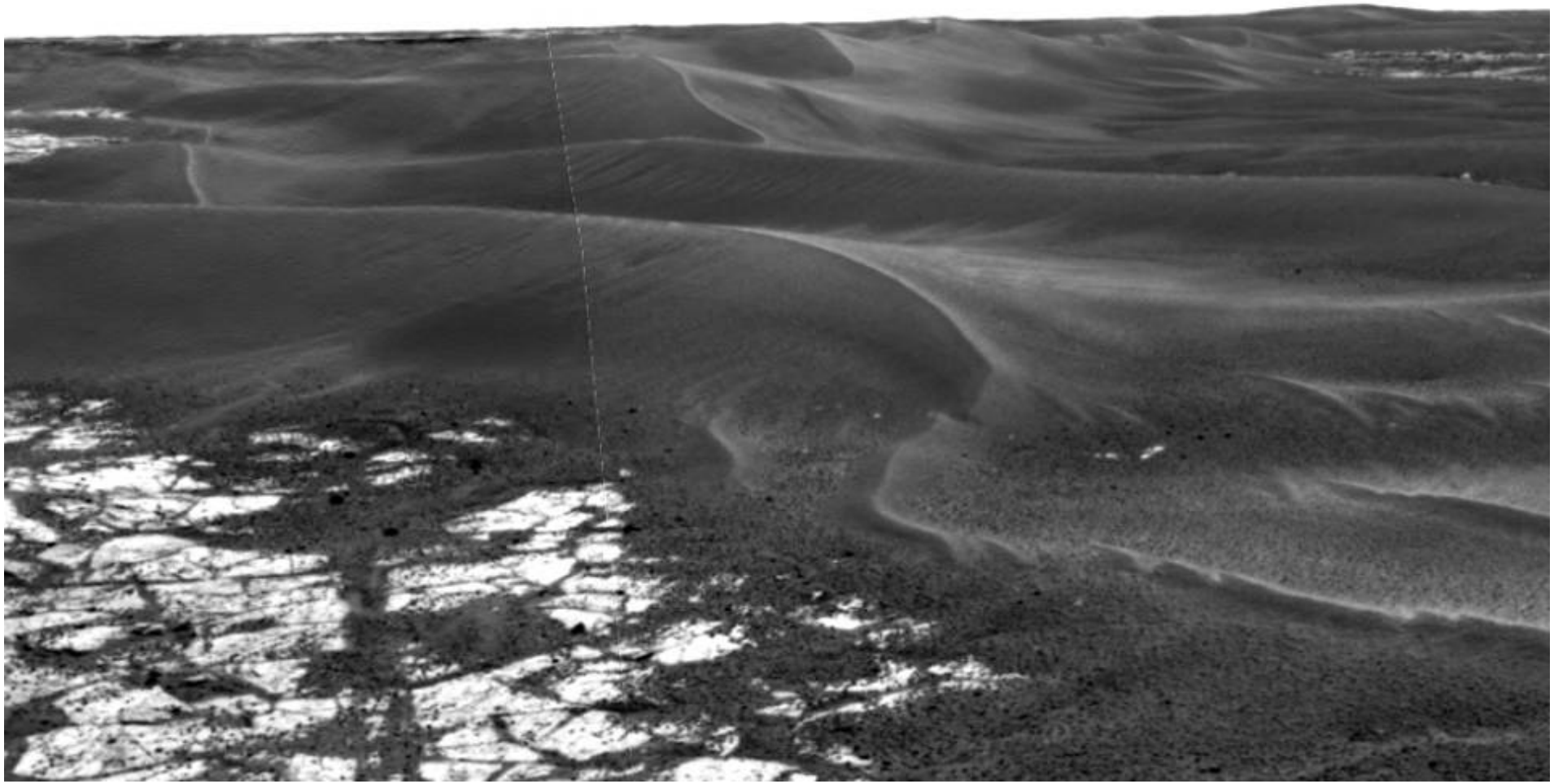


Compare to Opportunity "Ground Truth"



Sol 614 view of Purgatory Wall

Drifts >>1 m High



Summary

- Best Imaged, Best Characterized Landing Sites Ever
  - Complete HiRISE, CTX, CRISM Coverage
  - DTMs ~90+% of Ellipse at 1 m Postings; Photoclinometry Rest
  - Rock Maps Directly Image All Hazardous Rocks
    - Extrapolate to Smaller Ones
  - THEMIS Thermal Inertia & Surface Material Maps
- Can Directly Address All Engineering Constraints with Data
  - All Characteristics Appear within Capabilities (Next Talk)
  - Inescapable Hazards (e.g., craters, dunes) Minimal
  - No Unusual Earth-based Radar Properties
- Comparison to Previous Landing Sites
  - Holden, Eberswalde, Mawrth Dust Free Sites (Like Oppy)
  - Gale Dustier (Like MPF, Spirit Dust Devil Tracks)
  - Sites Generally Rougher at 1 km, 100 m and 5 m
    - Roughest Sites [Eberswalde & Mawrth Comparable to Columbia Hills]