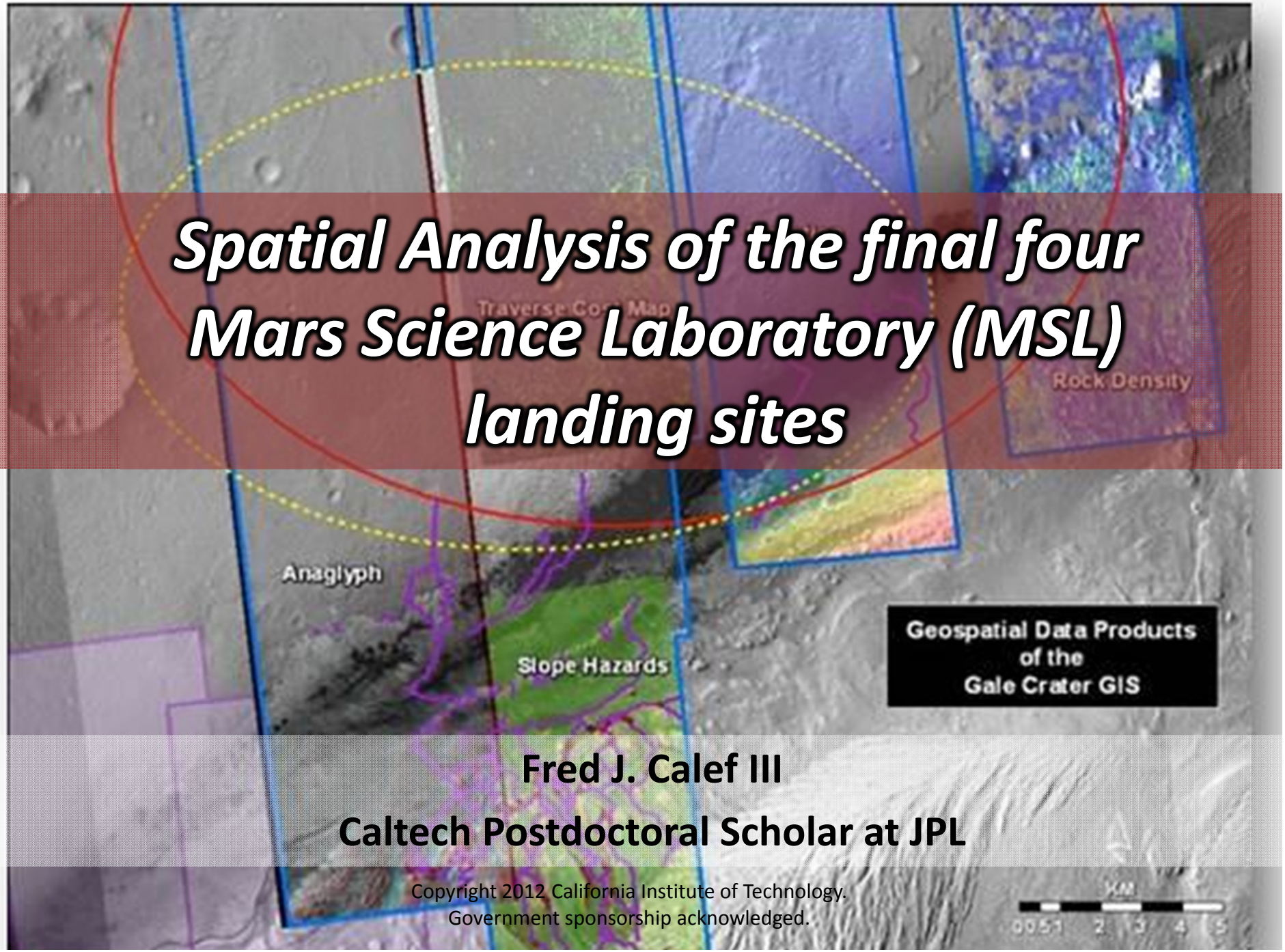
Spatial Analysis of the final four Mars Science Laboratory (MSL) landing sites



Fred J. Calef III

Caltech Postdoctoral Scholar at JPL

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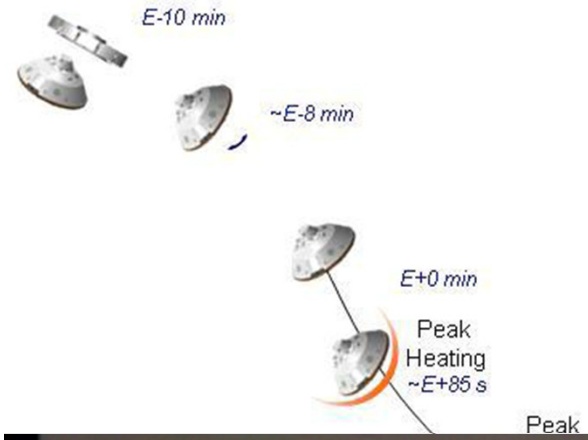
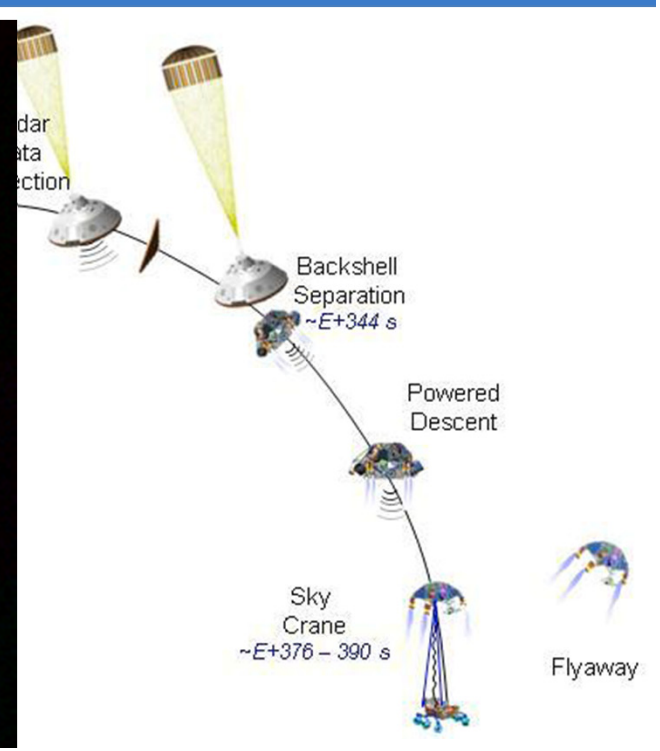
Government sponsorship acknowledged.

Outline

1. Where on Mars can we land?
   - MSL Landing Constraints
2. What data do we have?
   - Spatial Data Products
3. Image Integration into a Geographic Information System (GIS)
   - Georeferencing and Rectification
   - Resolution Pyramid
4. The Future of Landing Site Spatial Analysis
   - Tactical and Strategic Planning

MSL Landing Sequence



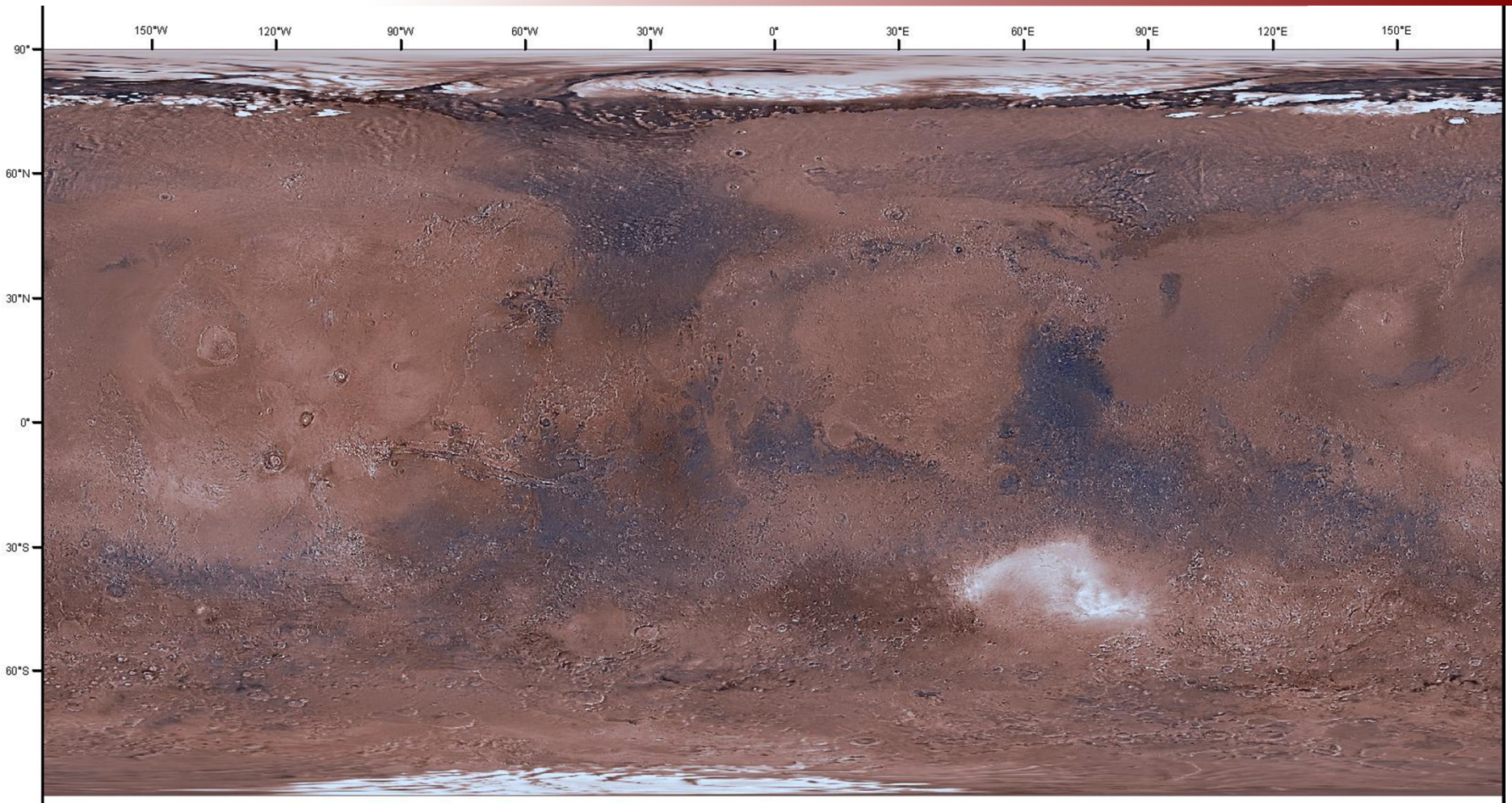


Engineering Constraints

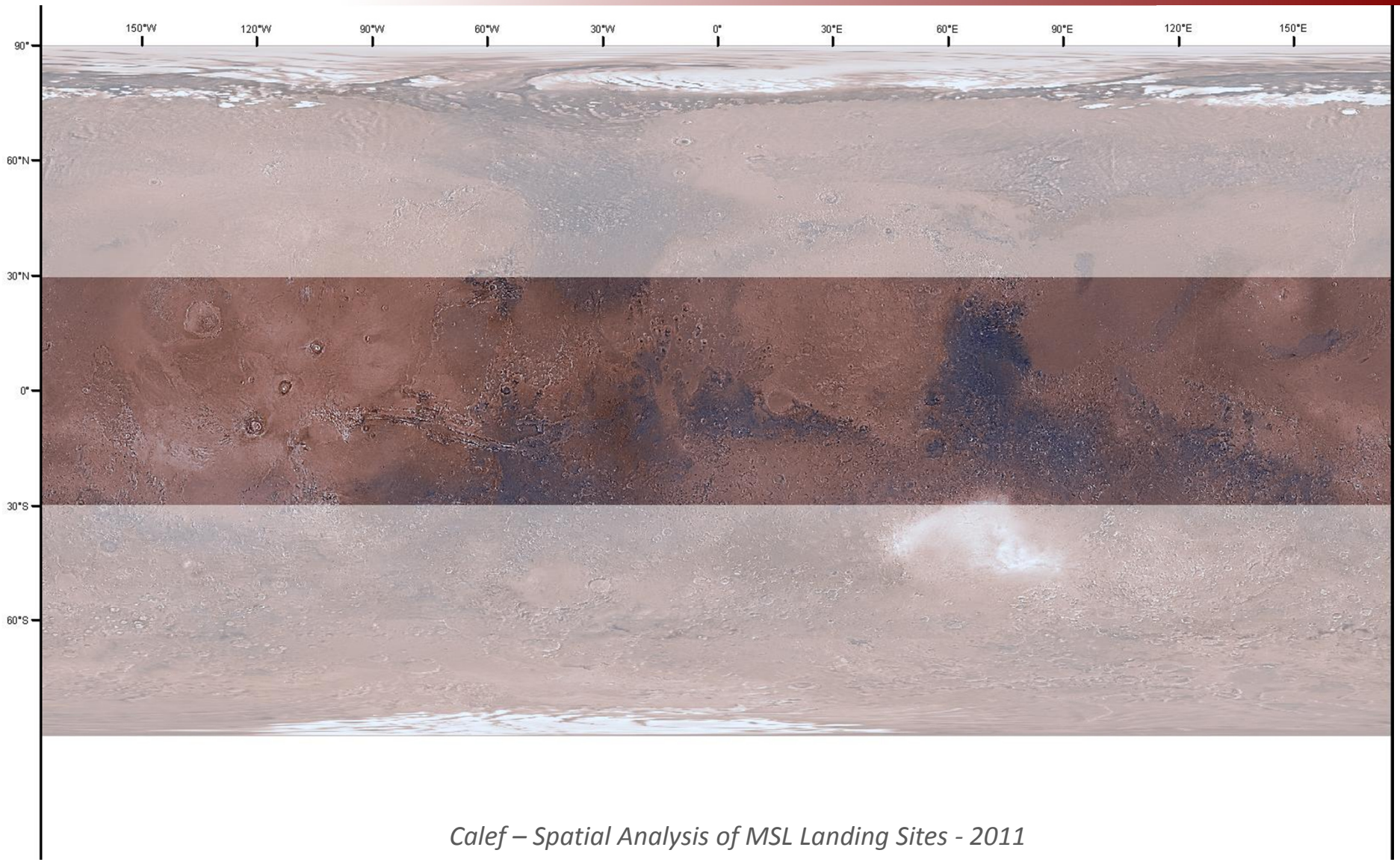
Table 3. Summary of Final Landing Site Engineering Constraints

Engineering Parameter	Requirement	Origin
Latitude	±30°	Thermal Management
Elevation	<-1 km wrt MOLA geoid	Sufficient atmosphere to slow spacecraft
Ellipse dimension	25 km by 20 km, roughly E-W	Aero-maneuvering accuracy
Terrain relief 1-1000 m baselines	100-130 m	Control authority and sufficient fuel during powered descent
Slopes at 2-5 m length scale	<30°	Rover stability at touchdown
Rock height and abundance	Less than 0.5% probability of at least one ≤0.55 m high rock in 4 m^2 area, Equivalent to rock abundance of <8%	Impacting rover belly pan or inside of wheels during touchdown
Radar reflectivity	Ka band reflective with radar backscatter cross section between -20dB and 15 dB	Radar altimeter (TDS) returns during descent
Load bearing surface No thick dust deposits	Thermal inertia >100 J m^{-2} $s^{-0.5}$ K^{-1} and albedo <0.25, Radar reflectivity >0.01 for load bearing bulk density	Rover trafficability No sinkage during touchdown

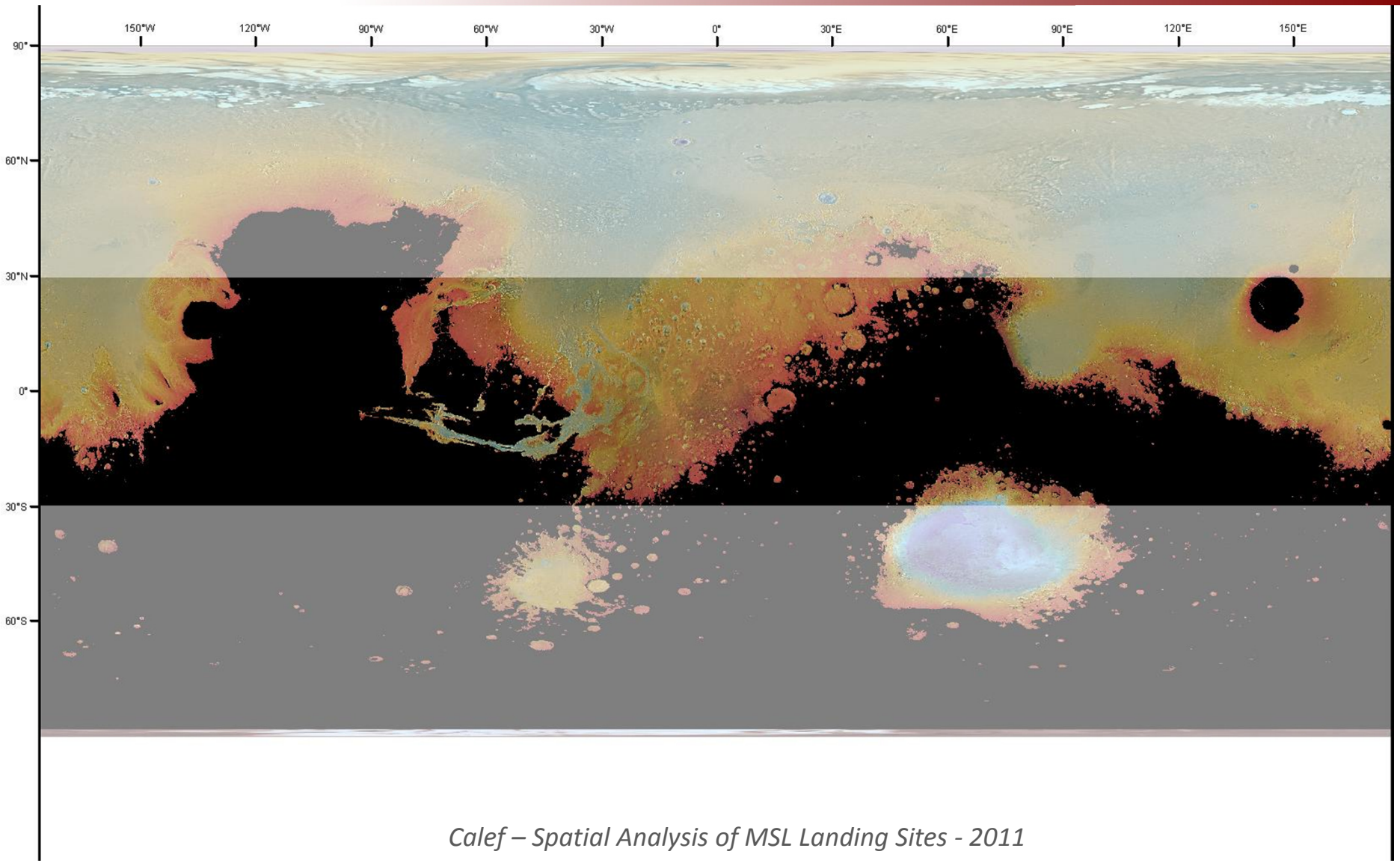
MSL Landing Constraints



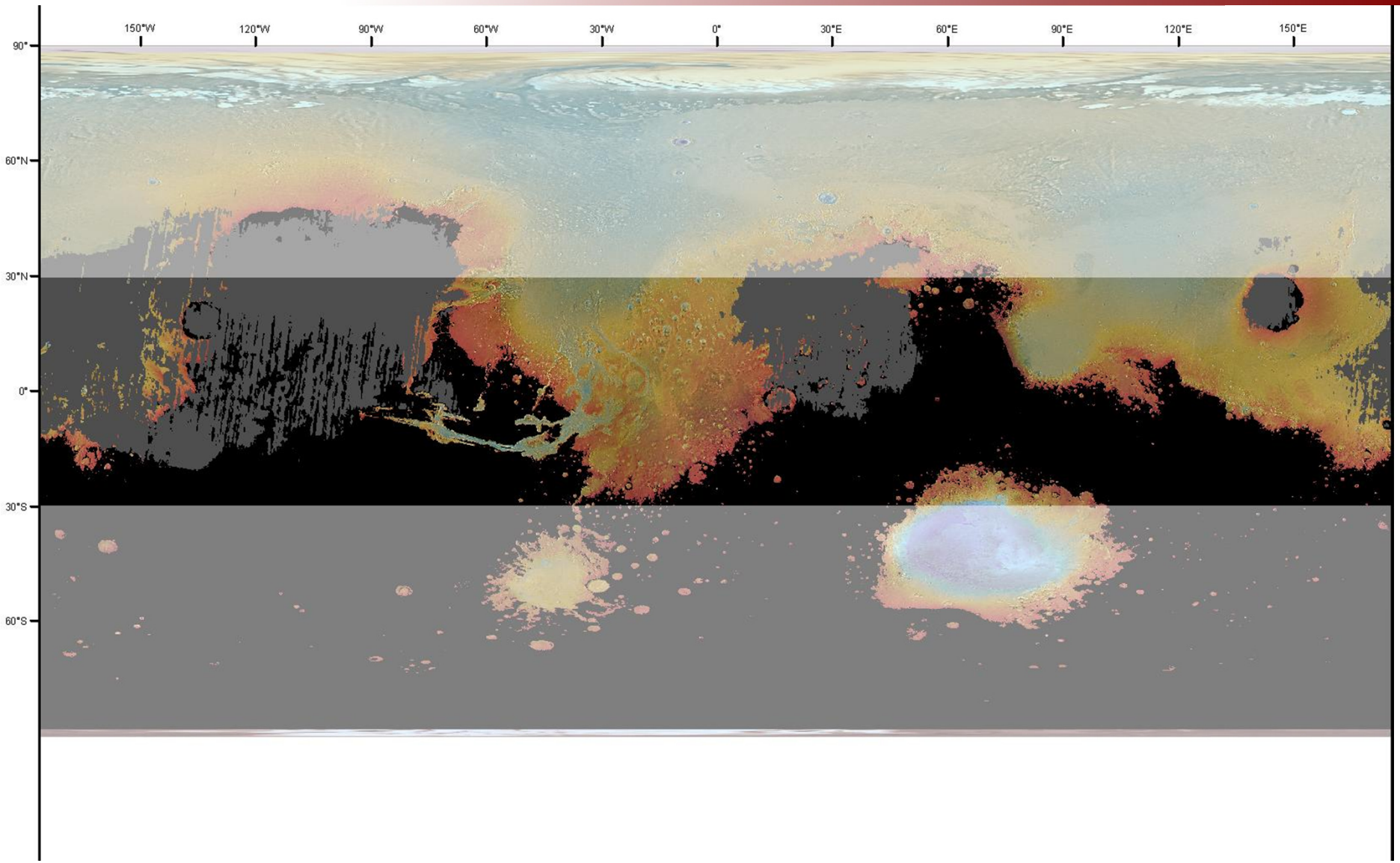
Latitude +-30 degrees



Elevation < -1 km



Thermal Inertia > 100 TIU



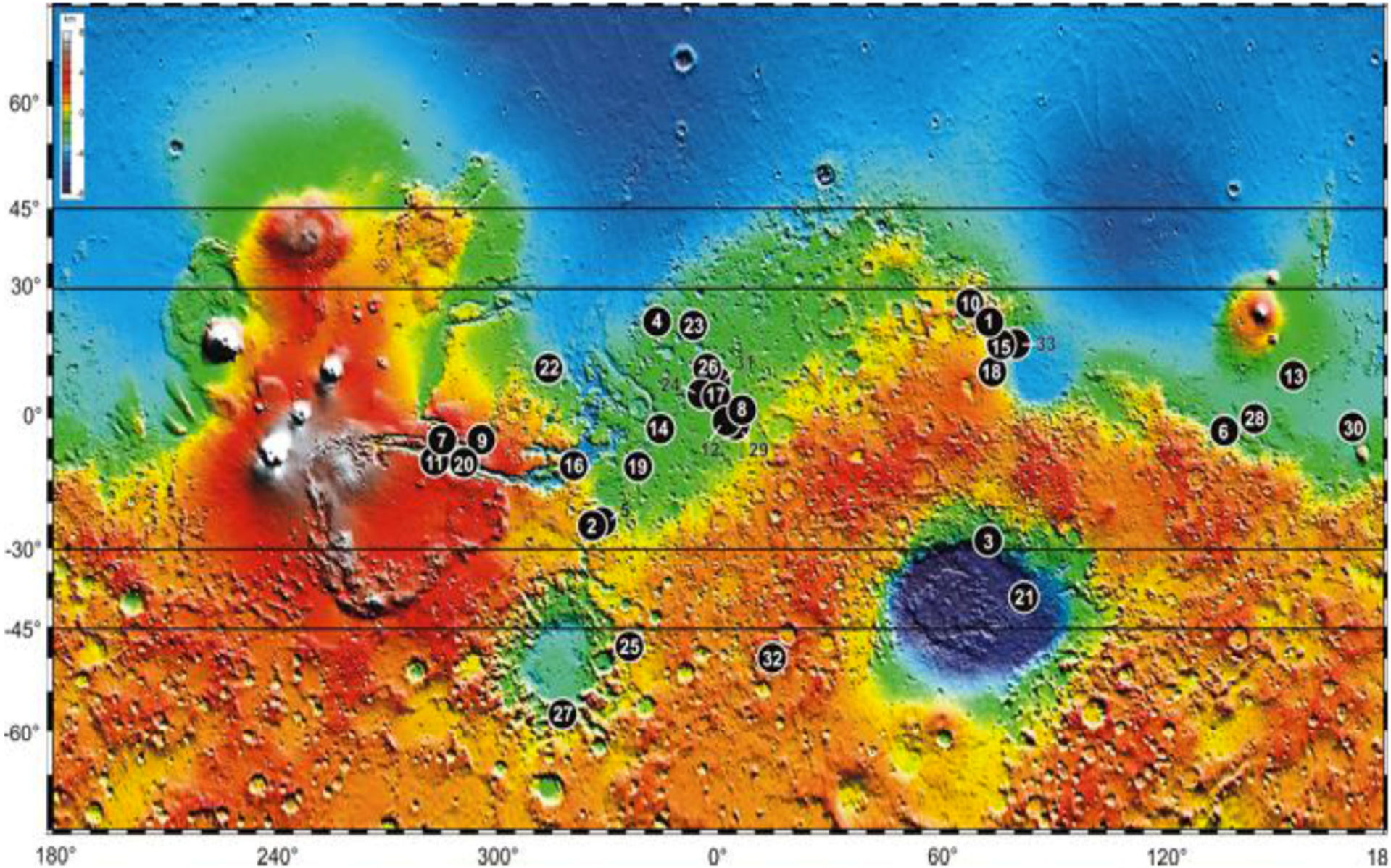
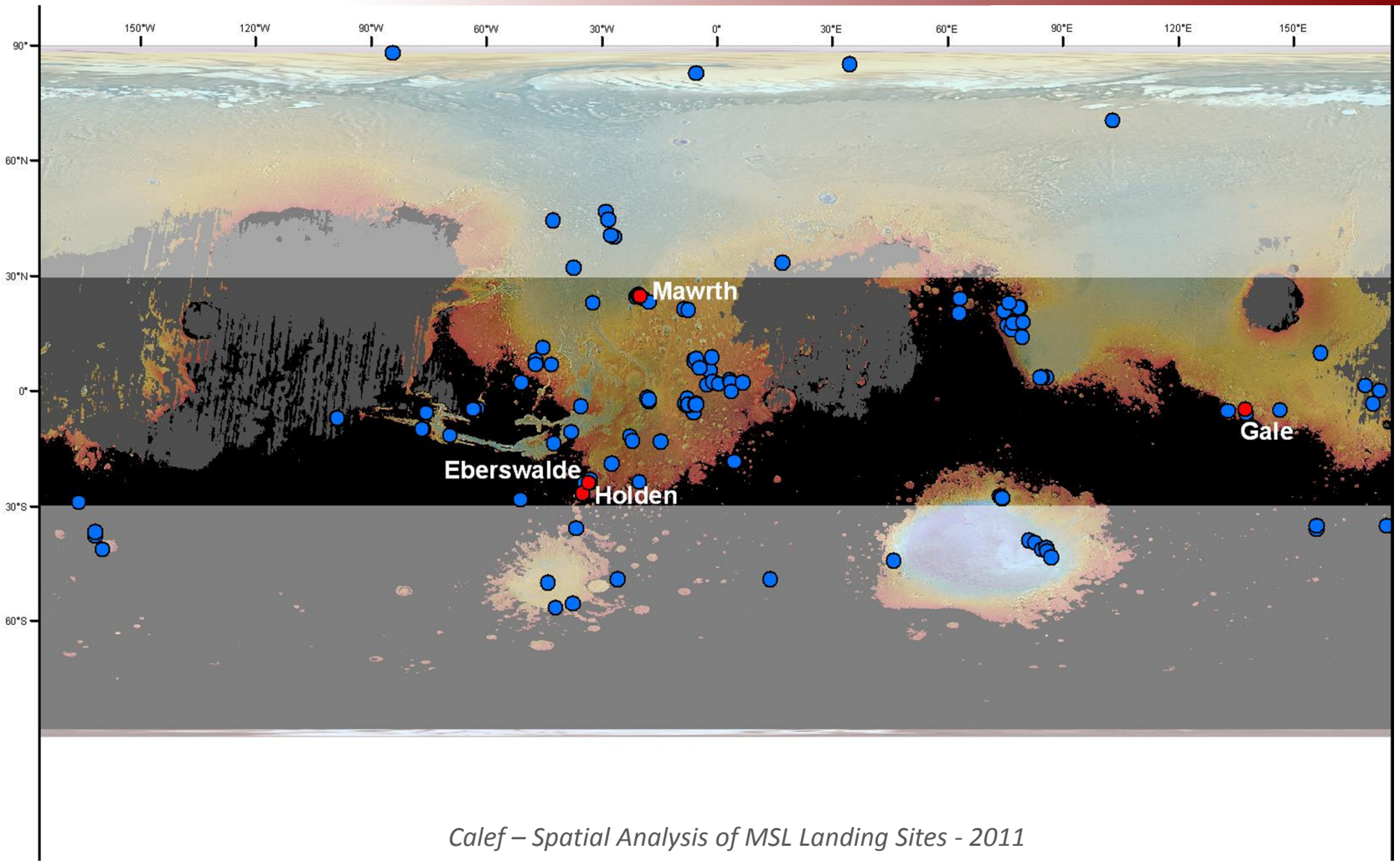


Figure 2. MOLA topographic map of Mars showing location of landing sites proposed for the Mars Science Laboratory at the first workshop (numbered in order of prioritization, Table 5). Revised engineering constraints later restricted landing sites to ±45° latitude and finally ±30°.

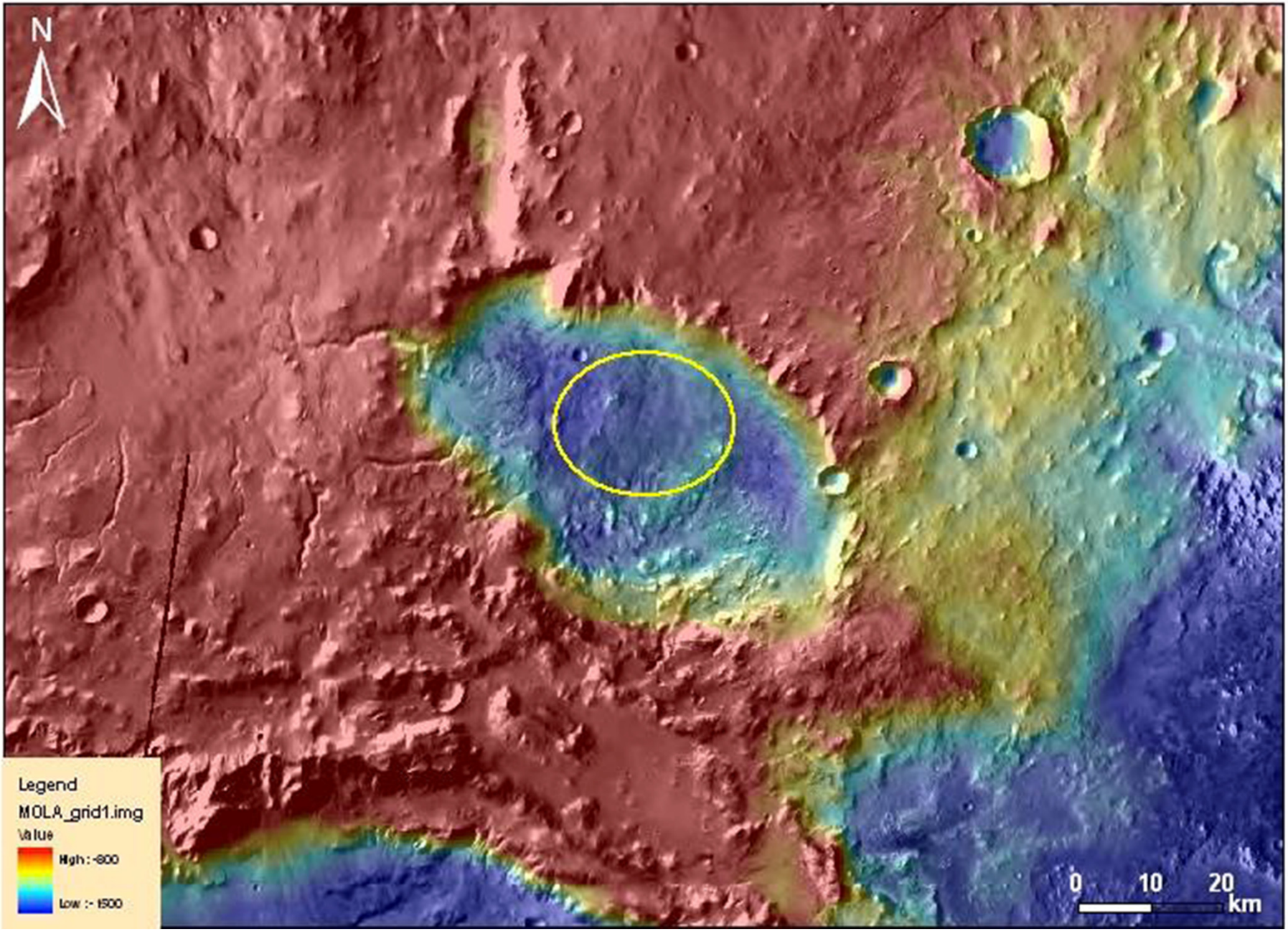
Science Constraints

	Miya	*SMer*	*Nili*	*Hold*	*Ebers*	*Maw2*	*Gale*
Diversity							
1) Multiple rock units obs. from orbit?	🔴	🟡	🟢	🟢	🟢	🟢	🟢
2) Well-defined strat./X-cutting relations?	🔴	🔴	🟡	🟢	🟢	🟡	🟢
3) Diverse mineralogy / systematic trends?	🔴	🟡	🟢	🟡	🟡	🟢	🟢
4) Diverse geomorphology / system. trends?	🔴	🔴	🟢	🟢	🟢	🟡	🟢
Context							
5) Geologic framework before landing?	🔴	🟡	🟡	🟢	🟢	🟡	🟡
6) Place MSL obs. into regional context?	🟡	🟡	🟡	🟢	🟢	🟢	🟢
7) Well-resolved chronology of rock units?	🟡	🟡	🟡	🟢	🟢	🟢	🟢
Habitability							
8) Min./Geomorph. evidence?	🔴	🟡	🟡	🟢	🟢	🟡	🟢
9) Indicators of water duration, pH, activity?	🔴	🔴	🟡	🟢	🟢	🟡	🟡
Preservation							
10) Timing of minerals wrt sedimentation?	🔴	🟡	🟡	🟢	🟢	🟡	🟡
11) Environment for preservation?	🔴	🔴	🟡	🟢	🟢	🟡	🟡

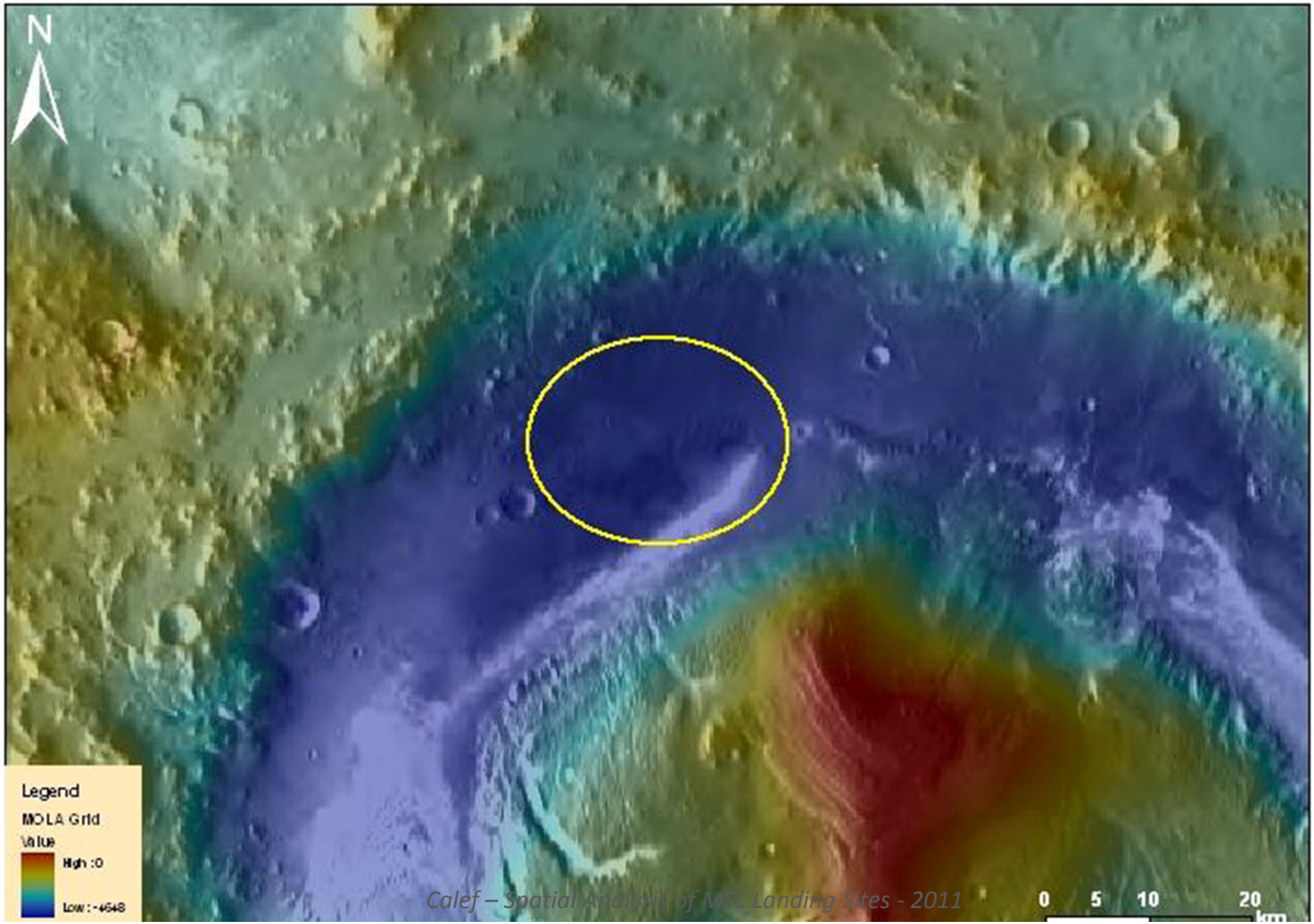
Science Sites



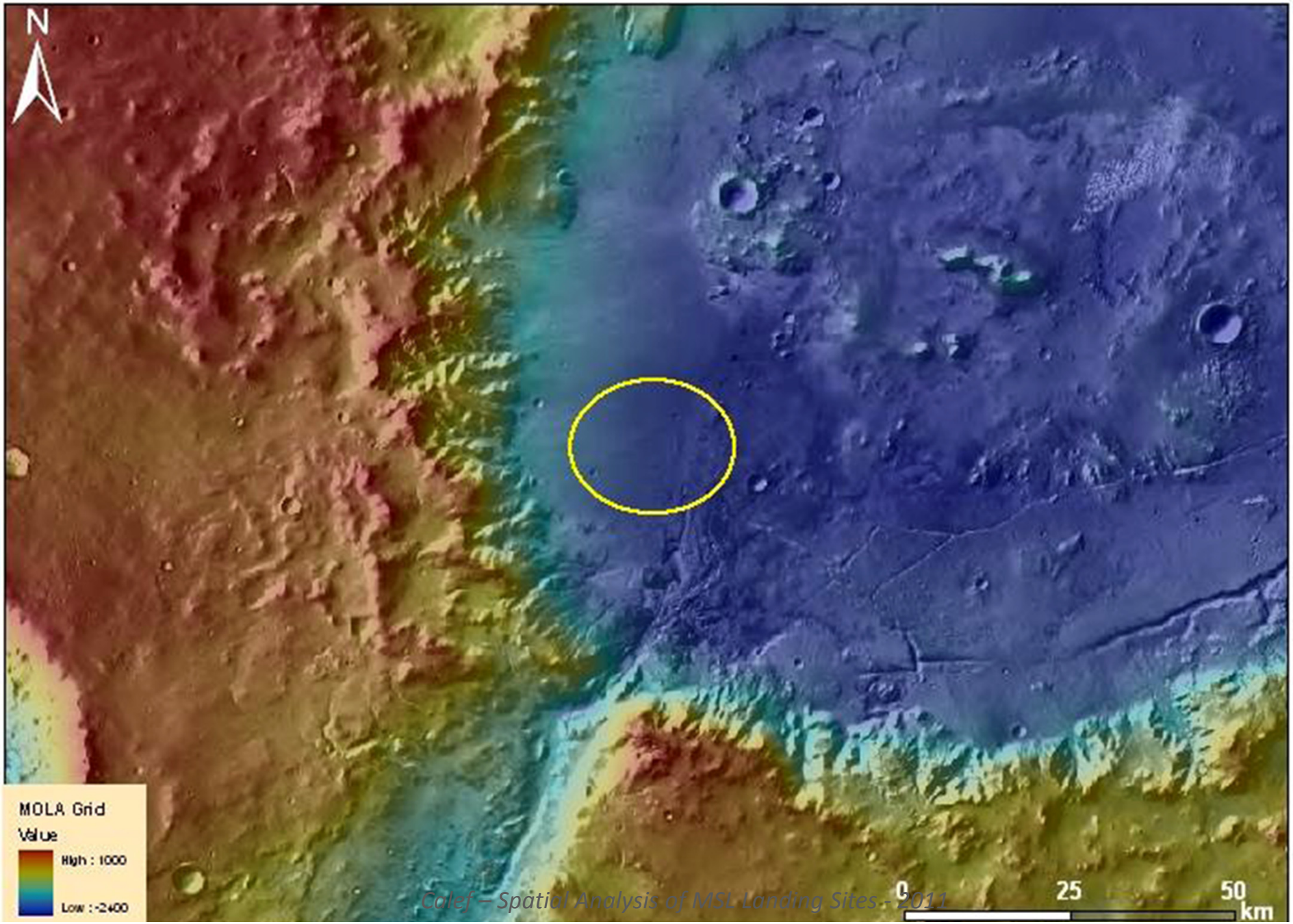
Eberswalde Crater: MOLA



Gale Crater: MOLA



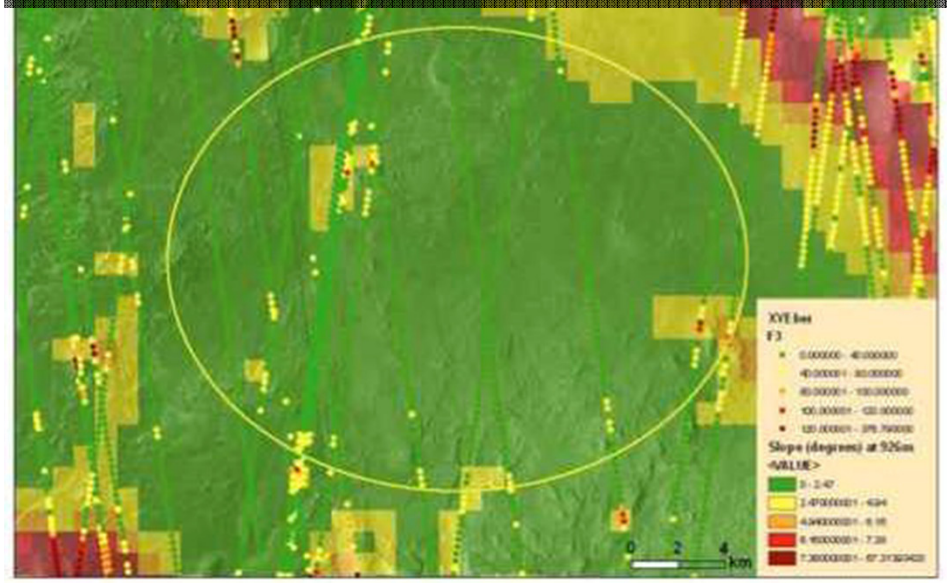
Holden Crater: MOLA



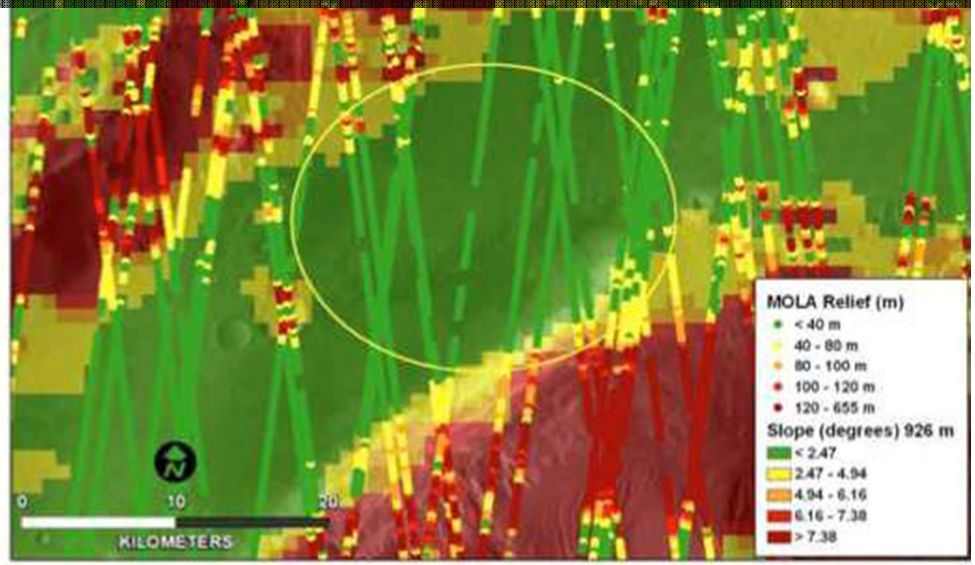
Mawrth Vallis Site 2: MOLA

MOLA Relief <100m over 1km

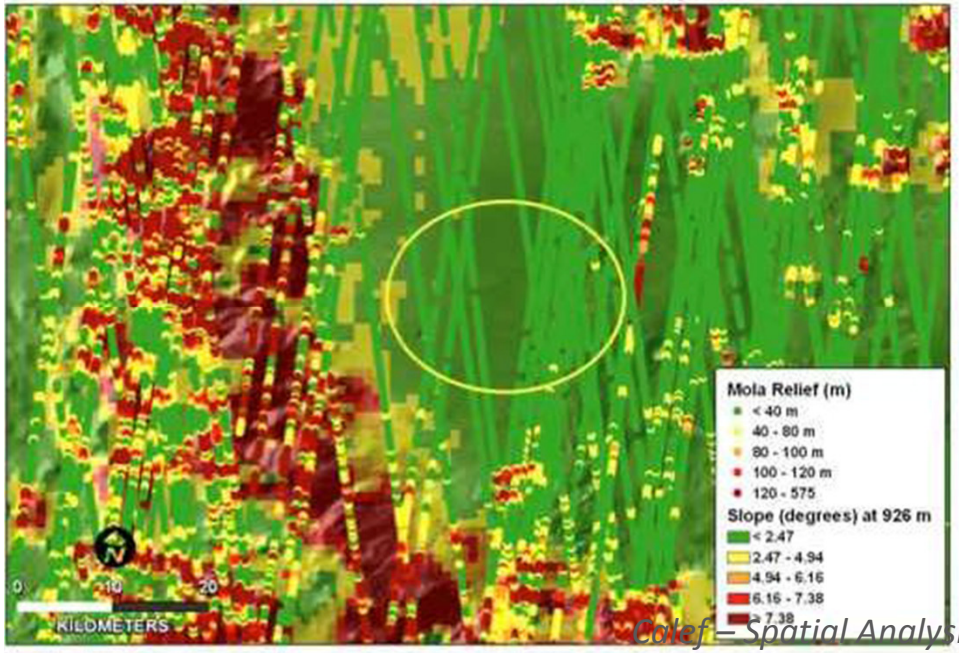
Eberswalde Crater: MOLA bins with MOLA Longtrack



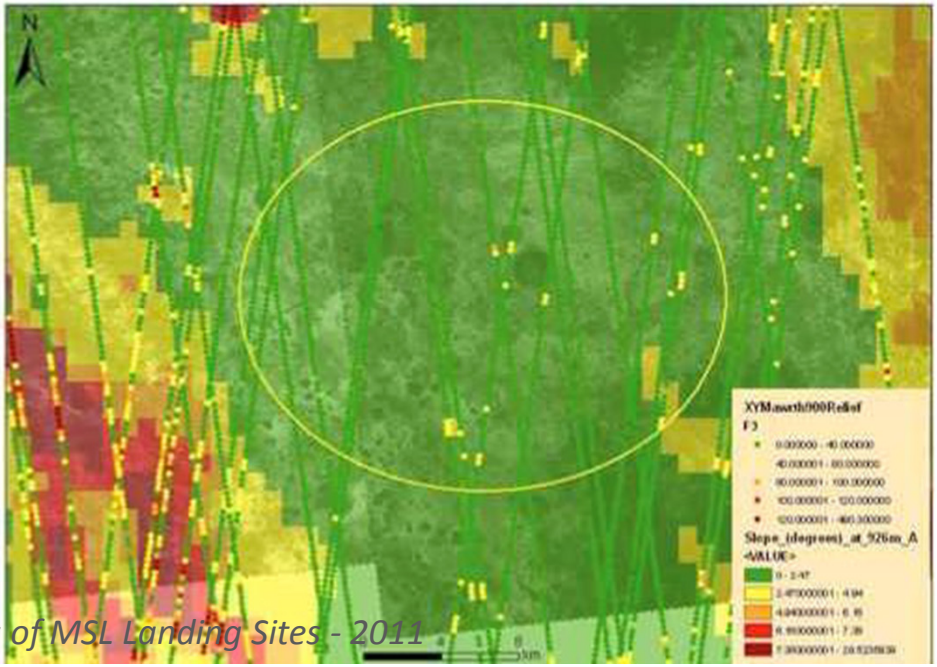
Gale Crater MOLA Bins with MOLA Longtrack



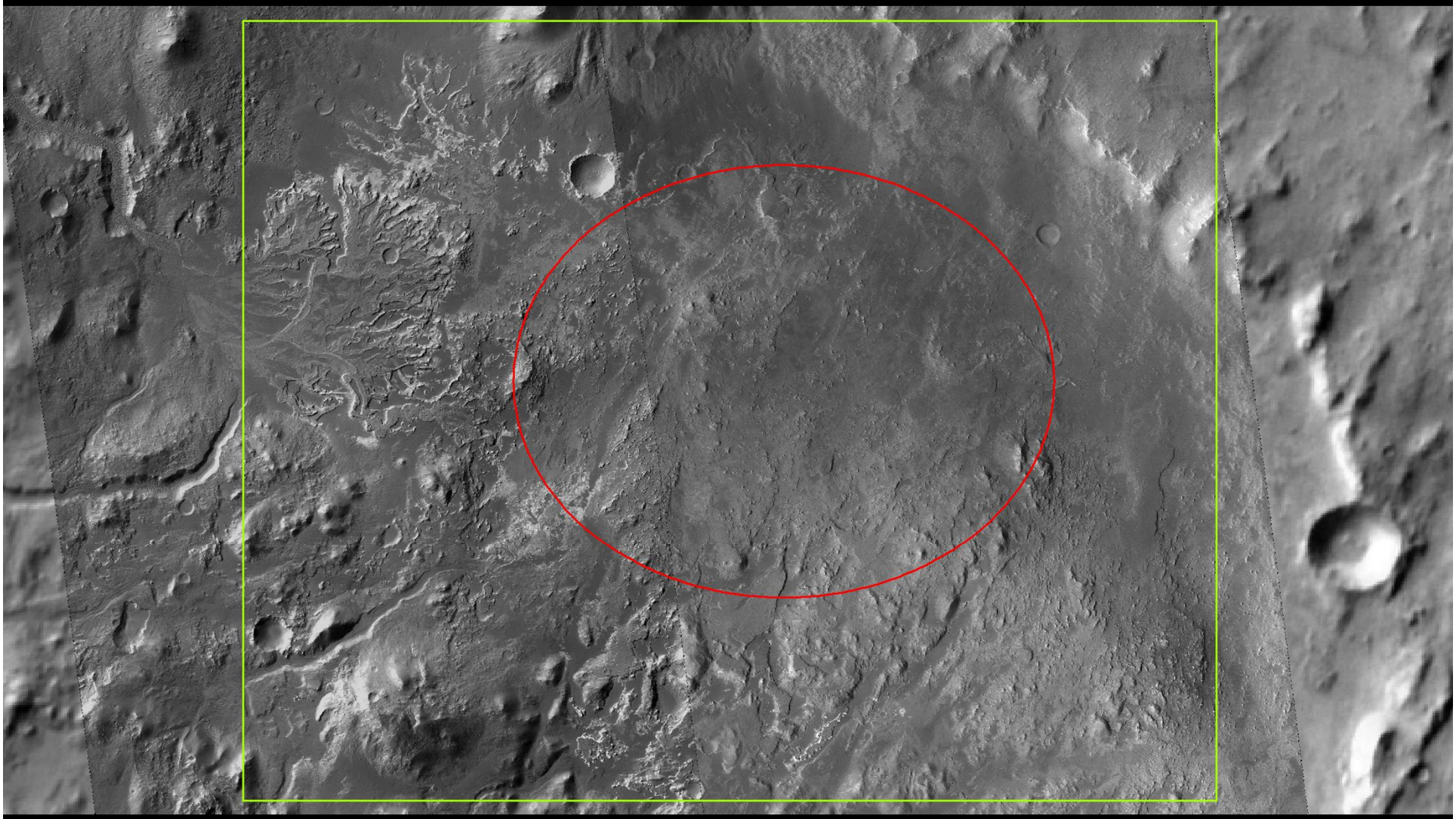
Holden Crater MOLA Bins with MOLA Longtrack



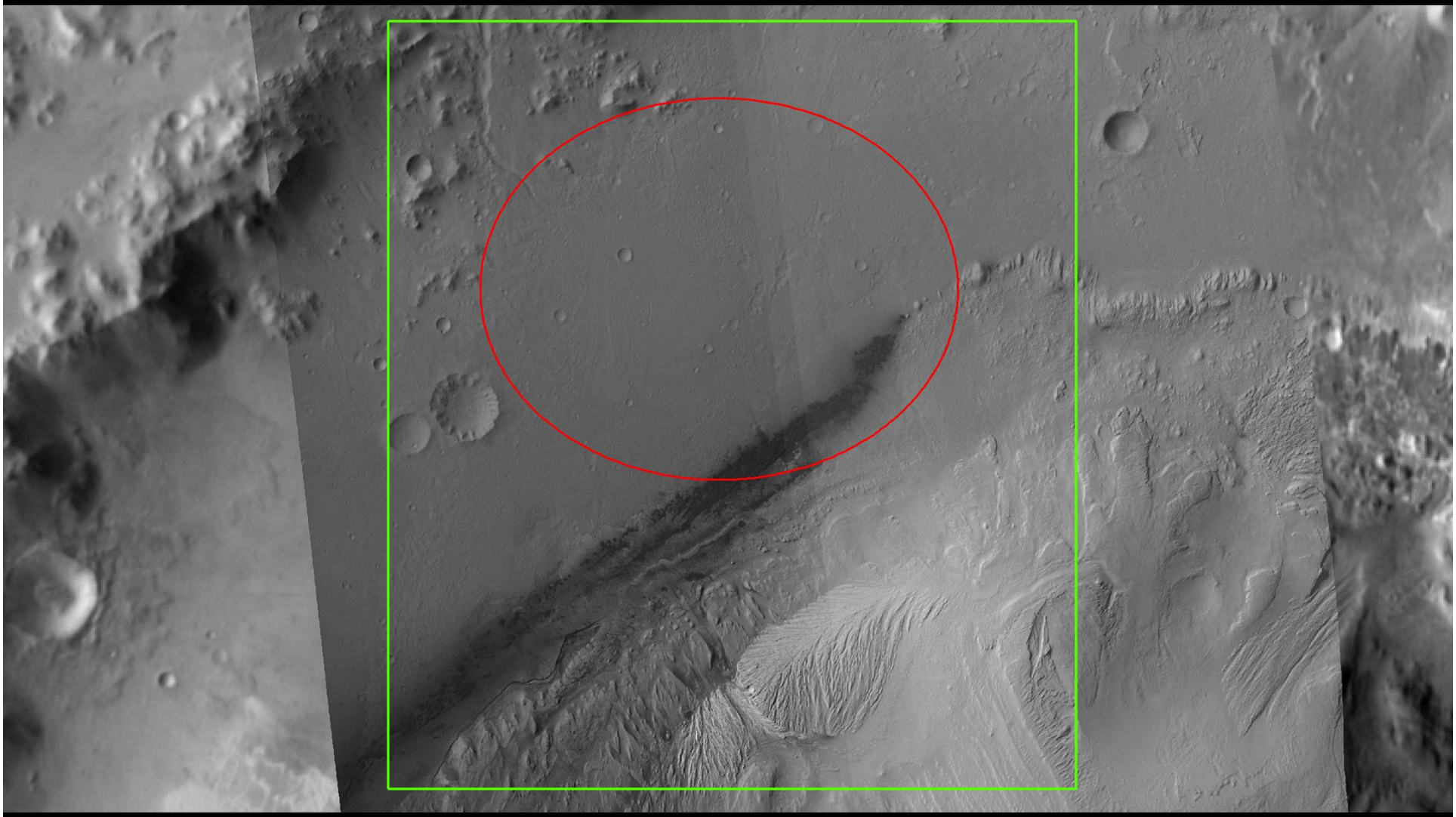
Mawrth Vallis MOLA Bins with MOLA Longtrack



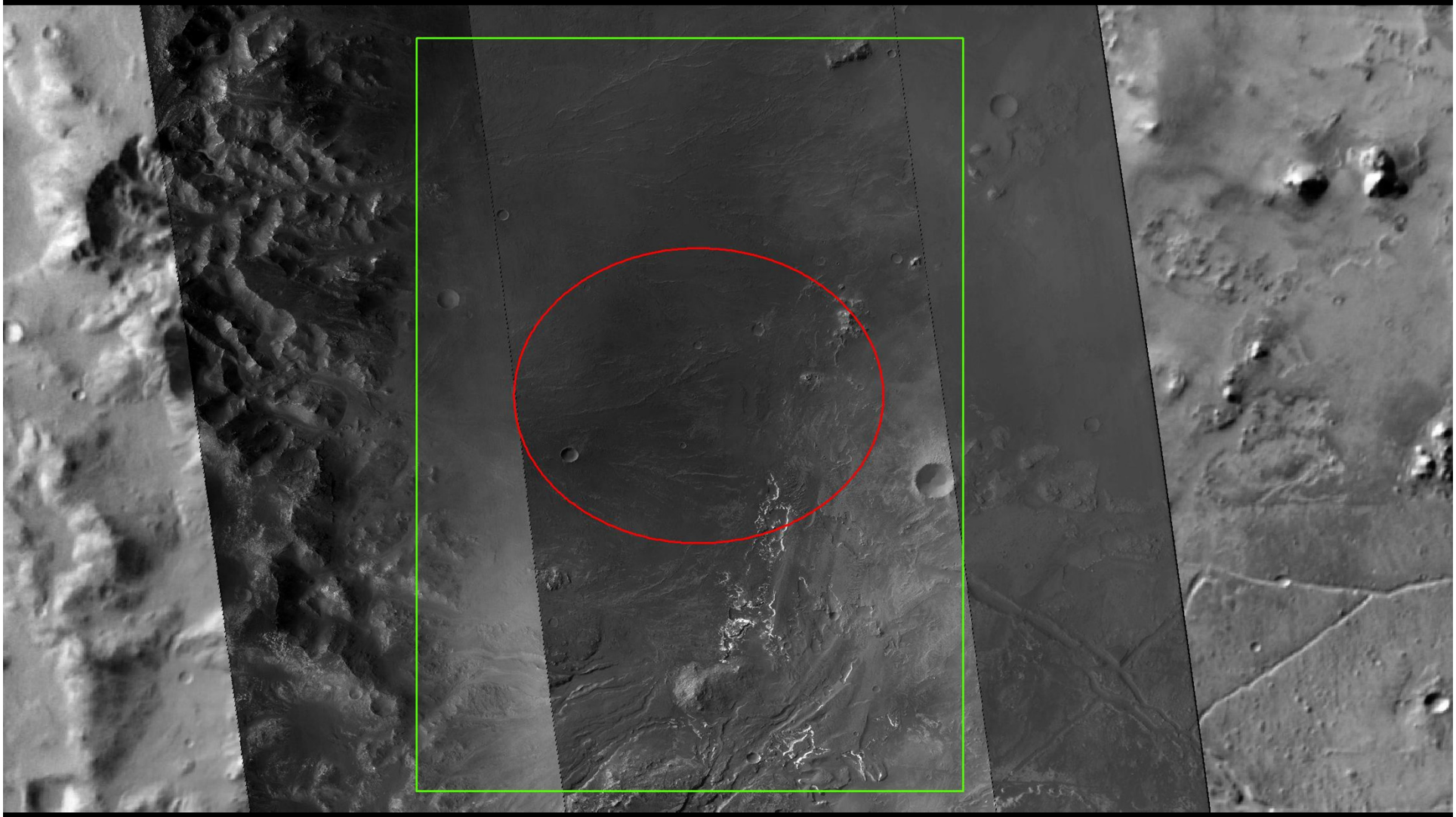
Eberswalde



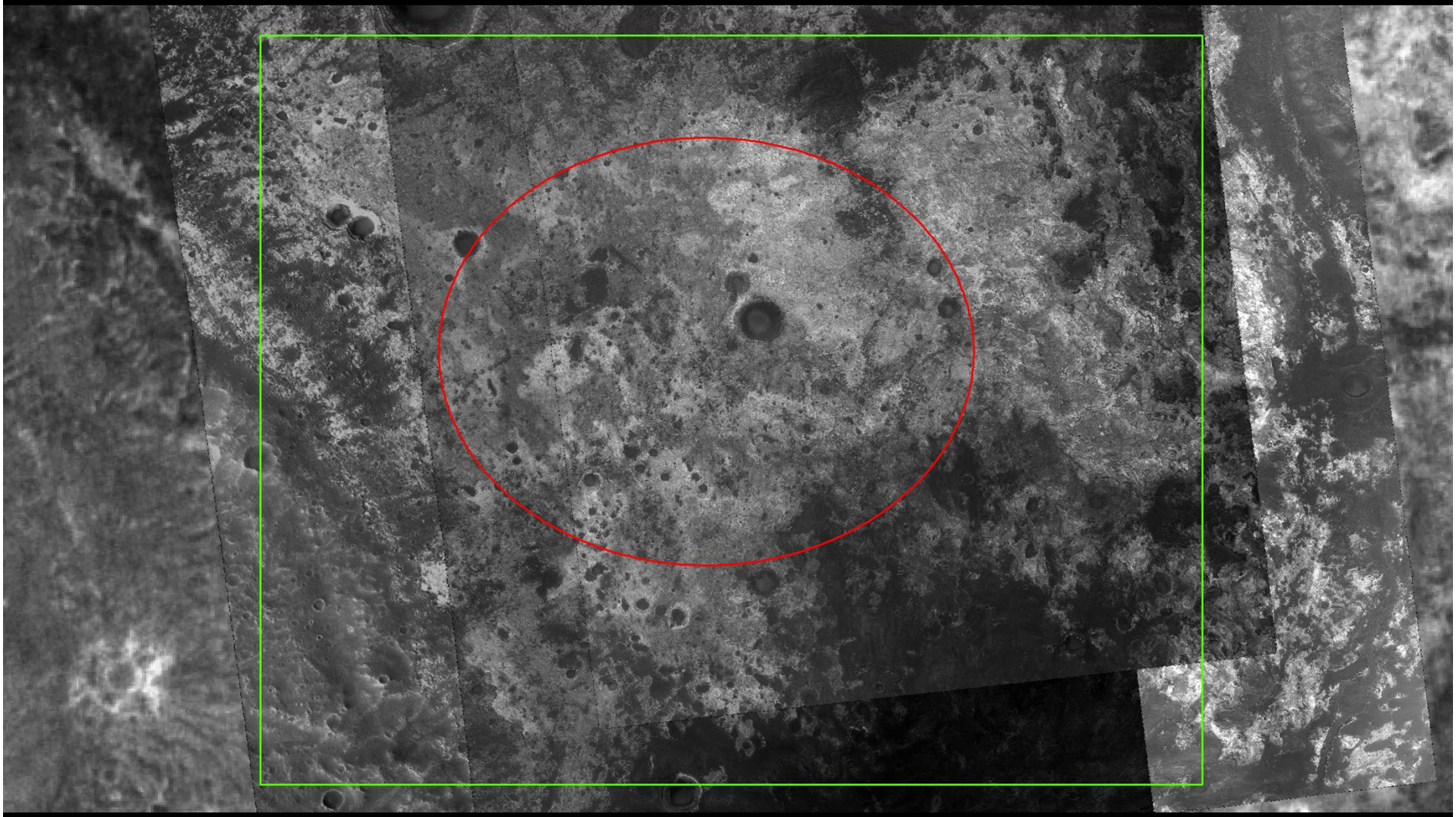
Gale



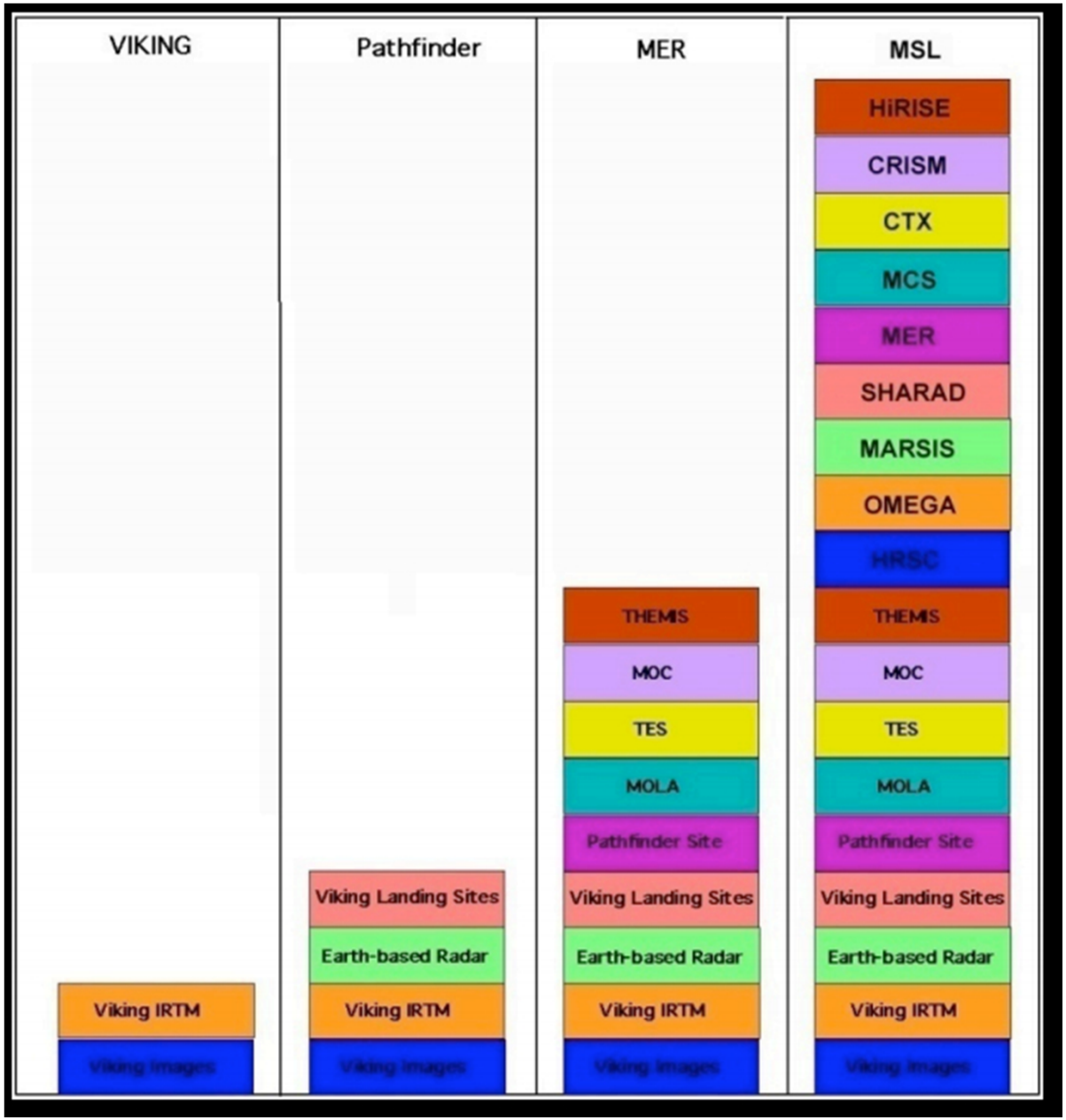
Holden



Mawrth

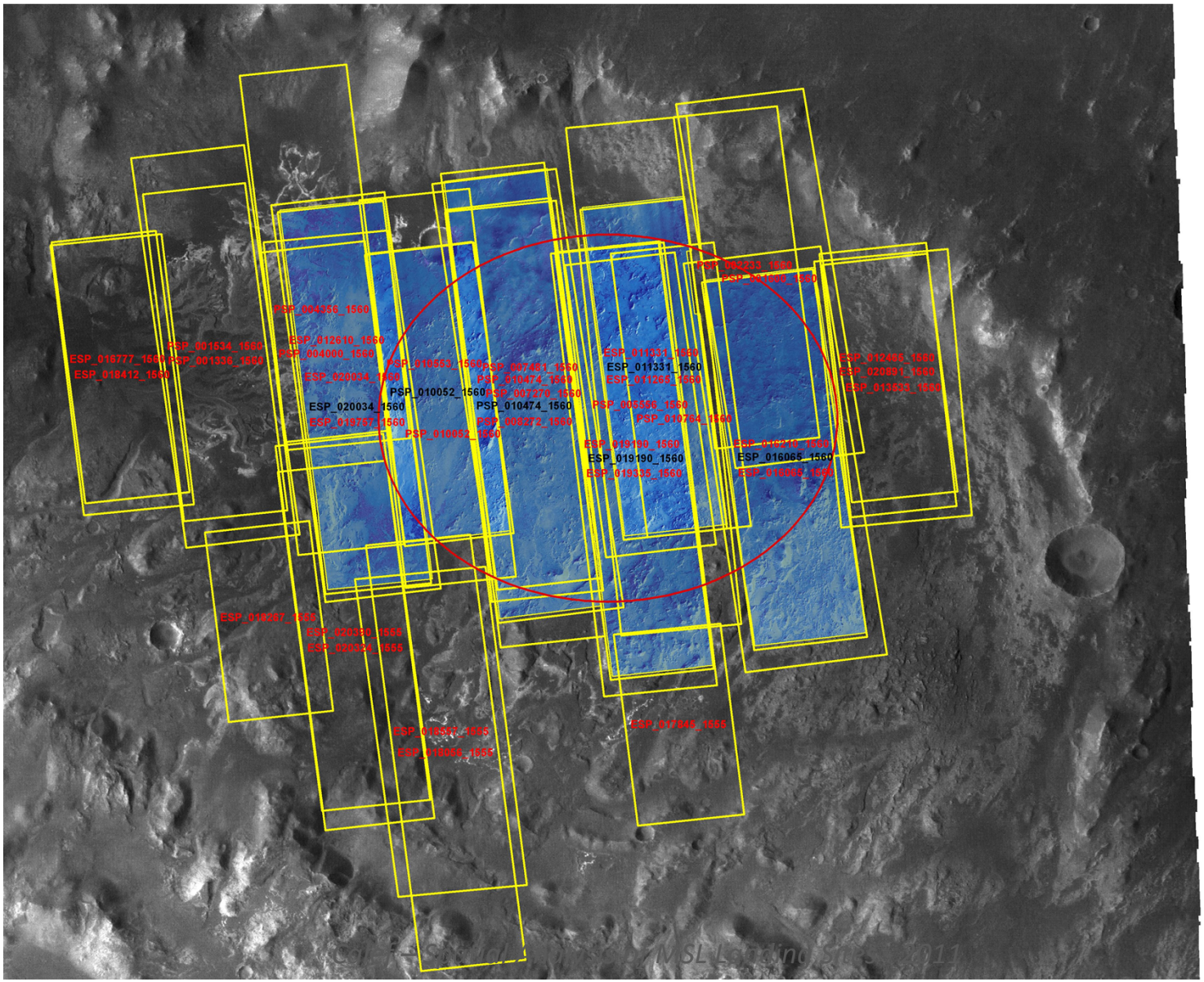


Available Instrument Data

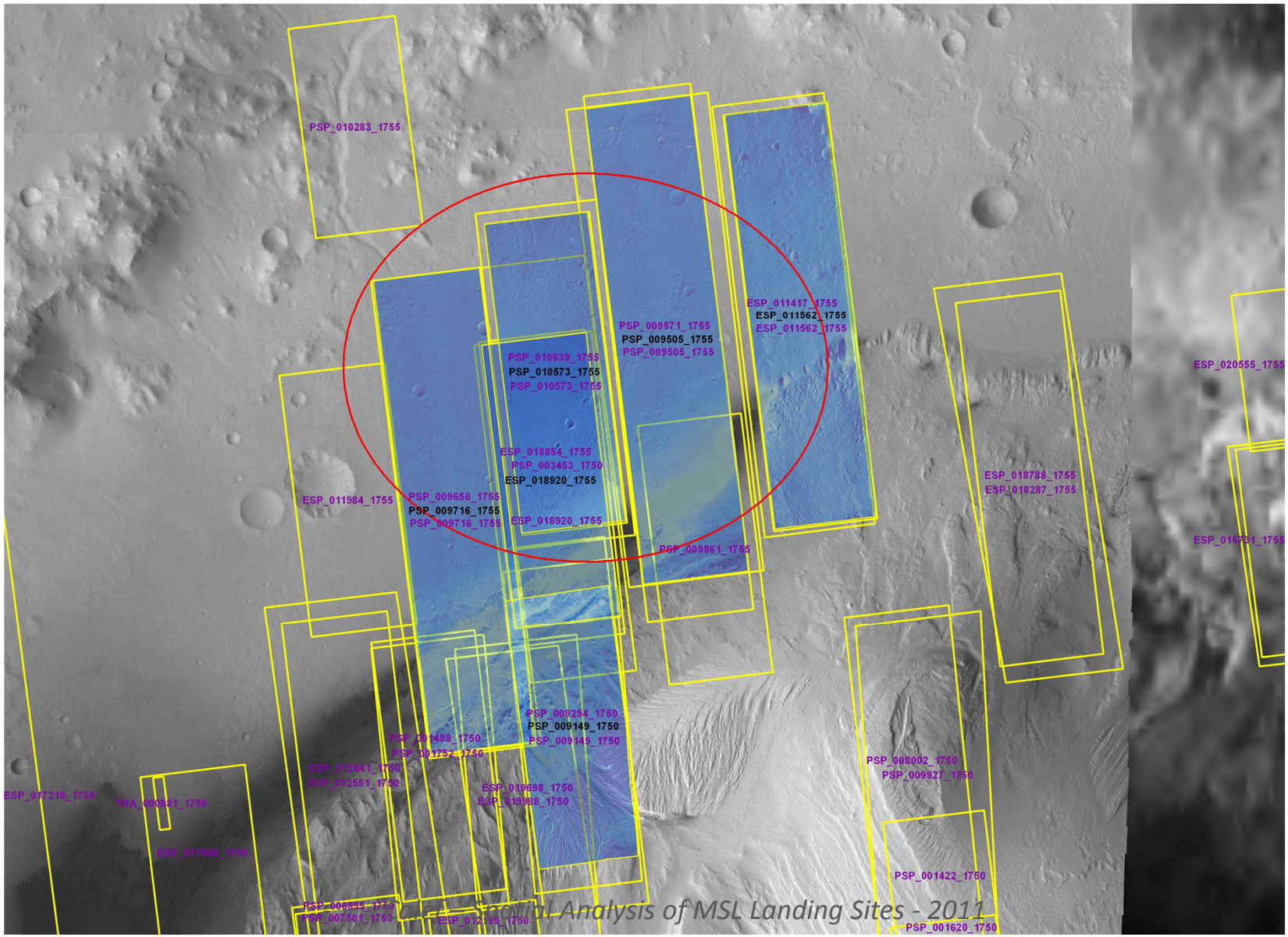


0.25m/pixel
18m/pixel
6m/pixel
13m/pixel
20-100m/p
2-5m/pixel
463m/pixel
~200-12m/p

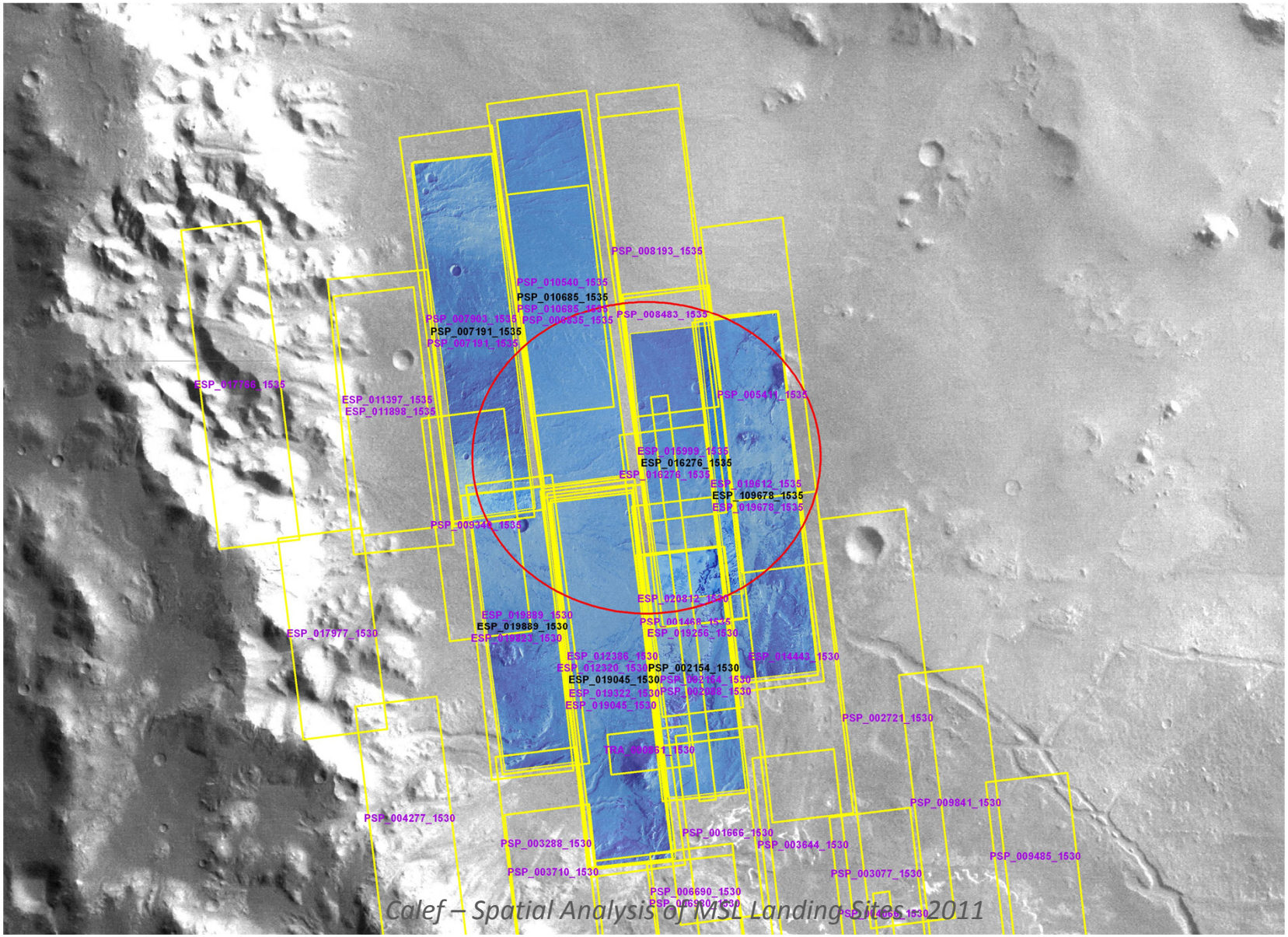
Eberswalde: HiRISE Footprints



Gale: HiRISE Footprints



Holden: HiRISE Footprints



Mawrth: HiRISE Footprints

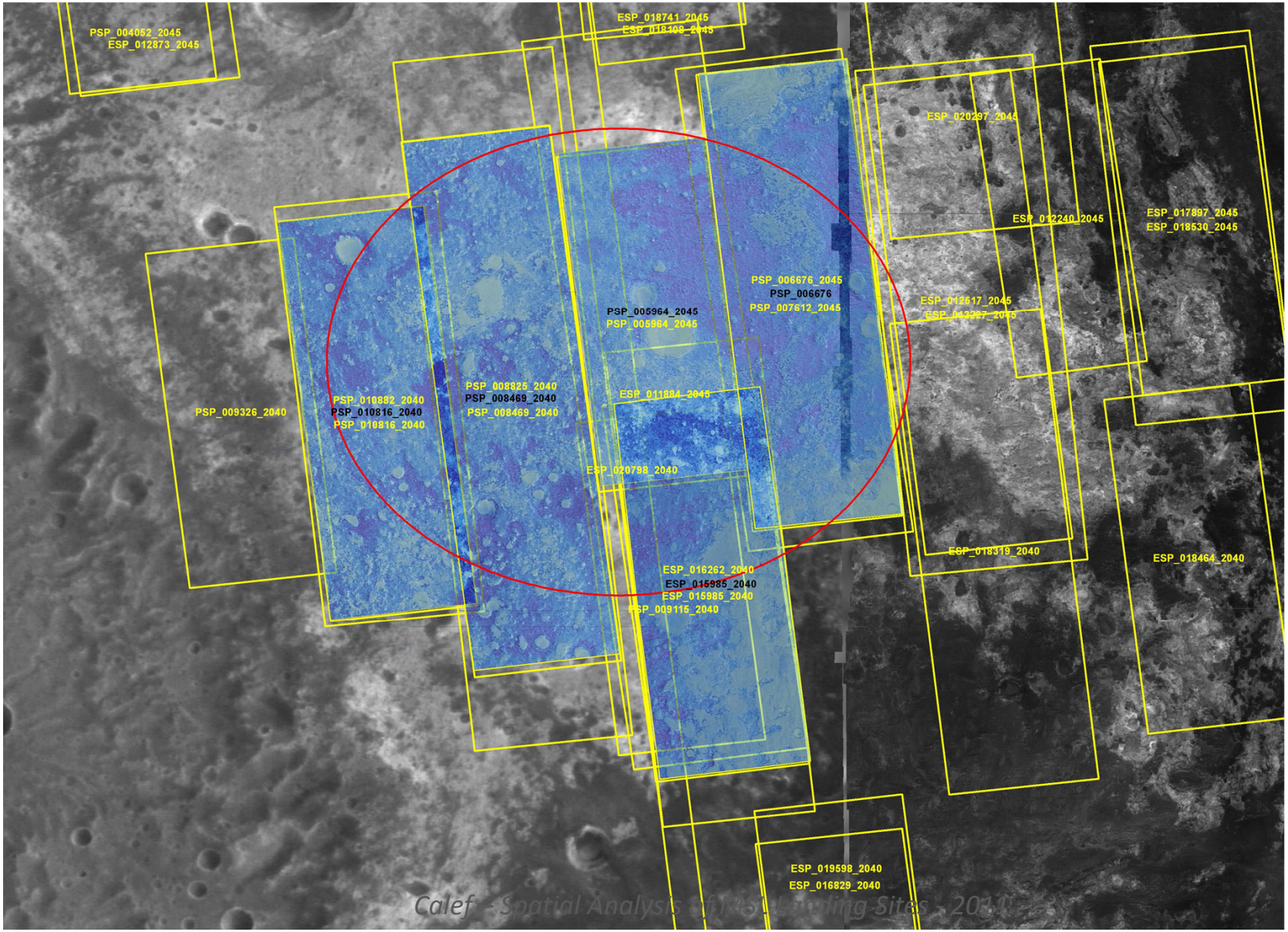
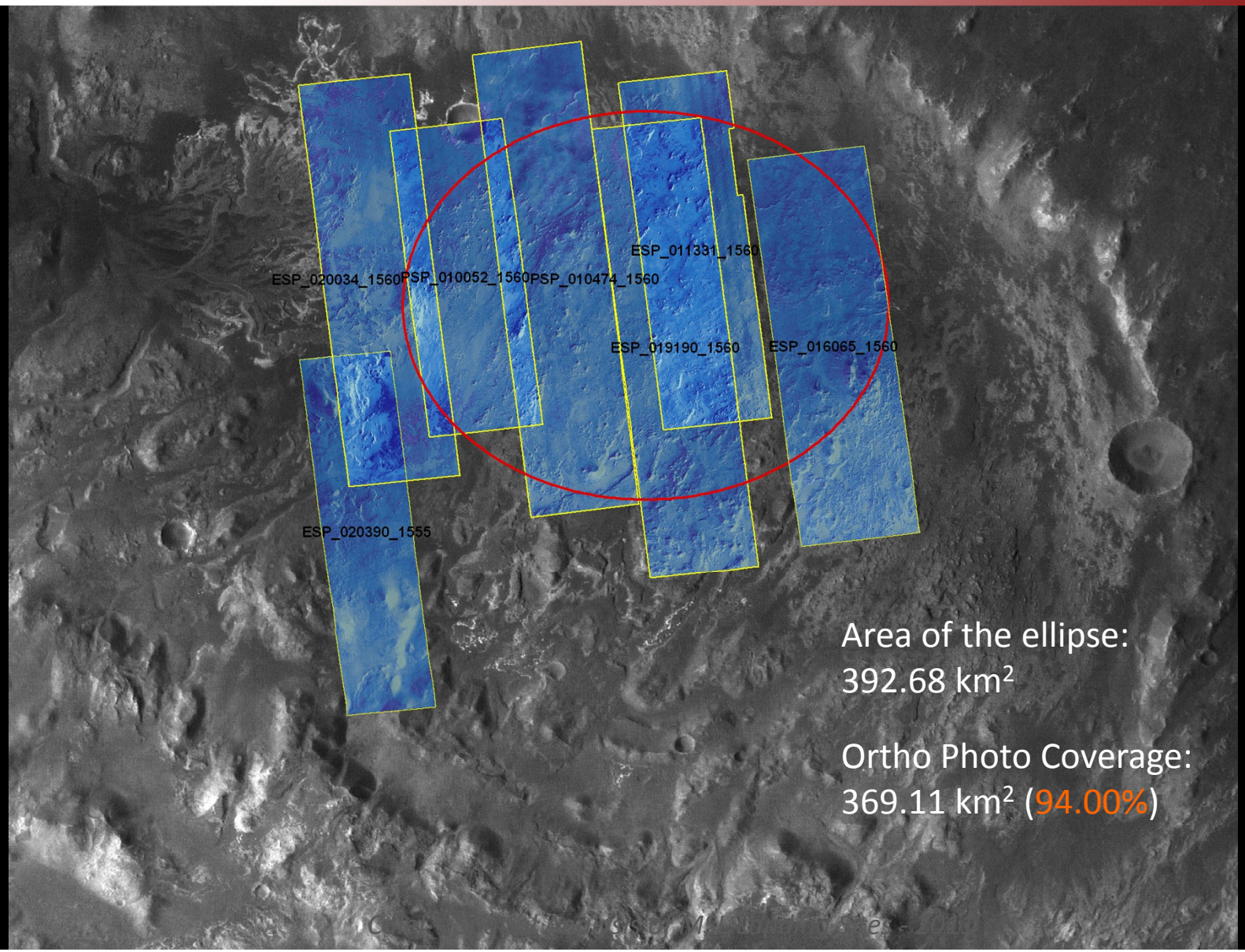


Table 4. HiRISE stereo pairs and images* used to make DEMs, orthophotos, rock maps, terrain classification and traversabilty maps at the time of landing site selection

Eberswalde Crater	Gale Crater	Holden Crater	Mawrth Vallis
PSP_008272_1560	PSP_009149_1750	PSP_002088_1530	PSP_005964_2045*
PSP_010474_1560*	PSP_009249_1750*	PSP_002154_1530*	ESP_011884_2045
PSP_010052_1560*	PSP_009505_1755*	PSP_007191_1535*	PSP_006676_2045*
PSP_010553_1560	PSP_009571_1755	PSP_007903_1535	PSP_007612_2045
ESP_011265_1560	PSP_009650_1755	PSP_010540_1535	PSP_008469_2040*
ESP_011331_1560*	PSP_009716_1755*	PSP_010685_1535*	PSP_008825_2040
ESP_016065_1560	PSP_010573_1755*	ESP_015999_1535	PSP_010816_2040*
ESP_016210_1560*	PSP_010639_1755	ESP_016276_1535*	PSP_010882_2040
ESP_019190_1560*	ESP_011417_1755	ESP_019045_1530*	ESP_015985_2040
ESP_019335_1560	ESP_011562_1755*	ESP_019322_1530	ESP_016262_2040*
ESP_019757_1560*	ESP_018854_1755*	ESP_019612_1535*	
ESP_020034_1560	ESP_018920_1755	ESP_019678_1535	
ESP_020324_1555*		ESP_019823_1530*	
ESP_020390_1555		ESP_019889_1530	

Images with an asterisk denote those used for computing rock lists and their derived products: rock abundance, cumulative fractional area, and "additional strikes".

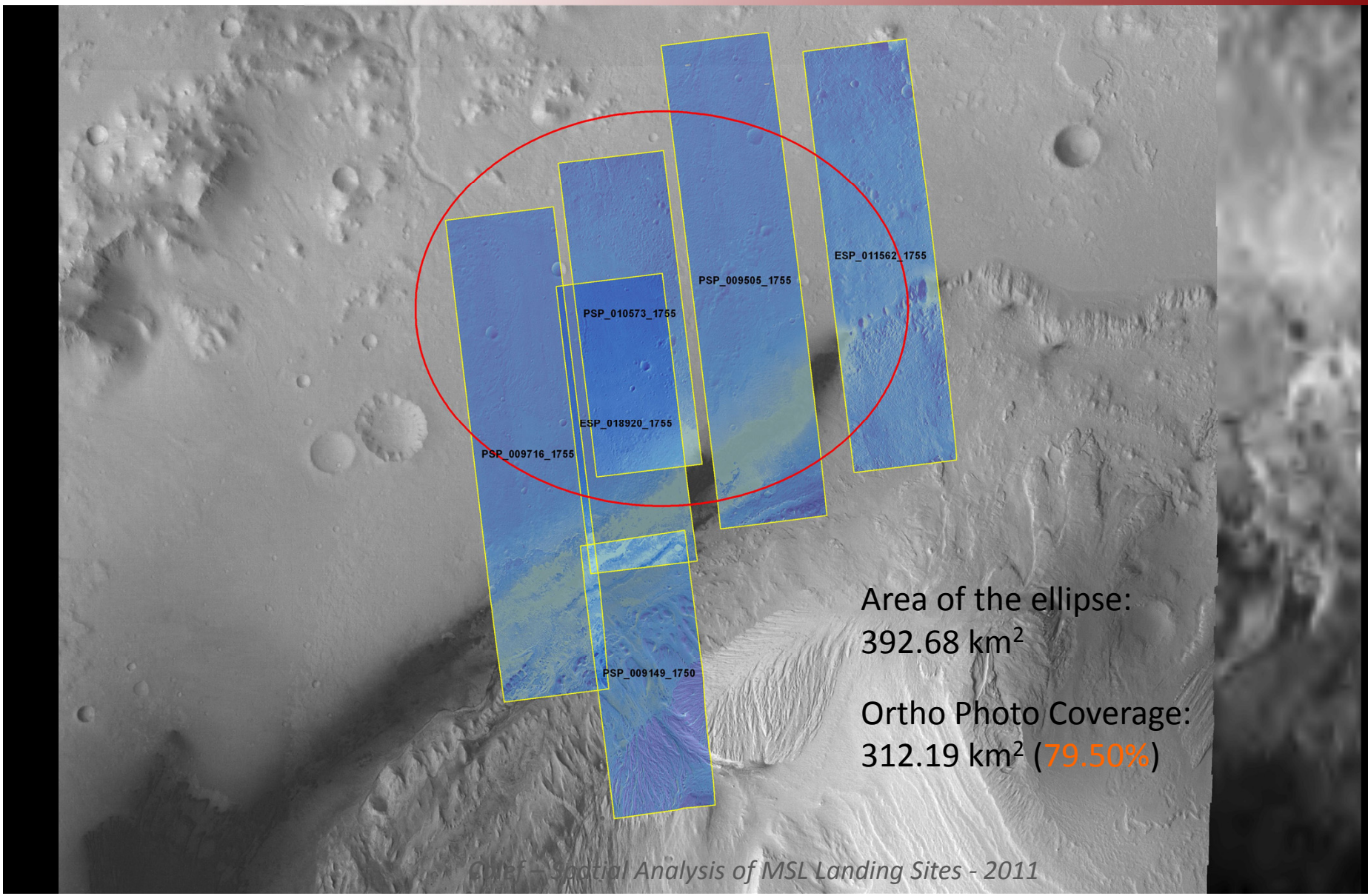
Orthophotos - Eberswalde



Area of the ellipse:
392.68 km^2

Ortho Photo Coverage:
369.11 km^2 (94.00%)

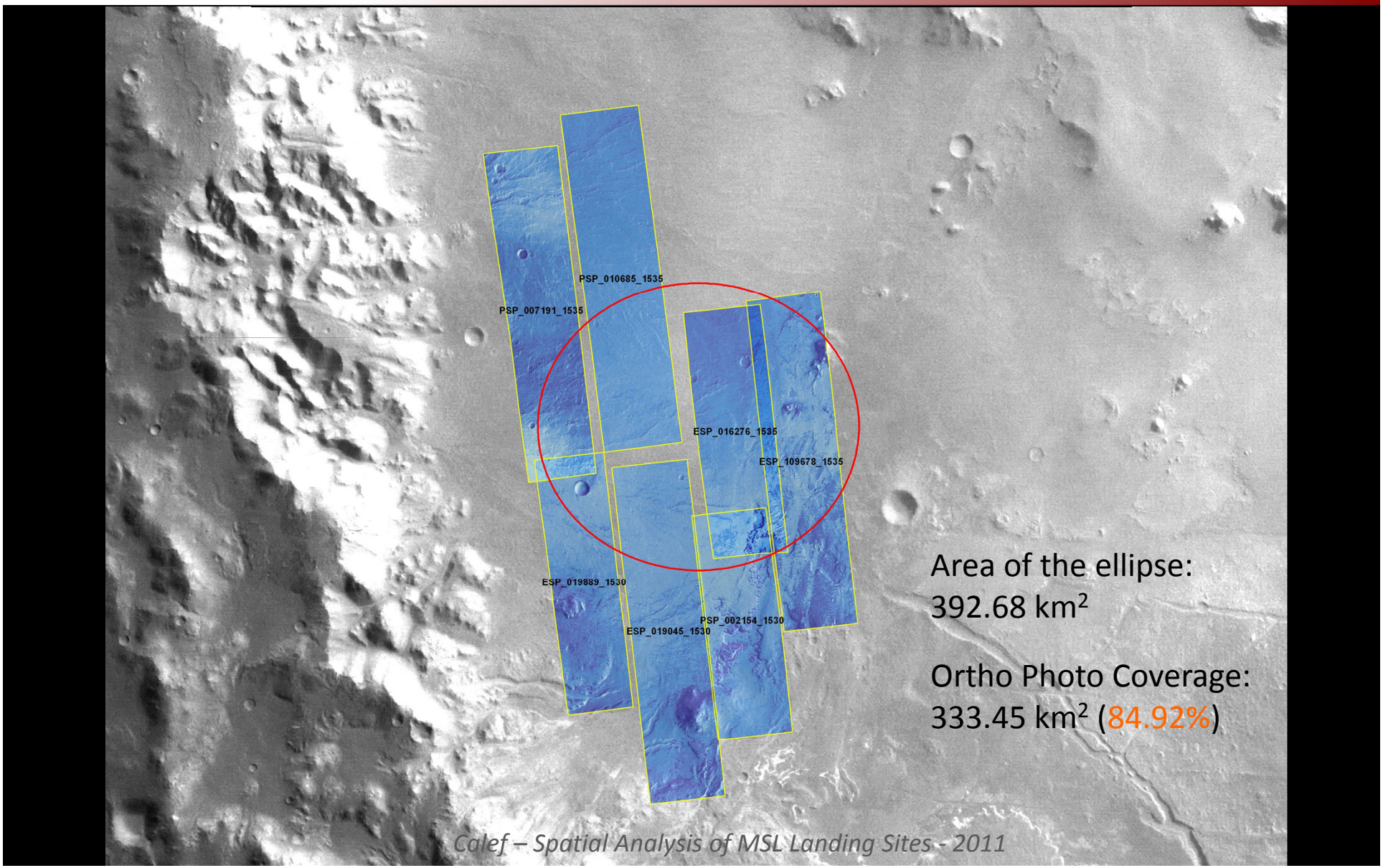
Orthophotos - Gale



Area of the ellipse:
392.68 km^2

Ortho Photo Coverage:
312.19 km^2 (79.50%)

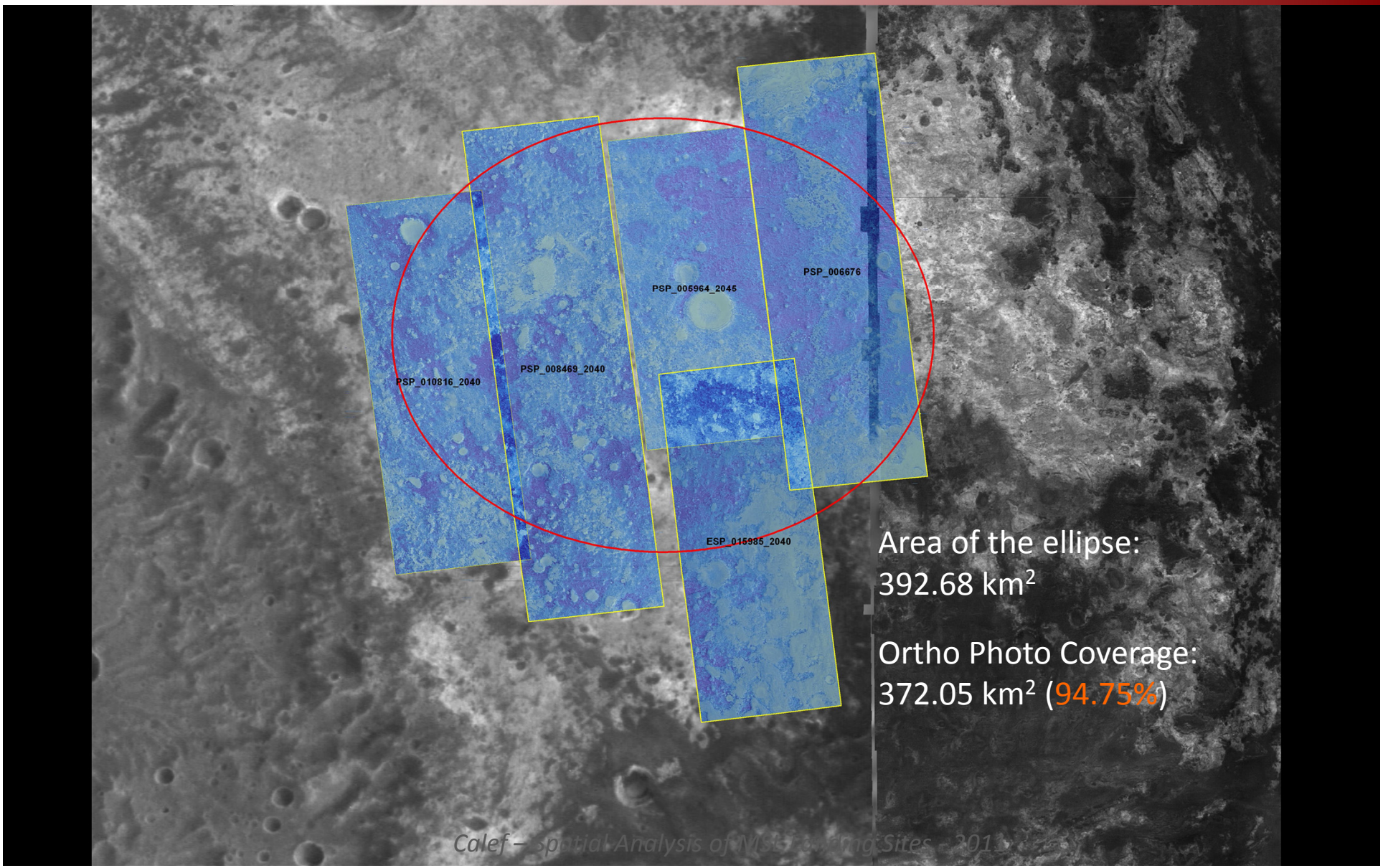
Orthophotos - Holden



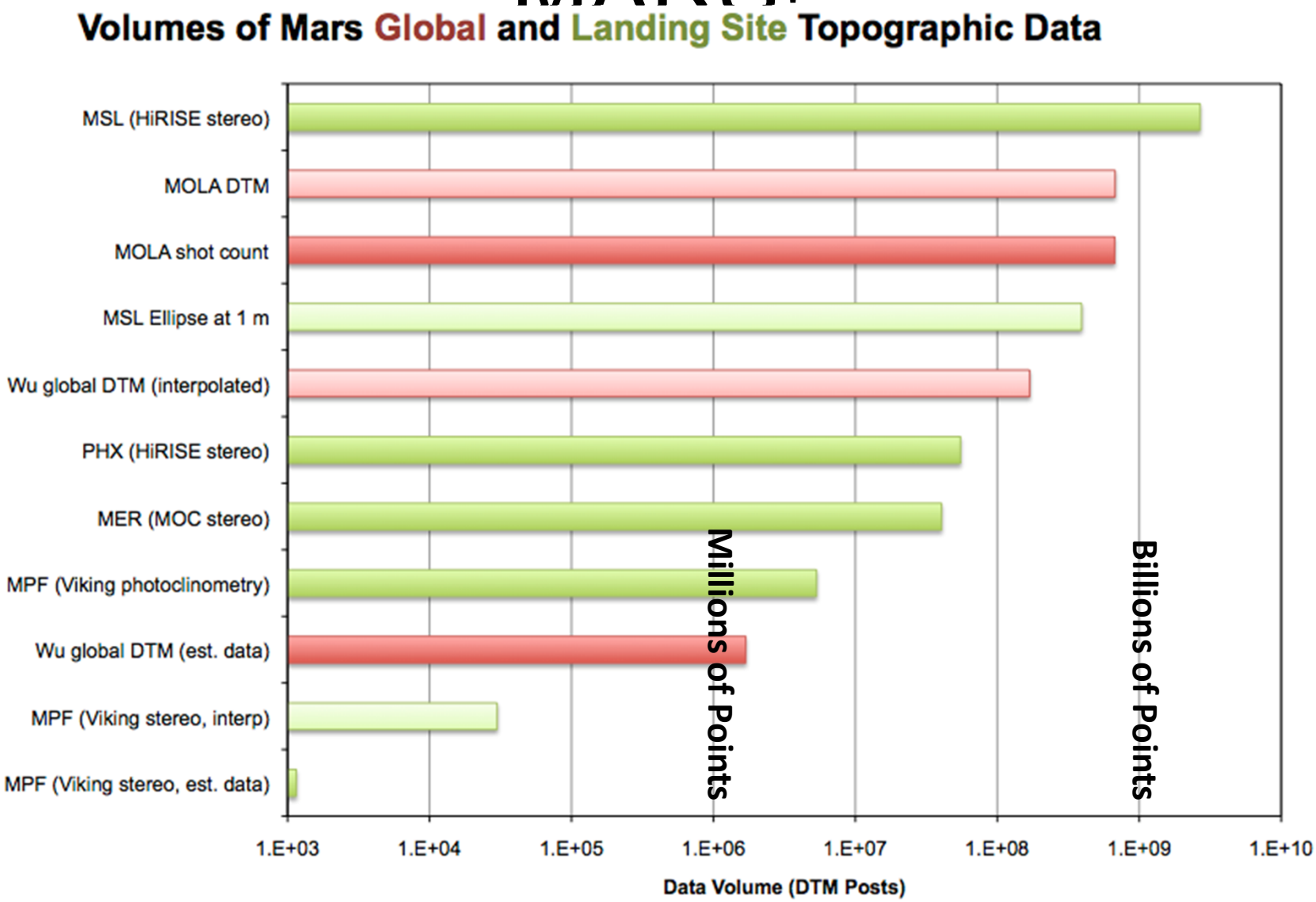
Area of the ellipse:
392.68 km^2

Ortho Photo Coverage:
333.45 km^2 (84.92%)

Orthophotos - Mawrth

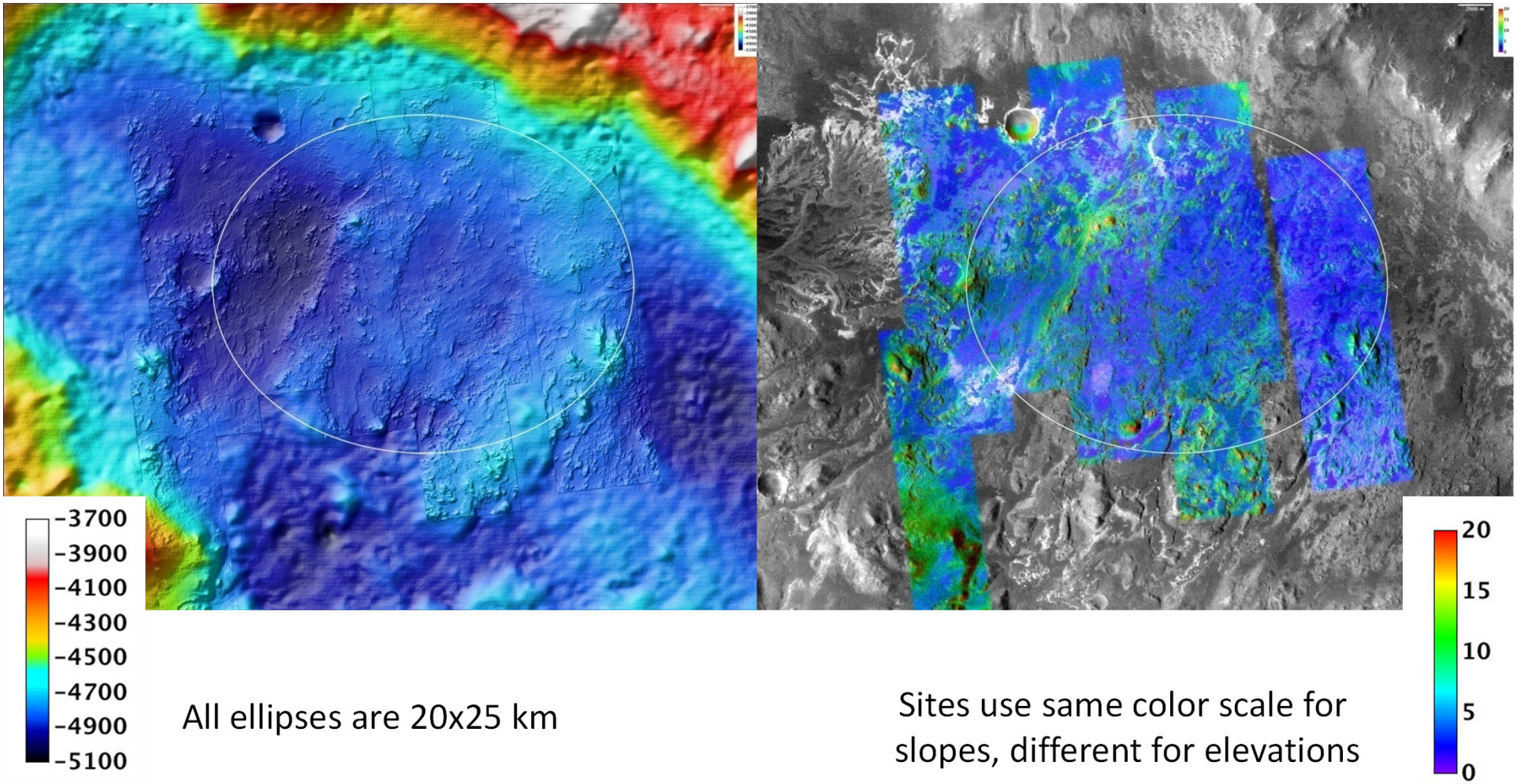


Elevation Data Volume = 4 x MARSI



Modified from Kirk et al. EPSC/DPS, 2011

Eberswalde

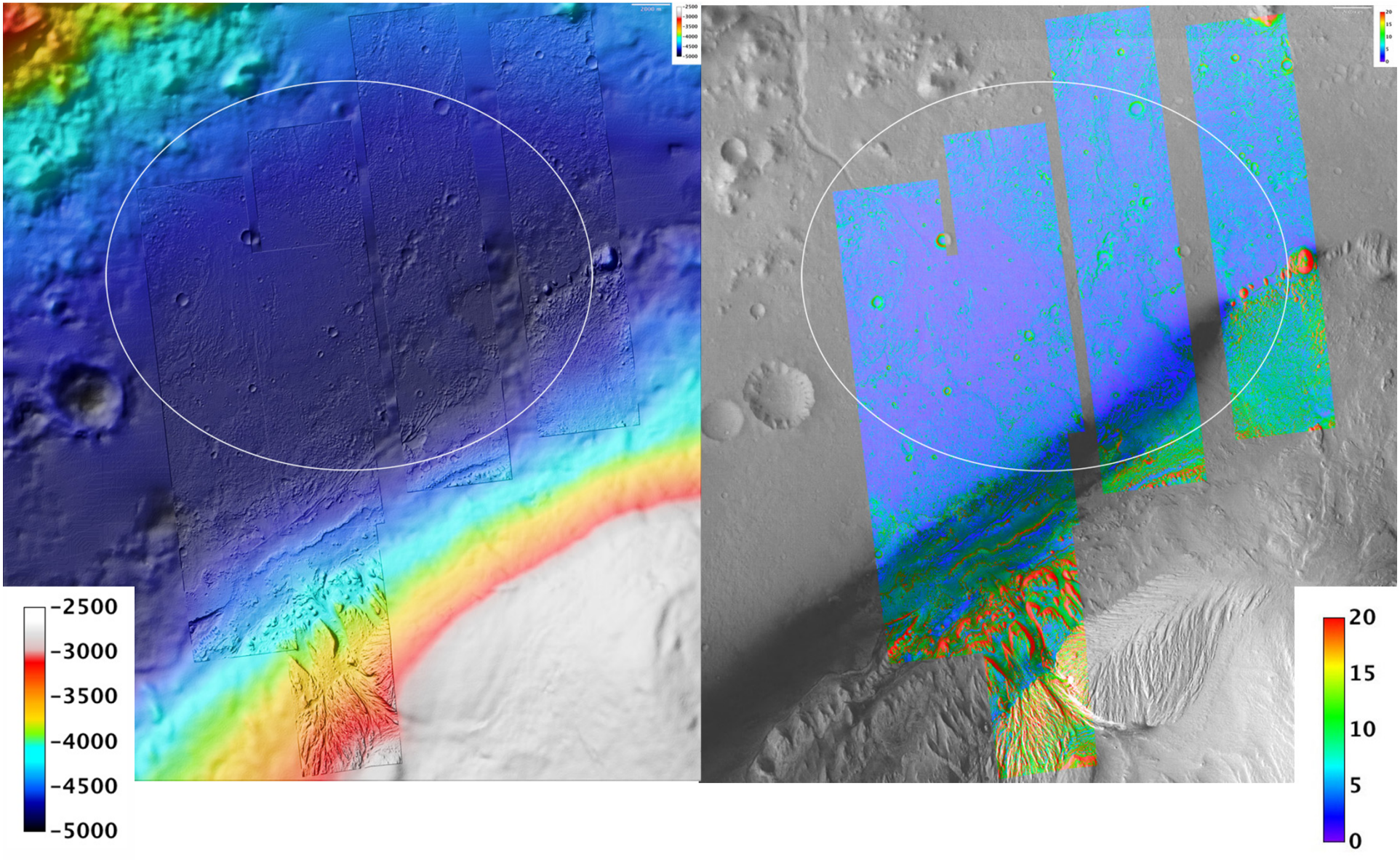


All ellipses are 20x25 km

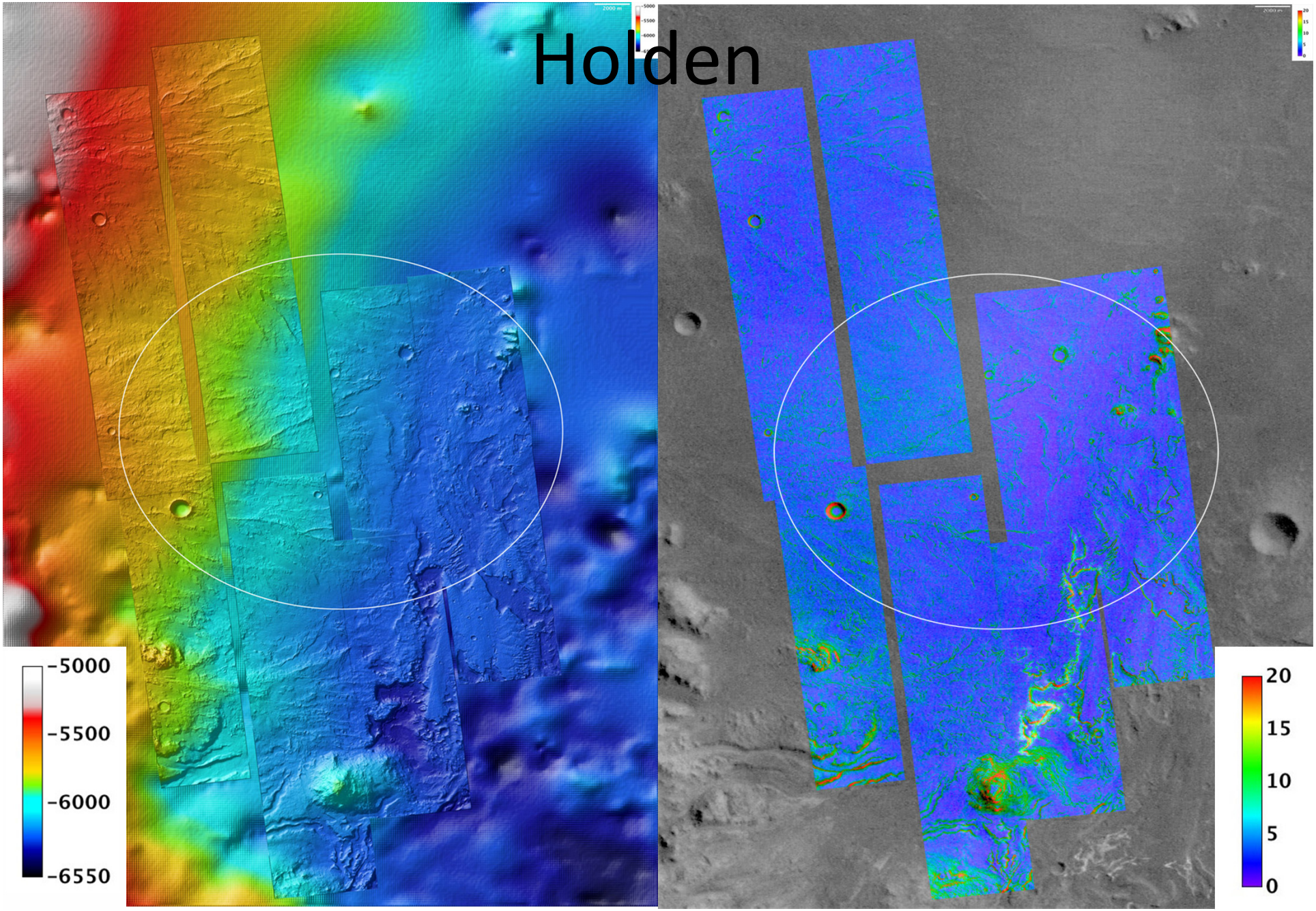
Sites use same color scale for slopes, different for elevations

Modified from Kirk et al. EPSC/DPS, 2011

Gale

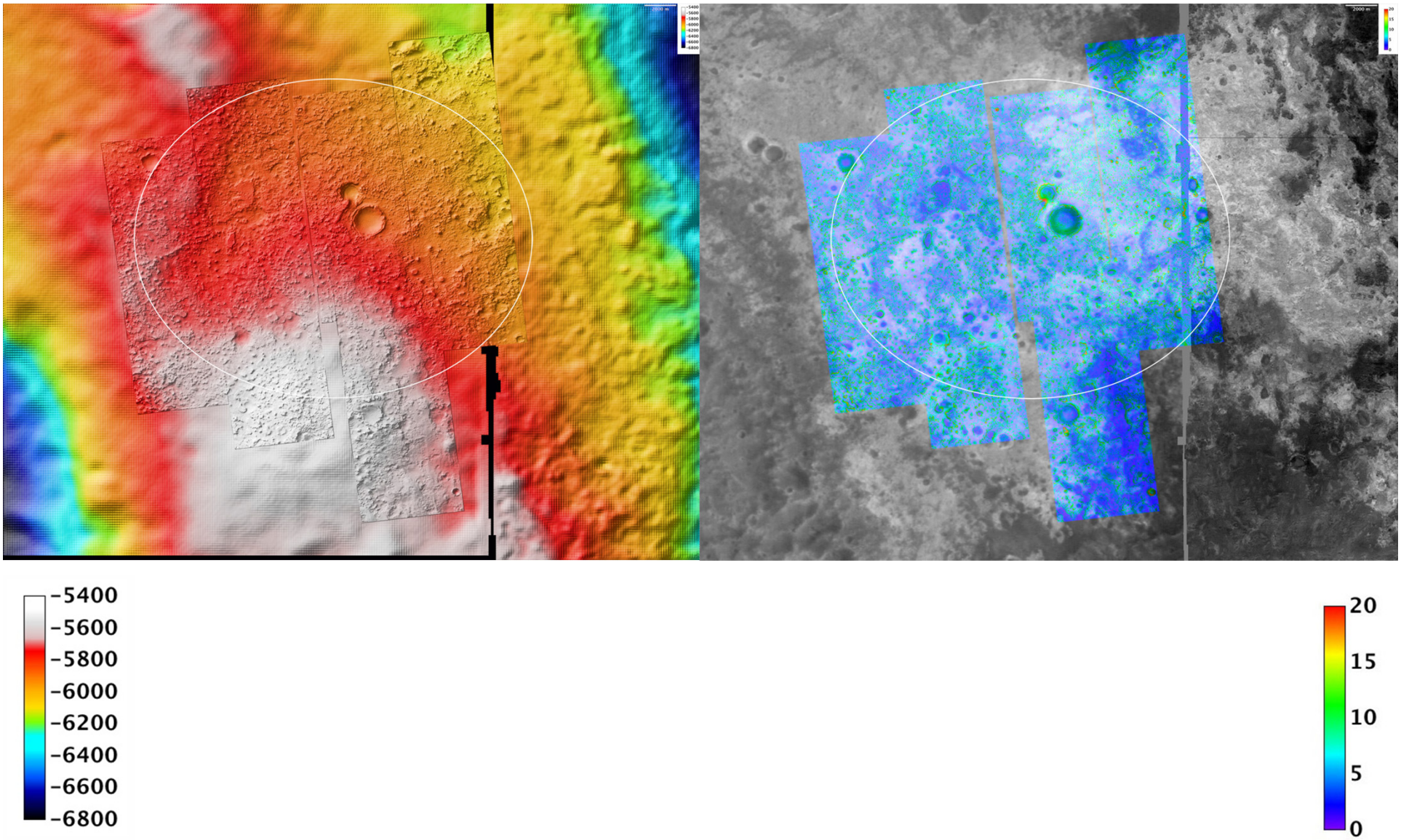


Modified from Kirk et al. EPSC/DPS, 2011



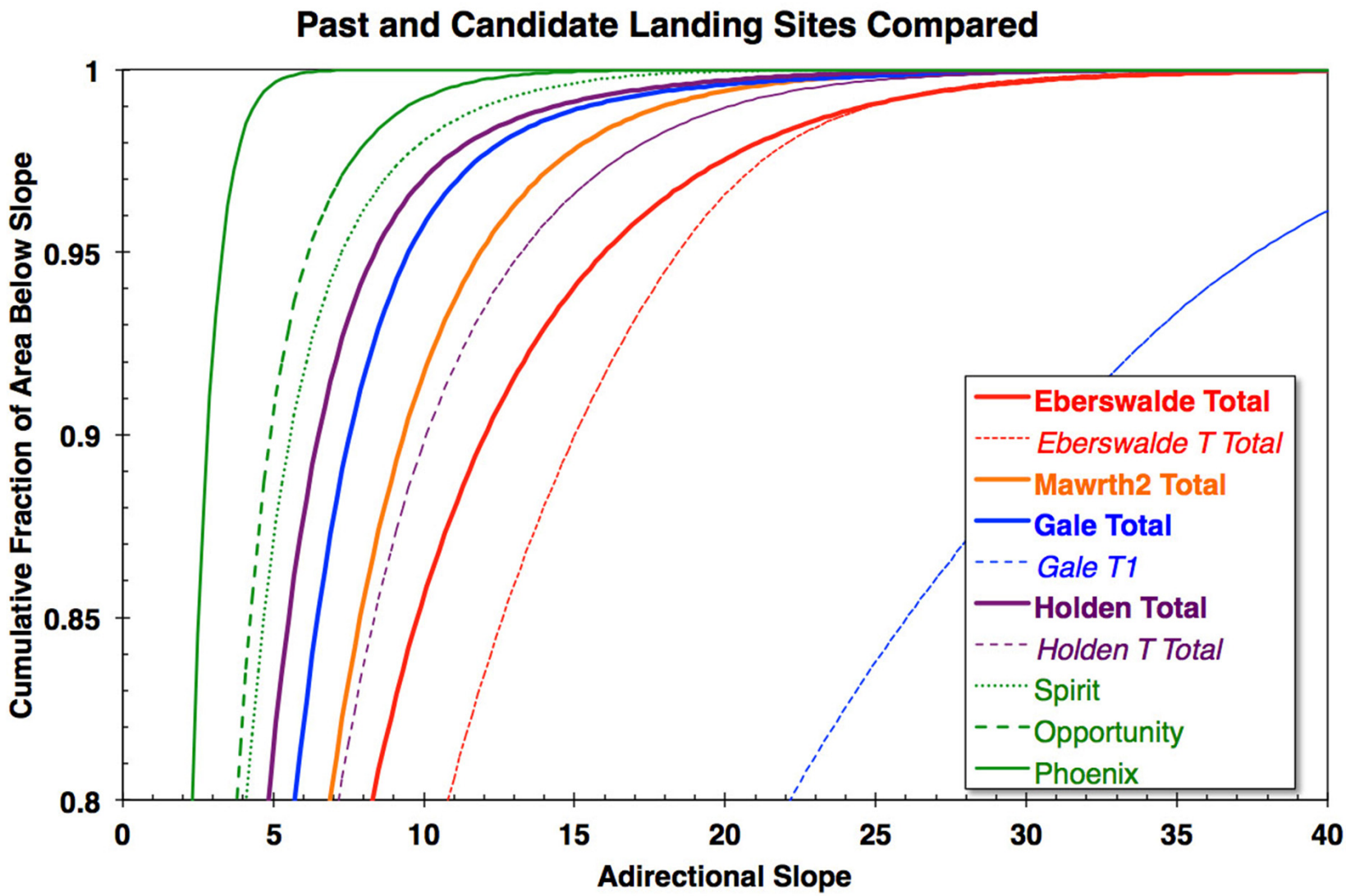
Modified from Kirk et al. EPSC/DPS, 2011

Mawrth



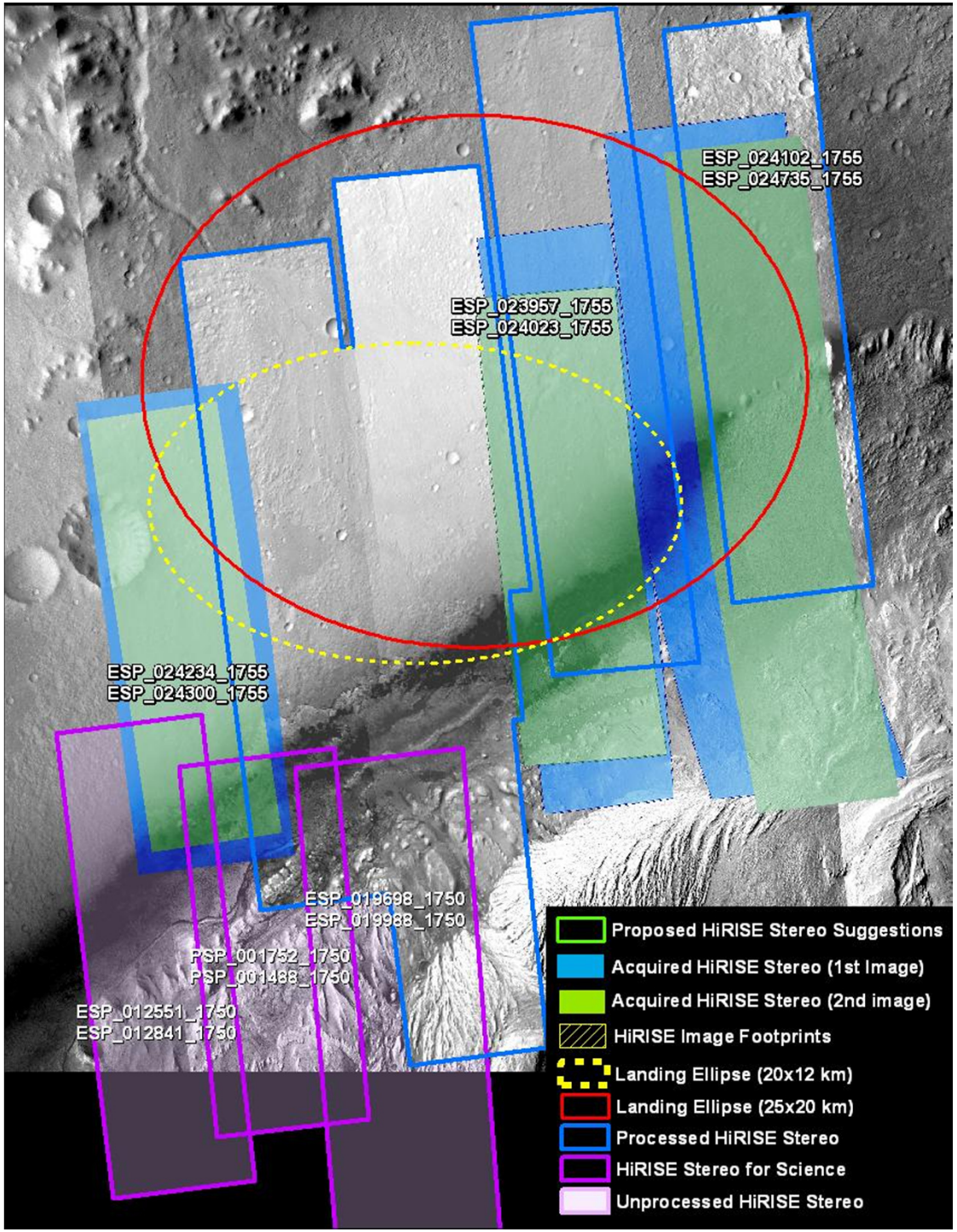
Modified from Kirk et al. EPSC/DPS, 2011

Adirectional Slope Distributions



Randy Kirk et al. EPSC/DPS, Nantes 2011

Gale HiRISE Stereo Coverage



GIS Integration and Georeferenceing

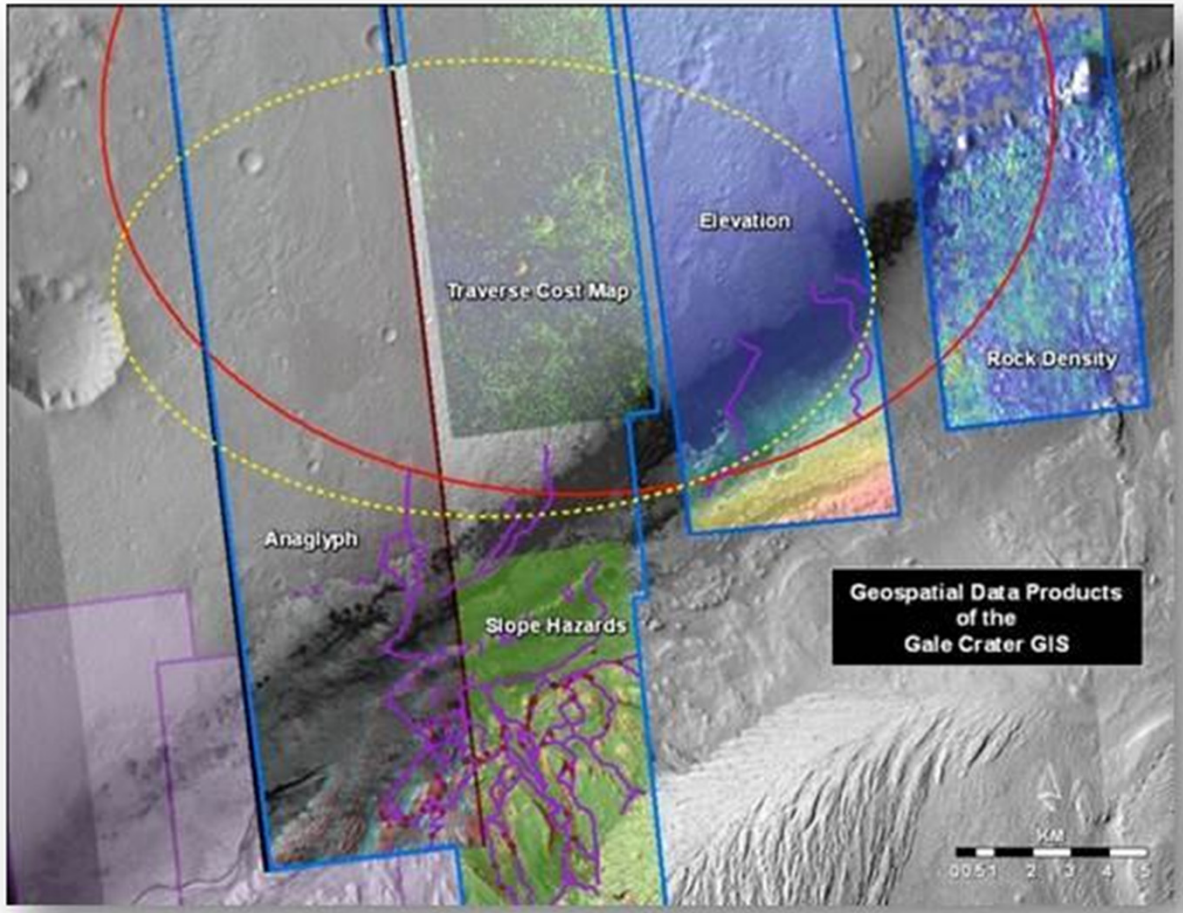
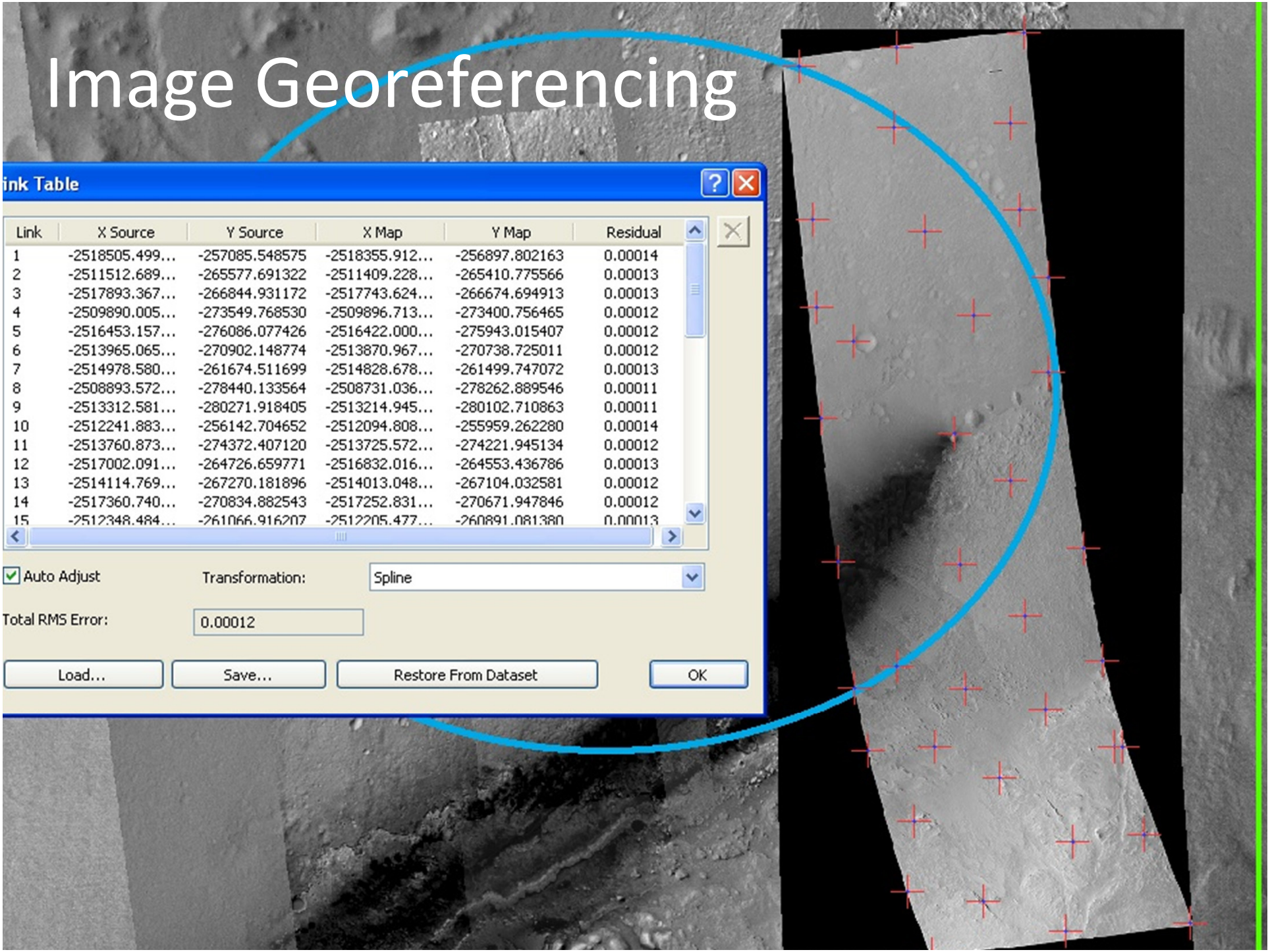


Image Georeferencing



Link	X Source	Y Source	X Map	Y Map	Residual
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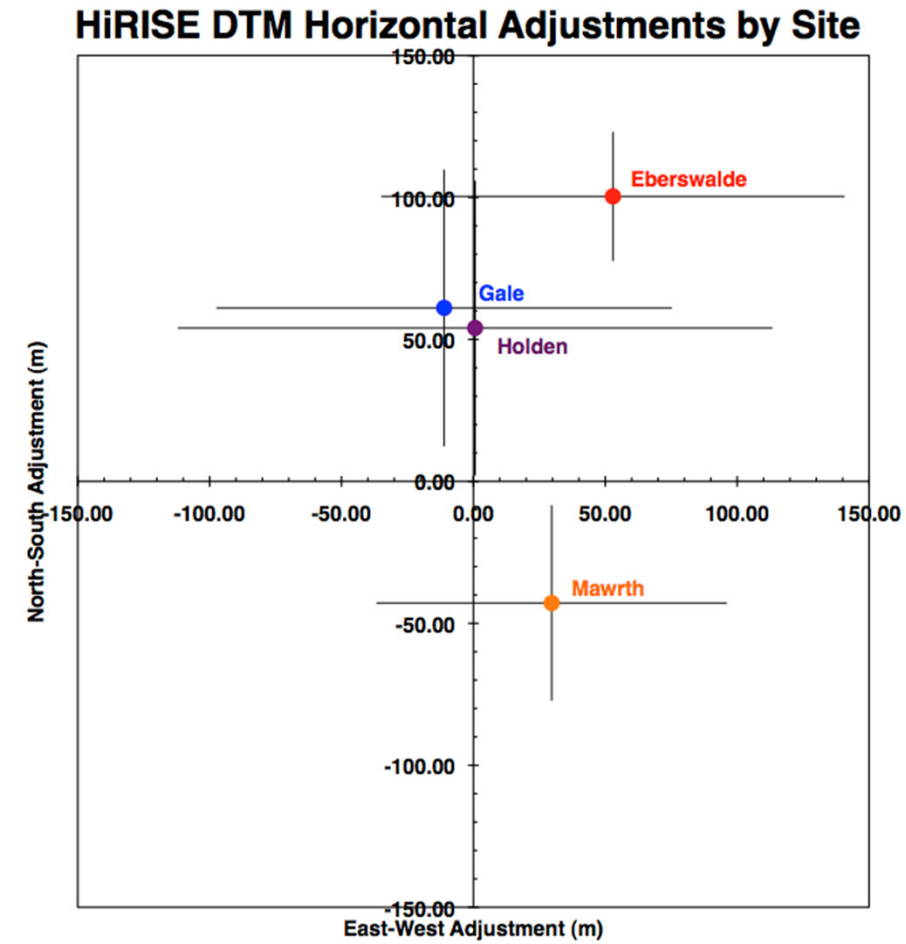
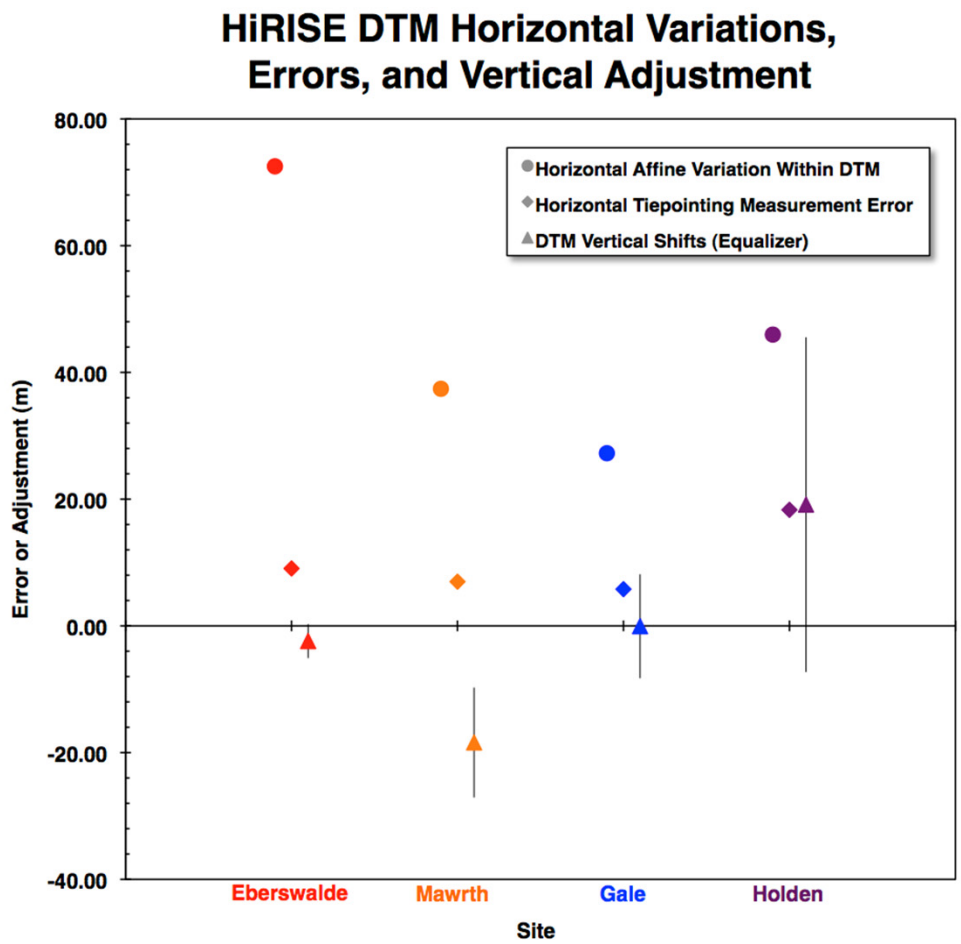
2	-2511512.689...	-265577.691322	-2511409.228...	-265410.775566	0.00013
3	-2517893.367...	-266844.931172	-2517743.624...	-266674.694913	0.00013
4	-2509890.005...	-273549.768530	-2509896.713...	-273400.756465	0.00012
5	-2516453.157...	-276086.077426	-2516422.000...	-275943.015407	0.00012
6	-2513965.065...	-270902.148774	-2513870.967...	-270738.725011	0.00012
7	-2514978.580...	-261674.511699	-2514828.678...	-261499.747072	0.00013
8	-2508893.572...	-278440.133564	-2508731.036...	-278262.889546	0.00011
9	-2513312.581...	-280271.918405	-2513214.945...	-280102.710863	0.00011
10	-2512241.883...	-256142.704652	-2512094.808...	-255959.262280	0.00014
11	-2513760.873...	-274372.407120	-2513725.572...	-274221.945134	0.00012
12	-2517002.091...	-264726.659771	-2516832.016...	-264553.436786	0.00013
13	-2514114.769...	-267270.181896	-2514013.048...	-267104.032581	0.00012
14	-2517360.740...	-270834.882543	-2517252.831...	-270671.947846	0.00012
15	-2512348.484...	-261066.916207	-2512205.477...	-260891.081380	0.00013

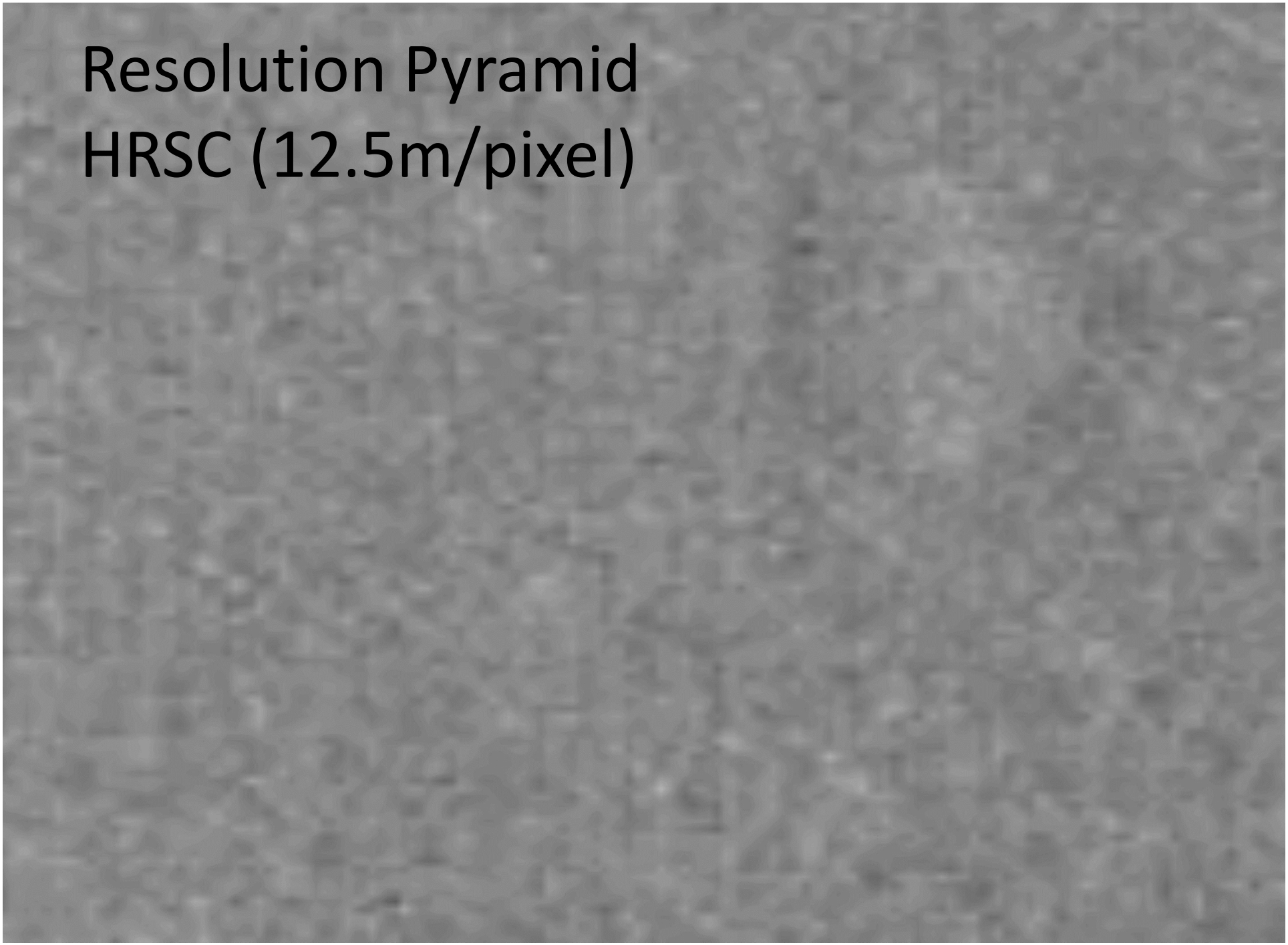
Horizontal and Vertical Transformation Statistics



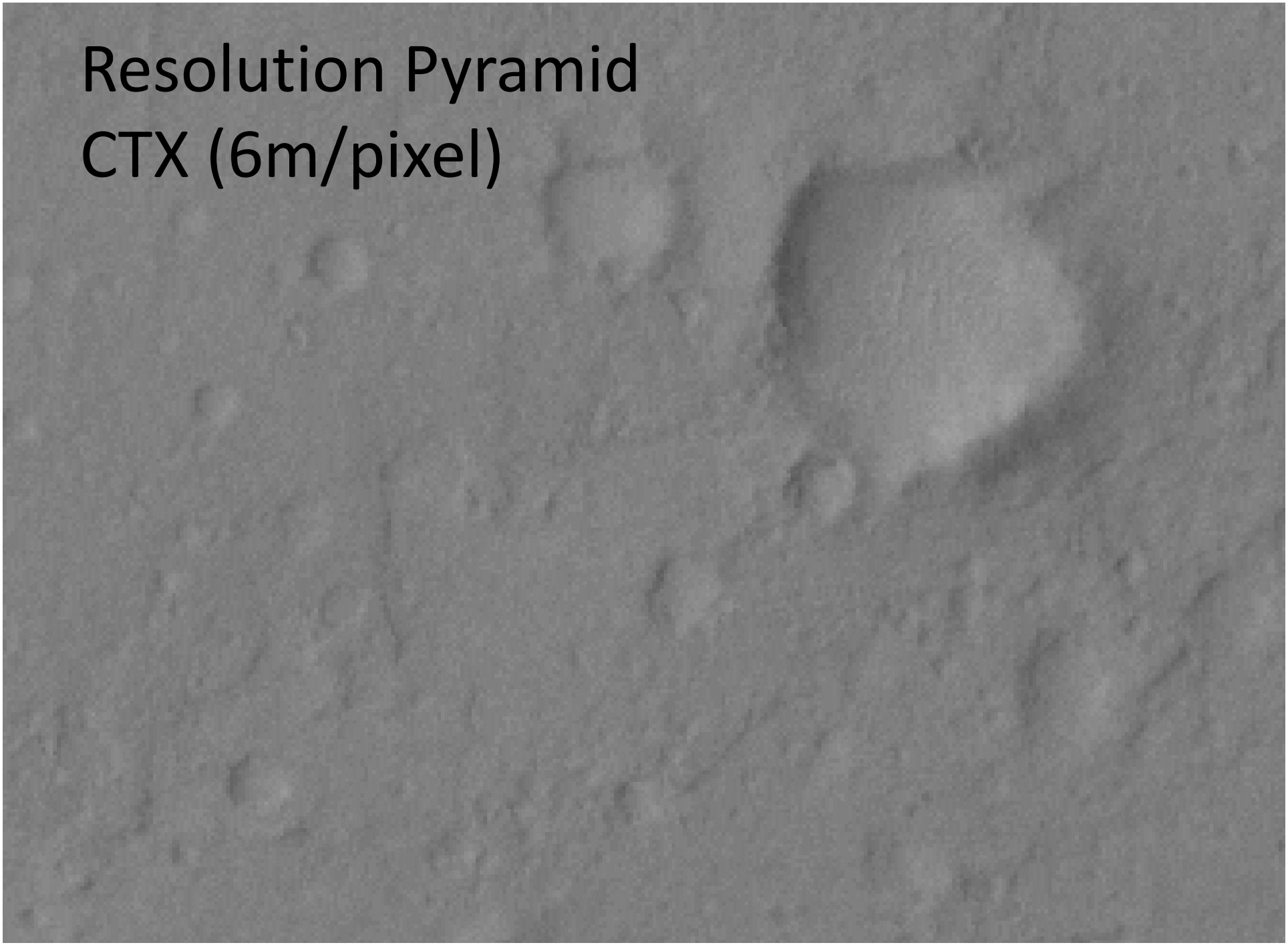


Randy Kirk et al. EPSC/DPS, Nantes 2011

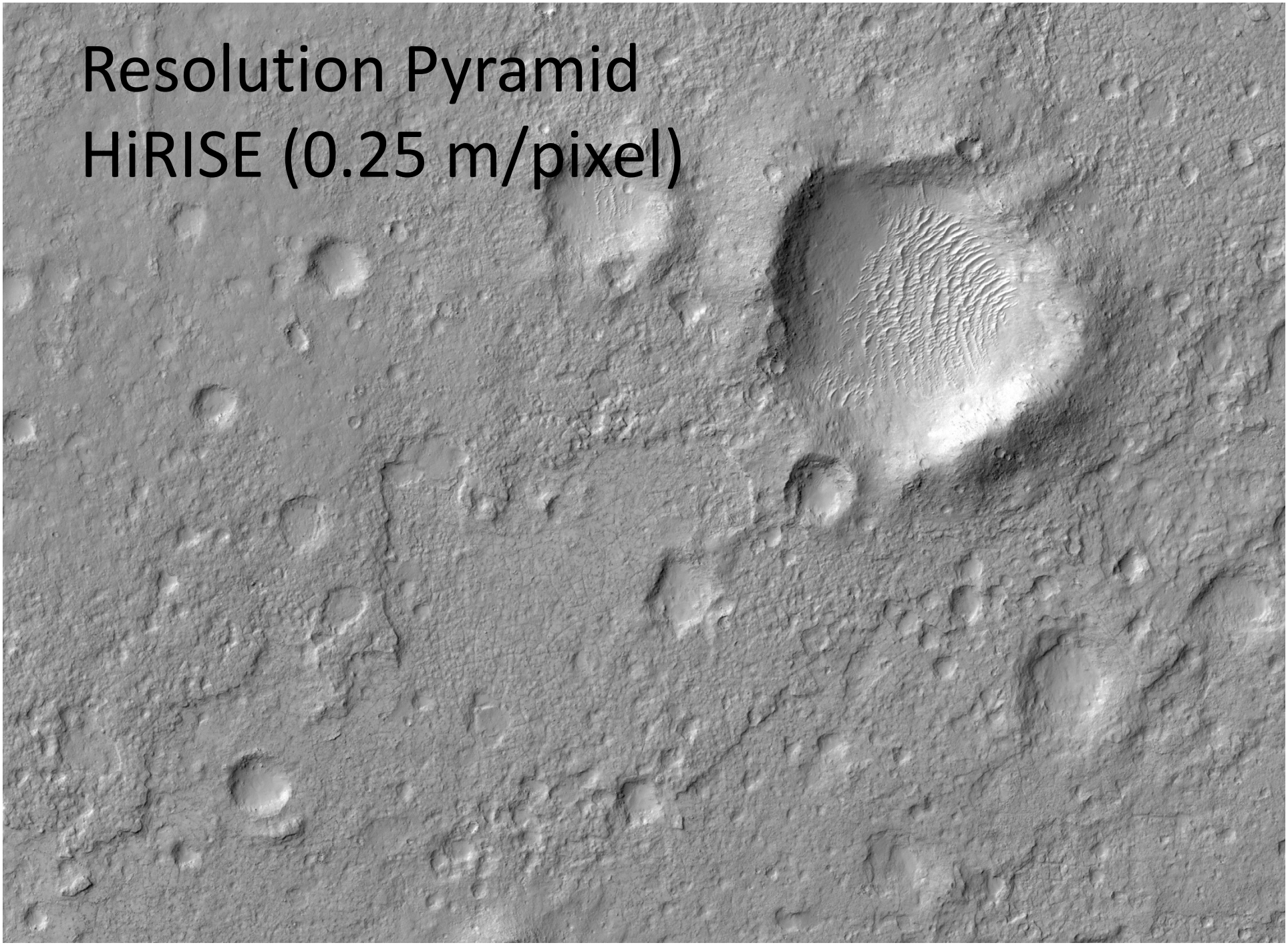
Resolution Pyramid
HRSC (12.5m/pixel)



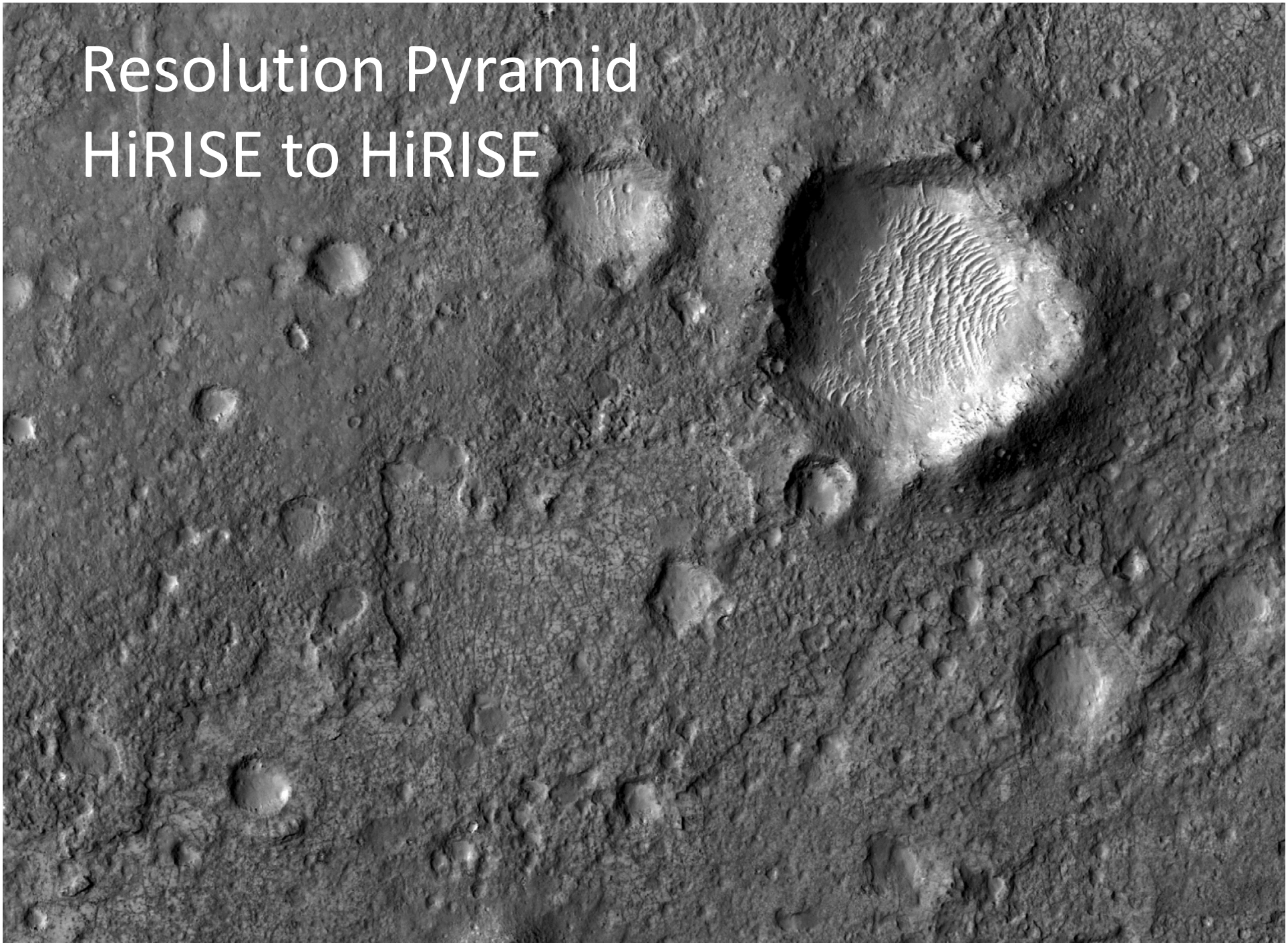
Resolution Pyramid
CTX (6m/pixel)



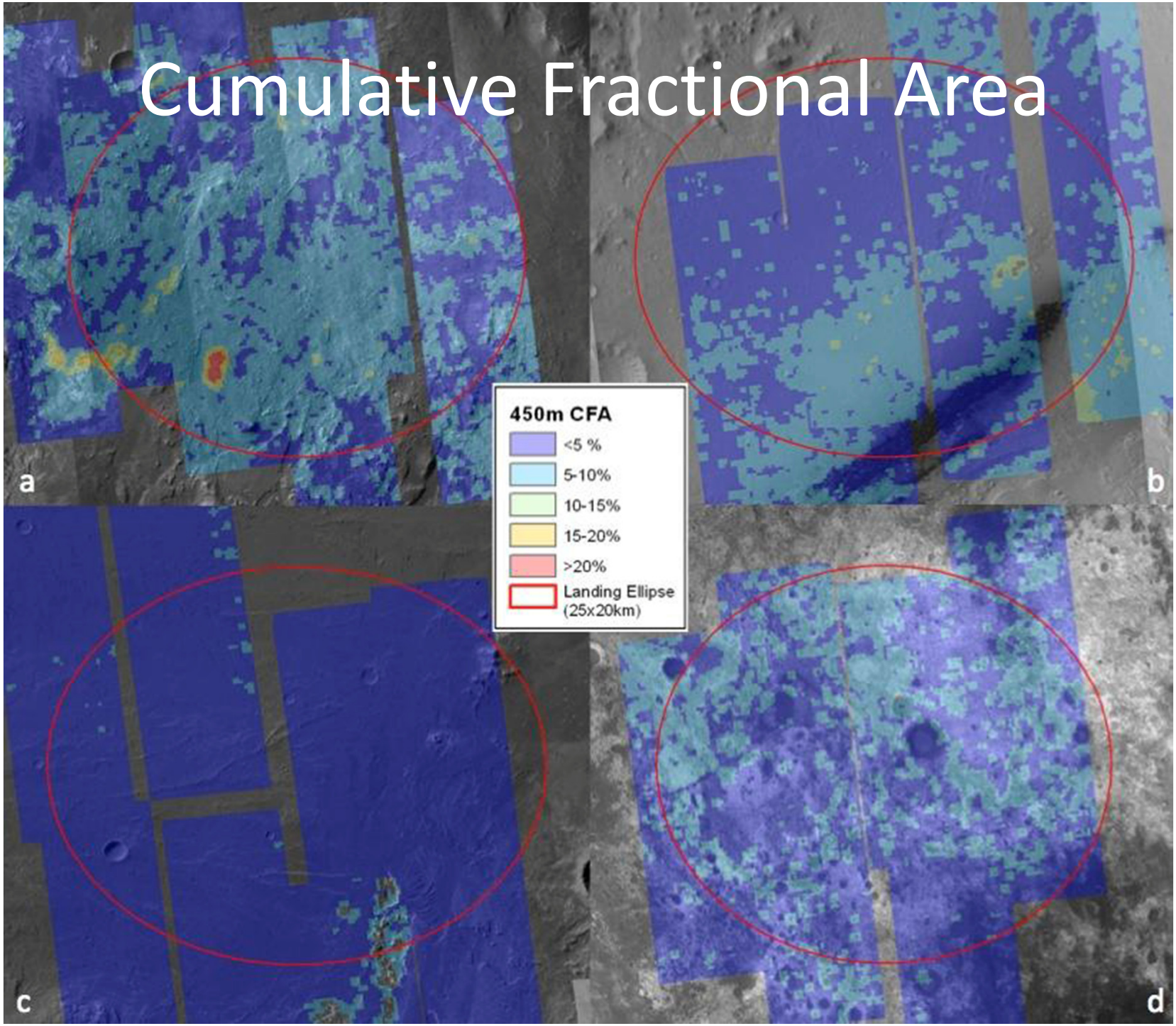
Resolution Pyramid
HiRISE (0.25 m/pixel)



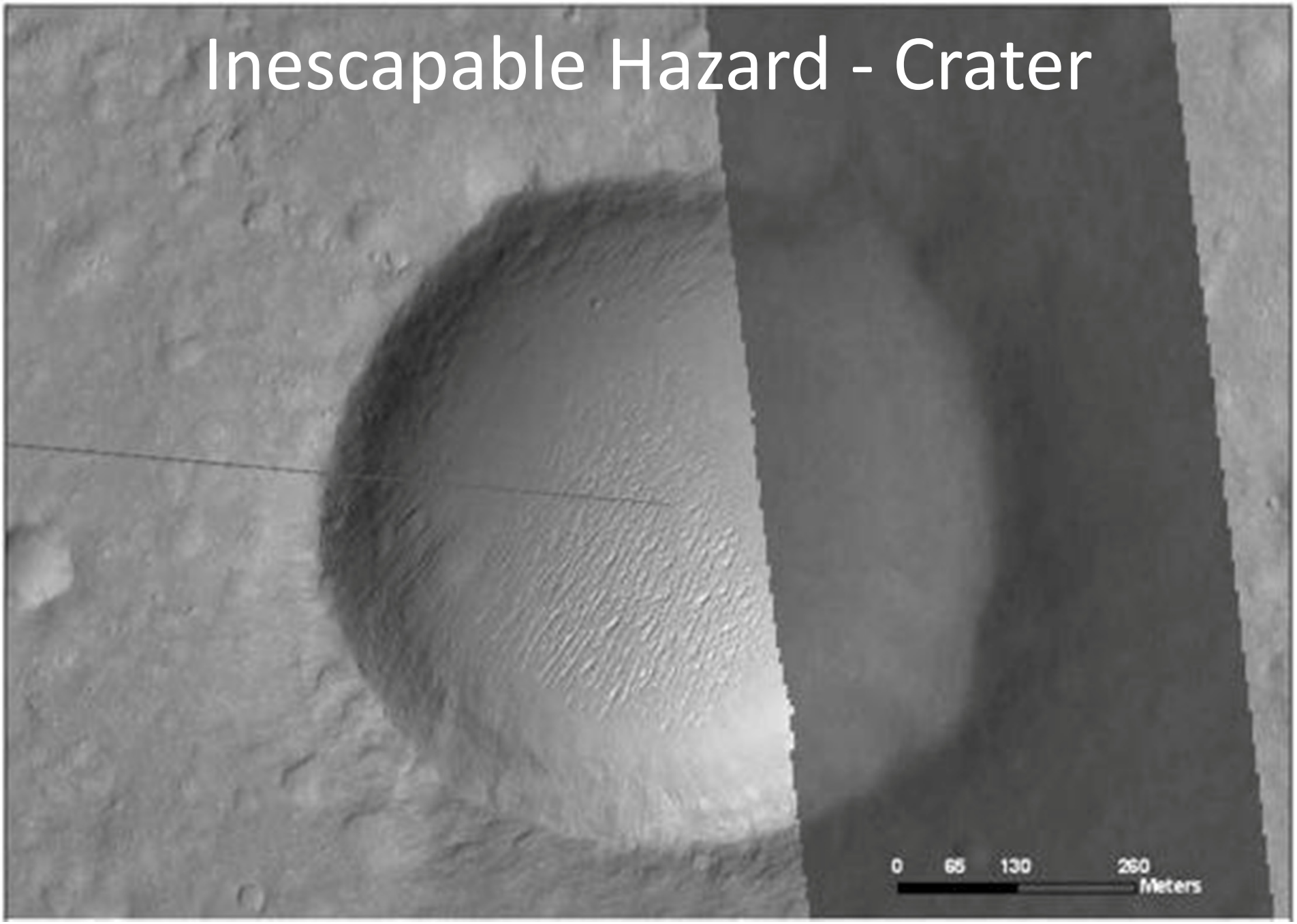
Resolution Pyramid
HiRISE to HiRISE



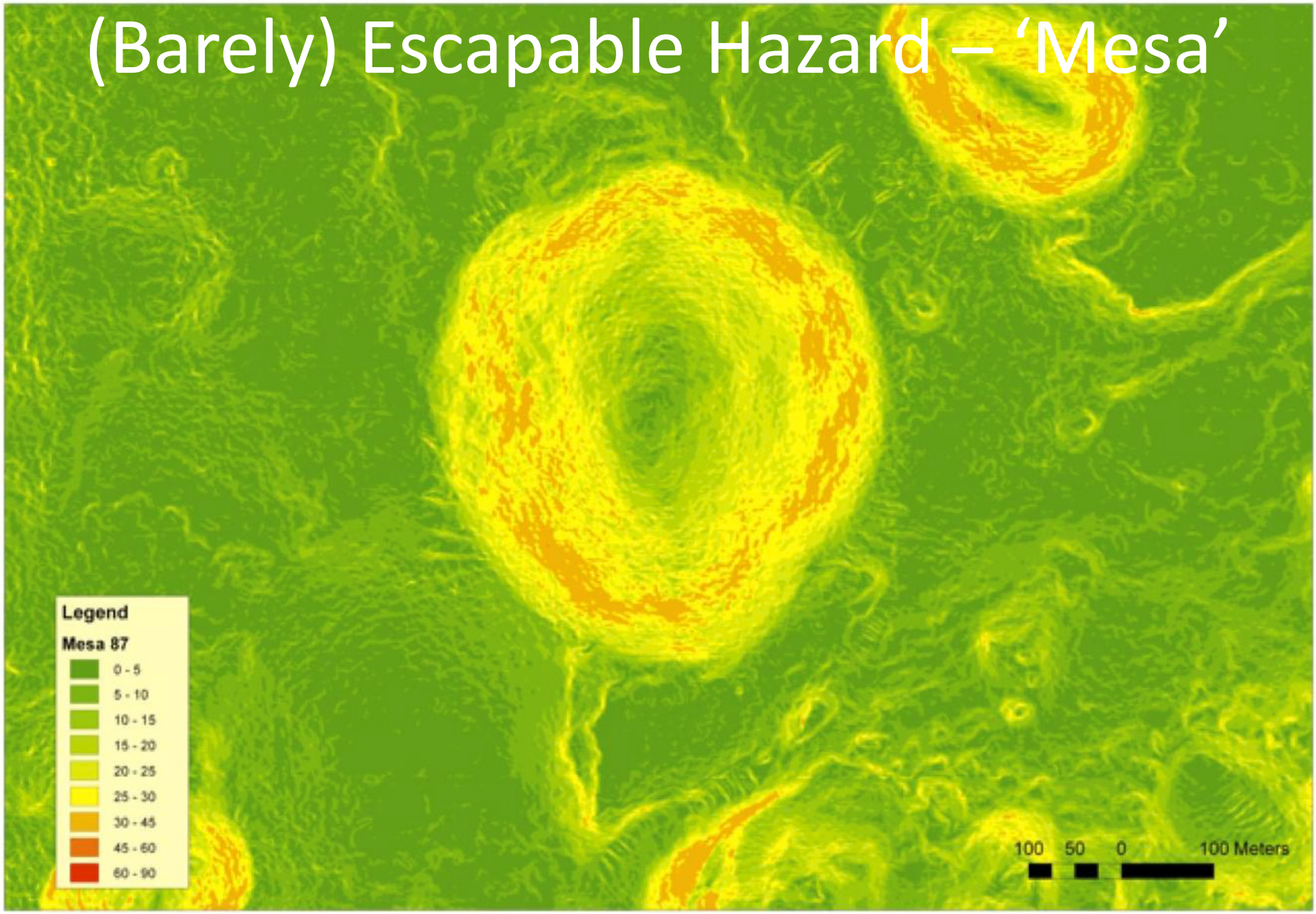
Cumulative Fractional Area



Inescapable Hazard - Crater

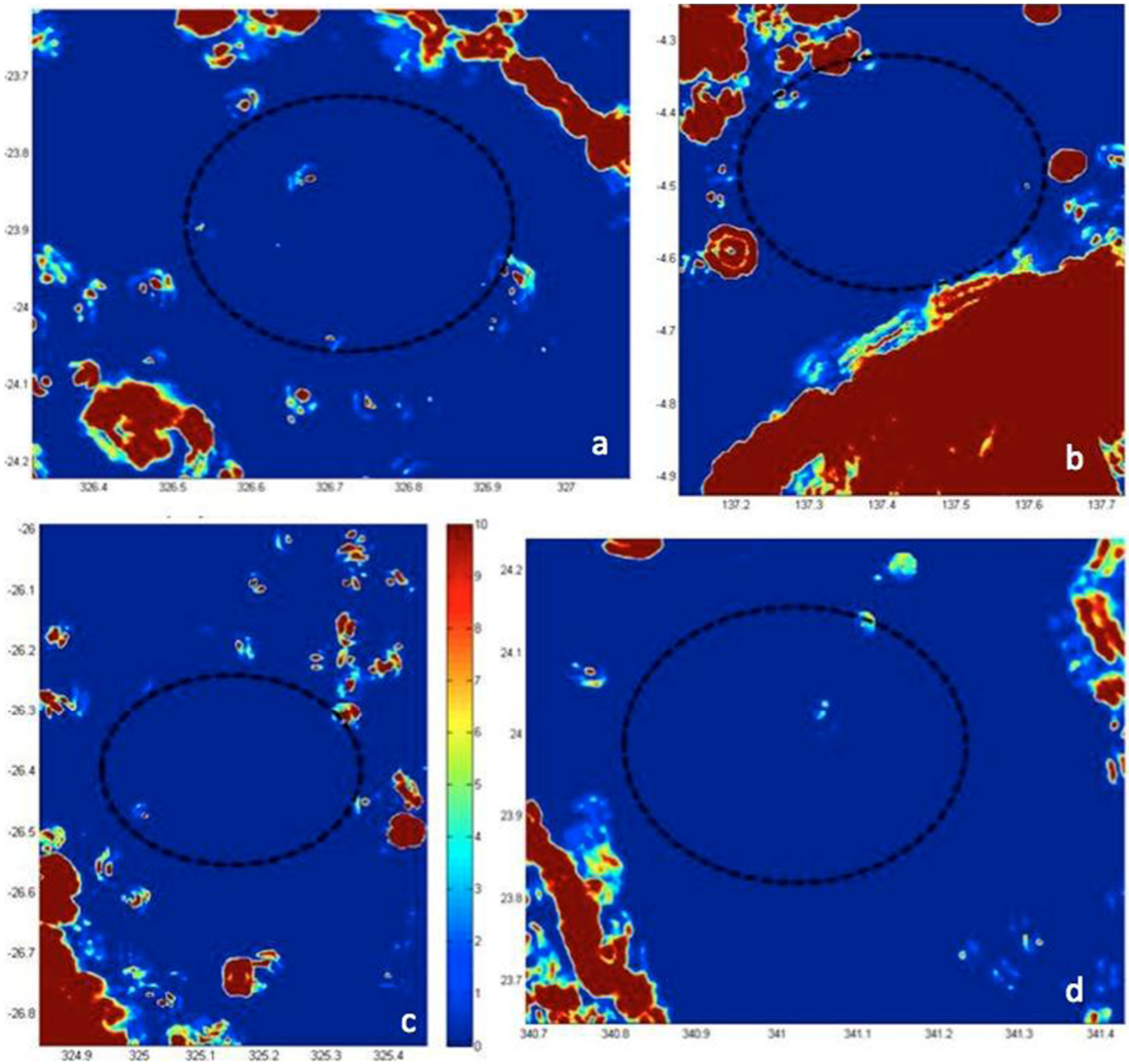


(Barely) Escapable Hazard – ‘Mesa’

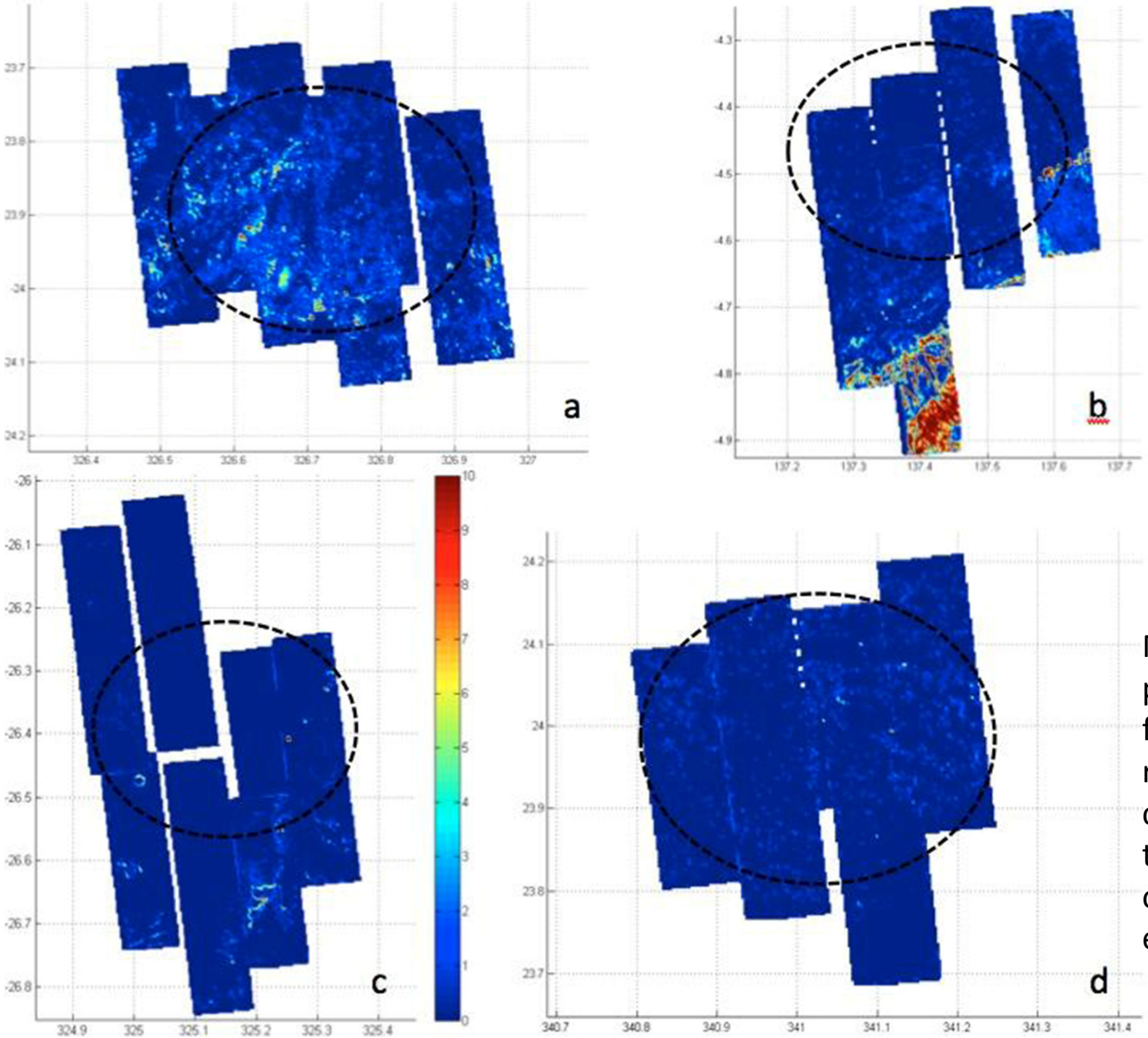


Traverse Hazards - Dunes

Fuel Allocation Failure Maps

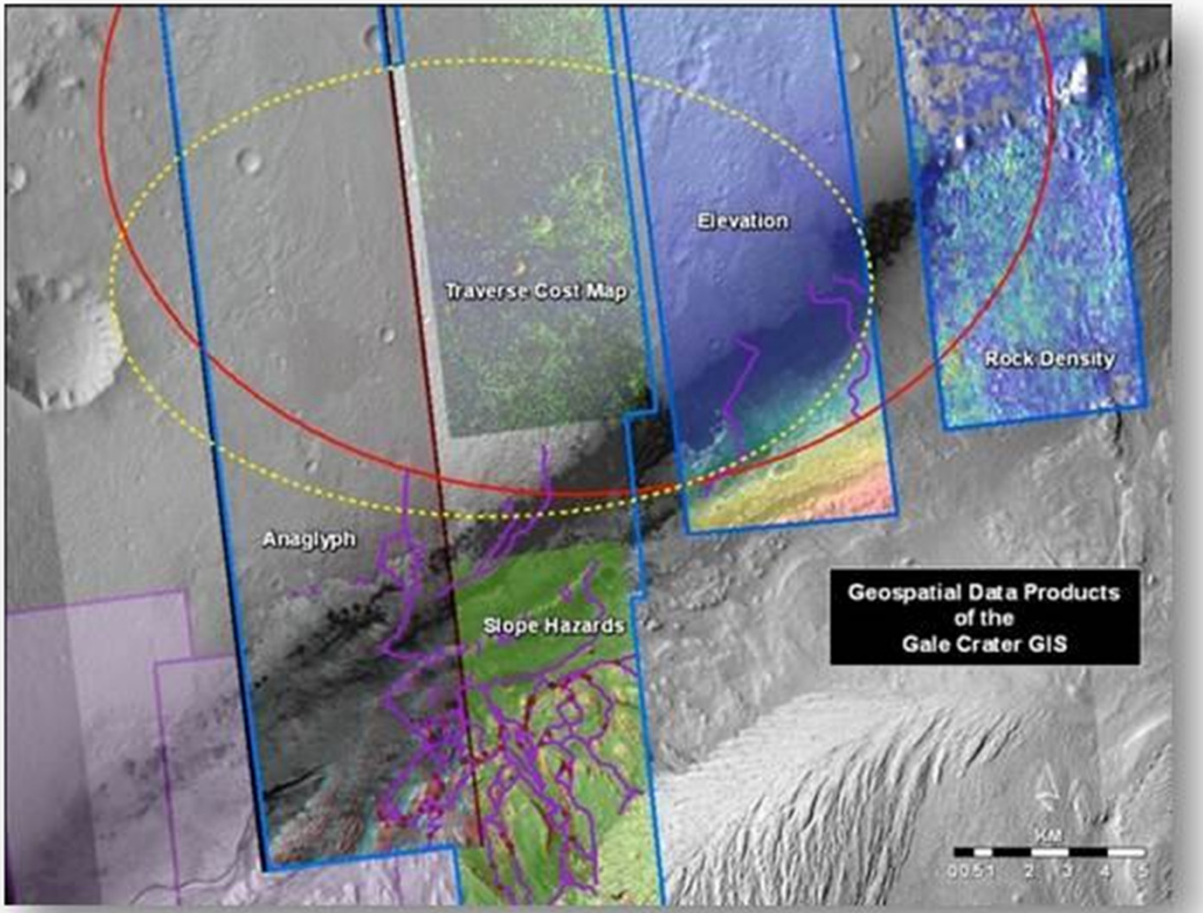


Touchdown Failure Maps



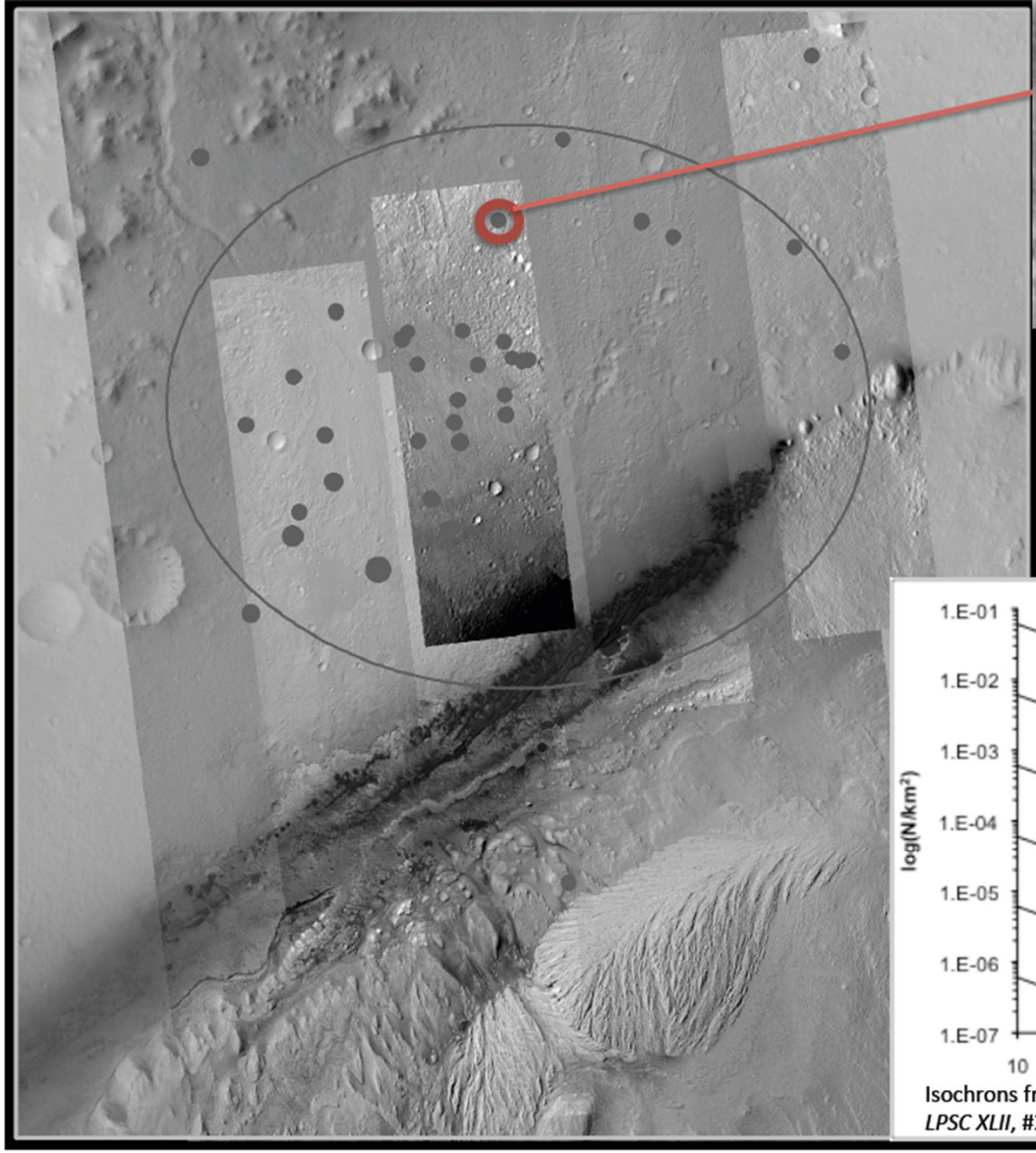
Maps show the probability of failure from rocks and slopes convolved with the probability of landing within each 150 m cell.

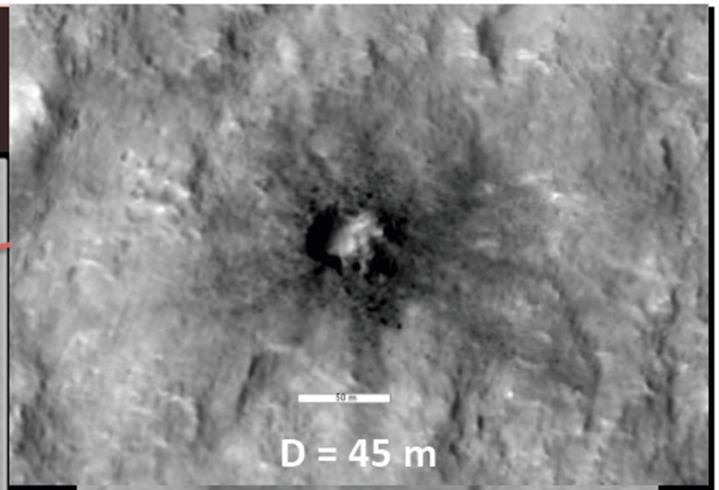
Future Tactical and Strategic Planning

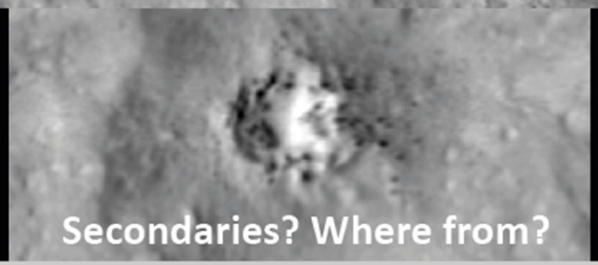


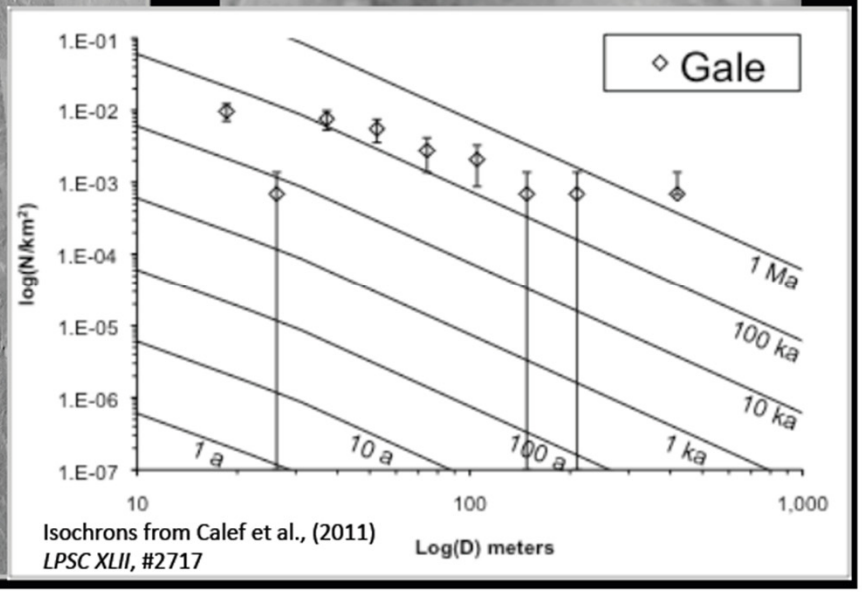
Calef – Spatial Analysis of MSL Landing Sites - 2011

Gale



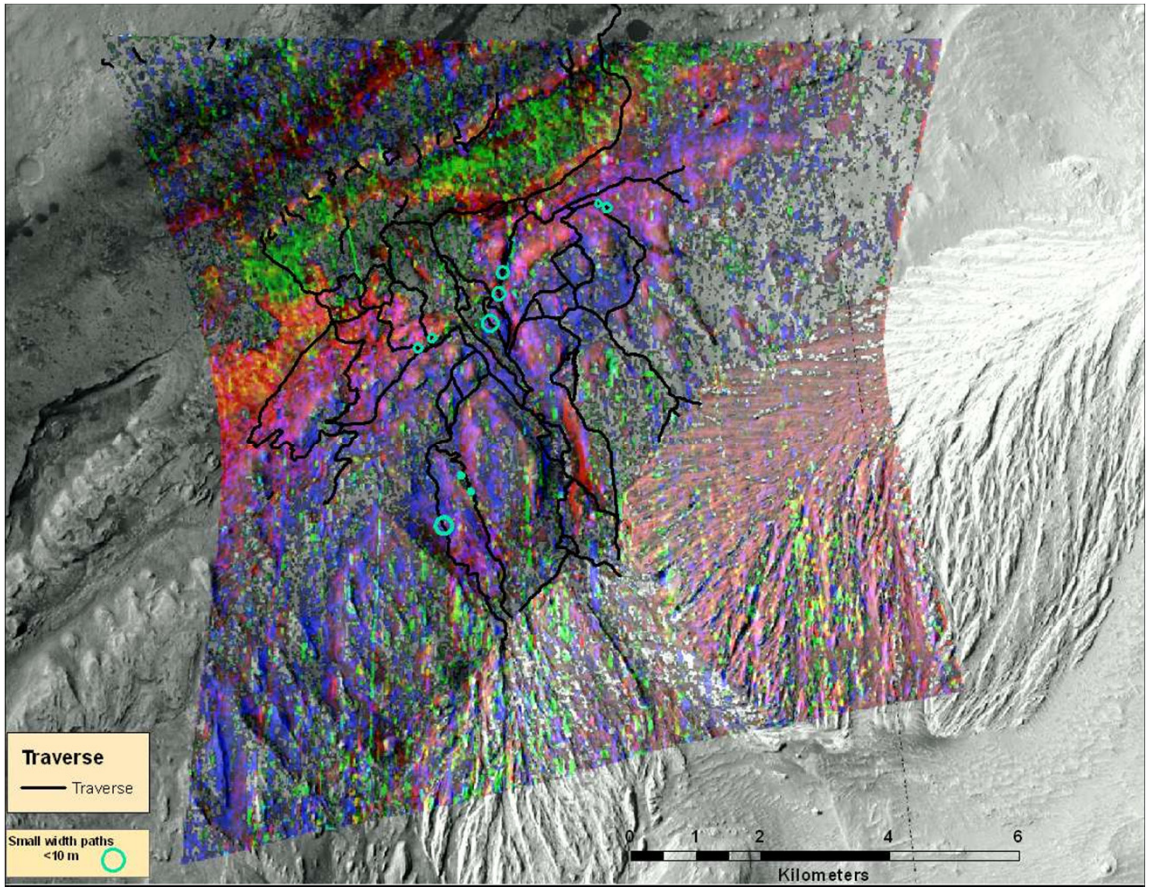






Isochrons from Calef et al., (2011)
LPSC XLII, #2717

Mineralogy across traverse routes



CRISM RGB mineral parameter maps (red = Fe-minerals, green = Fe/Mg-clay minerals, blue = sulfates) overlain on CTX mosaic.

Bright red regions correspond to olivine-bearing dunes, green regions contain nontronite, and dark blue regions contain sulfates. Orange and magenta regions contain sulfates and clay minerals in variable proportions.

Can get through mineral strata observed from orbit

Description and image taken from:
Milliken, R. E., et al. (2010), Paleoclimate of Mars as captured by the stratigraphic record in Gale Crater, Geophys. Research Letters, 37, L04201, doi:10/1029/2009GL041870.

Gale Crater

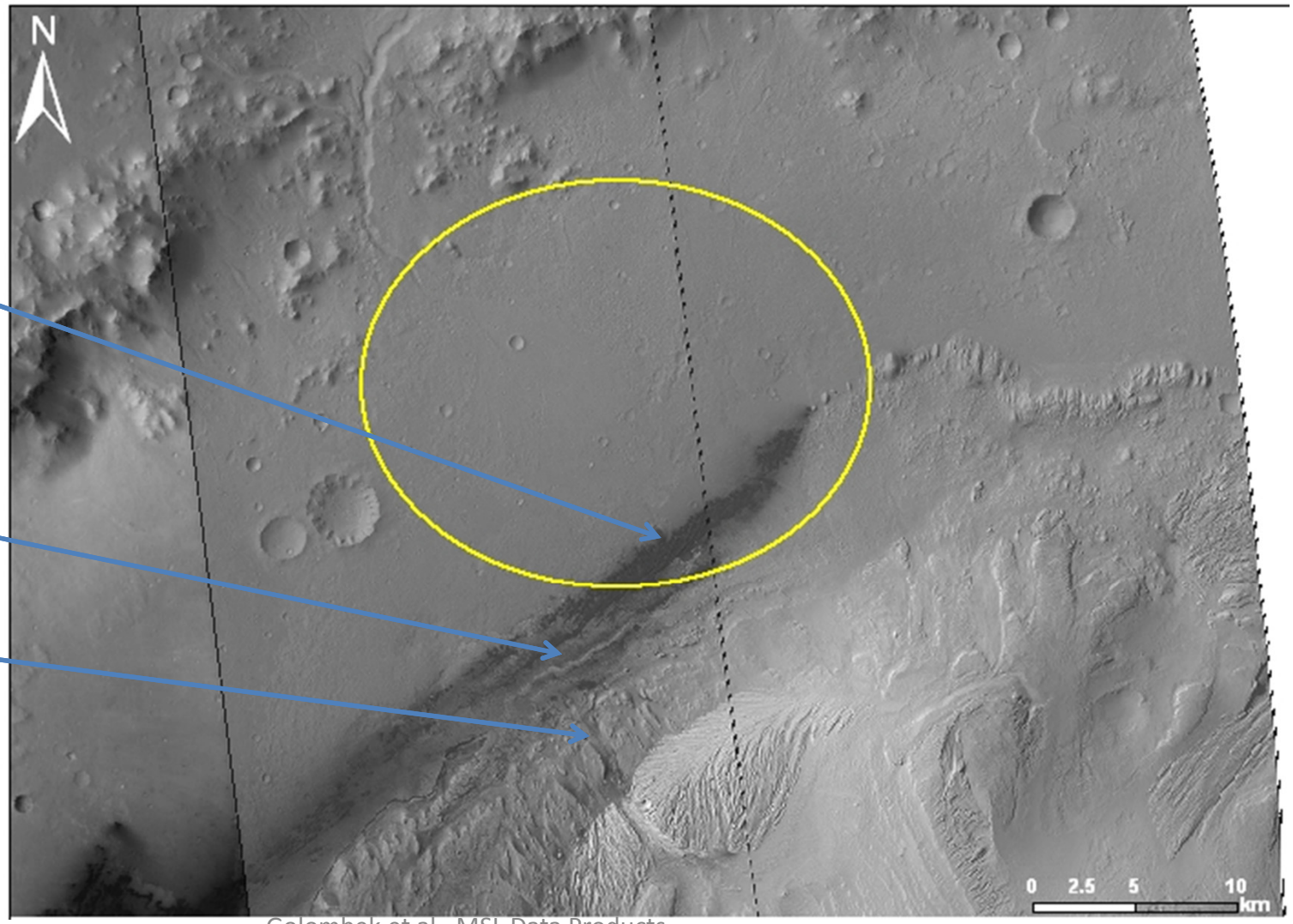
Cratered Plains –
No obvious Mobility
Concerns

Dark Dunes
Appear Fresh
Many Exceed 30°
Mobility
Impediment

Sample Strata Here

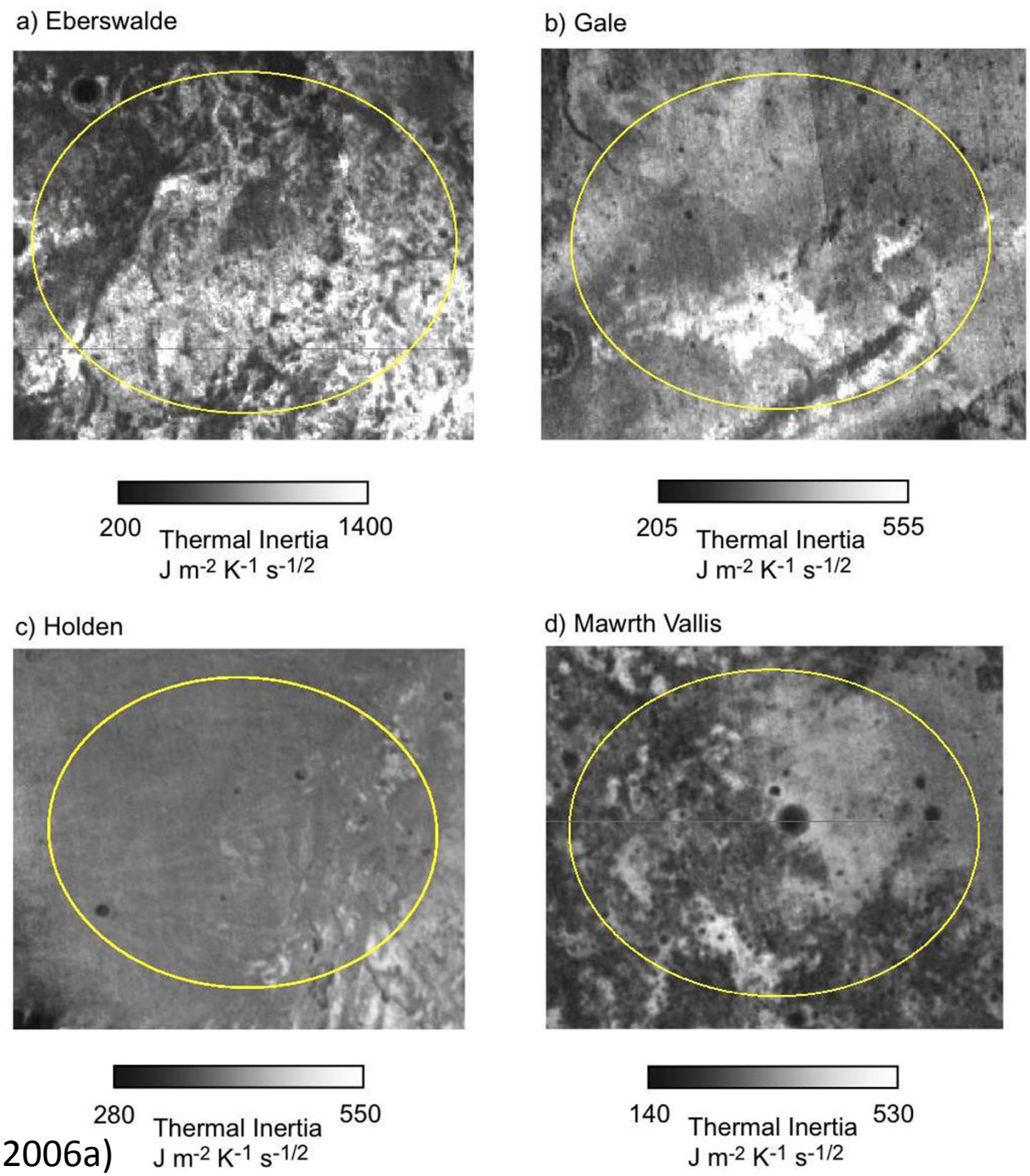
Drive up Canyon
Here

Can Access Mineral
Strata in CRISM
Can drive up
mound



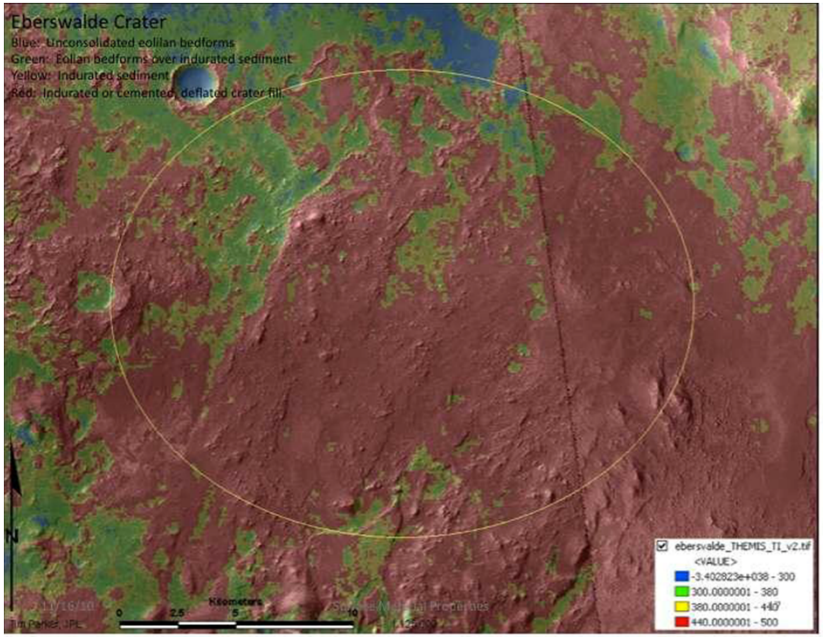
Golombek et al., MSL Data Products

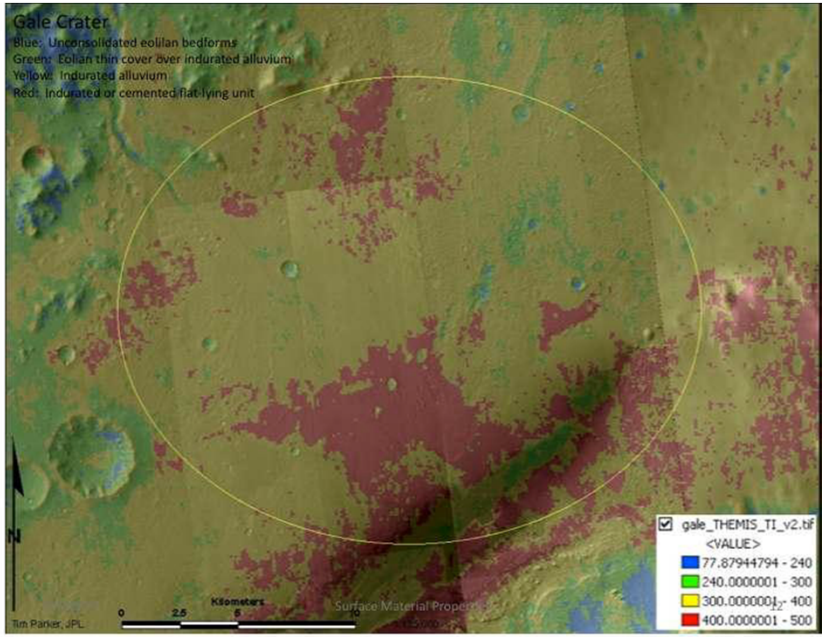
Thermal Inertia Maps

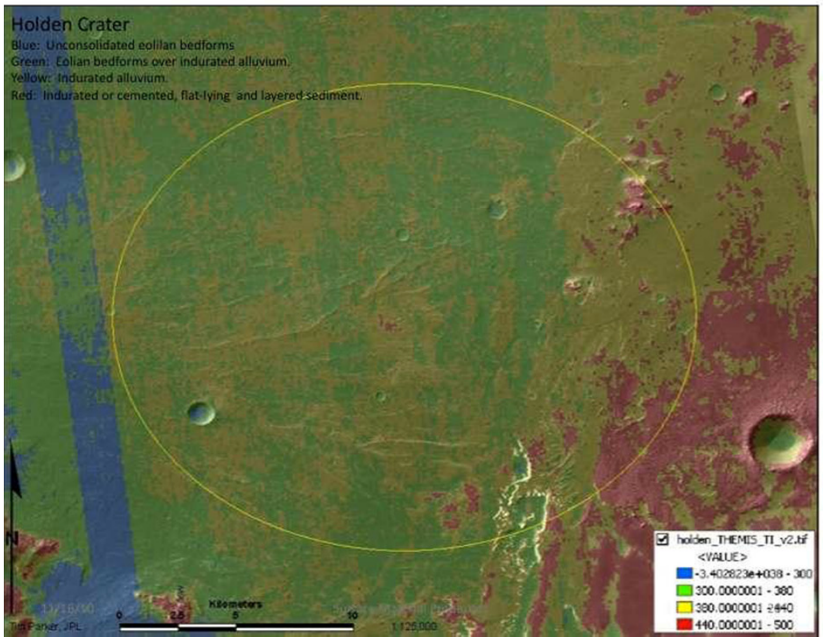


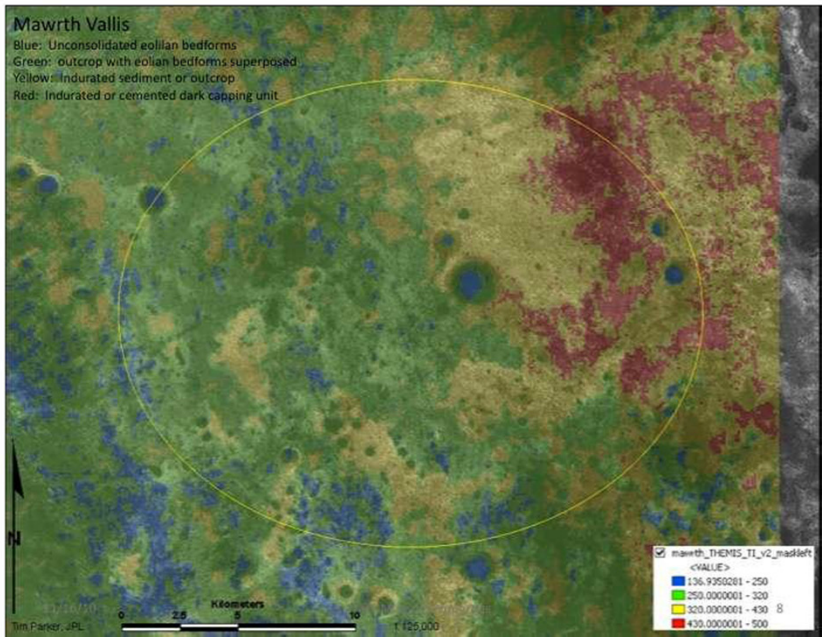
Fergason et al. (2006a)

Material Properties Map

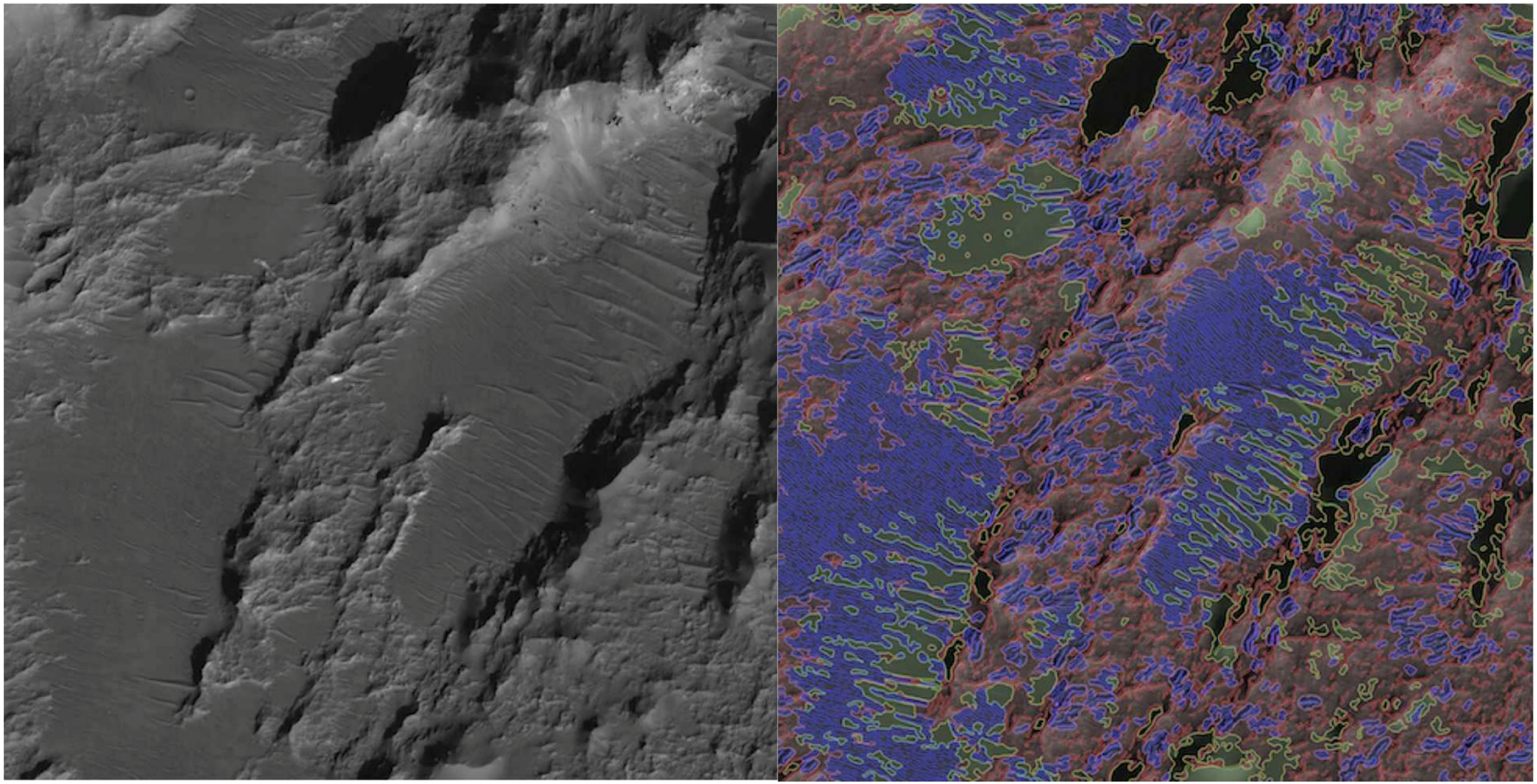






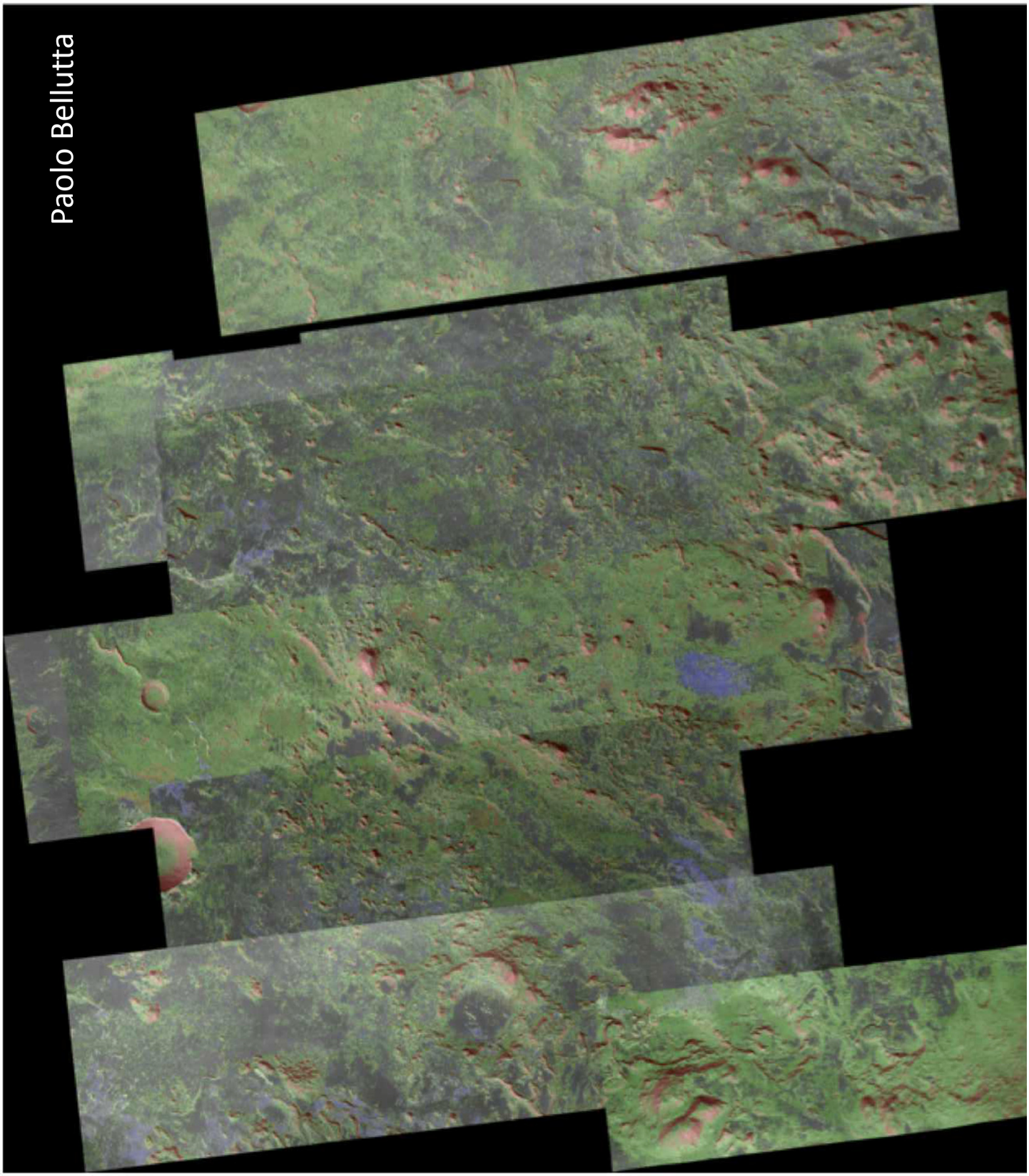


Automated Texture Analysis to identify geologic features



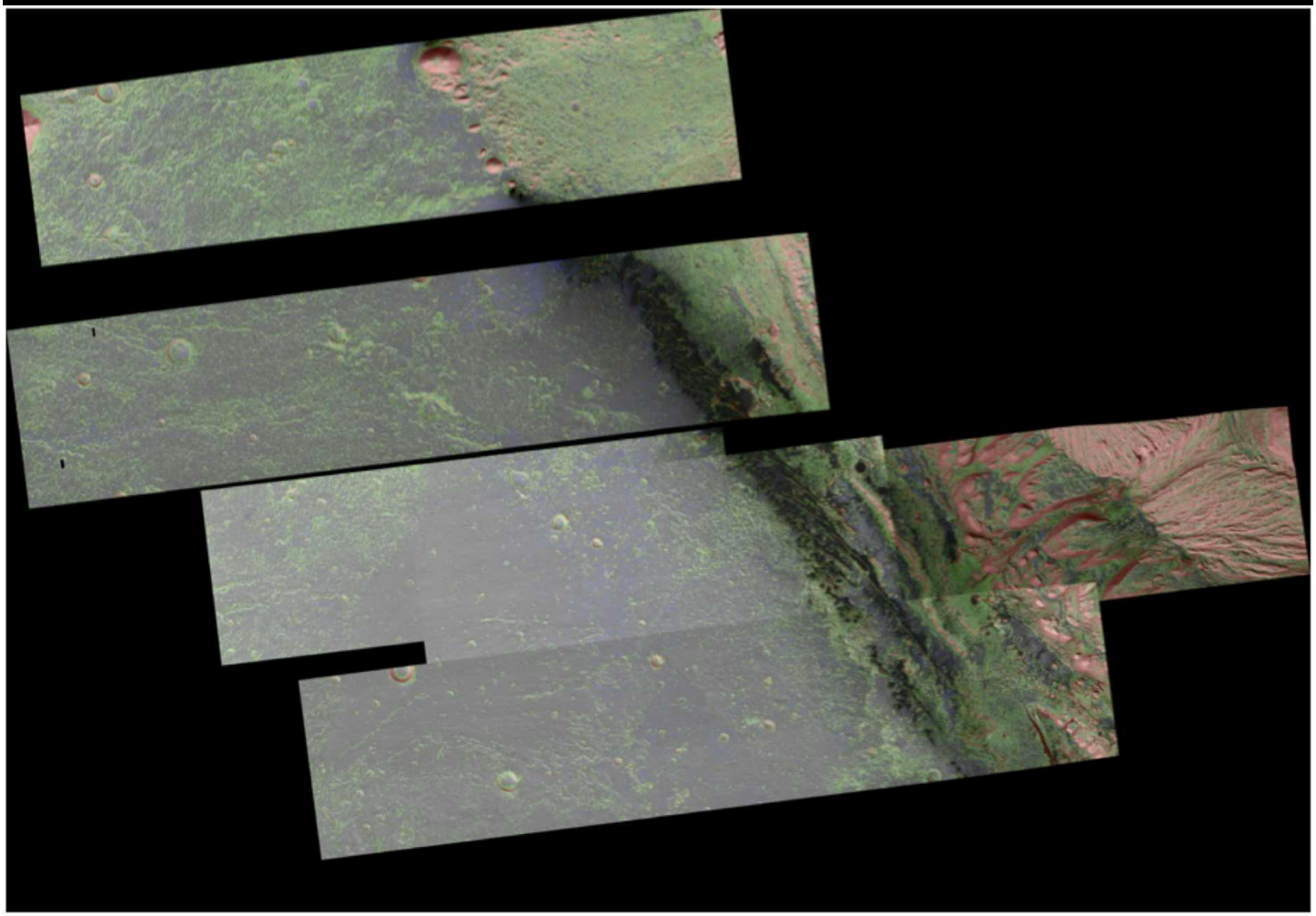
Traverse Cost Maps

Paolo Bellutta



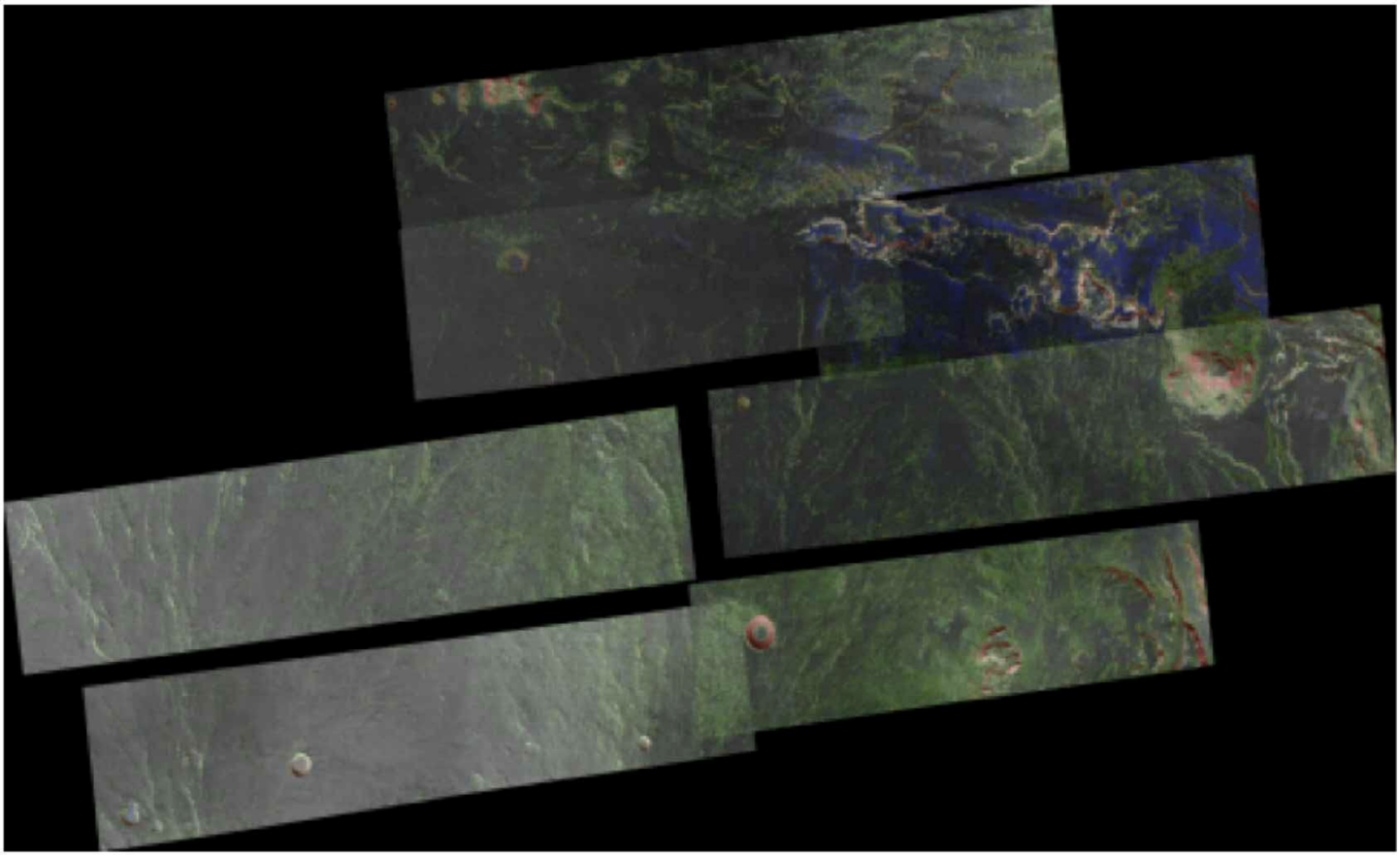
Traverse Cost Maps

Paolo Bellutta



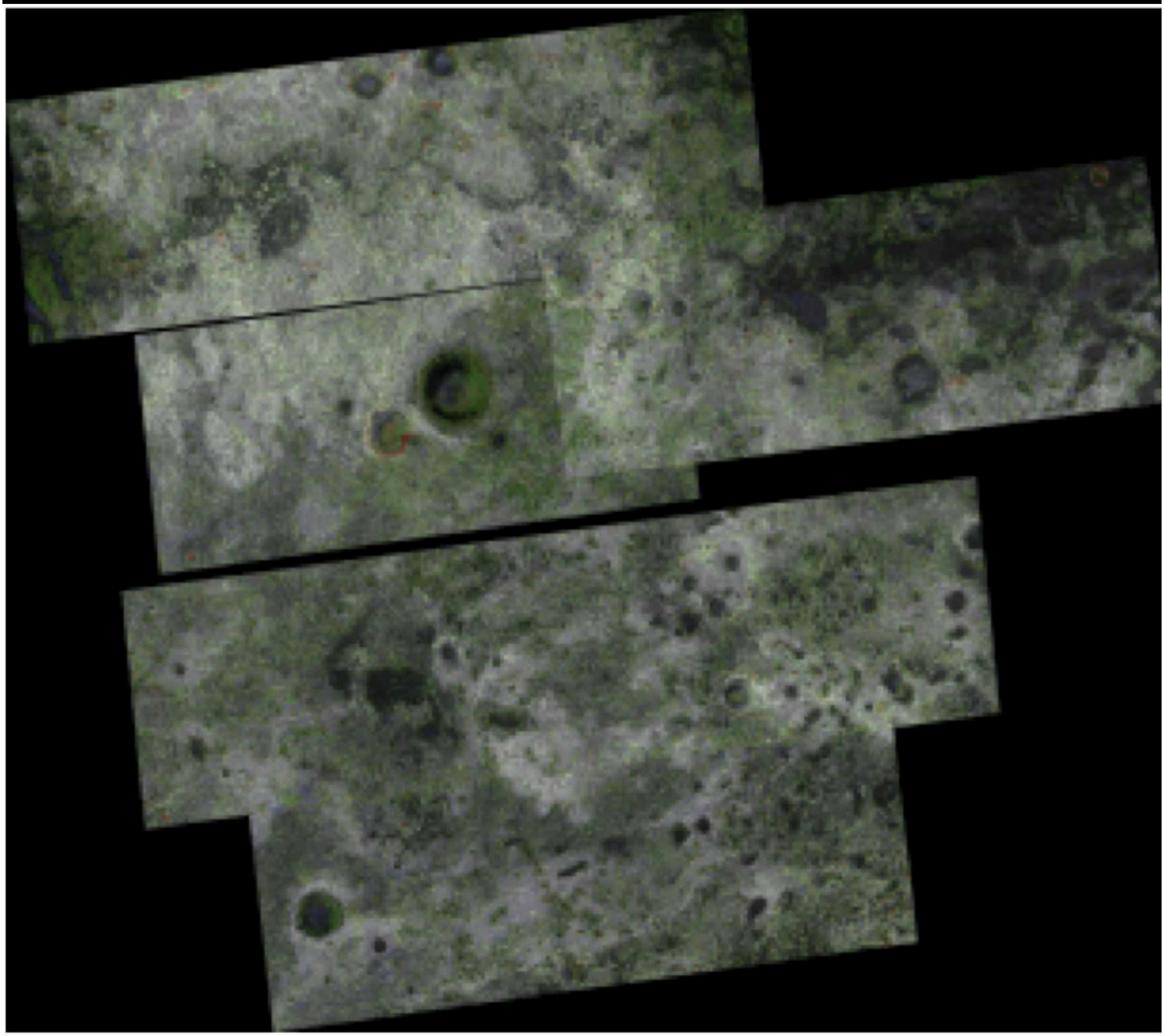
Traverse Cost Maps

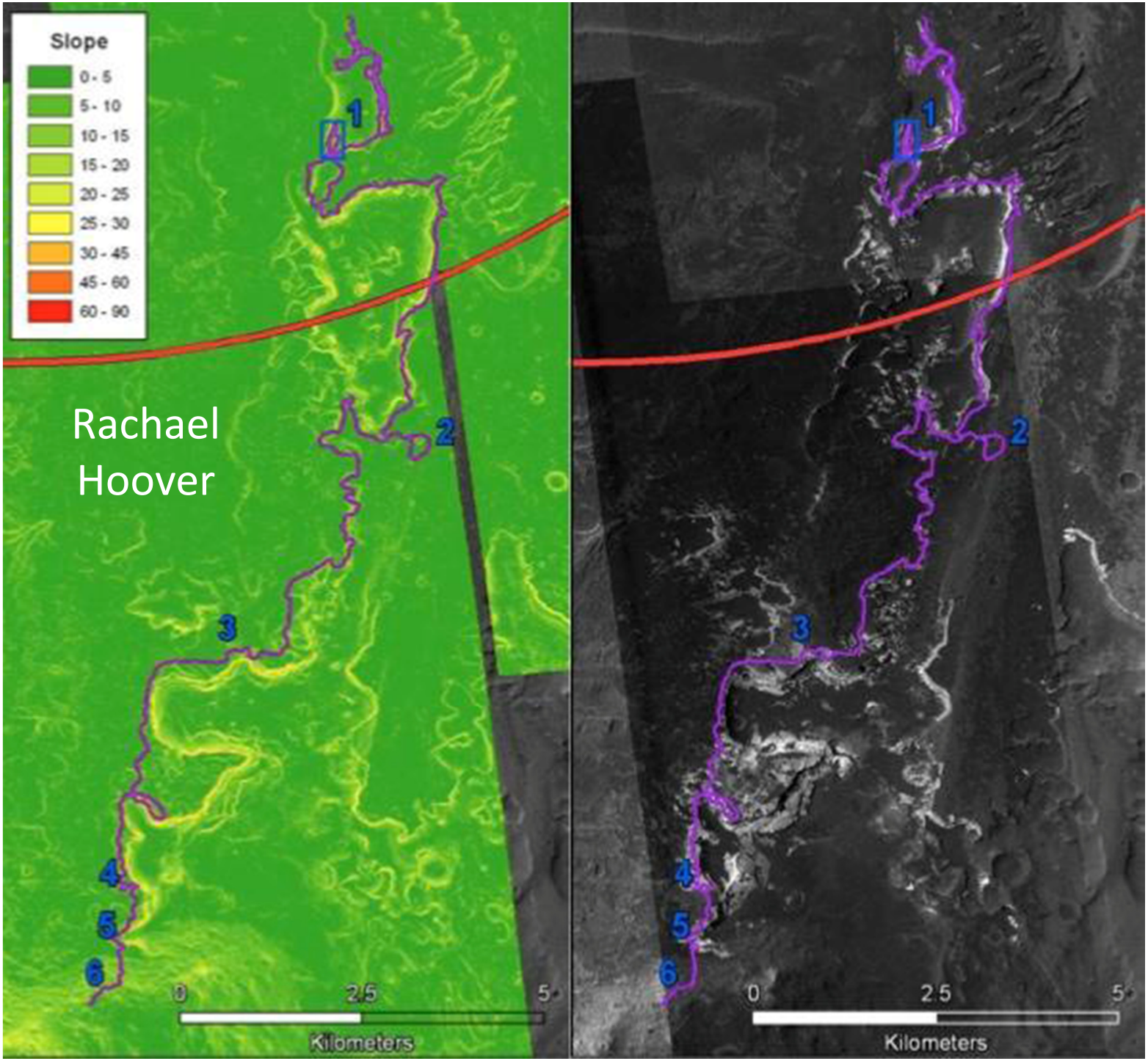
Paolo Bellutta



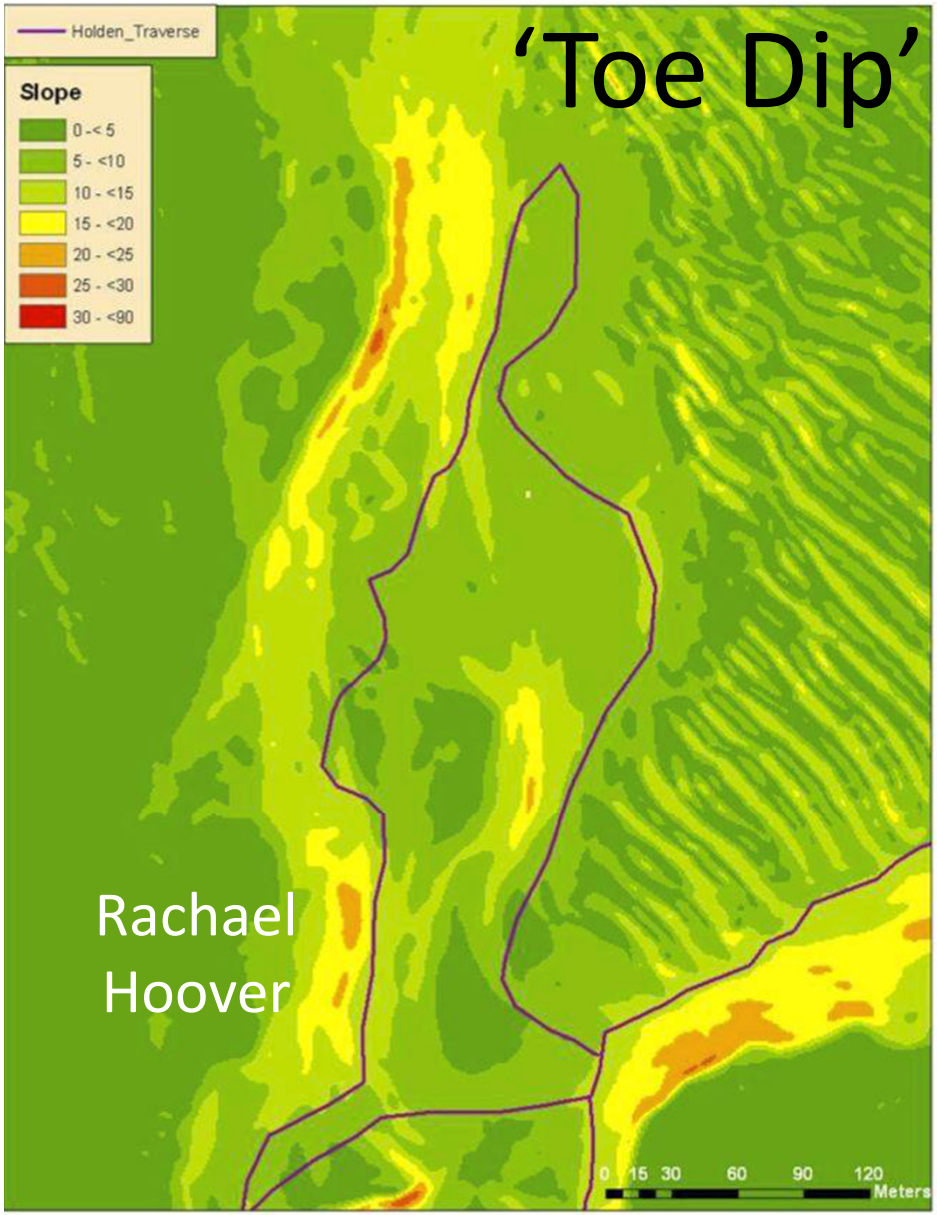
Traverse Cost Maps

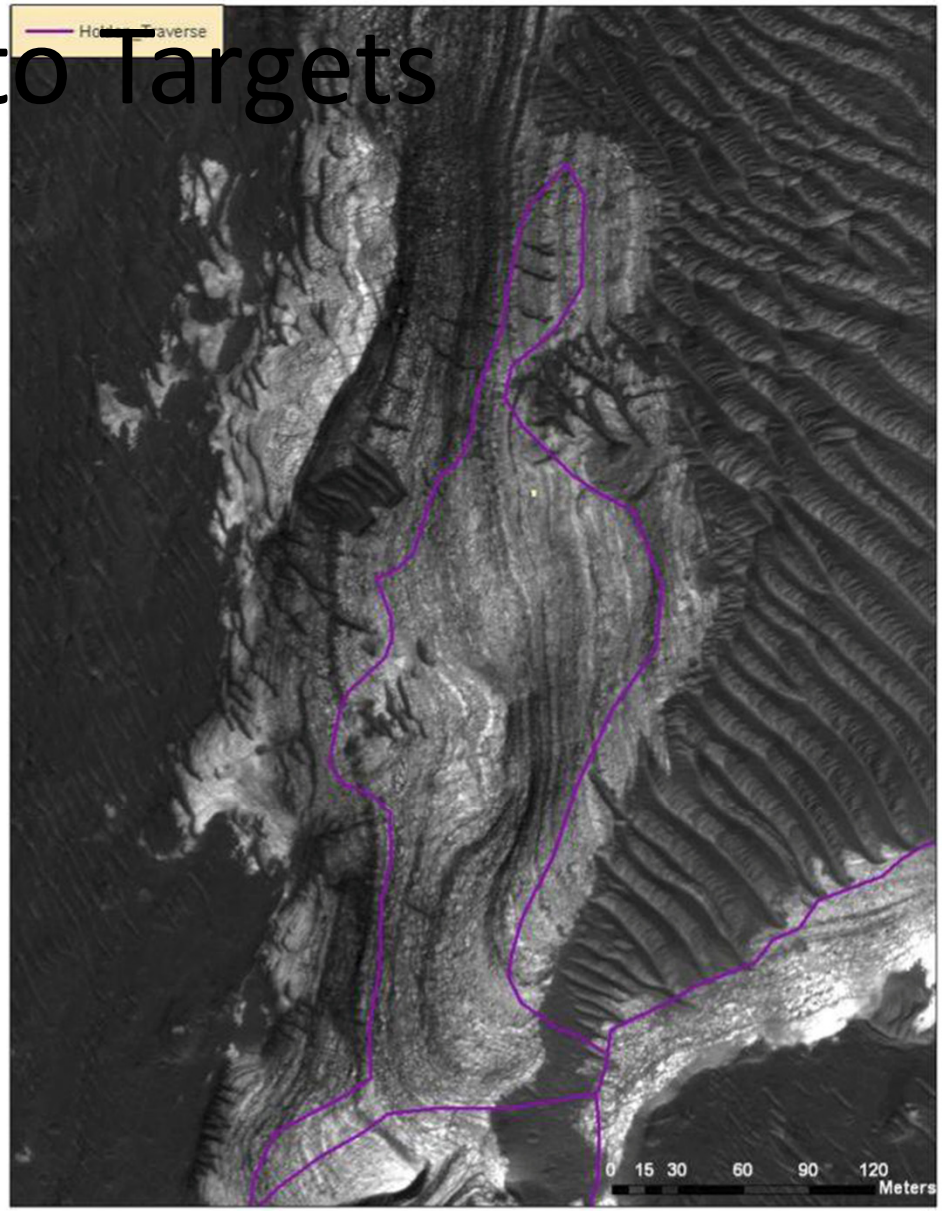
Paolo Bellutta




Slope
0 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 30
30 - 45
45 - 60
60 - 90
Rachael Hoover
1
2
3
4
5
6
0
2.5
5
Kilometers
1
2
3
4
5
6
0
2.5
5
Kilometers

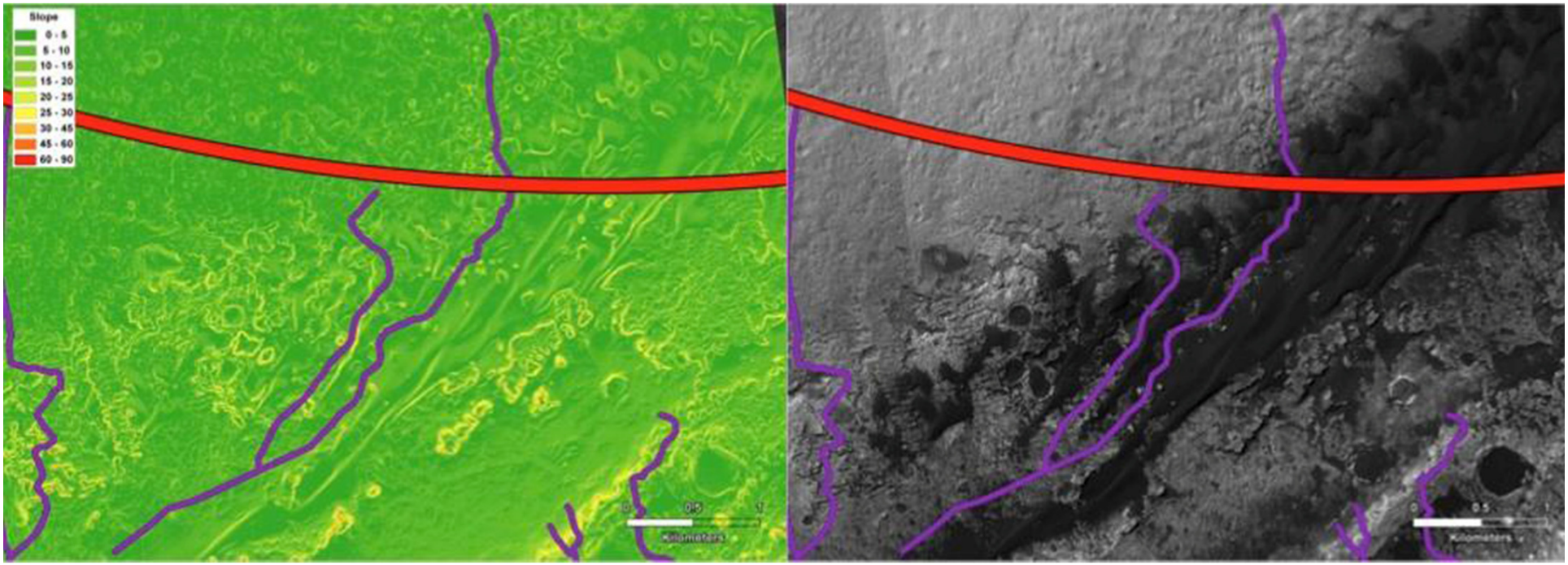
‘Toe Dip’ to Targets





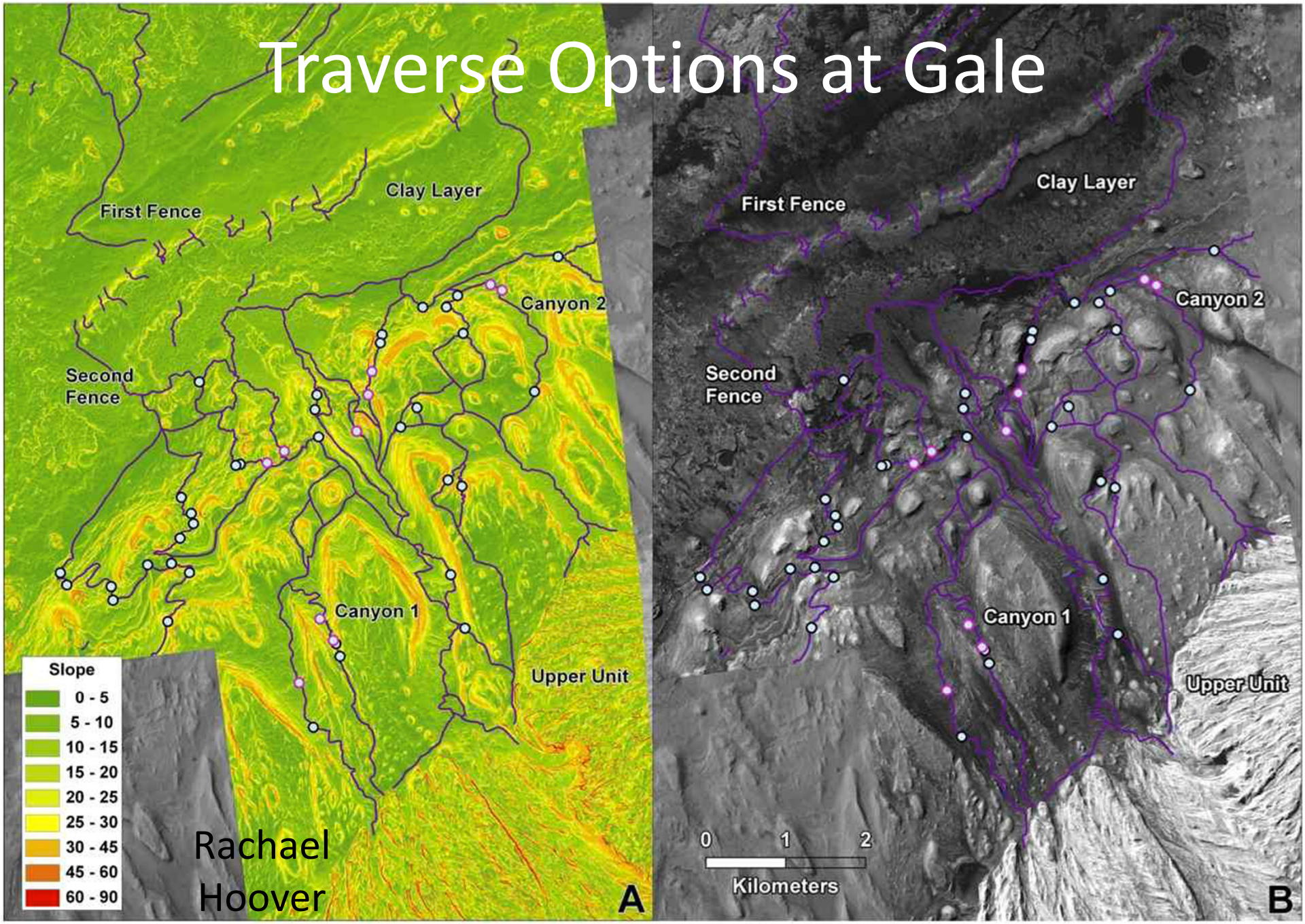
Rachael Hoover

Dunes? No Problem!



Rachael
Hoover

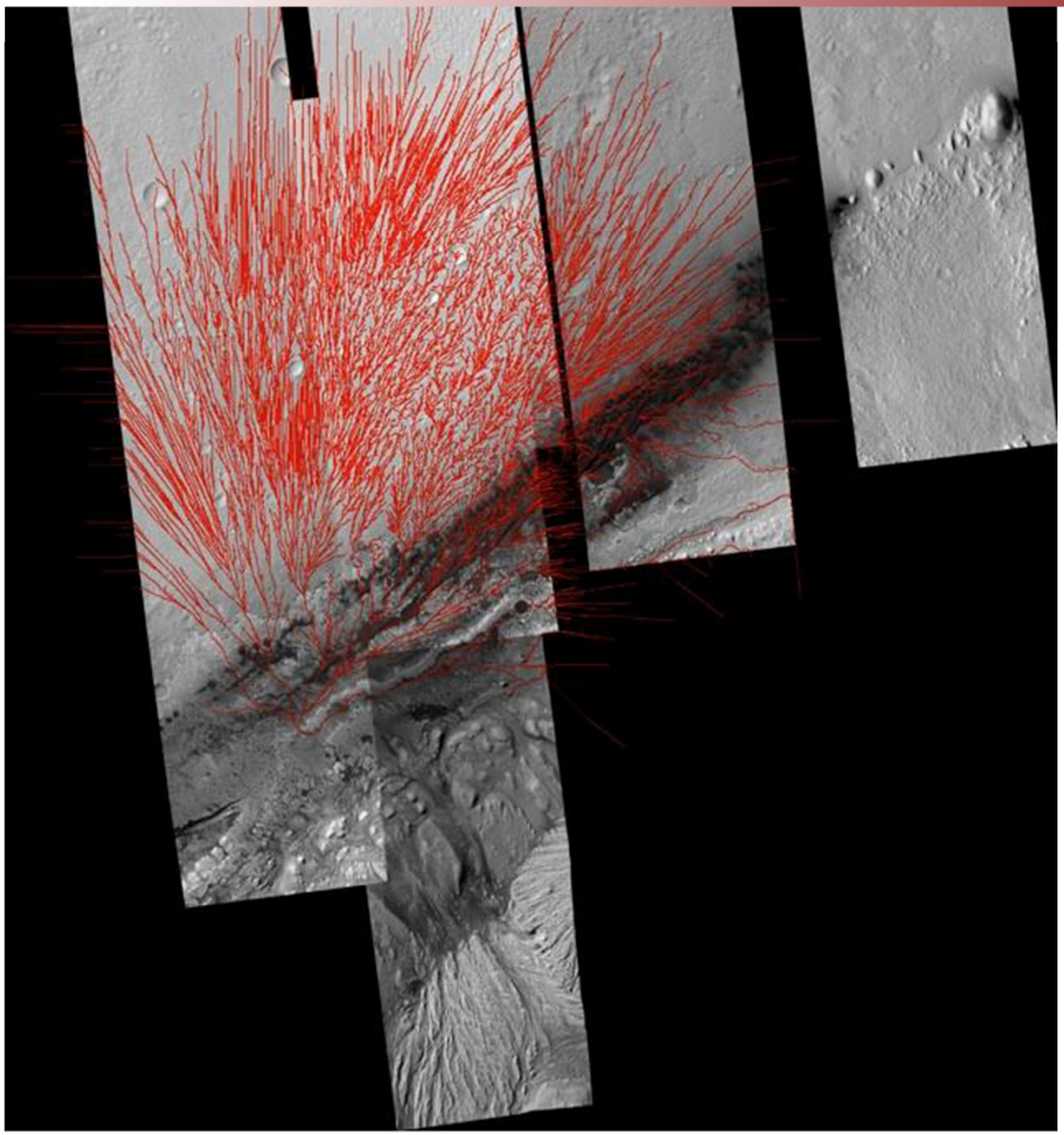
Traverse Options at Gale

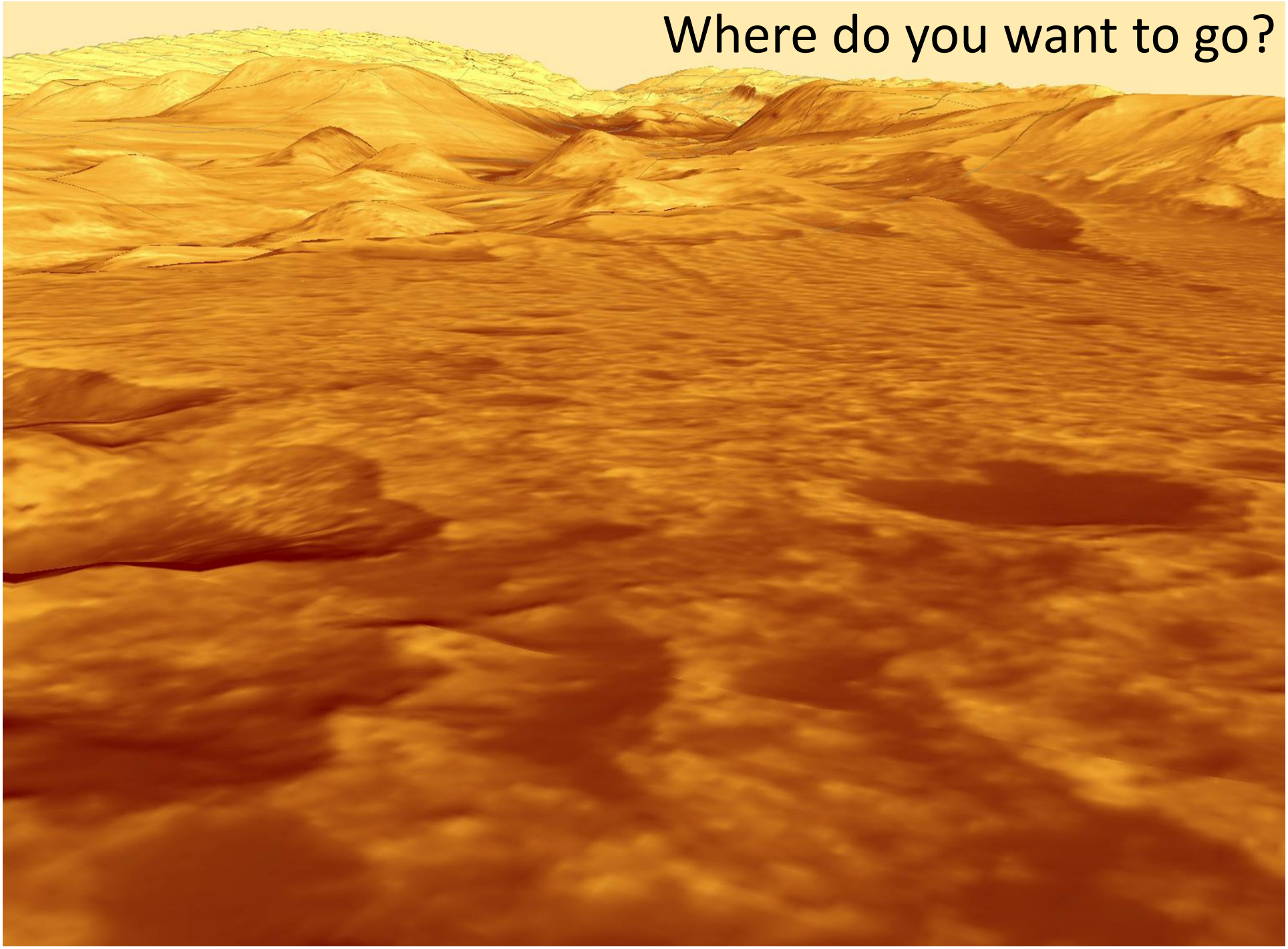


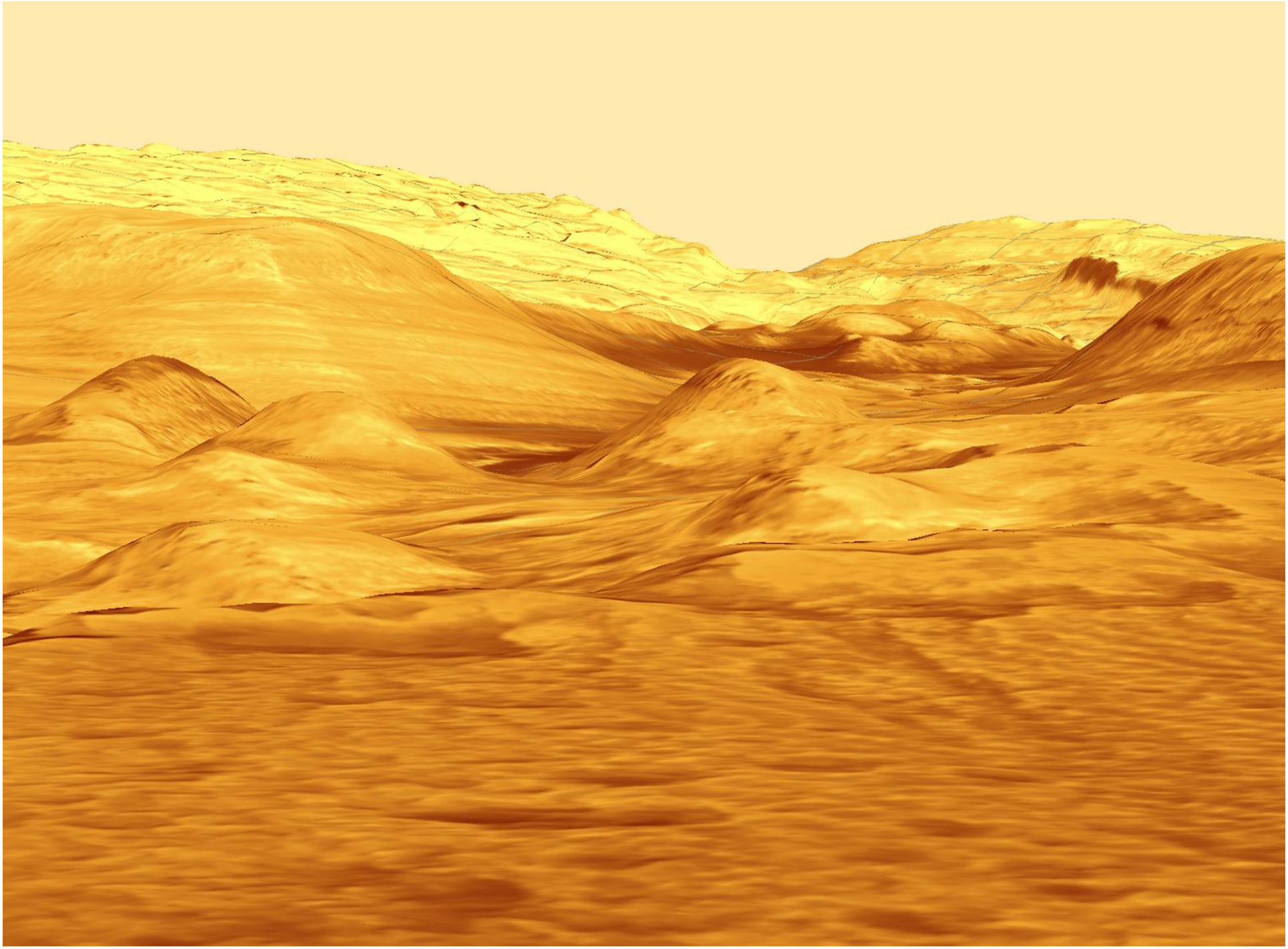
Rachael Hoover

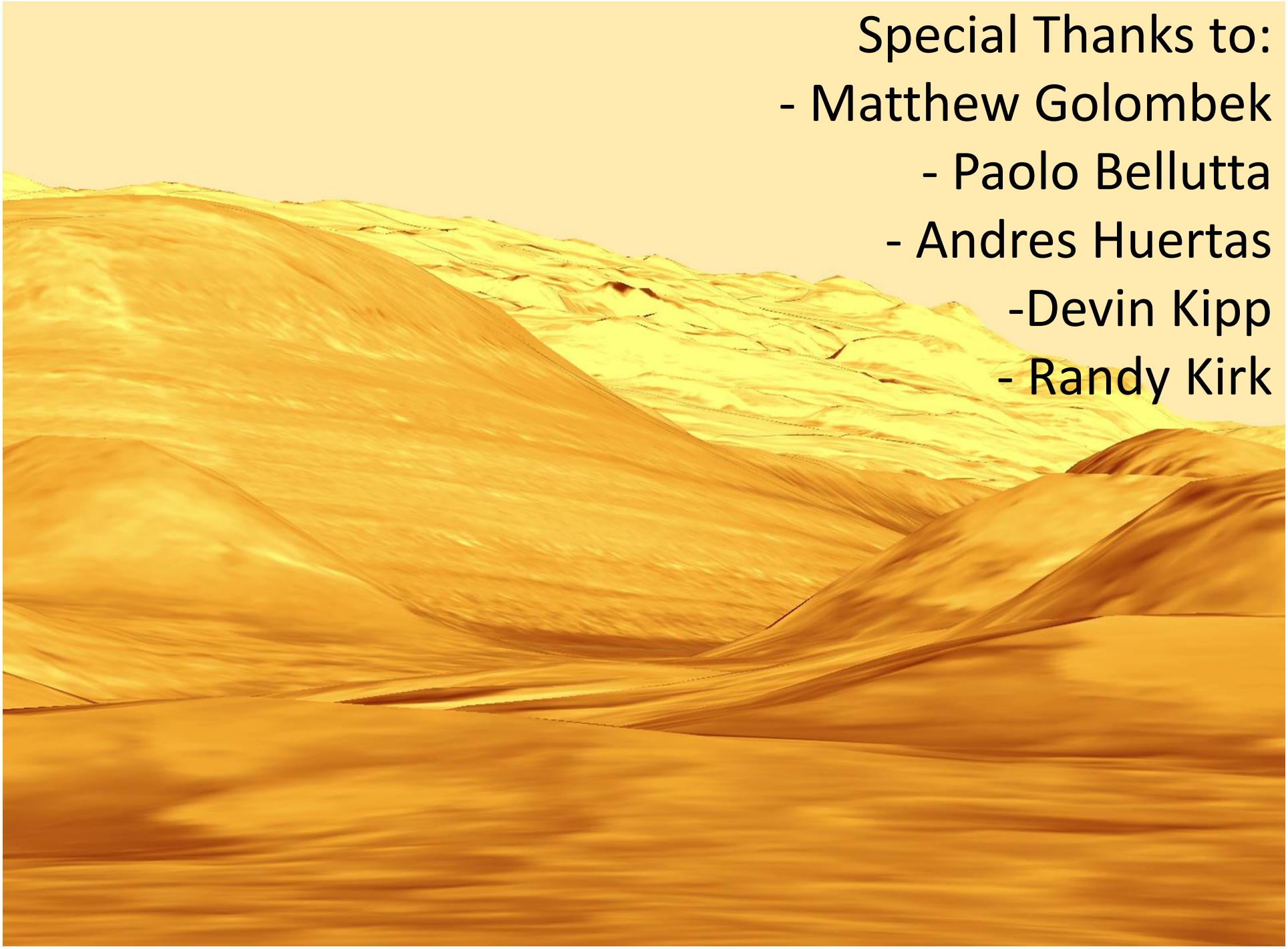
Gale Traverse Planning

Paolo Bellutta




Where do you want to go?





Special Thanks to:

- Matthew Golombek
- Paolo Bellutta
- Andres Huertas
-Devin Kipp
- Randy Kirk

Questions?

SELECTION OF THE MARS SCIENCE LABORATORY LANDING SITE

Journal Geophysical Research, 2011

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