Update on Landing Site Characterization

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Including work by:
R. Kirk, E. Howington-Kraus et al.: USGS Flagstaff – HiRISE Digital Elevation Models
A. Huertas, M. Golombek, Y. Cheng, D. Kipp: JPL – HiRISE Rock Maps
Gale Ascent Team

Fifth Mars Science Laboratory
Landing Site Workshop
May 18, 2011
DoubleTree Hotel
Monrovia, CA

Outline

- Characterization of MSL Landing Sites
  - wrt Other Landing Sites Complete at Last Workshop
  - Slopes, Rocks, Thermophysical Properties
- Provided Data Sets to Project
  - EDL – Slopes and Rocks
  - Traversability – Slopes, Rocks & Images
  - Thermal Inertia – See Fergason Presentation 4th Workshop
    - Derived Surface Temperature
- Show Data Sets Delivered – Used for
  - Simulations - Landing Safety – D. Kipp
  - Traversability – P. Bellutta, R. Welch
- Show Other Aspects
  - Inescapable Hazards
  - Science Aspects of Traversablity

Characterization of MSL Landing Sites

- Comparison to Other Landing Sites
  - All Sites Dust Free – Like Meridiani
  - Surface Materials – Soils, Sand, Eolian Bedforms, Rocks, Sedimentary Rocks
  - Slopes 1 km & 100 m: Holden Comparable to Rougher LS
    - Gale, Mawrth & Eberswalde Progressively Rougher
  - Slopes 5 m: Holden, Gale Comparable to VL1, MPF
    - Mawrth & Eberswalde Much Rougher:
      - Comparable to Columbia Hills
  - Rock Abundance – Varied but Ellipse Equivalent to Gusev Cratered Plains
    - 5-7% Rock Abundance, Generally Low Near Global Mode
  - No Unusual Radar Properties
    - Radar backscatter within engineering constraints
    - No roughness concerns
- Nothing of Concern wrt Comparison to Engineering Constraints
  - Simulation Results D. Kipp

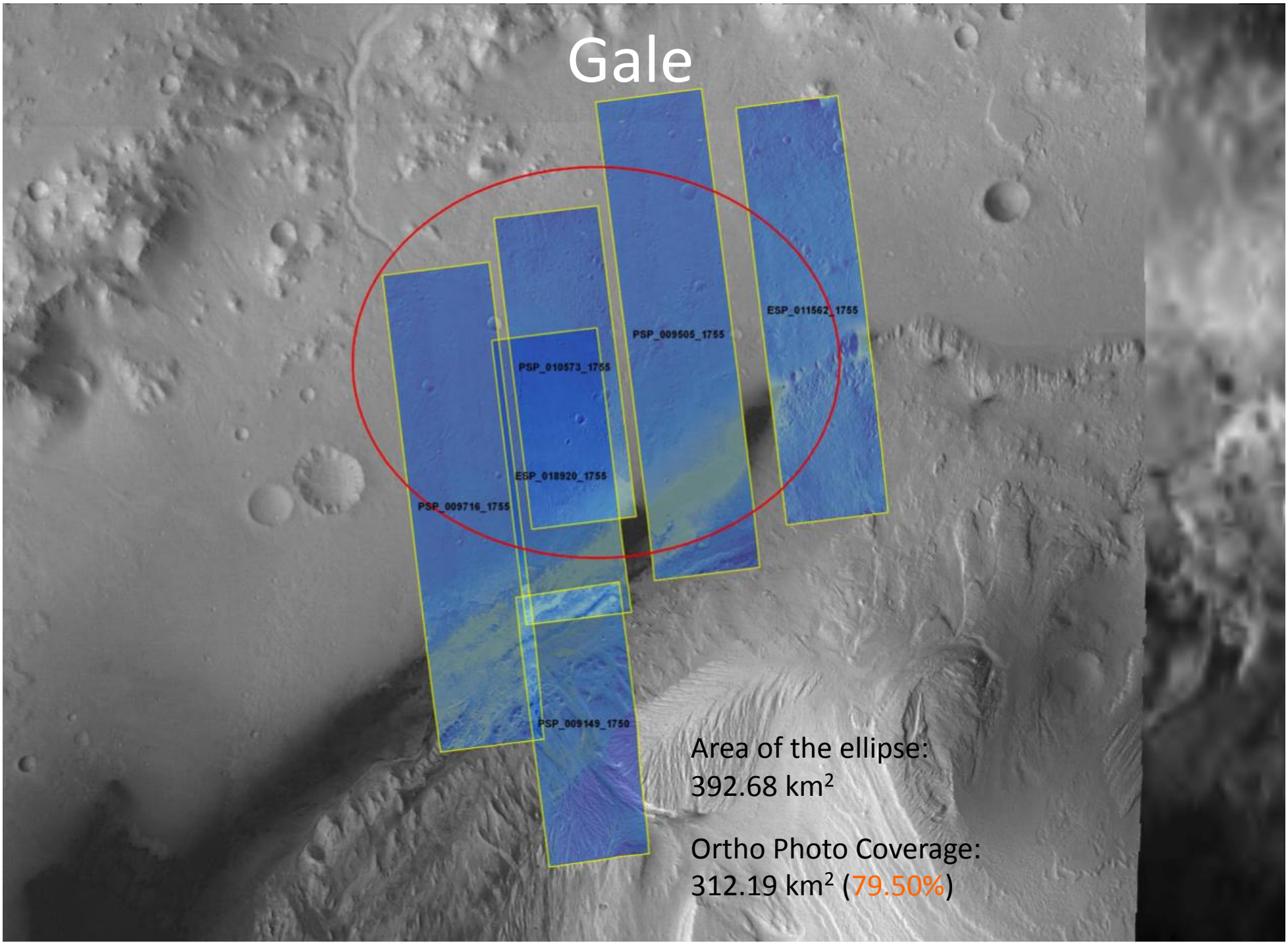
See Golombek et al. Presentation at 4th Workshop

HiRISE DEMs

DEMs by R. Kirk et al., USGS Flagstaff
See Presentation at 4th Workshop

Stereo Mapping Mature Technology
1 m Postings Sample 3-5 pixels (~25-30 cm/pixel)
Slope Maps Good to ~1° RMS

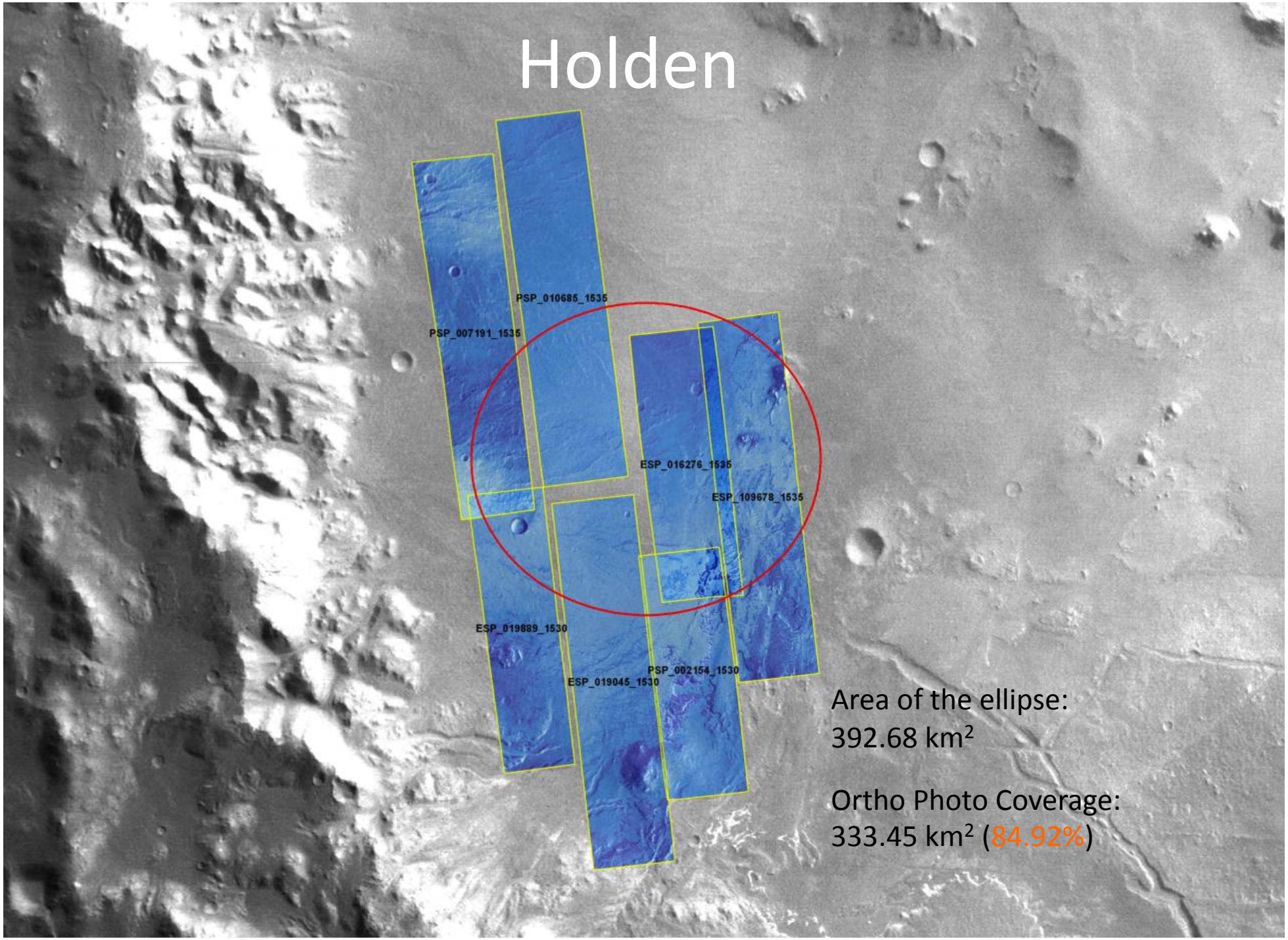
Gale



Area of the ellipse:
392.68 km^2

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

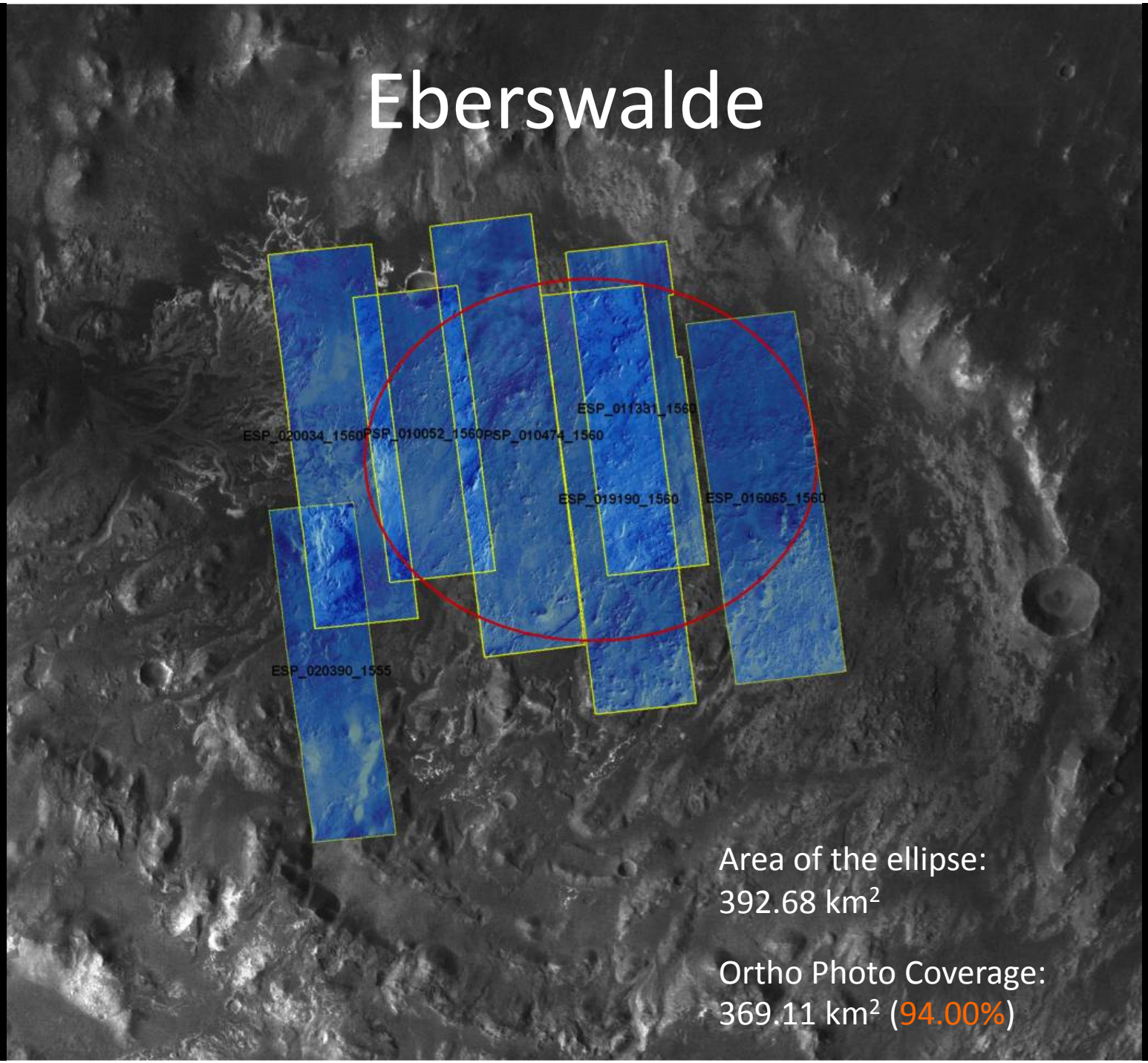
Holden



Area of the ellipse:
392.68 km^2

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

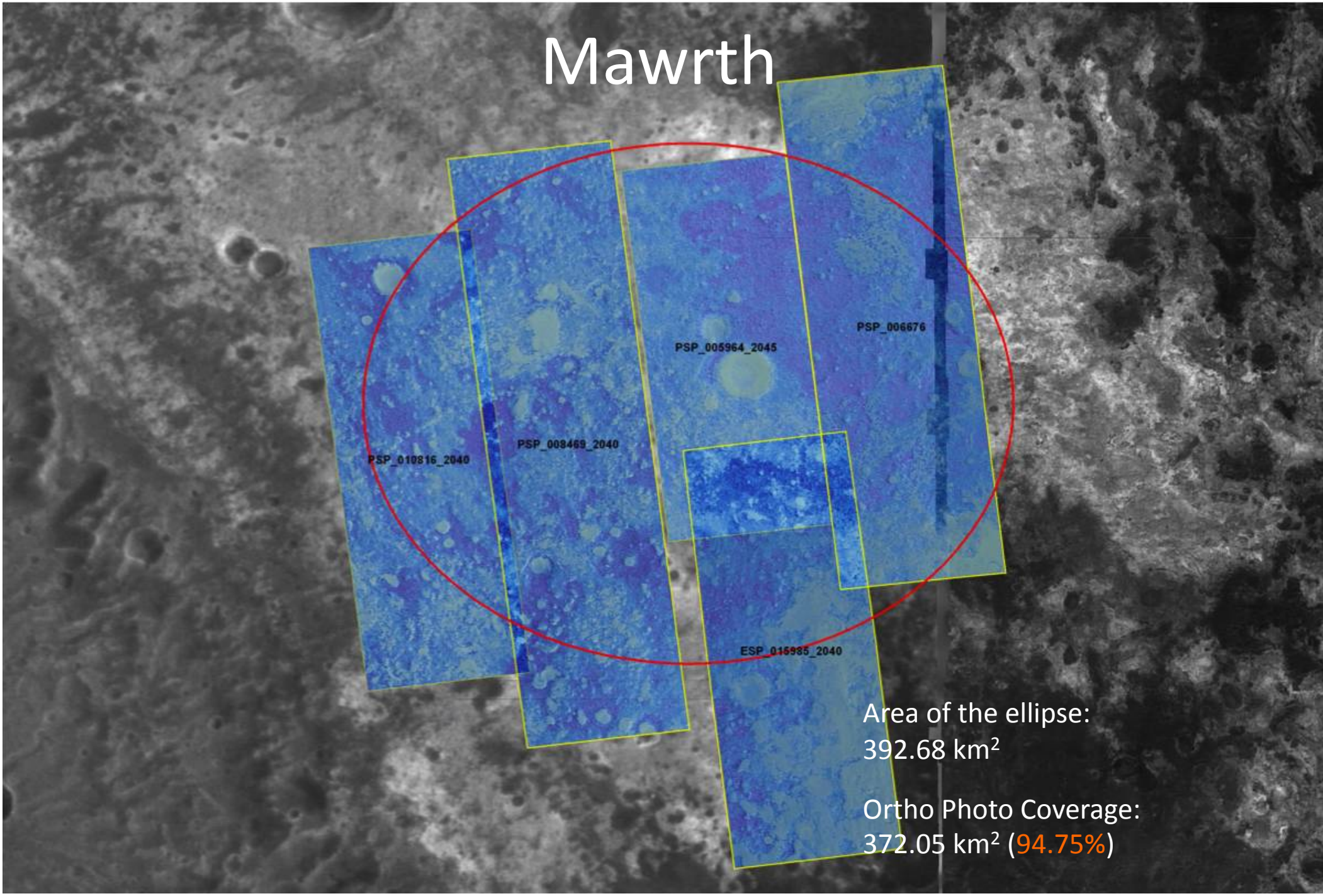
Eberswalde



Area of the ellipse:
392.68 km^2

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

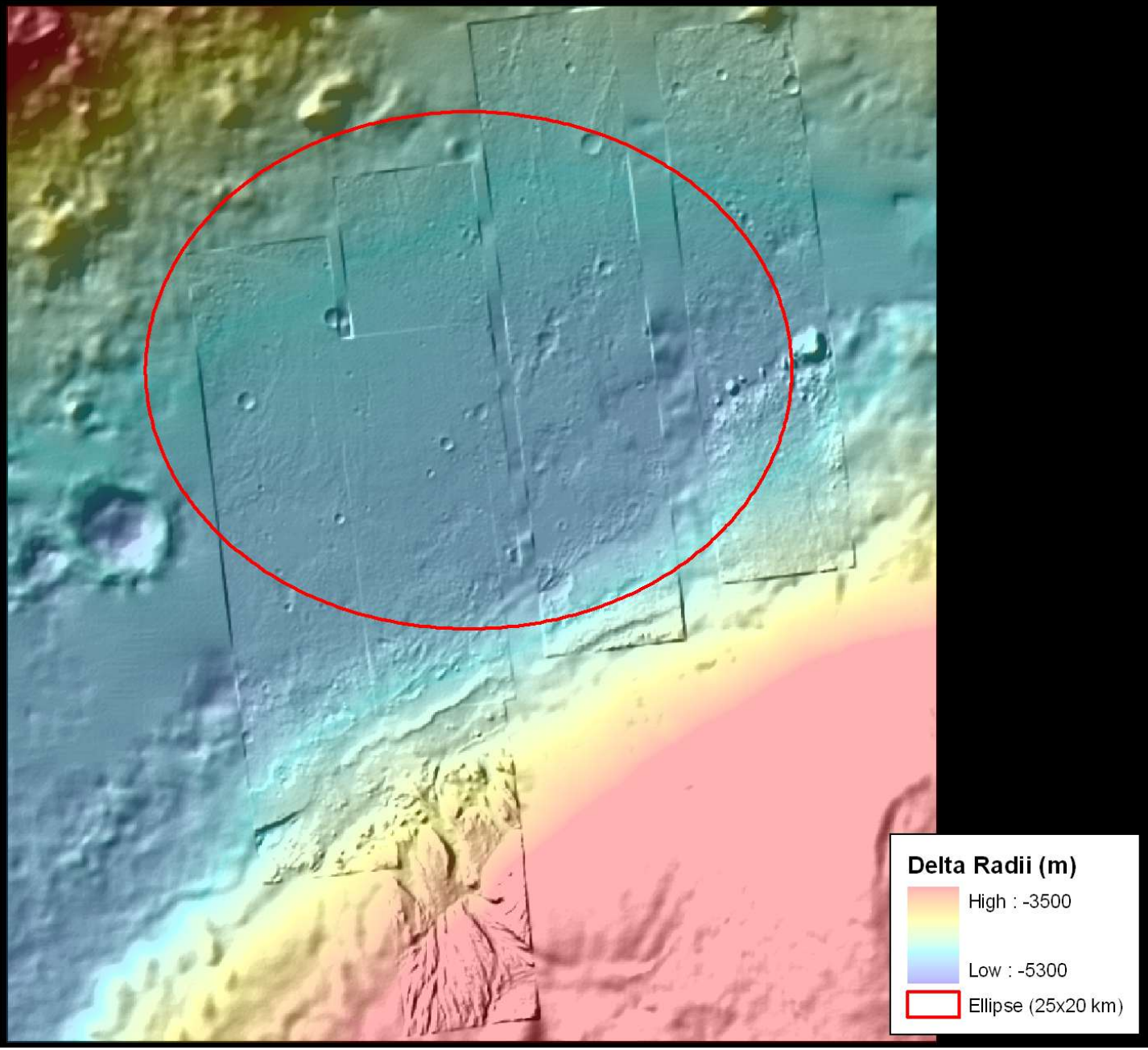
Mawrth



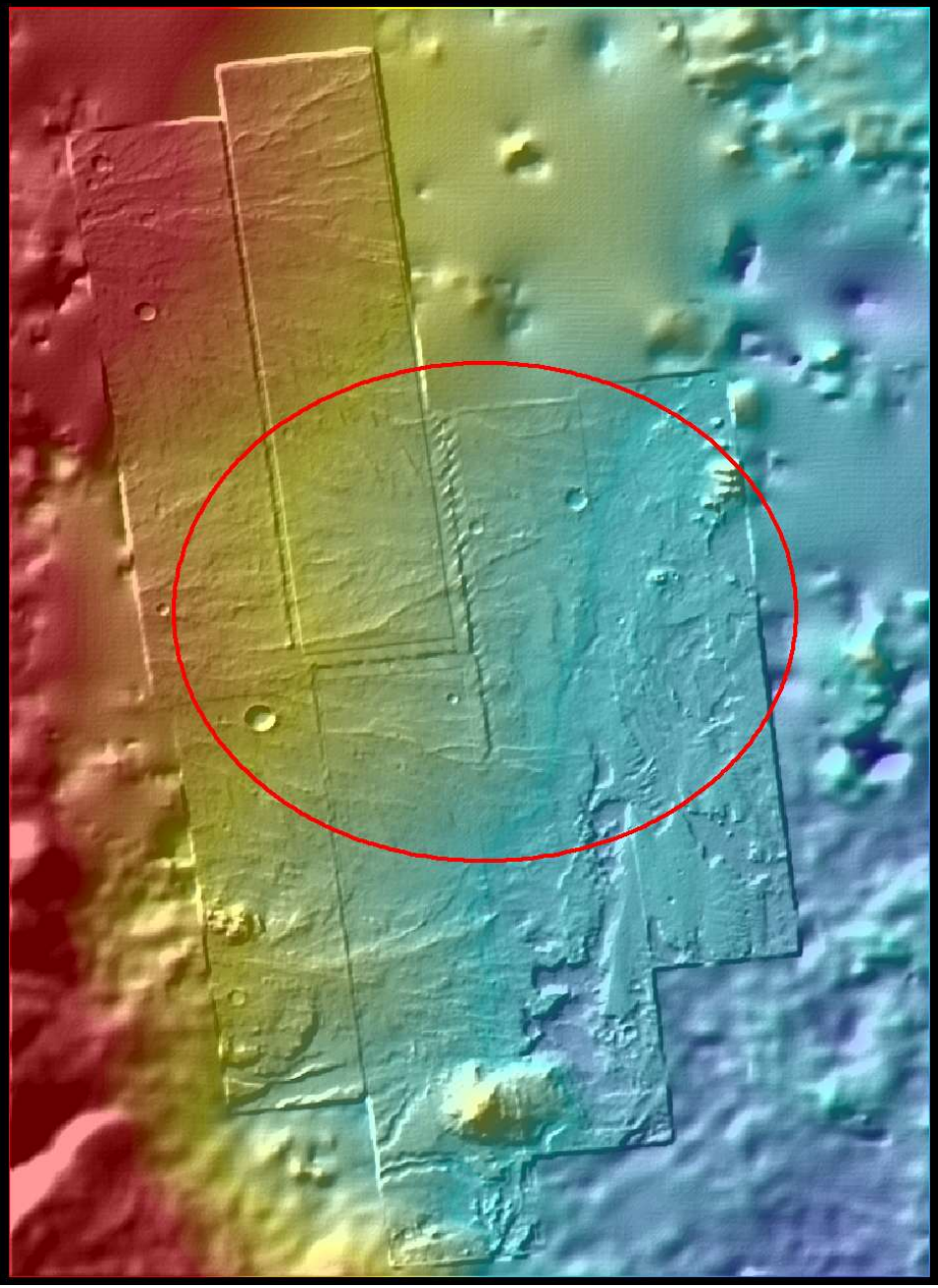
Area of the ellipse:
392.68 km^2

Ortho Photo Coverage:
372.05 km^2 (94.75%)

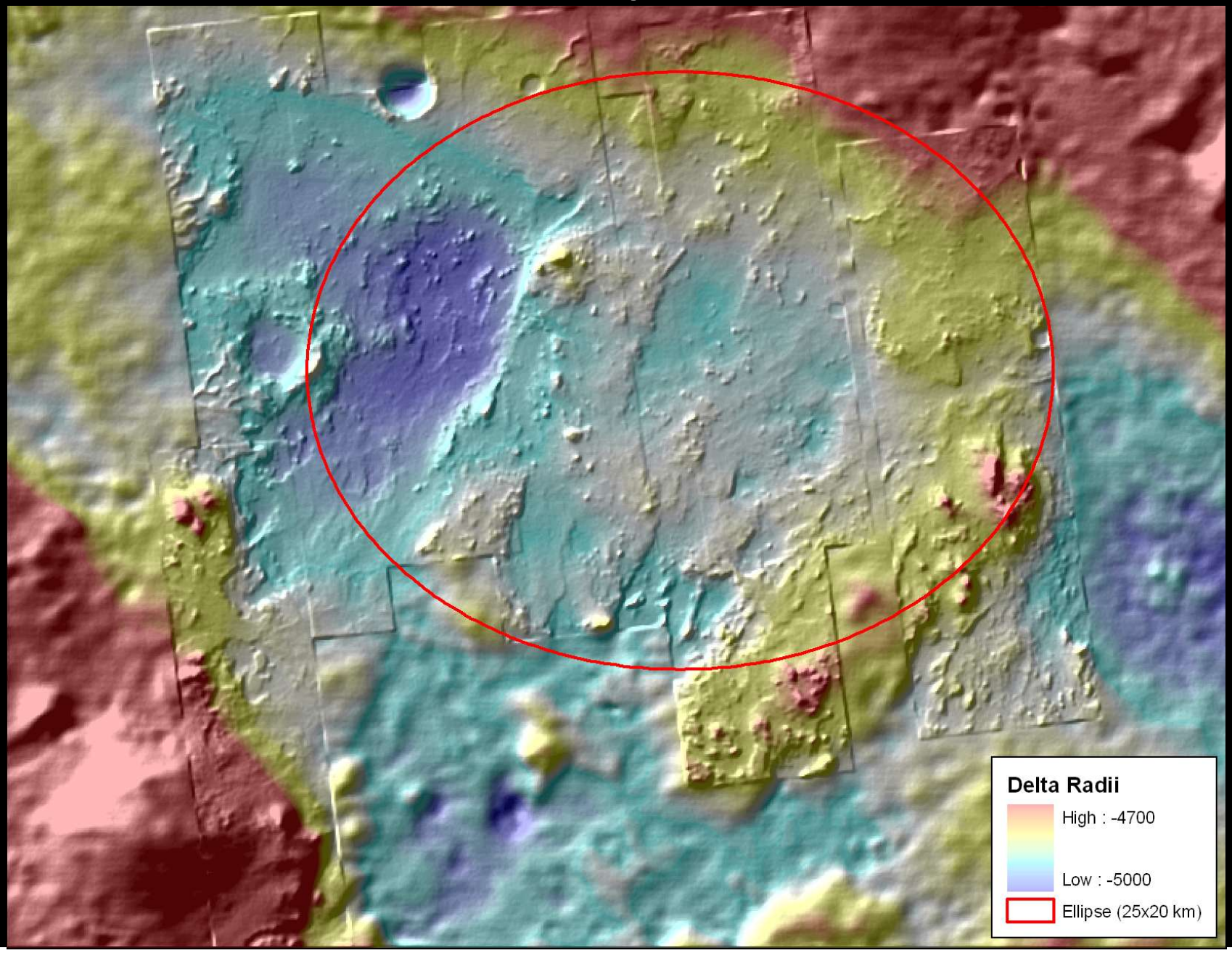
Gale: Ellipsoid Elevation



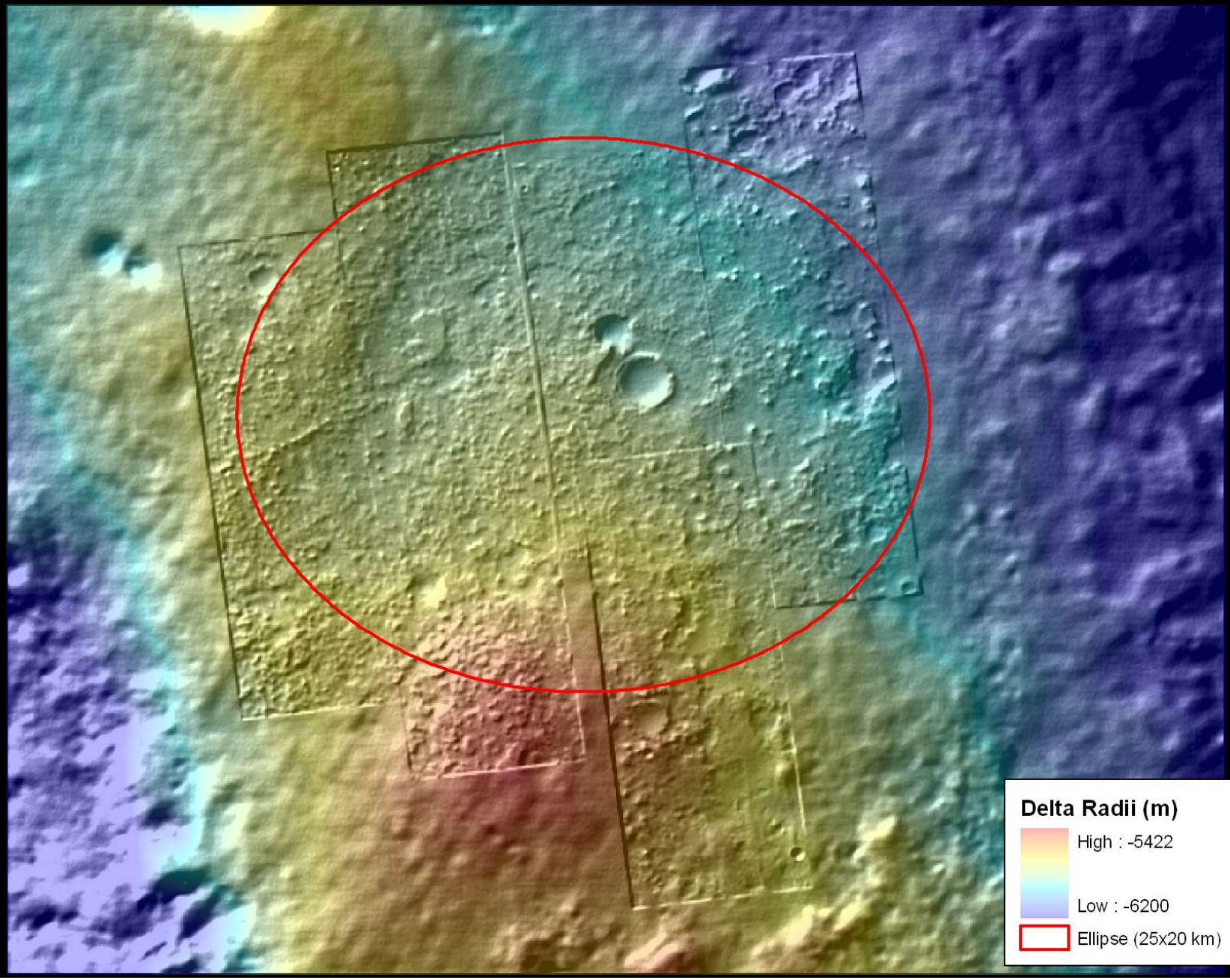
Holden: Ellipsoid Elevation



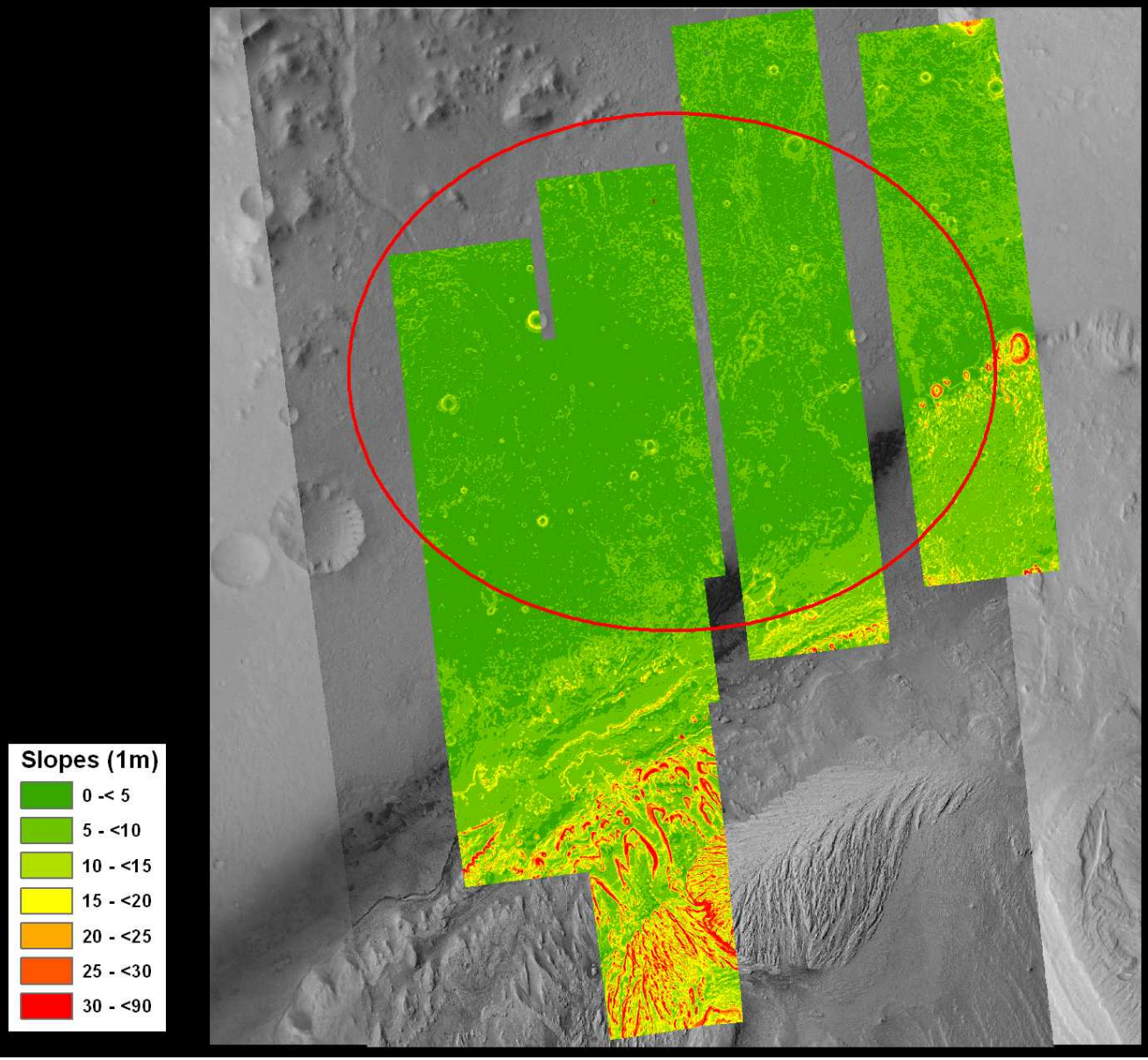
Eberswalde: Ellipsoid Elevation



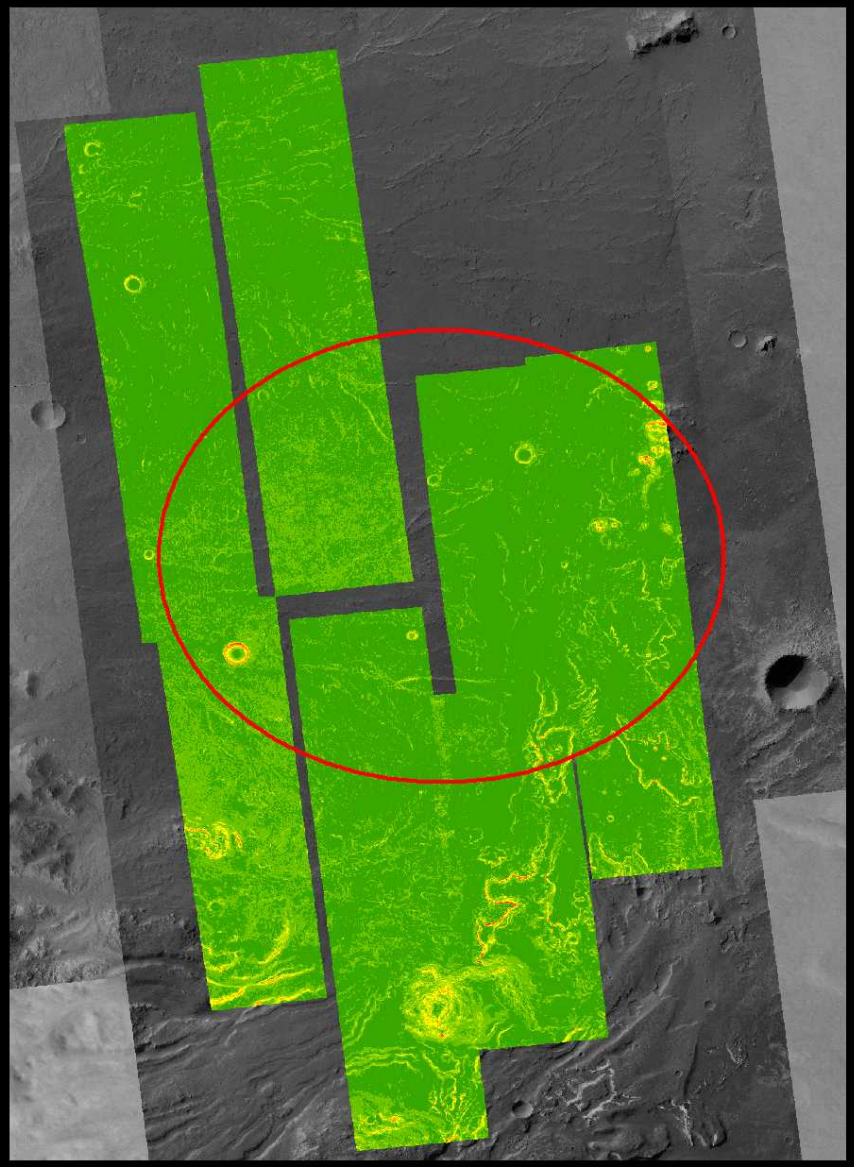
Mawrth: Ellipsoid Elevation



Gale Slopes (1m)



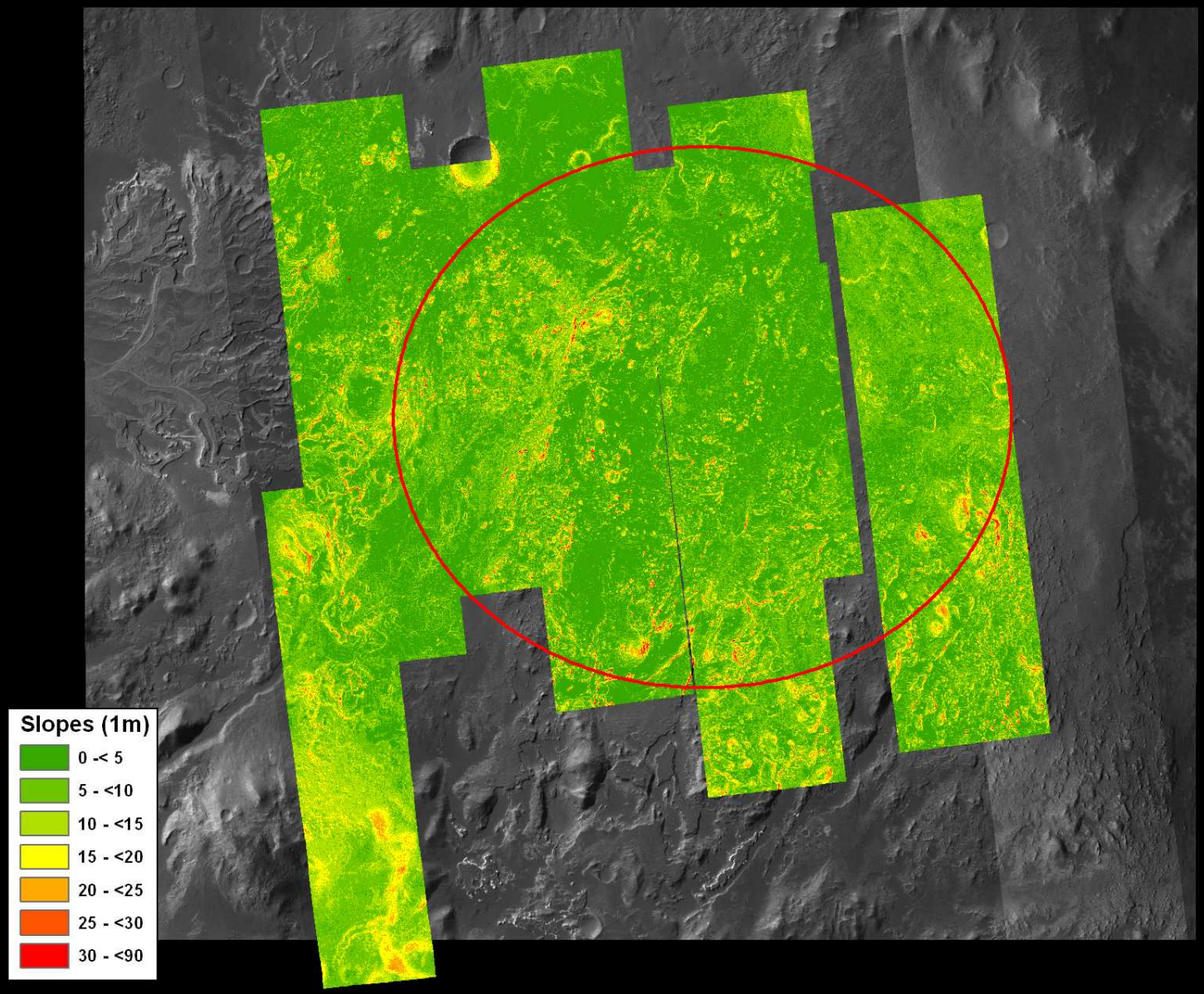
Holden Slopes (1m)



Slopes (1m)

- 0 -< 5
- 5 - <10
- 10 - <15
- 15 - <20
- 20 - <25
- 25 - <30
- 30 - <90

Eberswalde Slopes (1m)



Mawrth Slopes (1m)

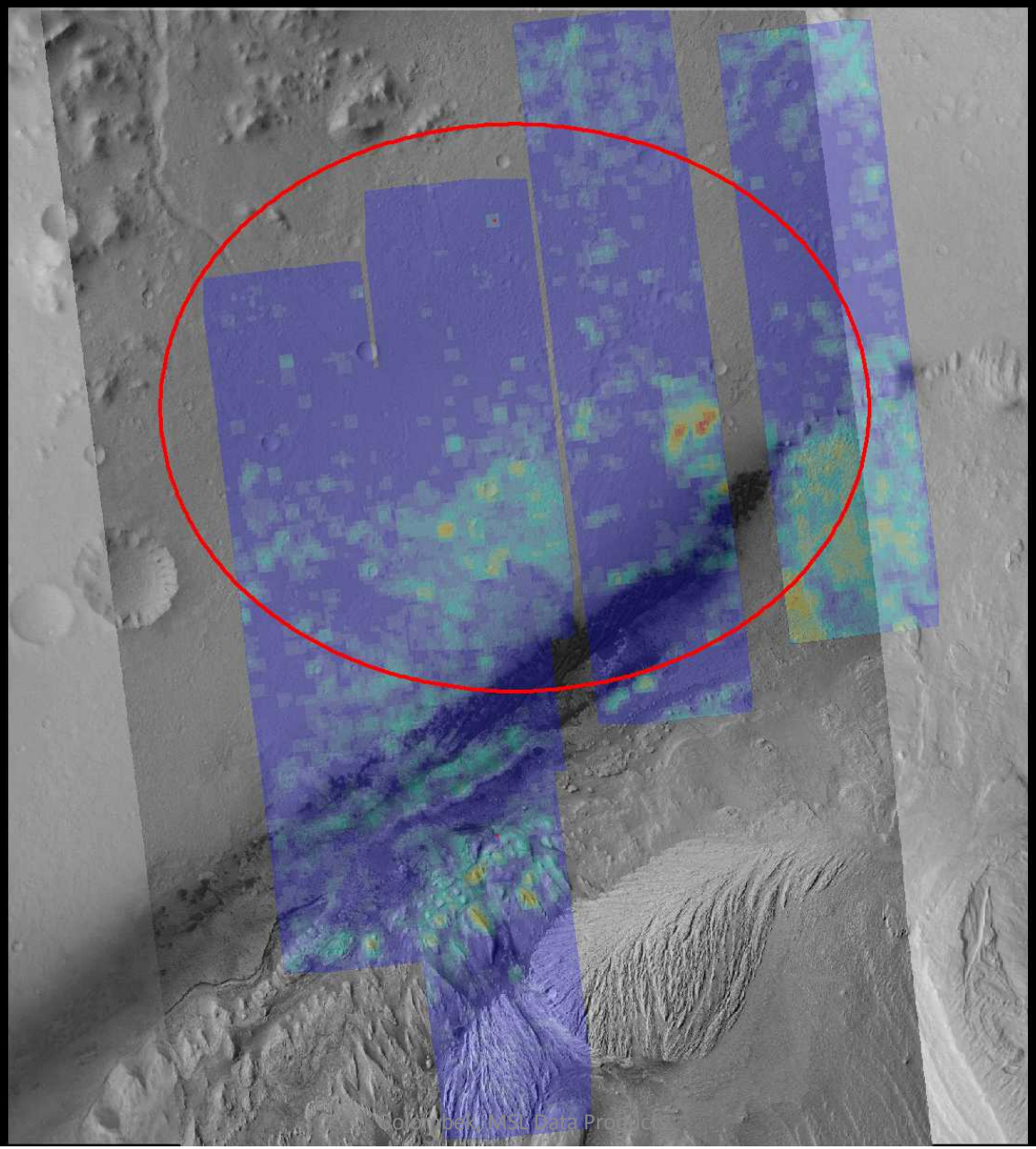
Rocks & Rock Maps

See Presentation at 4th Workshop

A. Huertas, M. Golombek, Y. Cheng & D. Kipp JPL

Diameter, Height and Location of All Rocks Detected
Cumulative Number in 150 m by 150 m Tiles of Image
Summary Size-Frequency Distribution in 450 m Squares
Best Fit Model from Rocks btw 1.5-2.25 m Diameter
Model Cumulative Fractional Area
Provided for Extrapolation to Rocks <1.5 m Diameter

Gale CFA 450 m



CFA 450 m

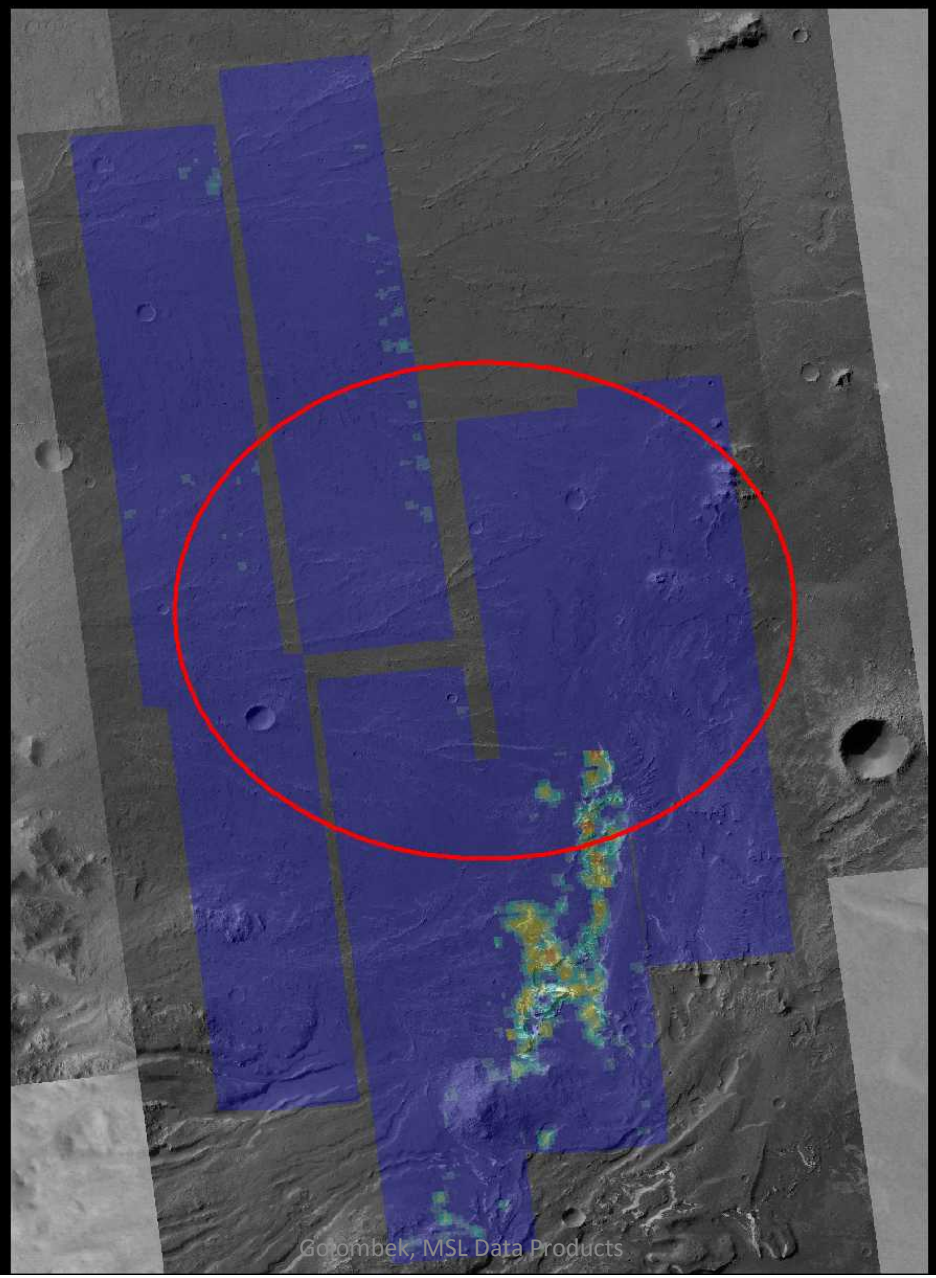
Value

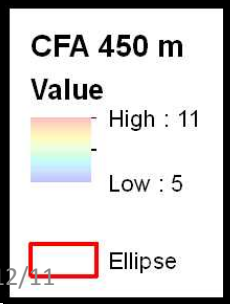
High : 17

Low : 5

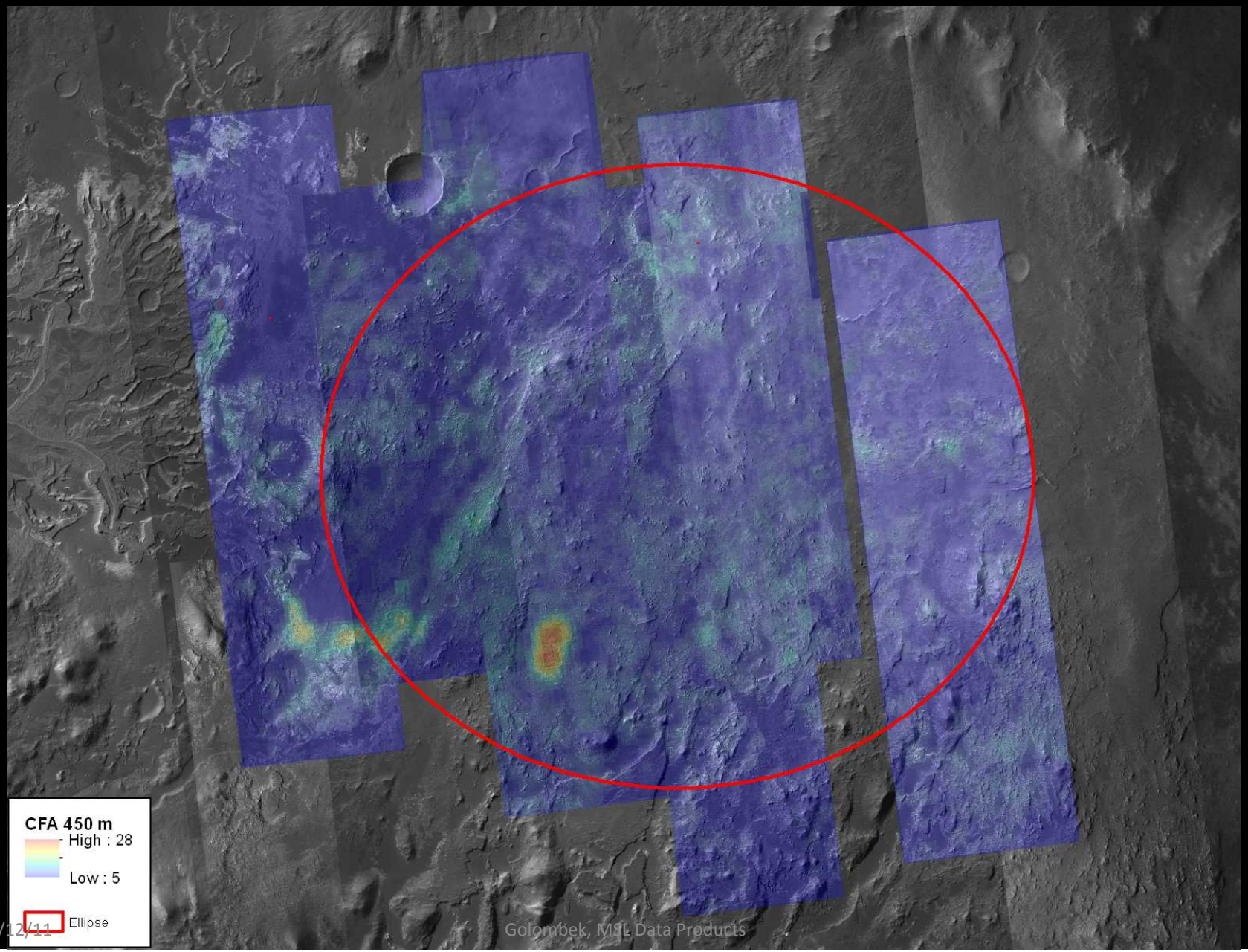
Ellipse

Holden CFA 450 m

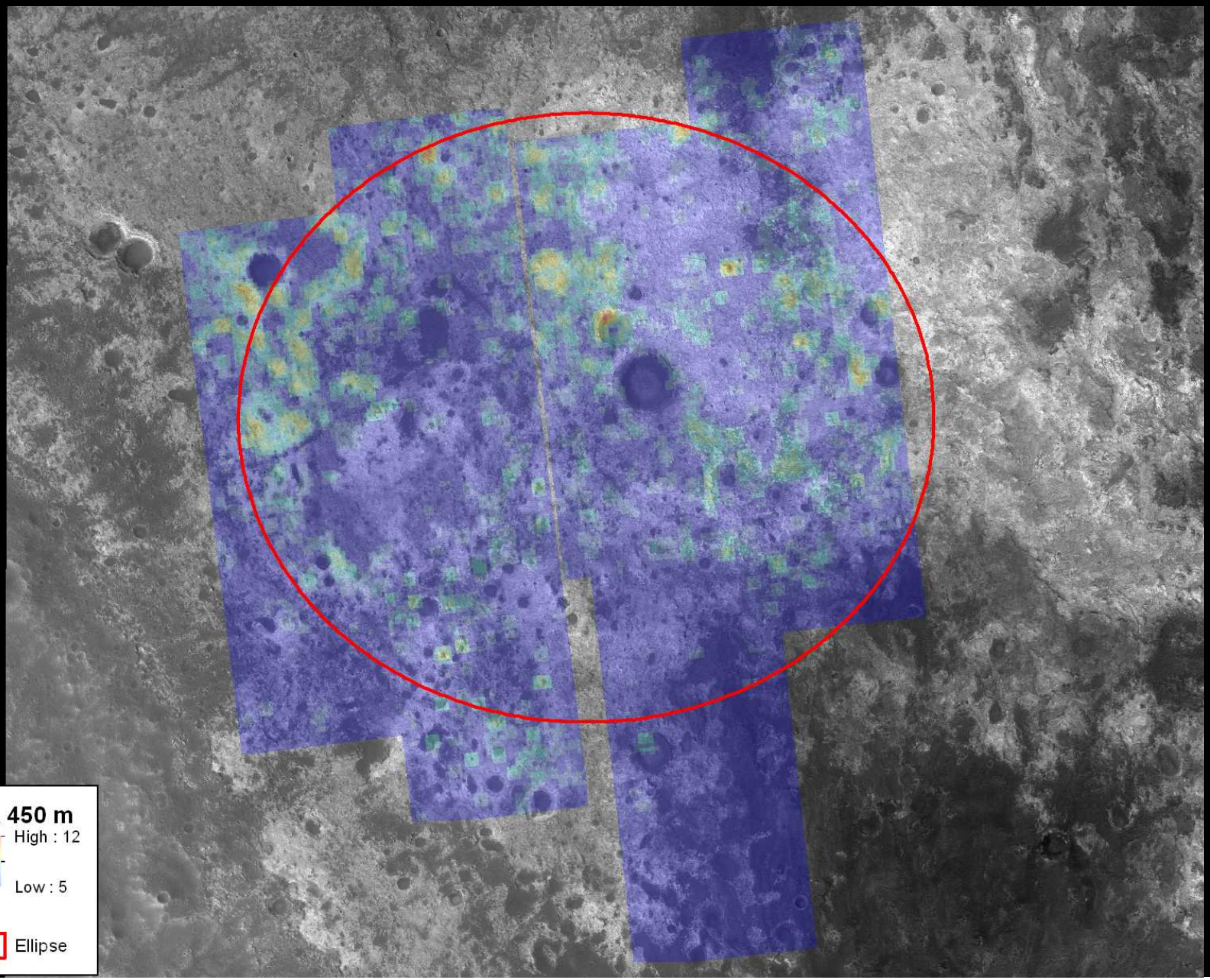




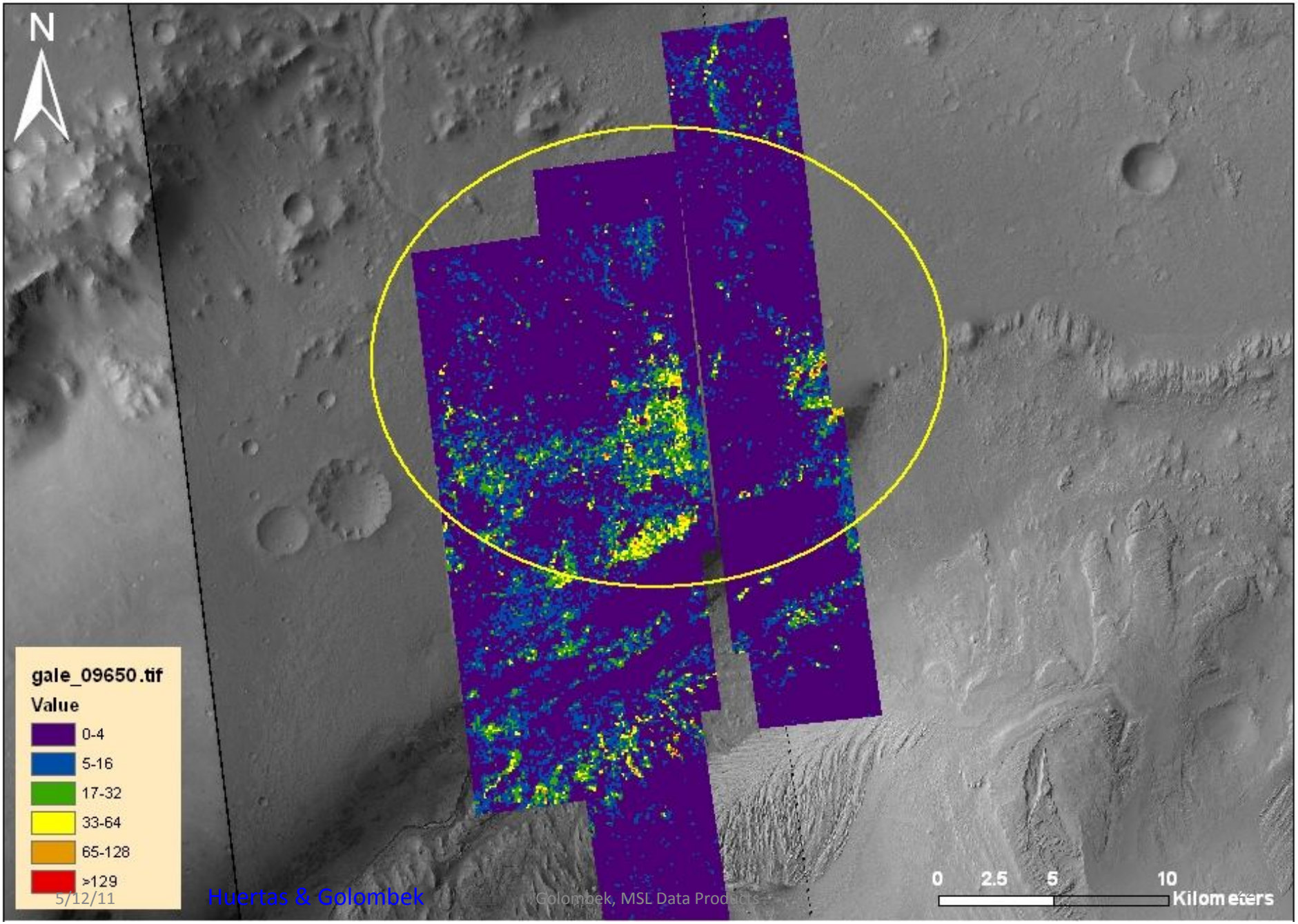
Eberswalde CFA 450 m



Mawrth CFA 450 m

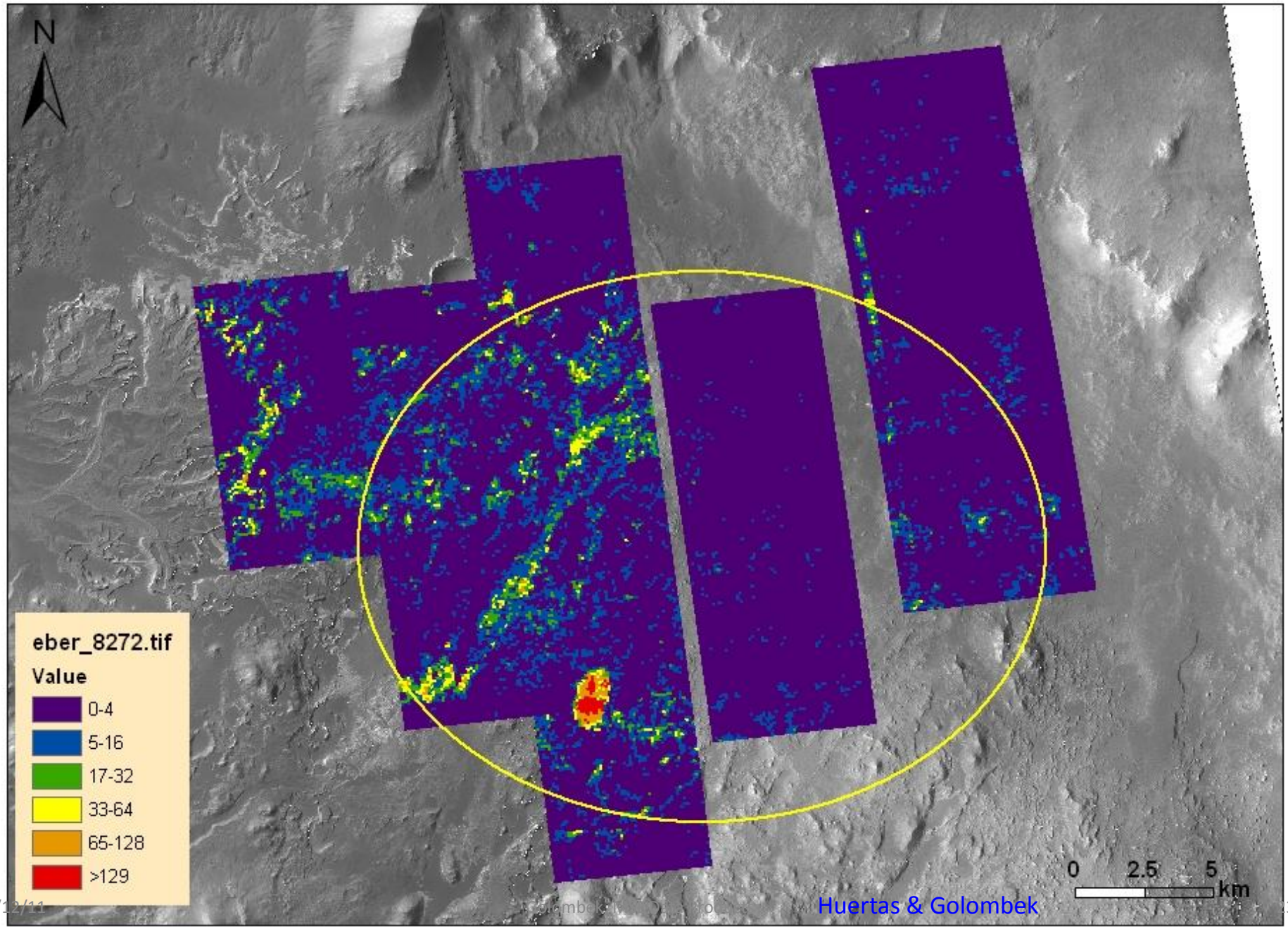


Gale Crater Rock Density



Huertas & Golombek

Eberswalde Crater Rock Density



Huertas & Golombek

Assessment of Inescapable Hazards at MSL Landing Sites

Rachael Hoover
Helen Sladek
Matt Golombek
Fred Calef
DTMs from Randy Kirk
4/15/2011
Council of Terrains
JPL

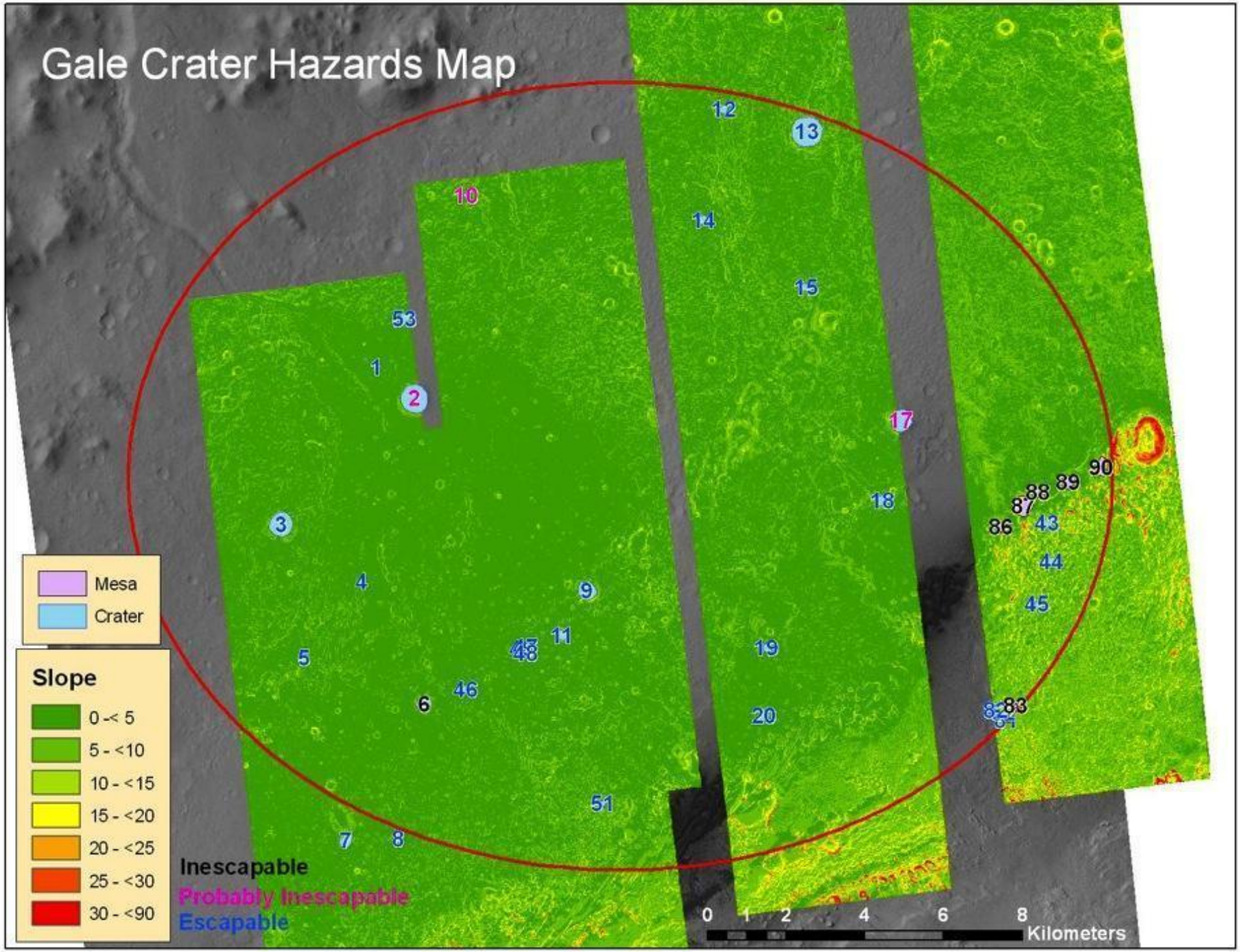
Inescapable Hazard Assessment

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

- Rover Stable >30 deg. Slope Could drive down if it had to

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

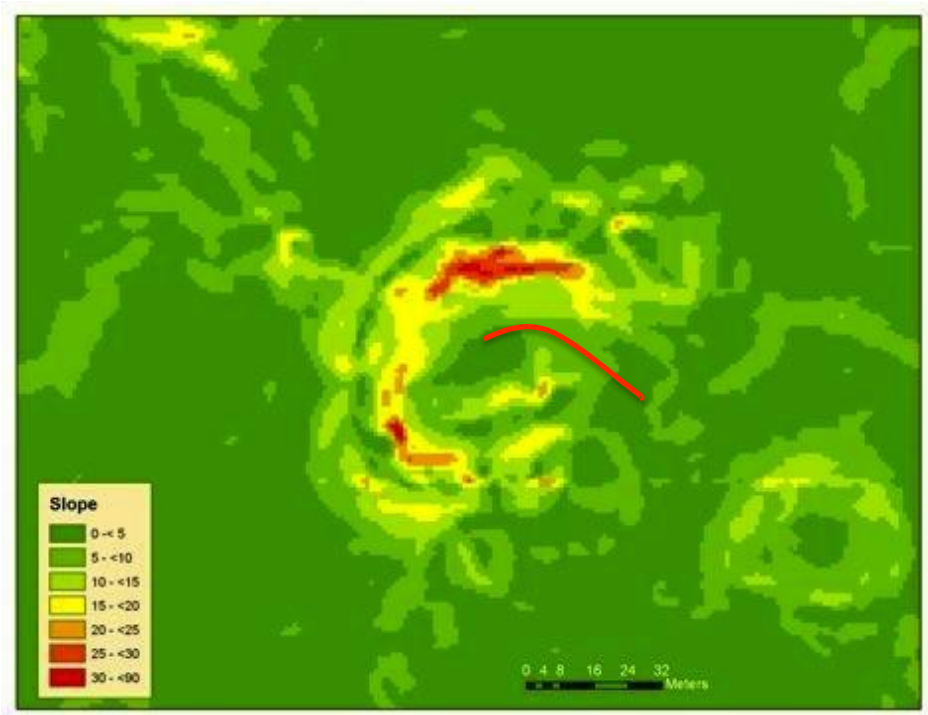
- **Approach**
  - Search 1 m slope maps to identify low slope areas ringed by high slopes
  - Evaluate traversability using slope and material properties [Outcrop vs. Sand]
  - Classify as Inescapable Hazard, Probably Inescapable, or Escapable Hazard

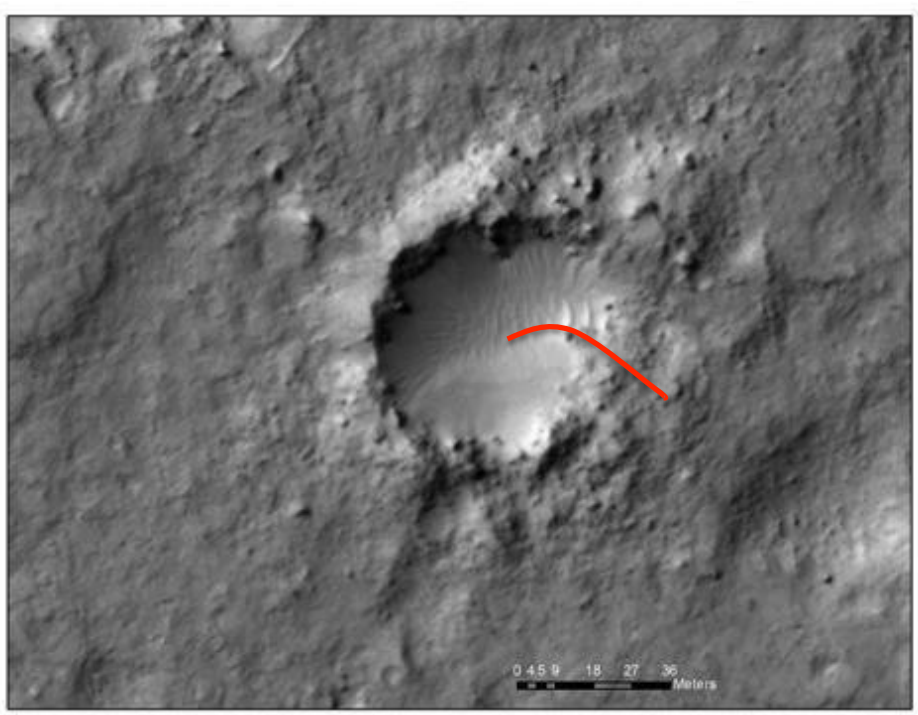

Gale Crater Hazards Map
Mesa
Crater
Slope
0 -< 5
5 - <10
10 - <15
15 - <20
20 - <25
25 - <30
30 - <90
Inescapable
Probably Inescapable
Escapable
0 1 2 4 6 8
Kilometers
12
13
10
14
15
53
1
2
17
90
89
88
87
86
43
18
3
44
4
9
45
11
48
19
5
46
6
20
83
51
7
8

Gale ID. 48

- Crater, ~62 m diameter
- 5 to 30° Slopes
- Sandy, eroded
- 3457 m^2
- 137.383, -4.562

- Escapable
- Egress routes 5 to 10° Slopes on outcrop

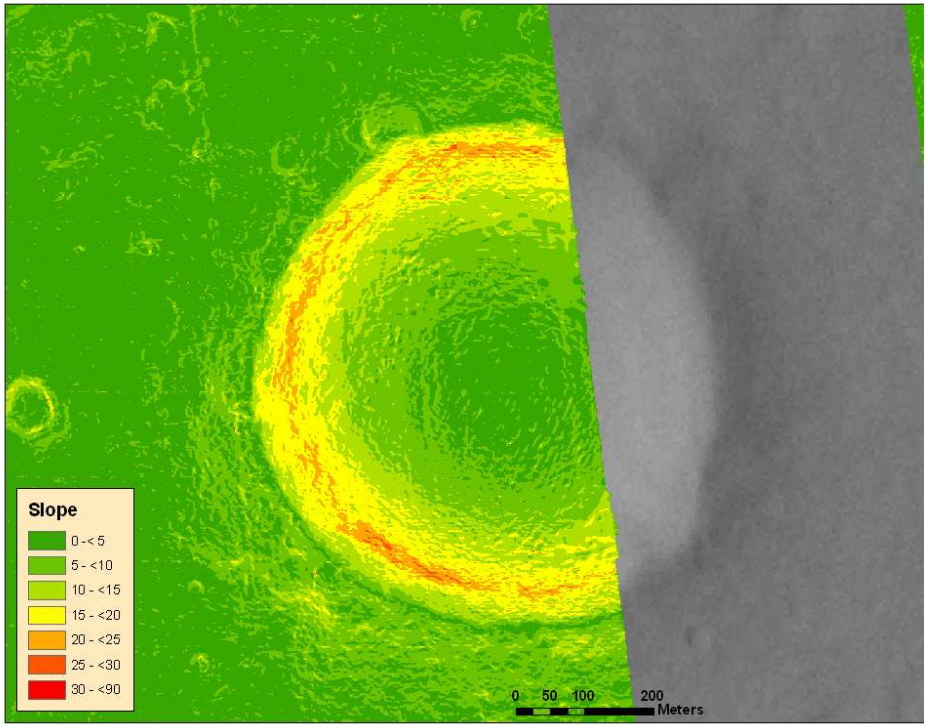


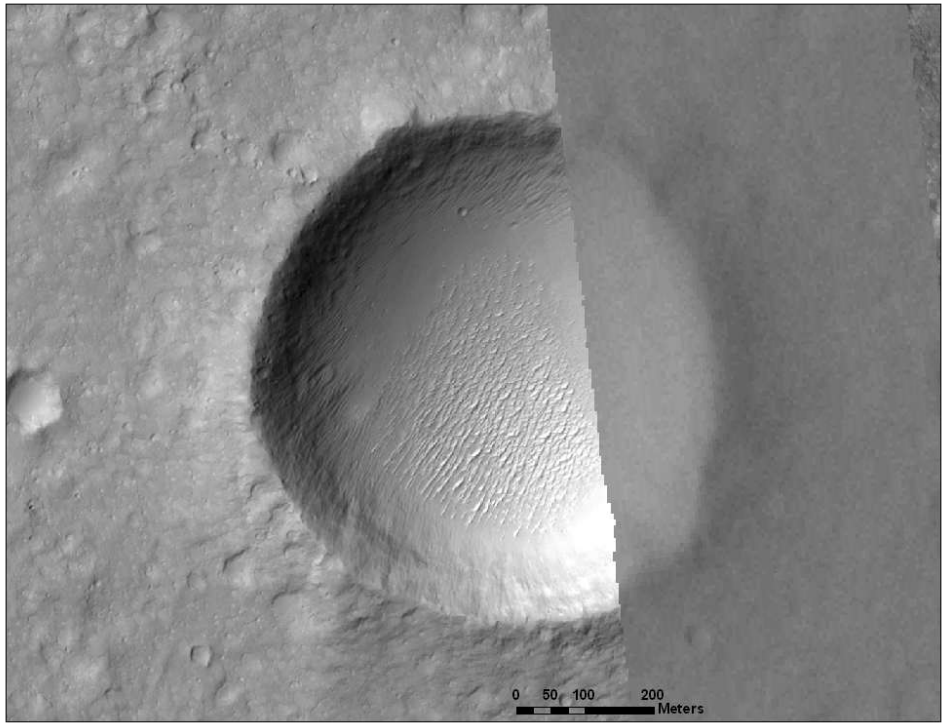


Gale ID. 2

- Crater, 740 m diameter
- >15 to 30° slopes
- Degraded, sandy
- 384830 m^2
- 137.335, -4.456

- Probably inescapable
- Based on slopes >15° and sandy materials
- Need Slopes to Right

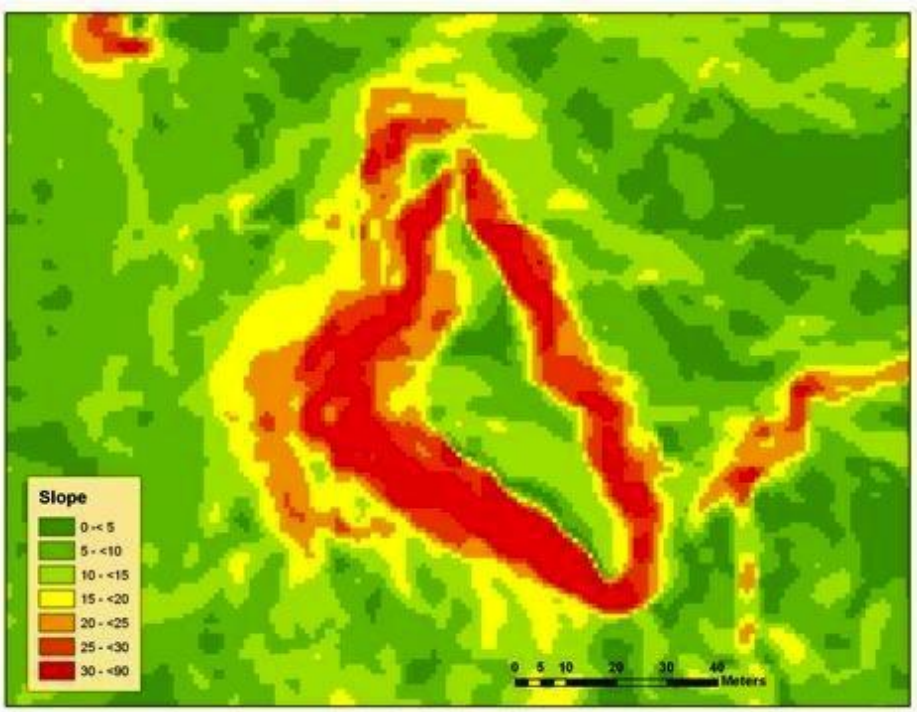


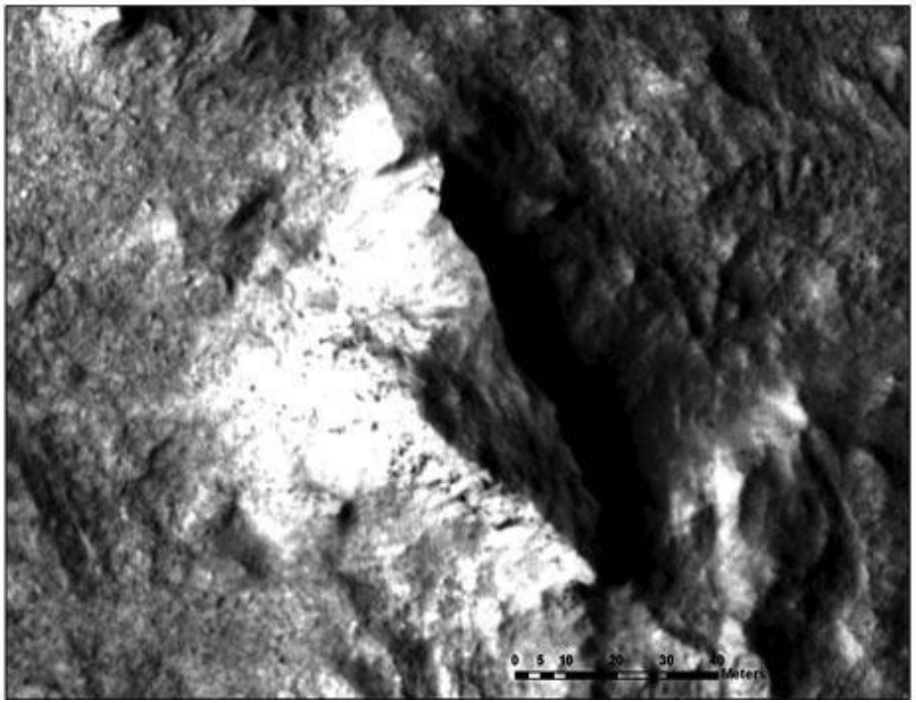


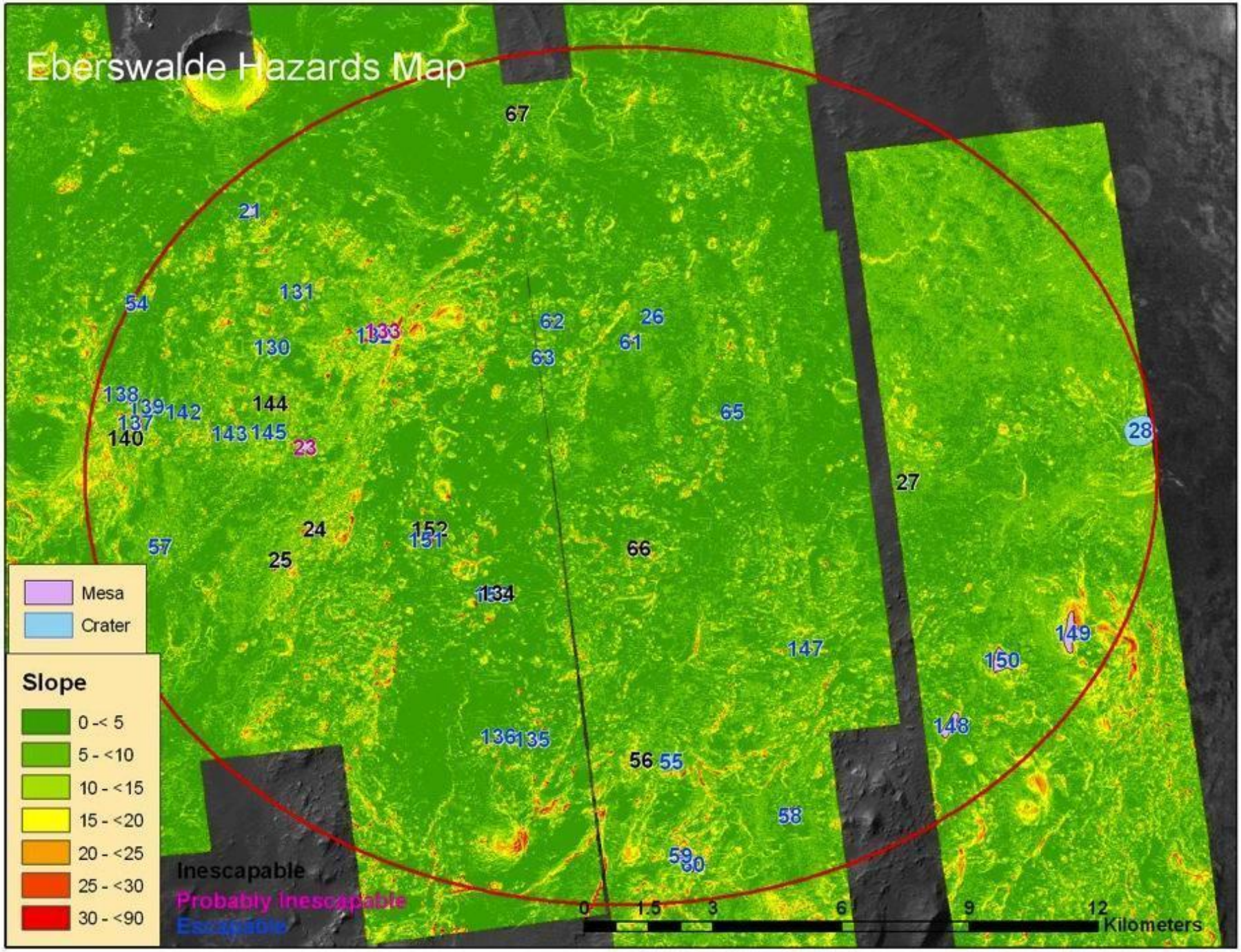
Gale ID. 83

- Mesa, 80 x 30 m
- 20 to 30° Slopes
- Outcrop
- 5481 m^2
- 137.594, -4.585

- Inescapable
- Most slopes are >30°



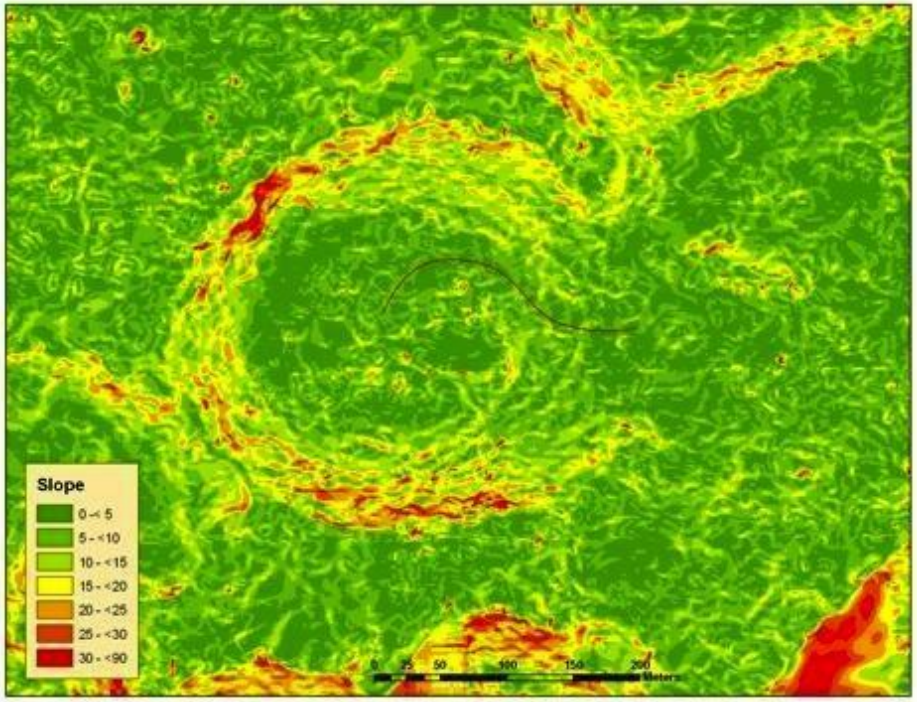


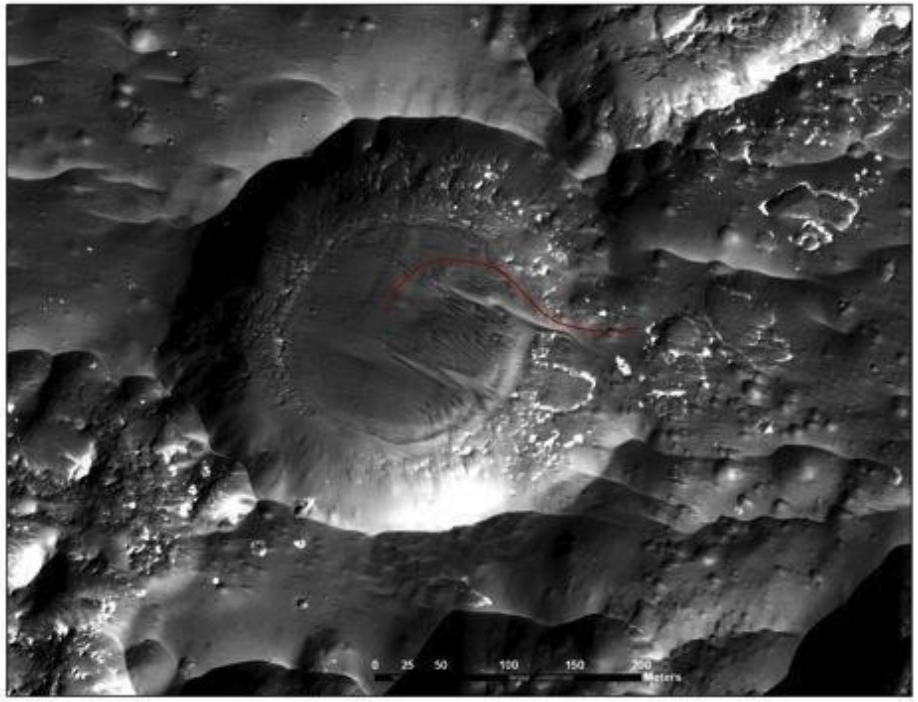

Eberswalde Hazards Map
Mesa
Crater
Slope
0 -< 5
5 - <10
10 - <15
15 - <20
20 - <25
25 - <30
30 - <90
Inescapable
Probably Inescapable
Escapable
0
1.5
3
6
9
12
Kilometers

Eberswalde ID. 55

- Crater, ~330 m diameter
- 0-25° slopes
- Sandy, some outcrop showing underneath
- 35604 m^2
- -33.238, -24.007

- Escapable
- Egress route 5-10° Slopes on sandy material

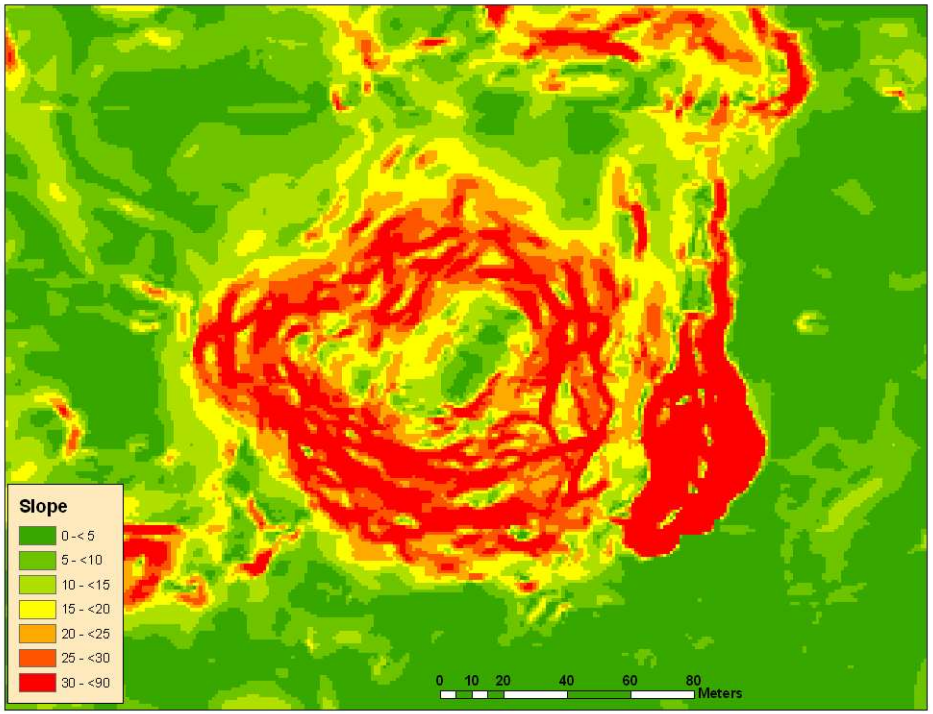


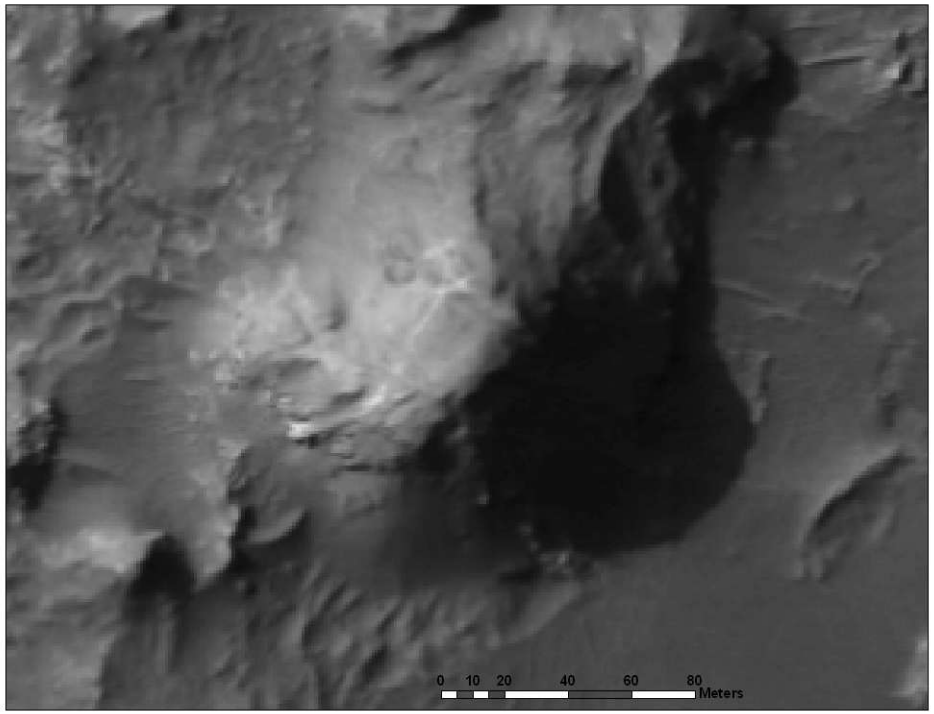


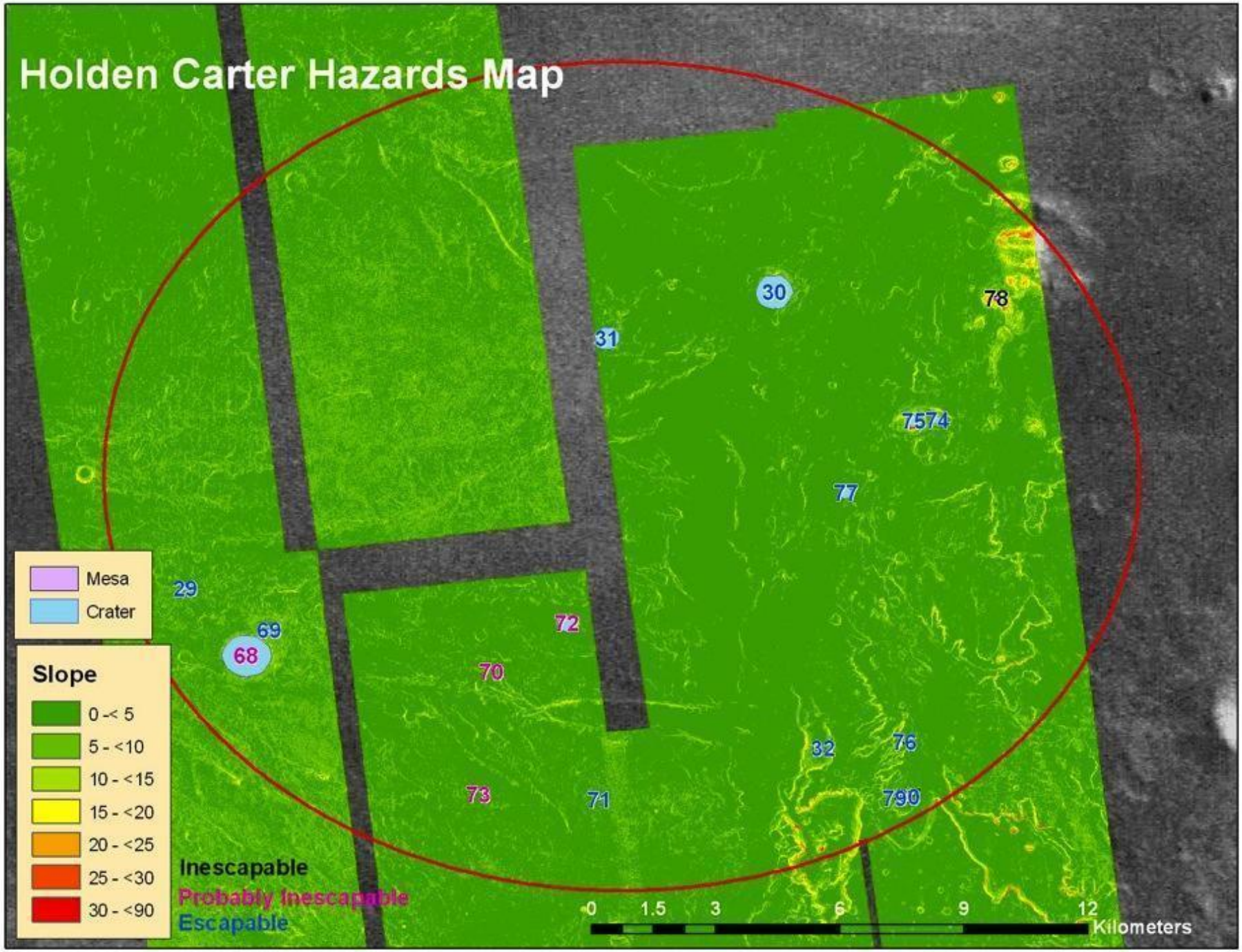
Eberswalde ID. 152

- Mesa, ~35 x 30 m
- 5 to 30° Slopes
- Outcrop
- 1101 m^2
- -33.332, -23.916

- Inescapable
- No obvious egress route



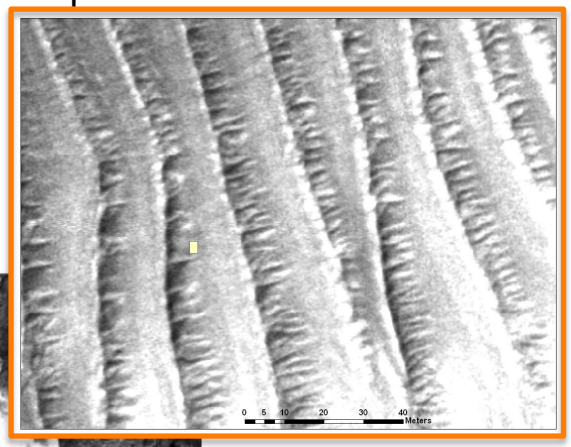


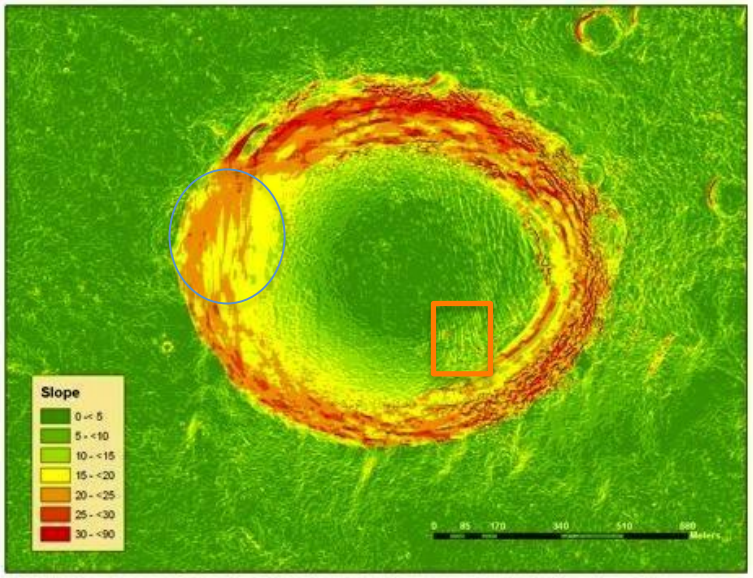

Holden Carter Hazards Map
Mesa
Crater
Slope
0 -< 5
5 - <10
10 - <15
15 - <20
20 - <25
25 - <30
30 - <90
Inescapable
Probably Inescapable
Escapable
0 1.5 3 6 9 12
Kilometers
30
78
31
7574
77
29
69
68
72
70
32
76
73
71
790

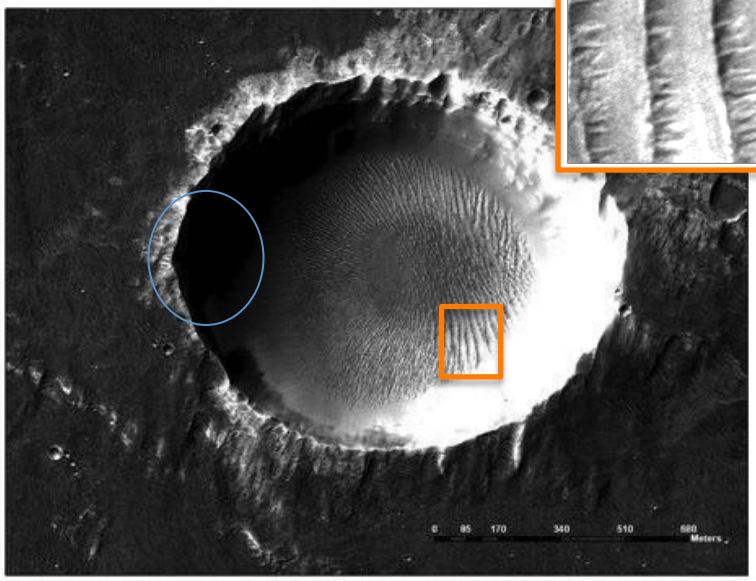
Holden ID. 68

- Crater, 1.2 km diameter
- 15 to 30° Slopes
- Sandy on bottom, outcrop on sides
- 925983 m^2
- -34.993, -26.474
- Large aeolian bedforms hazardous for landing and traversing
- Orange box shows zoomed in area
- Yellow box represent footprint of MSL (2 x 3m)

- Probably Inescapable
- Area circled indicates a possible escape route because of the lower slope. However shadows may be causing artificially low slopes

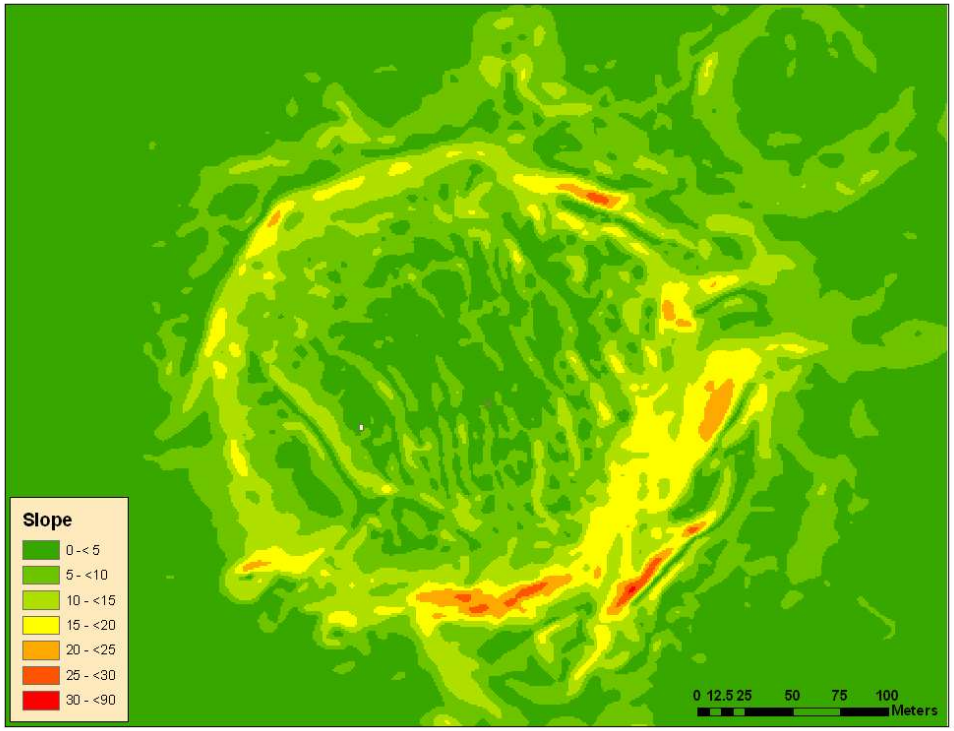


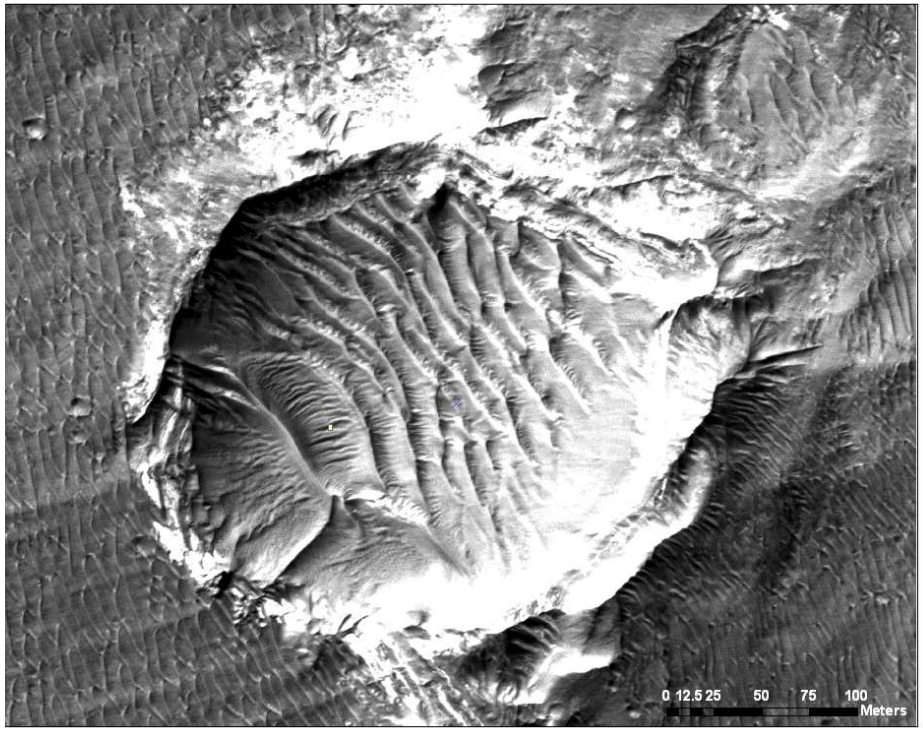




Holden ID. 77

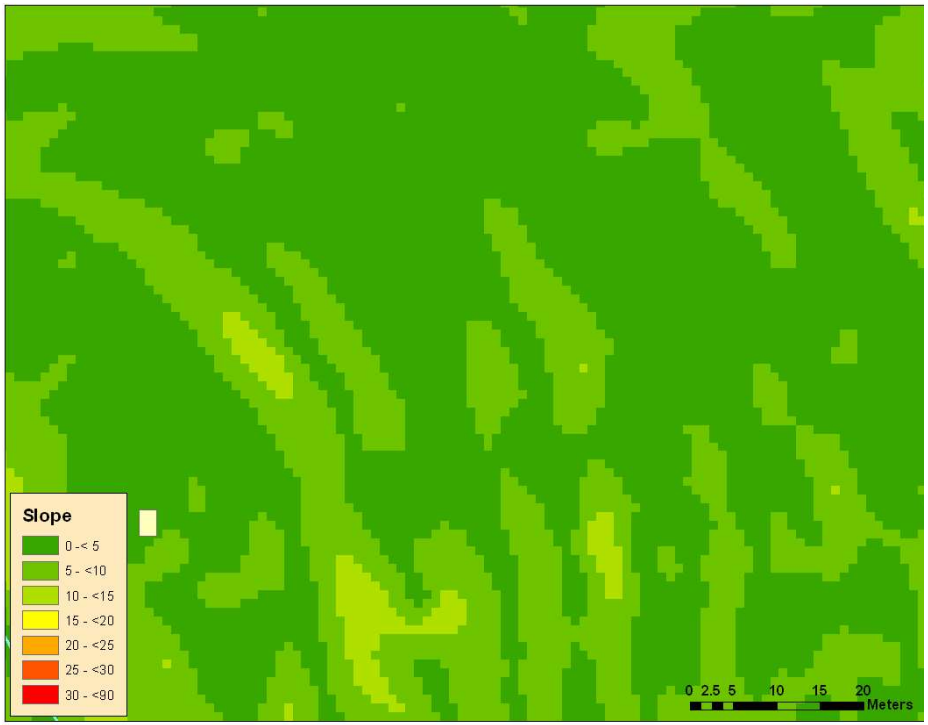
- Crater, 220 m diameter
- 10 to 20° Slopes
- Sand
- 65527 m^2
- -34.748, -26.408
- Yellow box represent footprint of MSL (2 x 3m)
- Inescapable
- Aeolian bedforms are probably not traversable (see next slide)

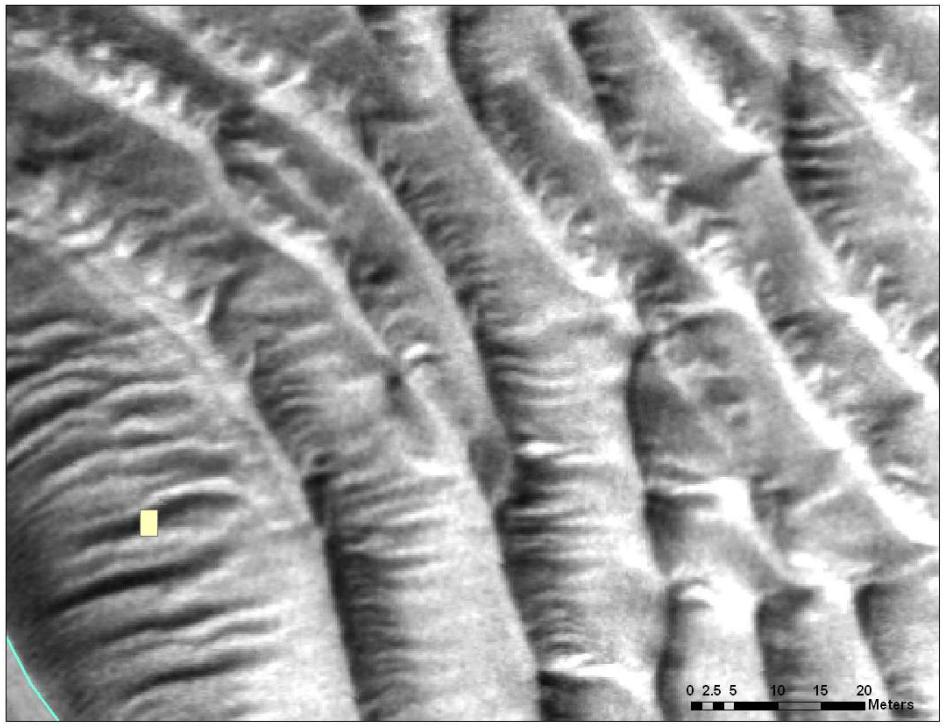


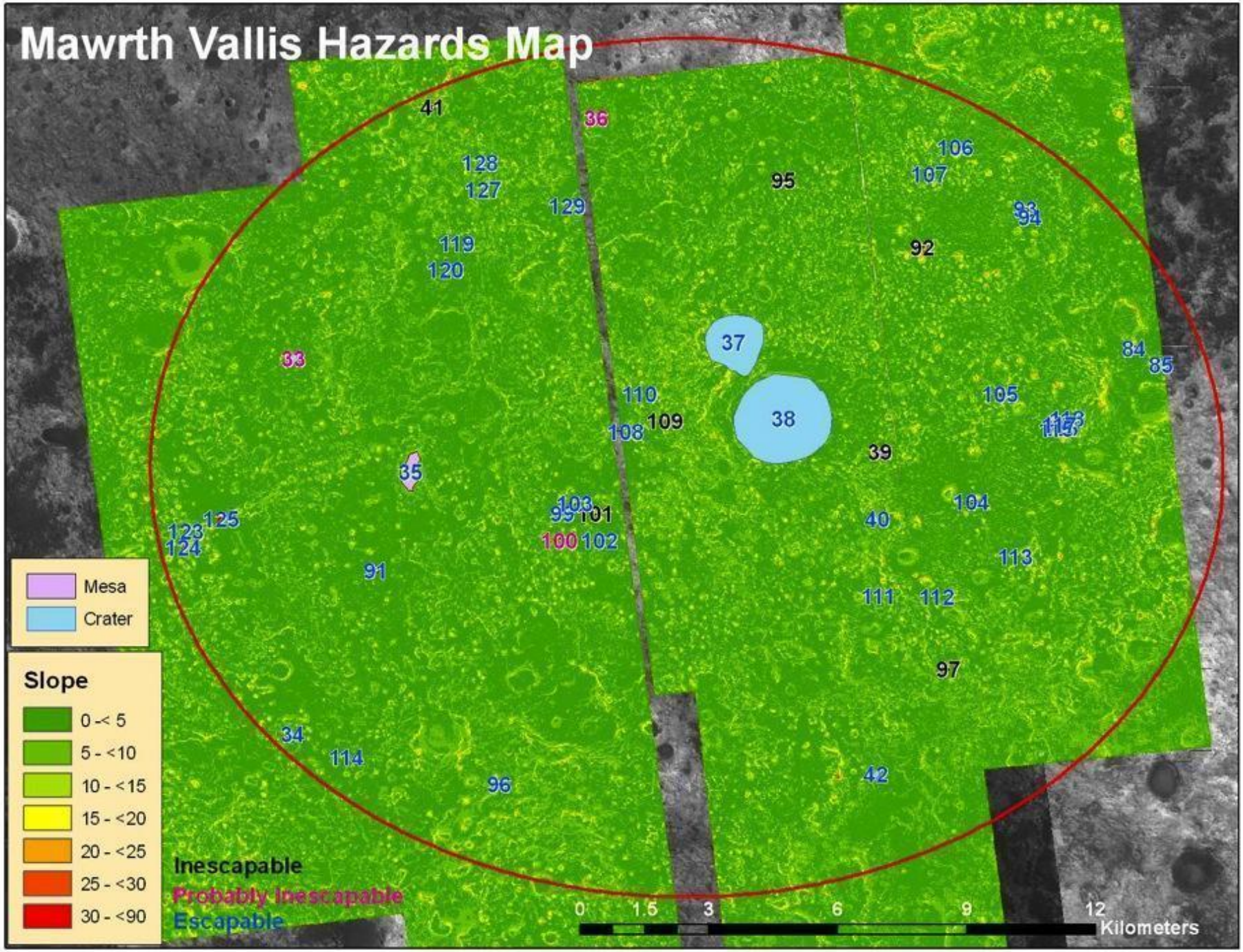


Holden ID. 77

- Aeolian Bedforms
- Yellow box represents footprint of MSL (2x3m)
- Large ripples could trap the rover and prevent the rover from traversing
- Inescapable ripples
- Even though slope map shows <5 degree slopes. Scale of the eolian bedforms suggests they could trap rover



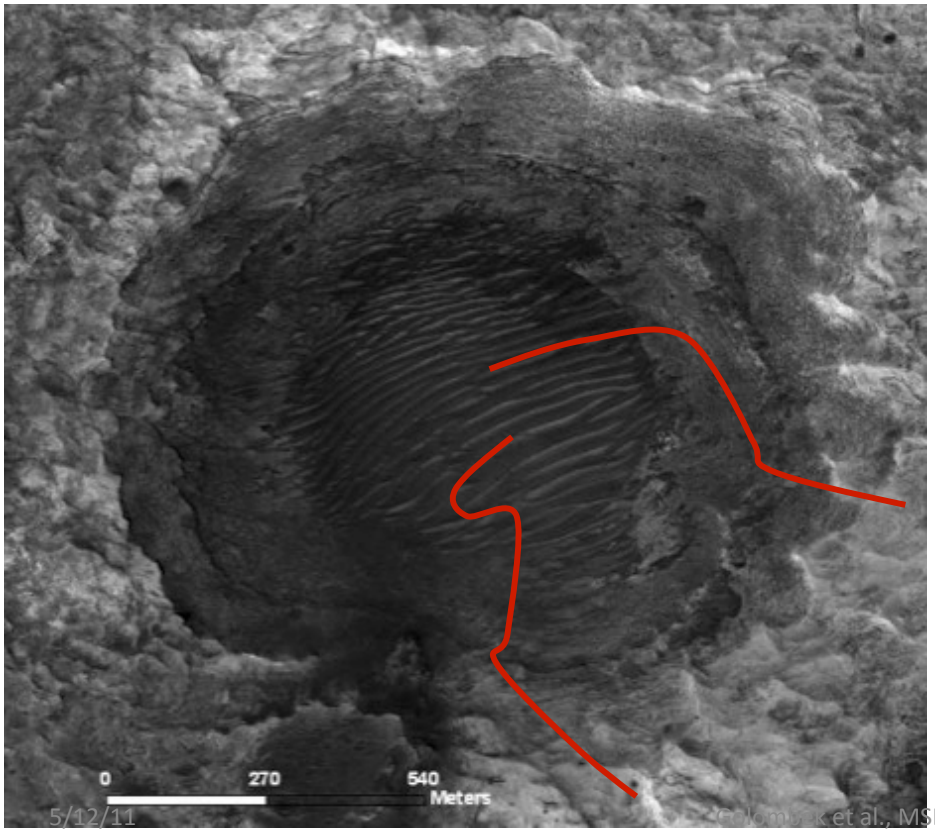


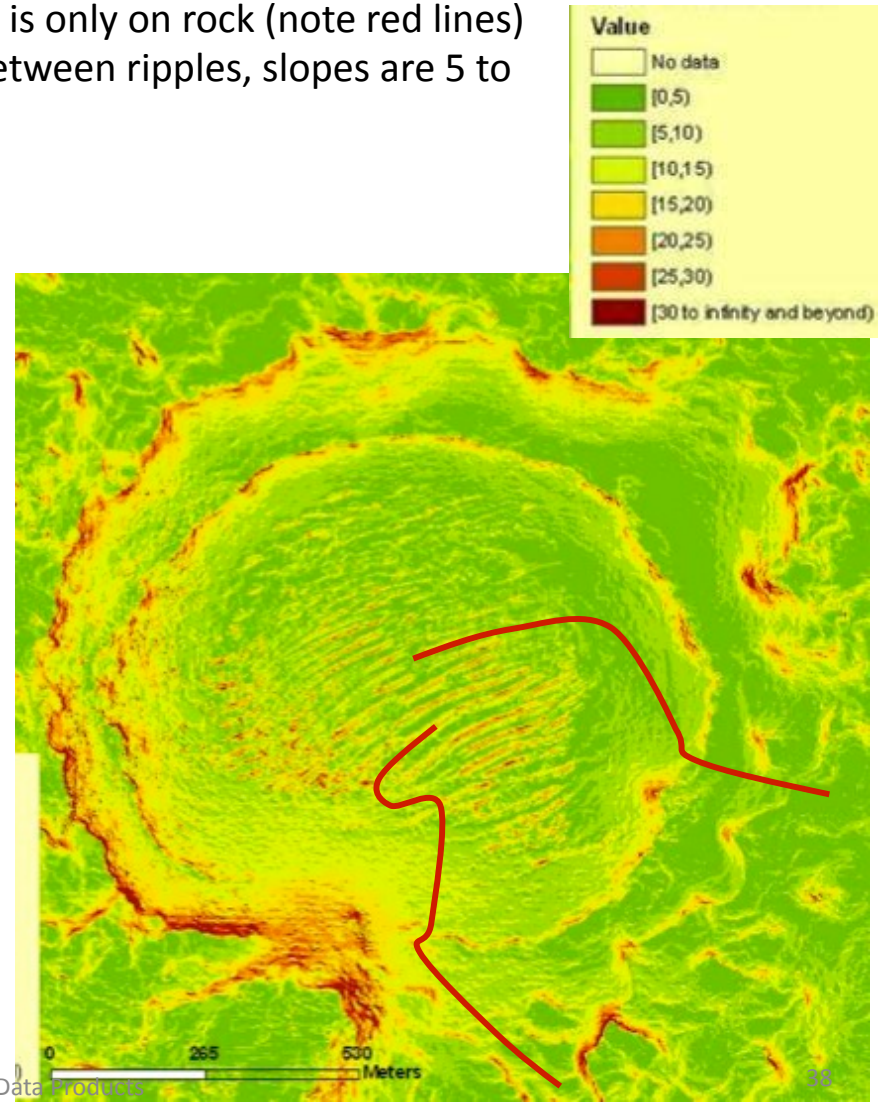

Mawrth Vallis Hazards Map
41
36
128
127
129
119
120
95
106
107
93
94
92
37
38
33
84
85
110
109
108
105
39
35
103
99
101
100
102
104
40
125
123
124
91
113
111
112
97
34
114
96
42
Mesa
Crater
Slope
0 -< 5
5 - <10
10 - <15
15 - <20
20 - <25
25 - <30
30 - <90
Inescapable
Probably Inescapable
Escapable
0
1.5
3
6
9
12
Kilometers

Mawrth ID. 37

- Crater, 1000m diameter
- 10 to >30° slopes
- Outcrop with sandy bottom
- 1458522 m^2
- -18.943, 24.037

- 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°

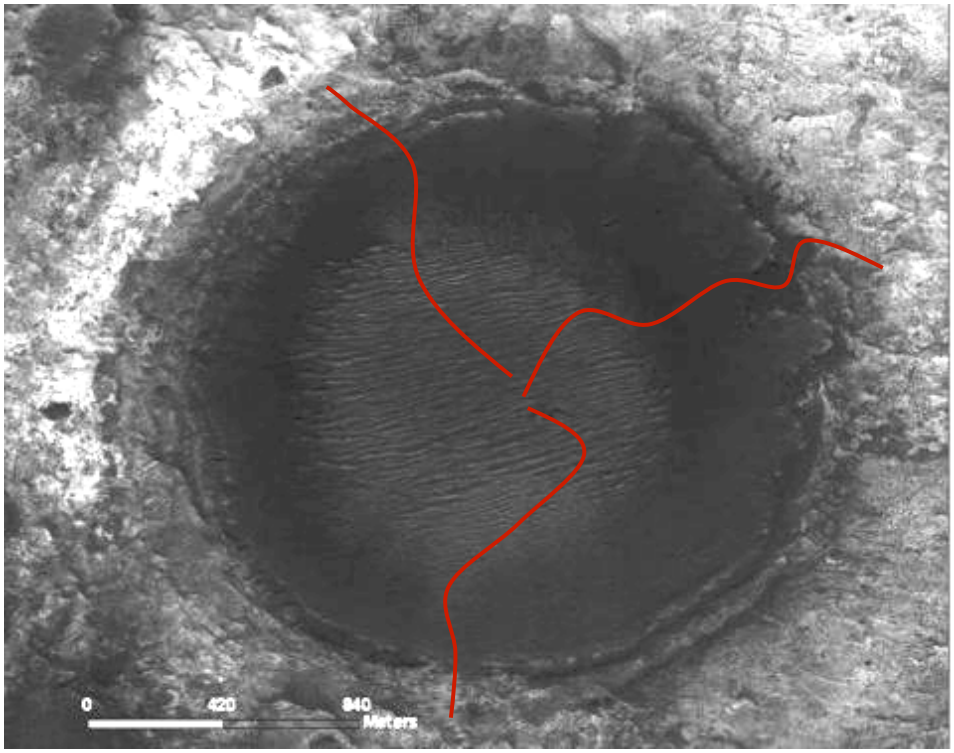


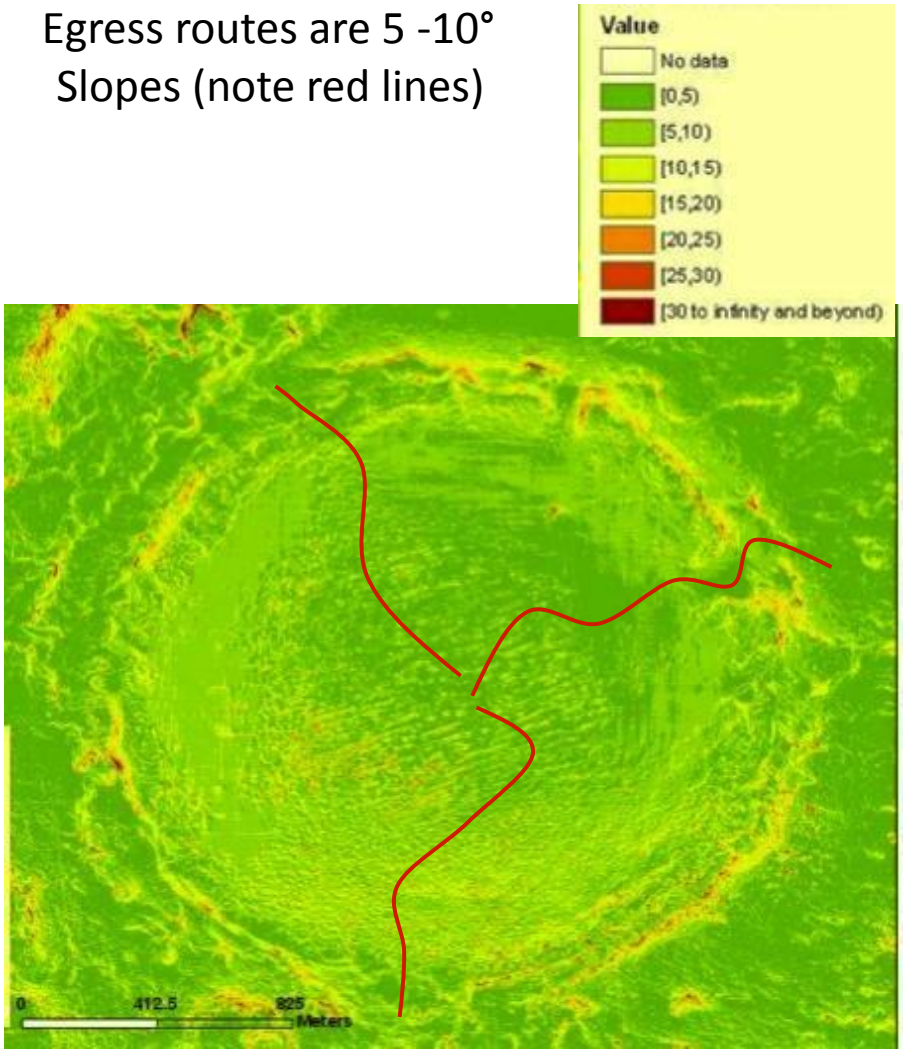


Mawrth ID. 38

- Crater, 2000m diameter
- 5 to 30° Slopes
- Outcrop rims with sandy bottom
- 3743503 m^2
- -18.922, 24.003

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

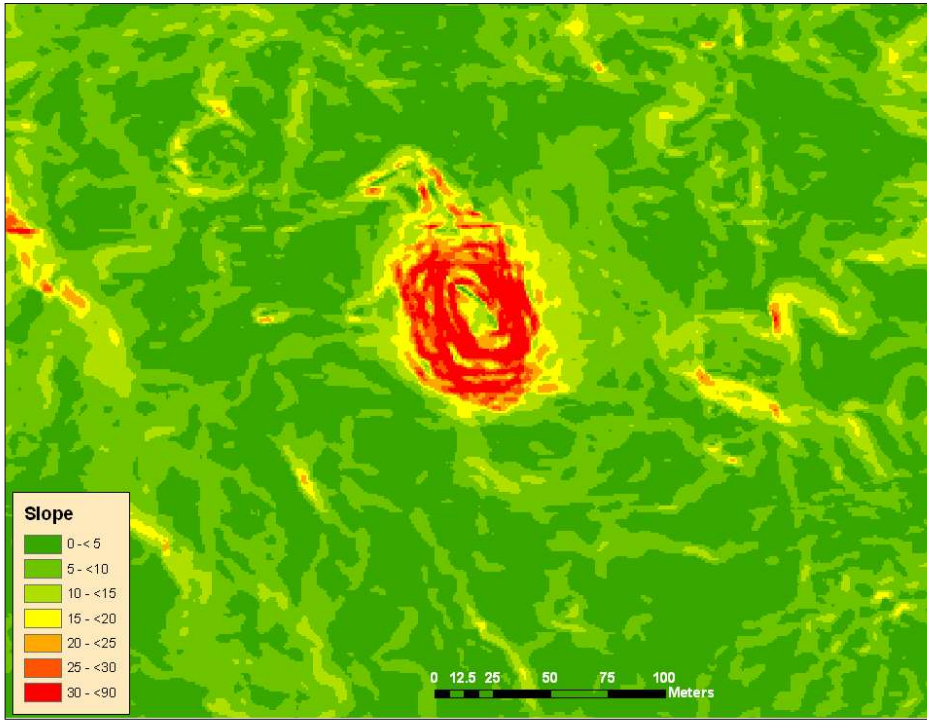


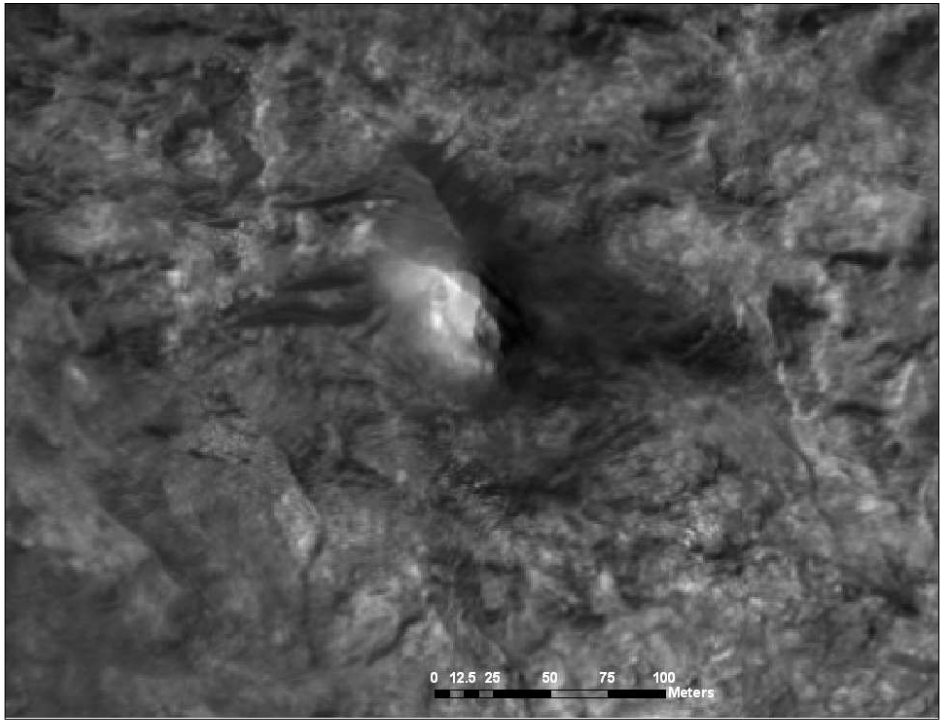


Mawrth ID. 41

- Mesa, 60 m diameter
- >30° Slopes
- Outcrop
- 5447 m^2
- 340.947 E, 24.133 N

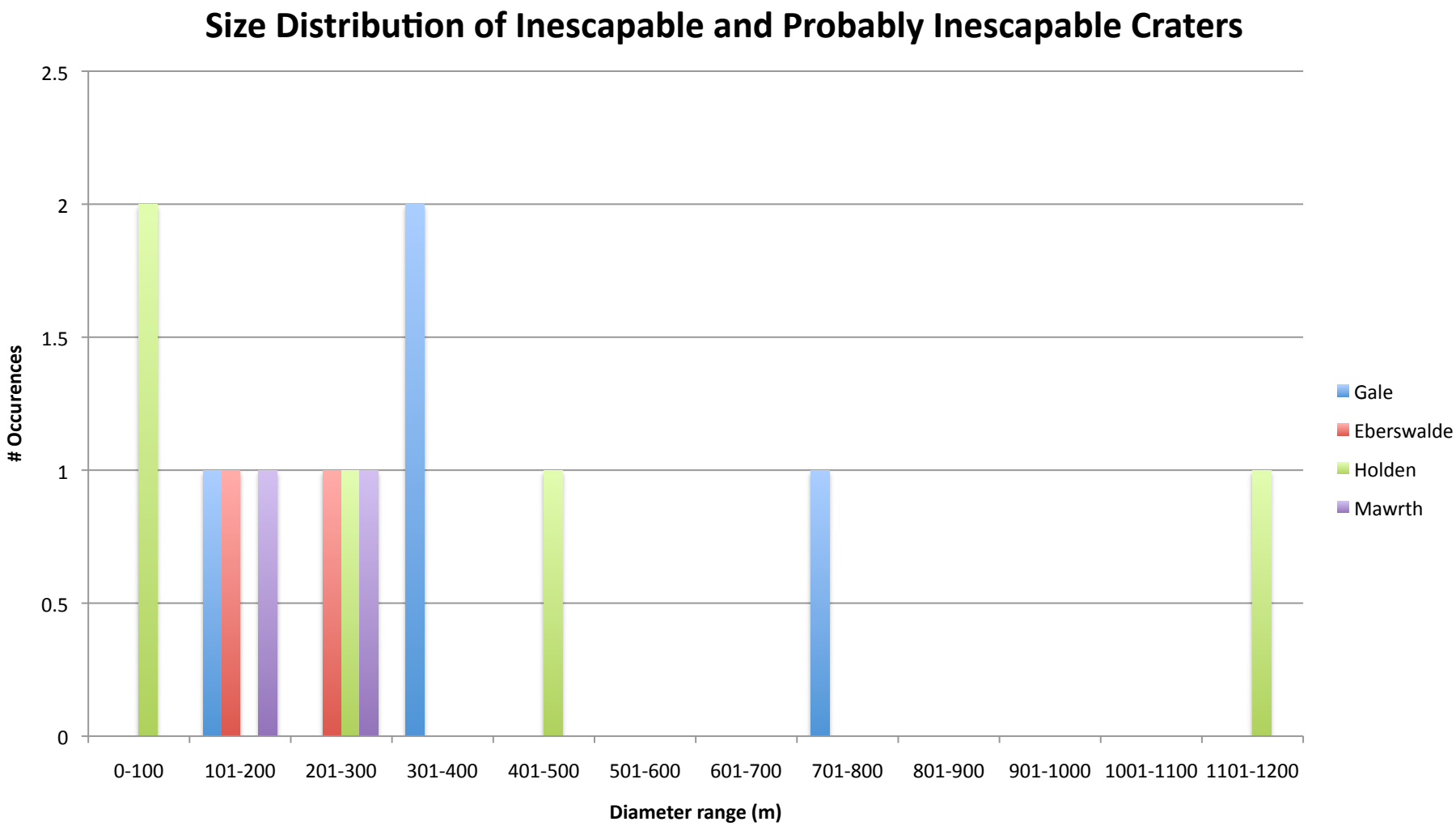
- Inescapable
- Slopes are >30°





Summary

- **Total of 143 possible inescapable hazards were assessed for all landing sites**
  - 37 in Gale
  - 42 in Eberswalde
  - 17 in Holden
  - 47 in Mawrth
- **Total of 24 inescapable hazards were found**
  - Gale: 6 mesas (ID. 83, 86, 87, 88, 89, 90); *0.115% of the ellipse*
  - Eberswalde: 2 craters (ID. 27, 56); *0.011% of the ellipse*
    - 8 mesas (ID. 24, 25, 66, 67, 134, 140, 144, 152); *0.010% of the ellipse*
  - Holden: 1 mesa (ID. 78); *0.002% of the ellipse*
  - Mawrth: 7 mesas (ID. 39, 41, 92, 95, 97, 101, 109); 0.005% of the ellipse
- **Total of 13 probably inescapable hazards were found**
  - Gale: 4 craters (ID. 2, 6, 10, 17); *0.189% of the ellipse*
  - Eberswalde: 2 mesas (ID. 23, 133); *0.007% of the ellipse*
  - Holden: 4 craters (ID. 68, 70, 72, 73); *0.270% of the ellipse*
  - Mawrth: 2 craters (ID. 33, 36); *0.013% of the ellipse*
    - 1 mesas (ID. 100); *0.00001% of the ellipse*
- **Total of 106 escapable hazards were found**
  - Gale: 24 craters (ID. 1, 3, 4, 5, 6, 7, 8, 11, 12, 13, 14, 15, 18, 19, 20, 43, 44, 45, 46, 47, 48, 49, 51, 53),
    3 mesas (ID. 52, 81, 82)
  - Eberswalde: 4 craters (ID. 26, 28, 55, 153), 26 mesas (ID. 21, 54, 57, 58, 59, 60, 61, 62, 63, 65, 130, 131, 132, 135, 136, 137, 138, 139, 142, 143, 145, 147, 148, 149, 150, 151)
  - Holden: 9 craters (ID. 29, 30, 31, 32, 69, 71, 74, 75, 77), 3 mesas (ID. 76, 79, 80)
  - Mawrth: 6 craters (ID. 34, 37, 38, 40, 42, 114), 31 mesas (ID. 35, 84, 85, 91, 93, 94, 96, 99, 102, 103, 104, 105, 106, 107, 108, 110, 111, 112, 113, 115, 116, 117, 118, 119, 120, 123, 124, 125, 127, 128, 129)



•This graph displays the size distribution of inescapable and probably inescapable craters.

•The majority of hazards have a diameter <300 m.

•Gale has one large hazard with a diameter >700 m and Holden has one large hazard with a diameter >1100 m.

Conclusions

- The negative relief inescapable hazards cover a very small portion of each ellipse
  - Holden: 0.270% of the ellipse
  - Gale: 0.189% of the ellipse
  - Mawrth: 0.013% of the ellipse
  - Eberswalde: 0.011% of the ellipse
- Inescapable Hazards and Probably Inescapable Hazards are not considered an additional concern for the landing site selection because the number of inescapable hazards are few and cover a very small area.
- Additionally, positive relief inescapable hazards are not inescapable
  - If the mission depended on it, Rover Planners believe that the could could drive down slopes >30 degrees.

Mars Science Laboratory Landing Sites: Science Traversability Issues

R. Hoover
M. Golombek
F. Calef
JPL

Contributions from
Kenneth Herkenhoff, Randy Kirk
Timothy Parker

MSL Traversability Review
JPL 321-216
May 12, 2011

Science Related Traversability Questions

- Can Access Stratigraphy in Gale Mound?
- Can Access Science Targets at Eberswalde?
- Can Access Science Targets at Holden?
- Are there Large Untraversable Areas in Ellipses?
  - Especially Mawrth – Targets in Ellipse

Traverse Route Assessment

Used slope maps created from HiRISE DEMs and HiRISE visible imagery to determine traversability

Several assumptions were used when determining if the rover could drive across an area:

>30 degrees:

Not traversable up slope

15 - 30 degrees:

Traversable on rock, not sand

< or = 15 degrees:

Traversable in sand or outcrop

These assumptions are based on MER rover experience. However, it may be possible for MSL to traverse slops as high as 20 degrees on material with any type of cohesion (sand and soil).

HiRISE visible imagery was used when Determining the surface material:

Light material:

Probably outcrop

Darker material:

Probably sand

Aeolian bedforms:

Sand

Stratigraphy:

Rock

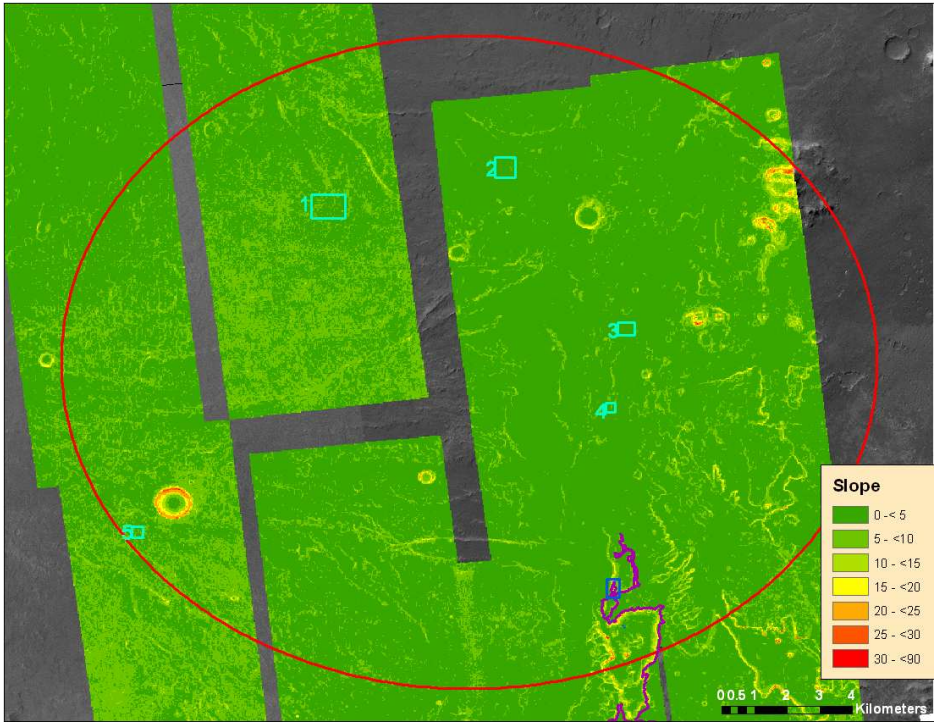
Approach

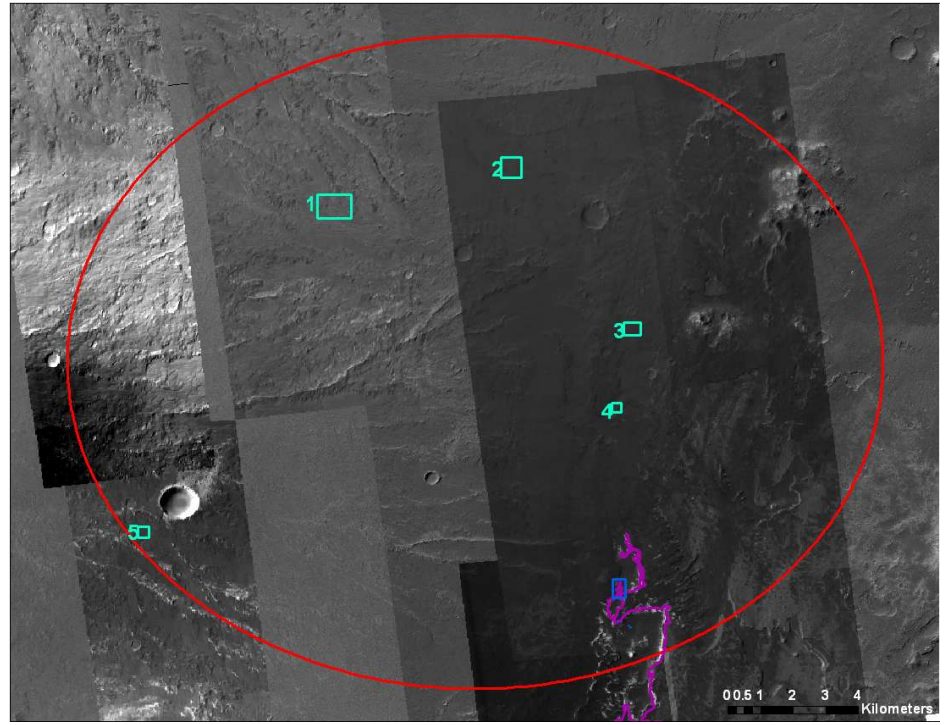
- Inspected 1 m slope maps for traversable paths
- Created paths indicating a potential traverse route that were at least 10 m wide, narrower paths between 5-10 meters are identified
- Areas along traverse route evaluated based on slope and surface material
- Indentified critical areas where error in slope map may prohibit driving, called choke points

Mawrth Slopes (1m)

No Major Science Related Traversabilty Issues

Holden Ellipse





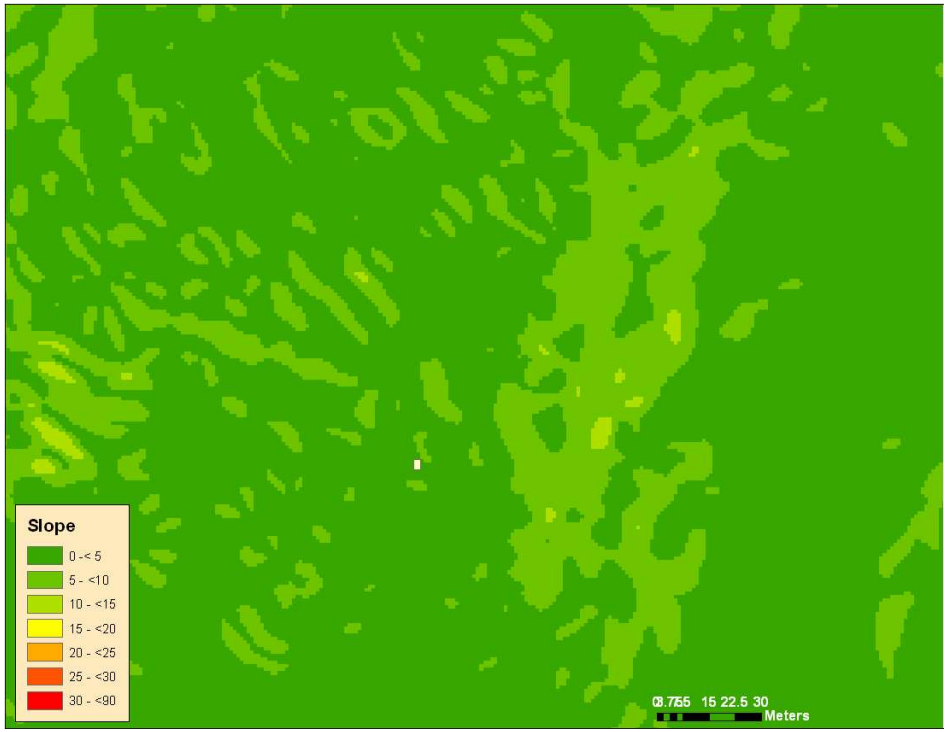
-Ripples throughout the ellipse

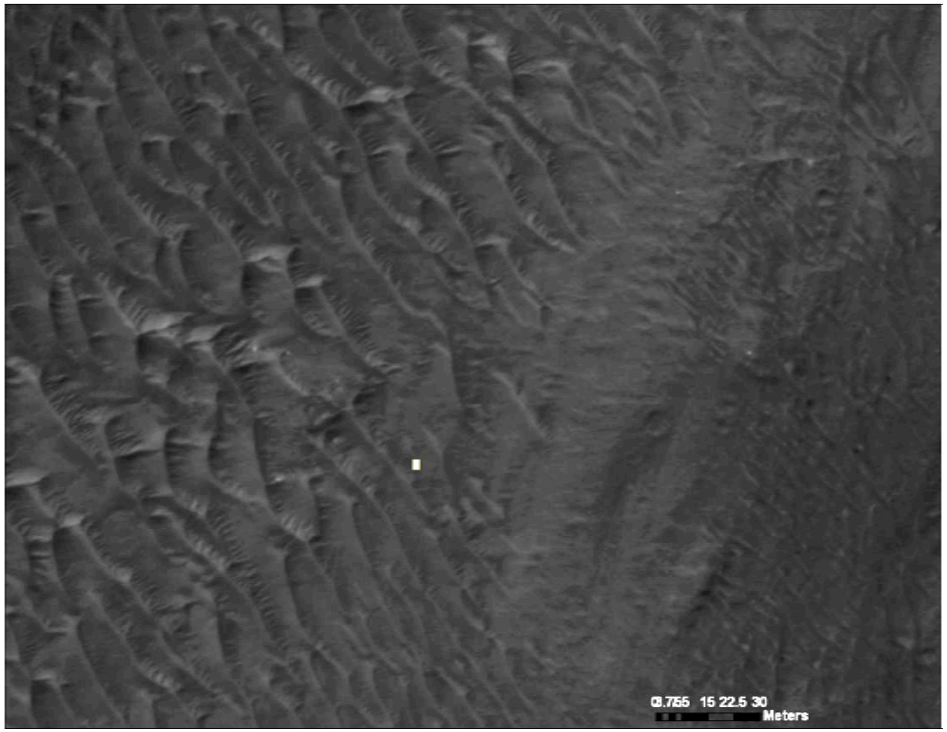
-Large enough relative to rover, will need to navigate through, probably like Opportunity at Meridiani Planum where ripples large [Endurance to Victoria to Santa Maria]

-Areas in light blue boxes shown on next few slides as examples of ripples

-Representation of all ripples throughout the ellipse

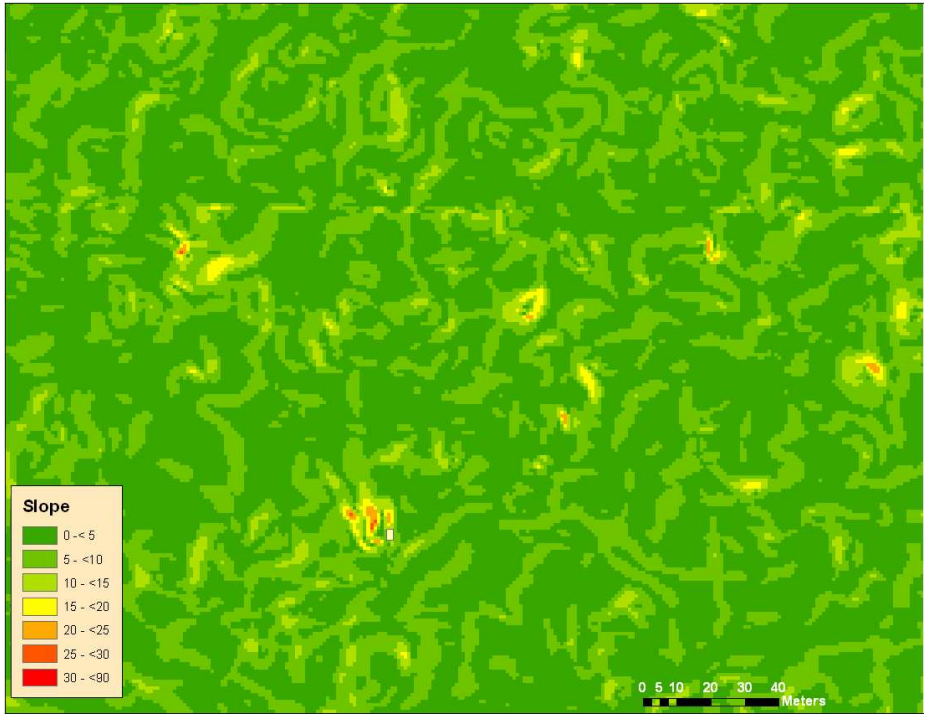
Holden Ripples Box 4

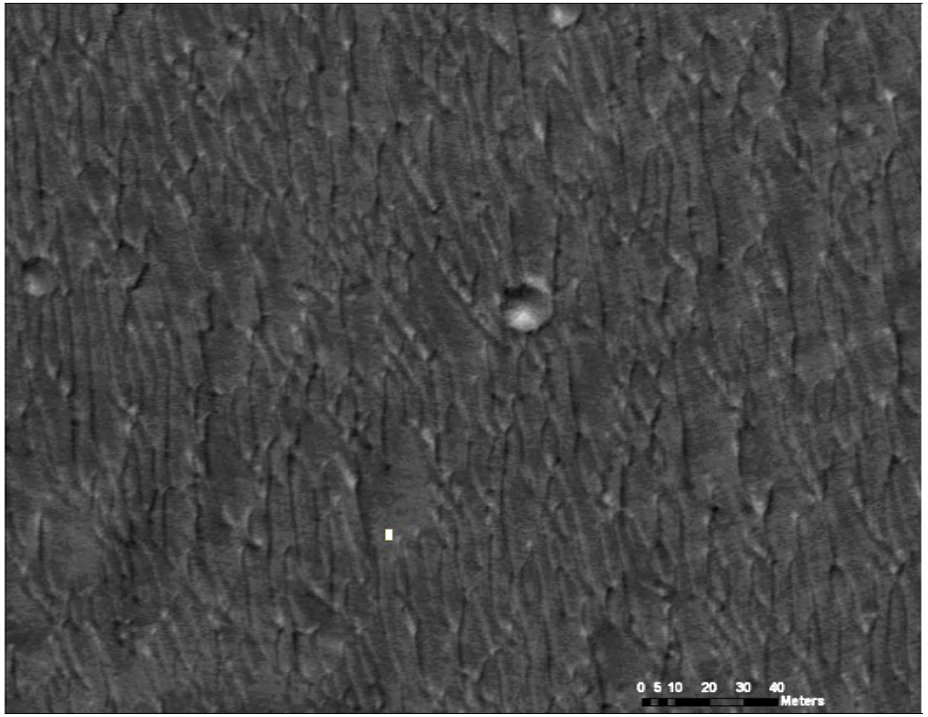




-MSL Footprint shown as yellow box (2x3 m)
-Ripples large relative to MSL; Must navigate through

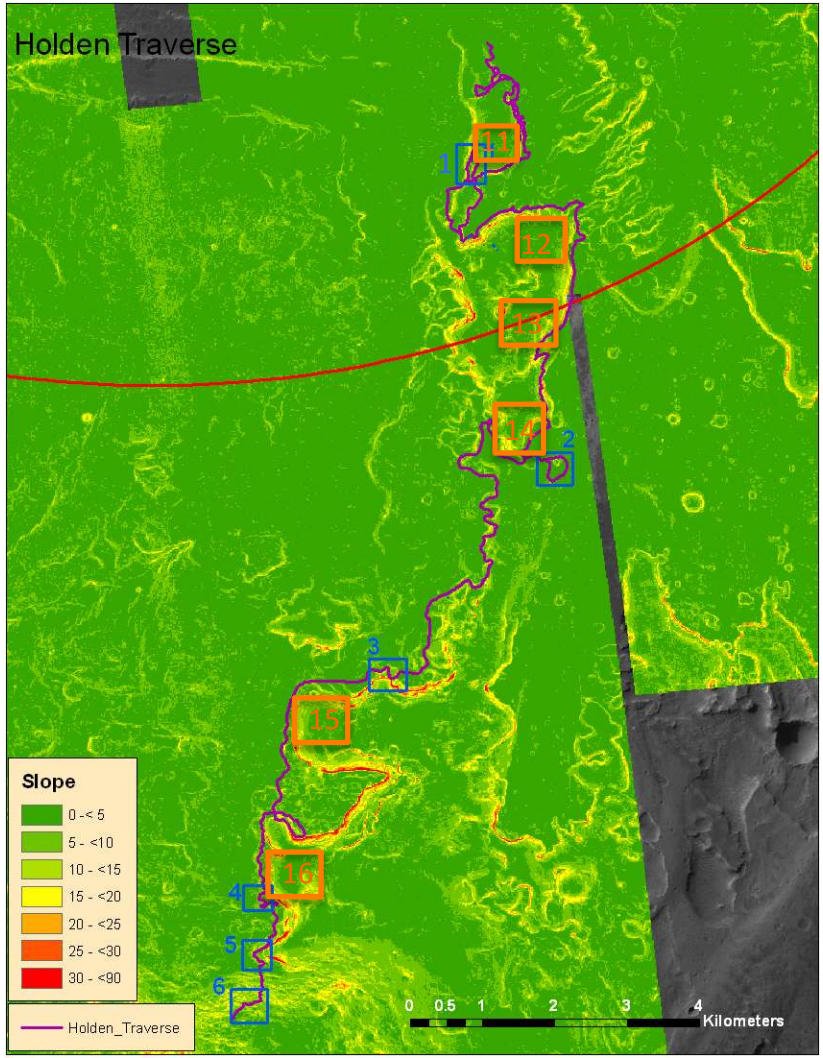
Holden Ripples Box 5

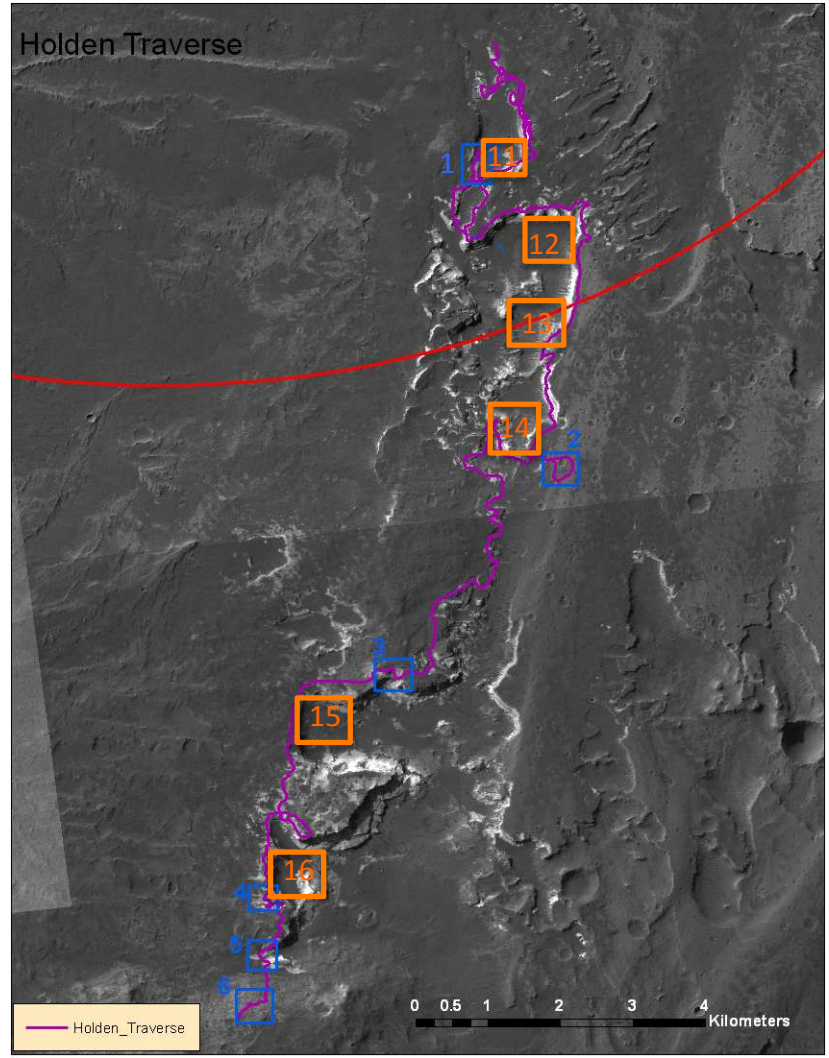




-MSL Footprint shown as yellow box (2x3 m)
-Ripples large relative to MSL; Must navigate through

Holden Traverse routes through Canyon

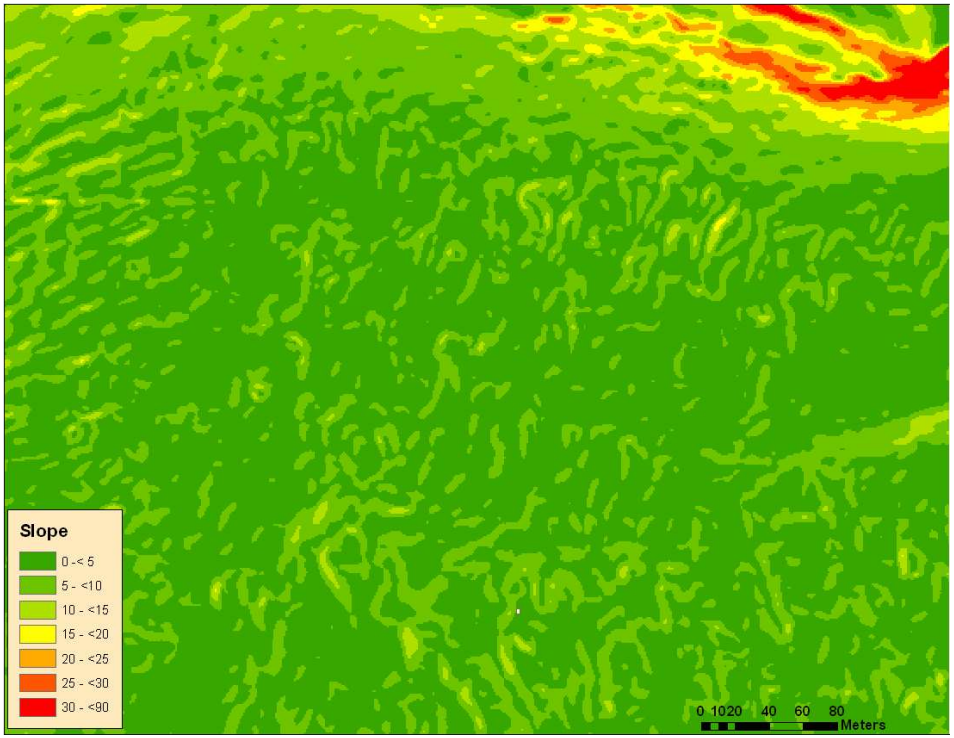


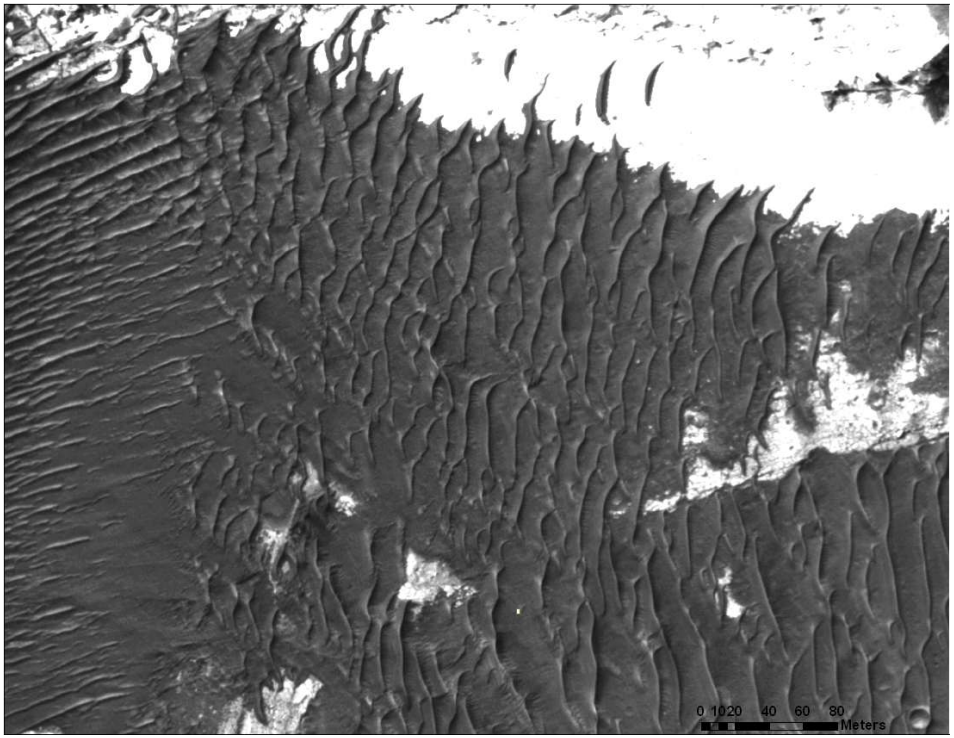


-Areas in blue boxes indicate areas of scientific interests (Identified by Ross Irwin, Smithsonian Institution, "Notional Traverse and Science Targets in Holden Crater", 4th Wkshp)

-Orange areas ripples inside canyons; Ripples inside canyon are probably not traversable, shown on next slides; Traverse outside canyon, dip in, can access all areas of interest

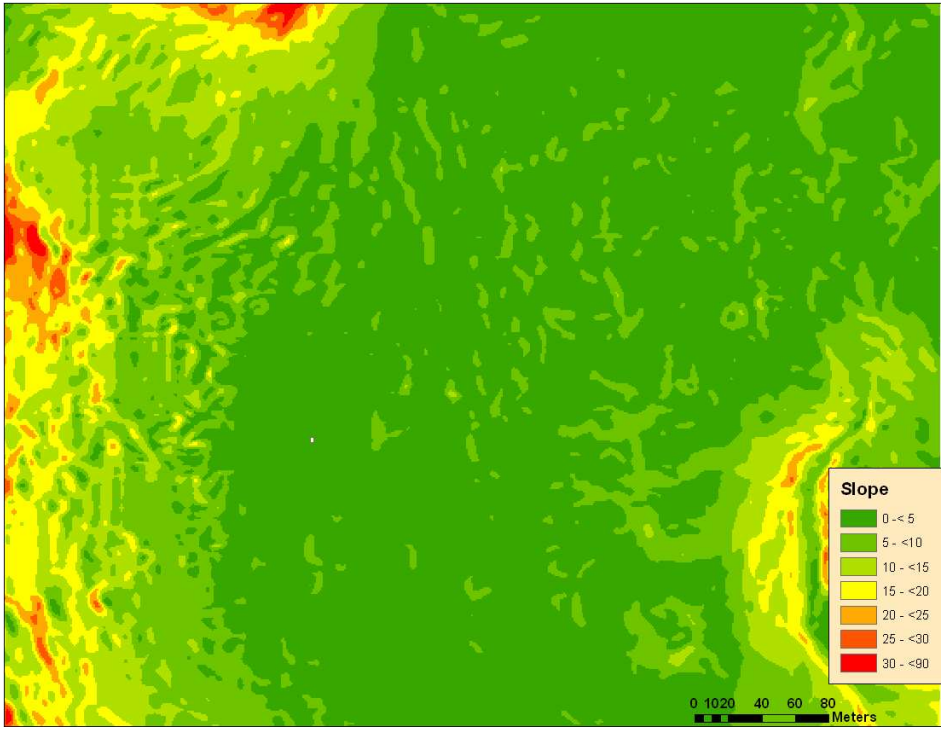
Holden Orange Box 15

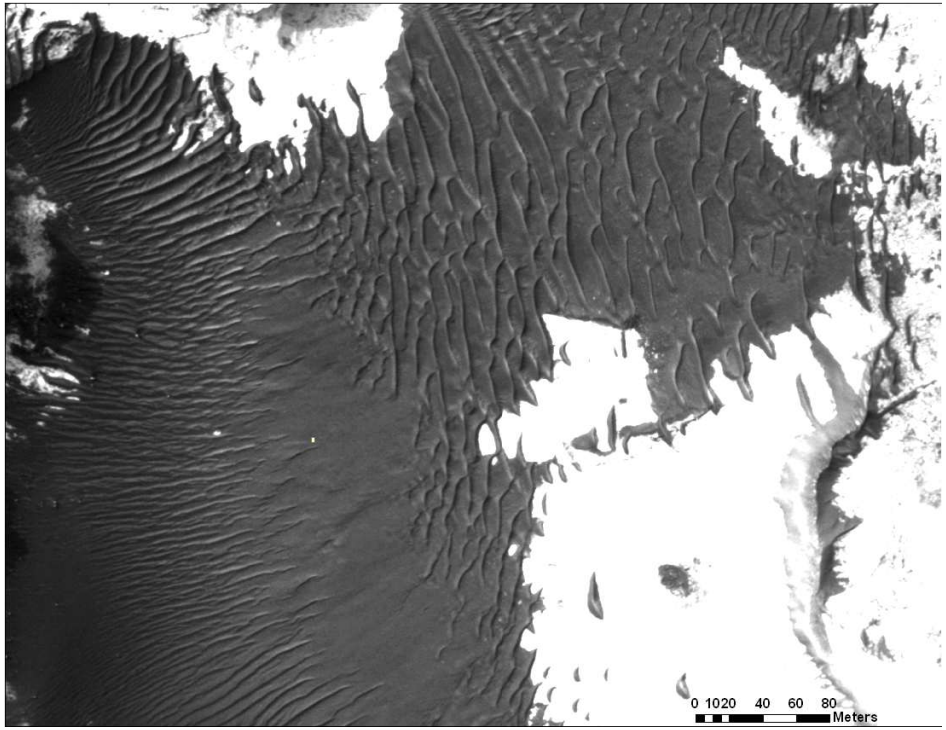




-Large ripples within canyon are probably not traversable
-MSL Footprint shown as yellow box (2x3 m)

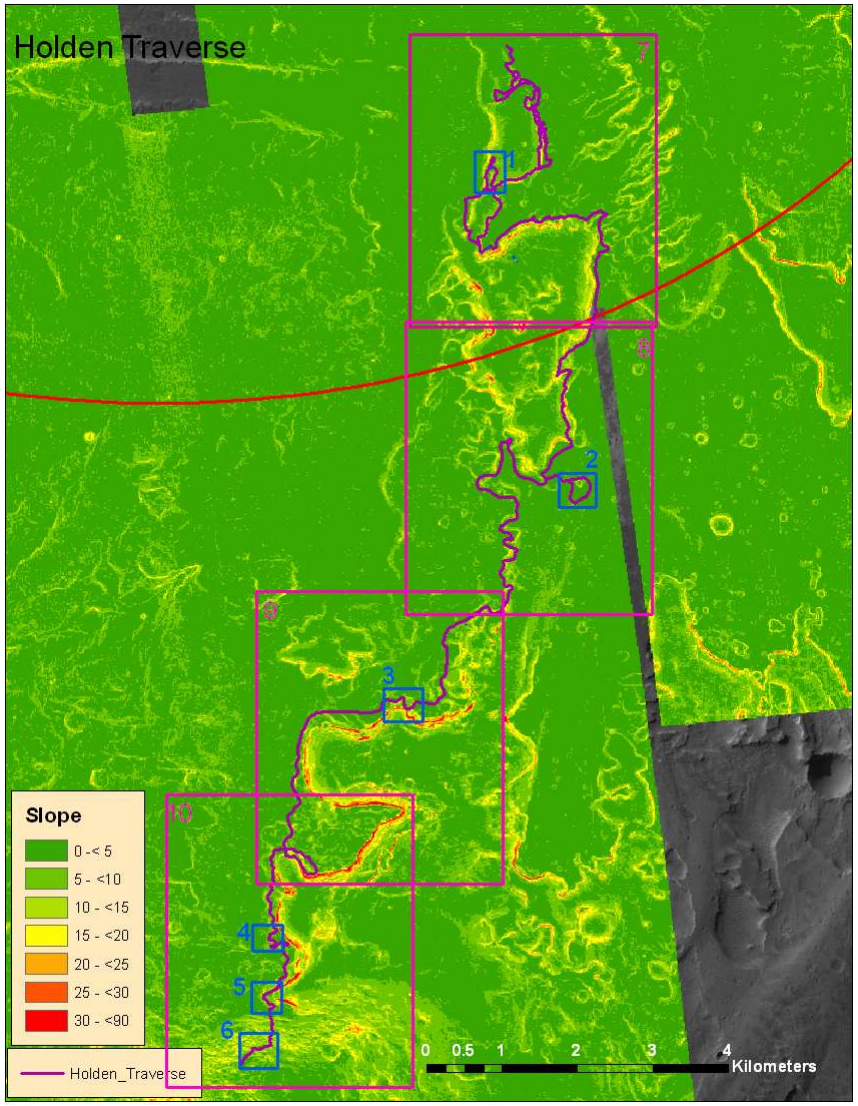
Holden Orange Box 16

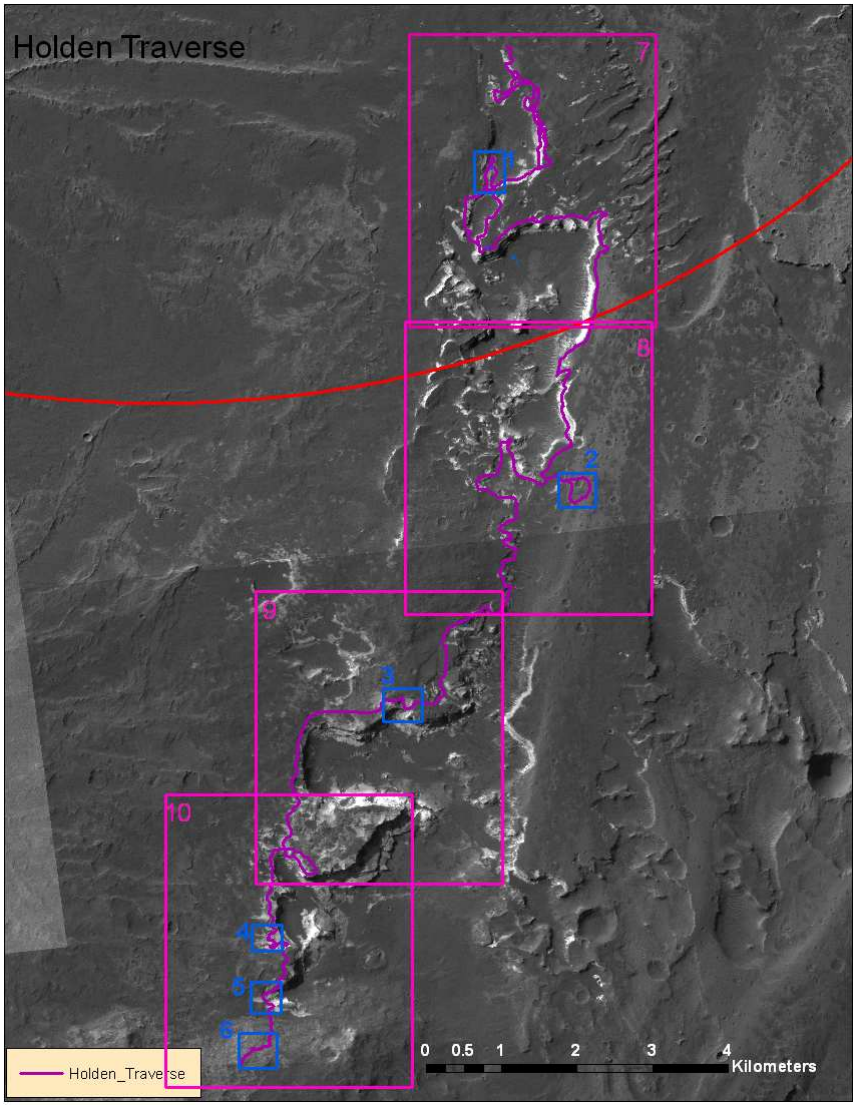




-Large ripples within canyon are probably not traversable
-MSL Footprint shown as yellow box (2x3 m)

Holden Traverse Overview

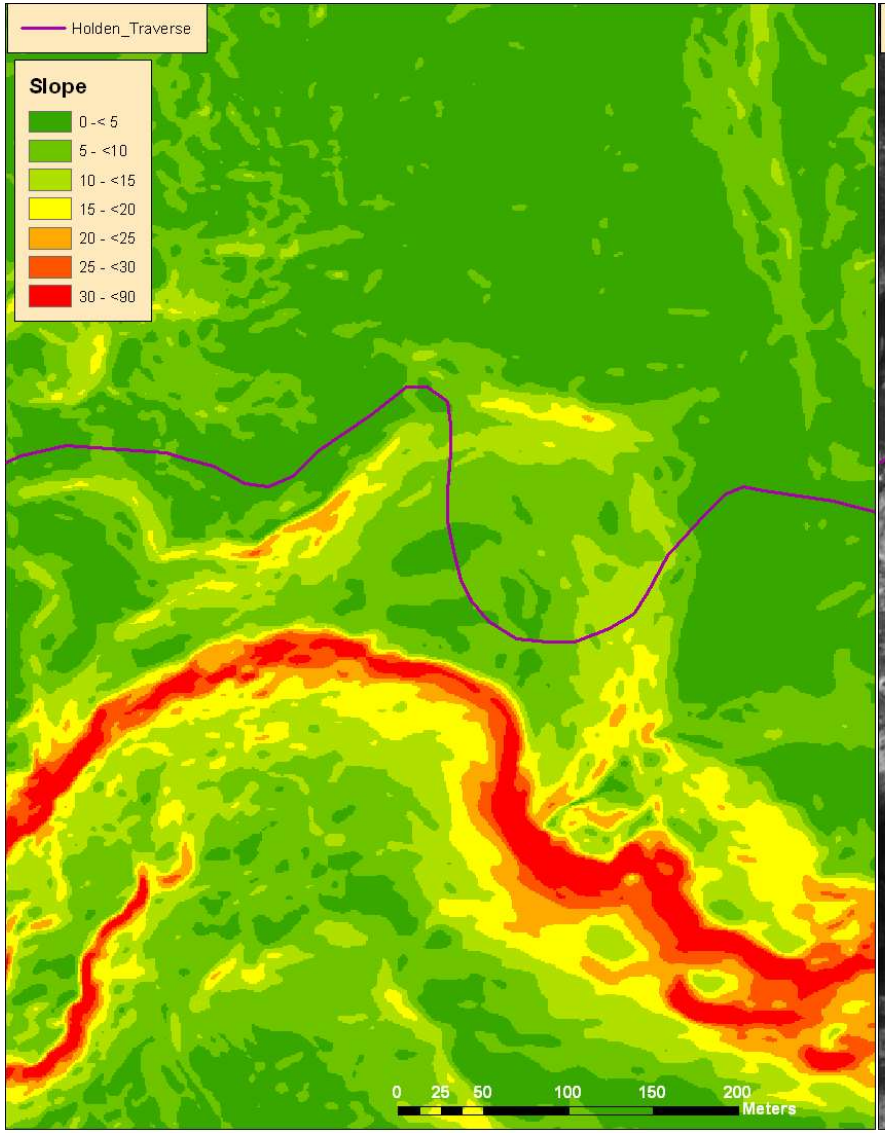




-Areas in pink boxes shown on next slides

-Traverse outside canyon, dip in, can get to all locations of science interest identified by Ross Irwin

Holden Blue Box 3

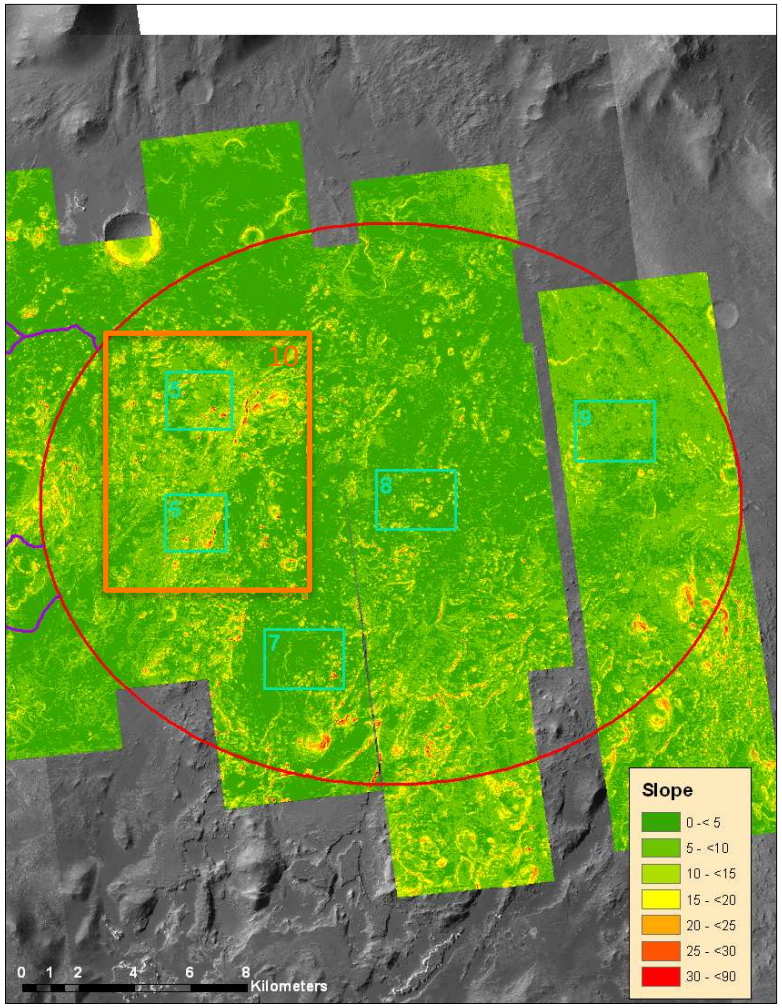


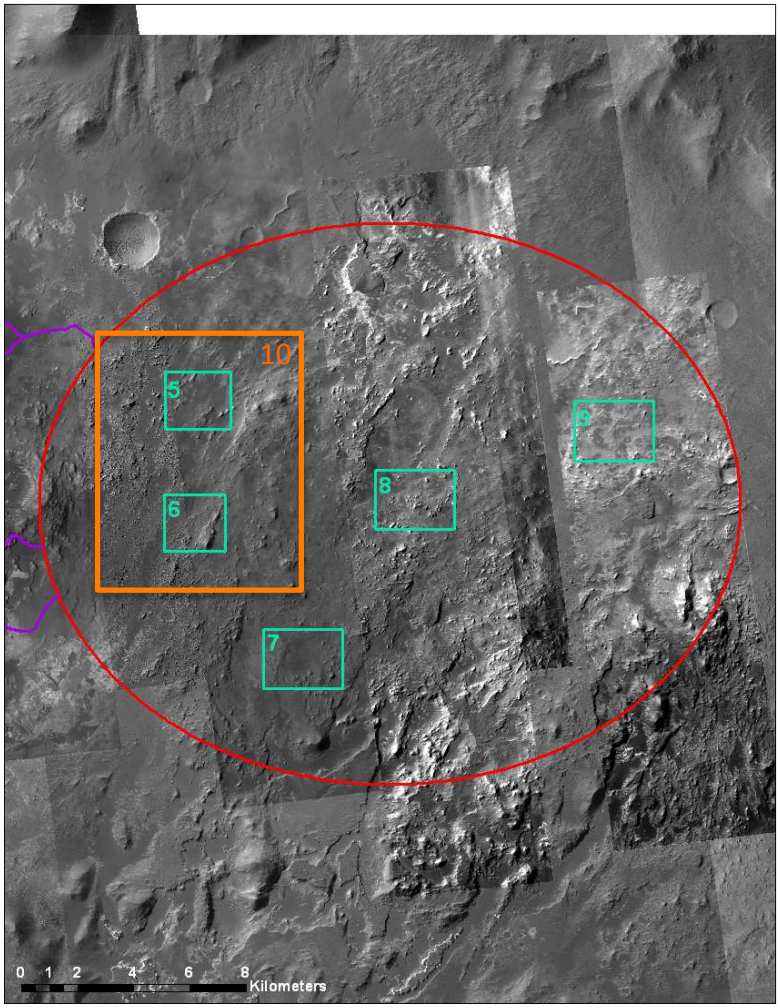
-Target: Light toned layered deposits

Holden Summary

- Ripples Omnipresent in Holden Ellipse
  - Scale Similar to Rover
  - Require Navigation like Opportunity
- Giant Ripples Present in Canyons of Interest
  - Probably Not Traversable or so slow not worth trying
- Areas of Science Interest Identified R. Irwin
  - Can all be accessed
  - Traverse on top, dip in at multiple locations

Eberswalde Ellipse Overview

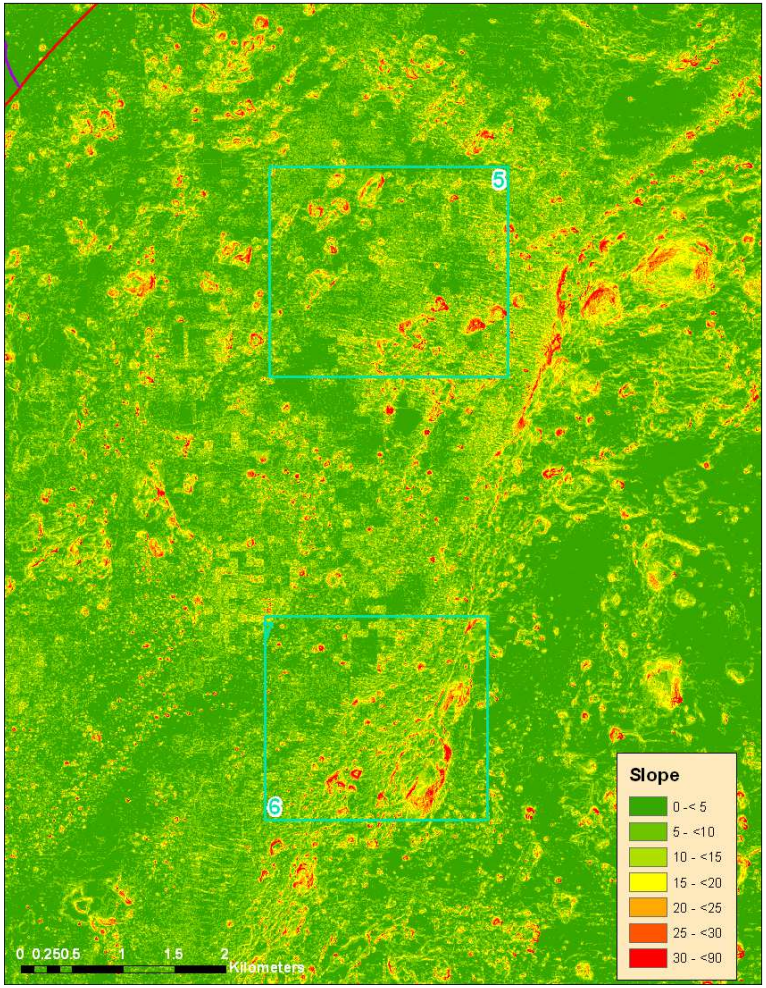


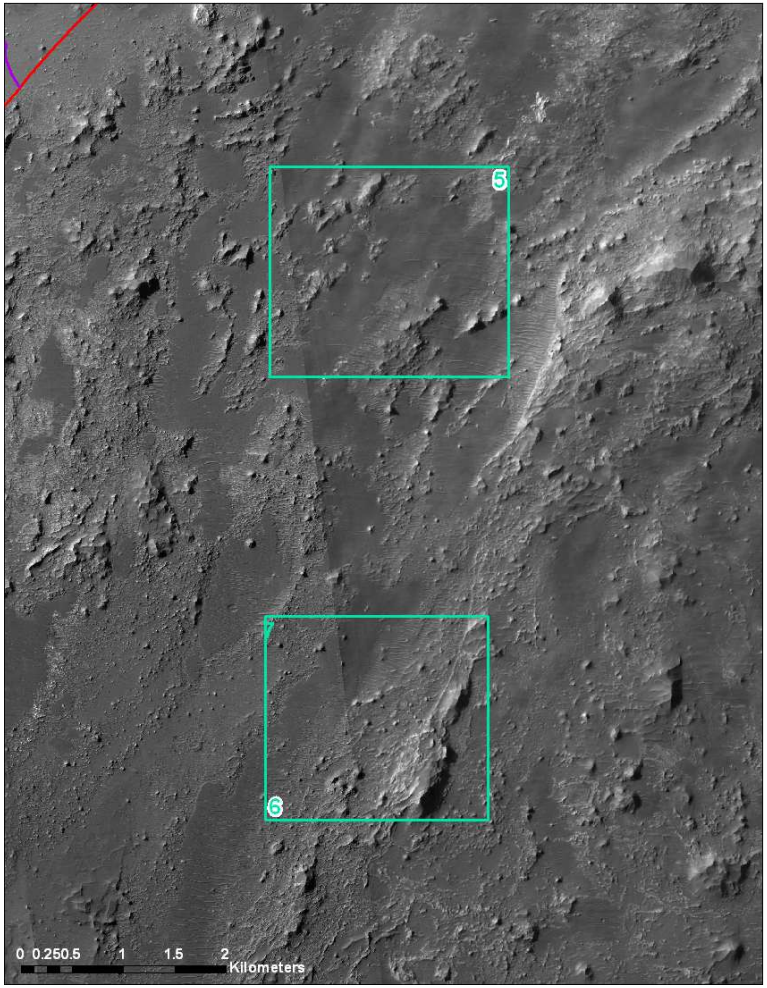


-These areas represent the terrain throughout the Eberswalde Ellipse

-The area outline in orange is the area that will be difficult to traverse in order to reach the delta. More detail of this area shown in boxes 5 and 6 on the next slides.

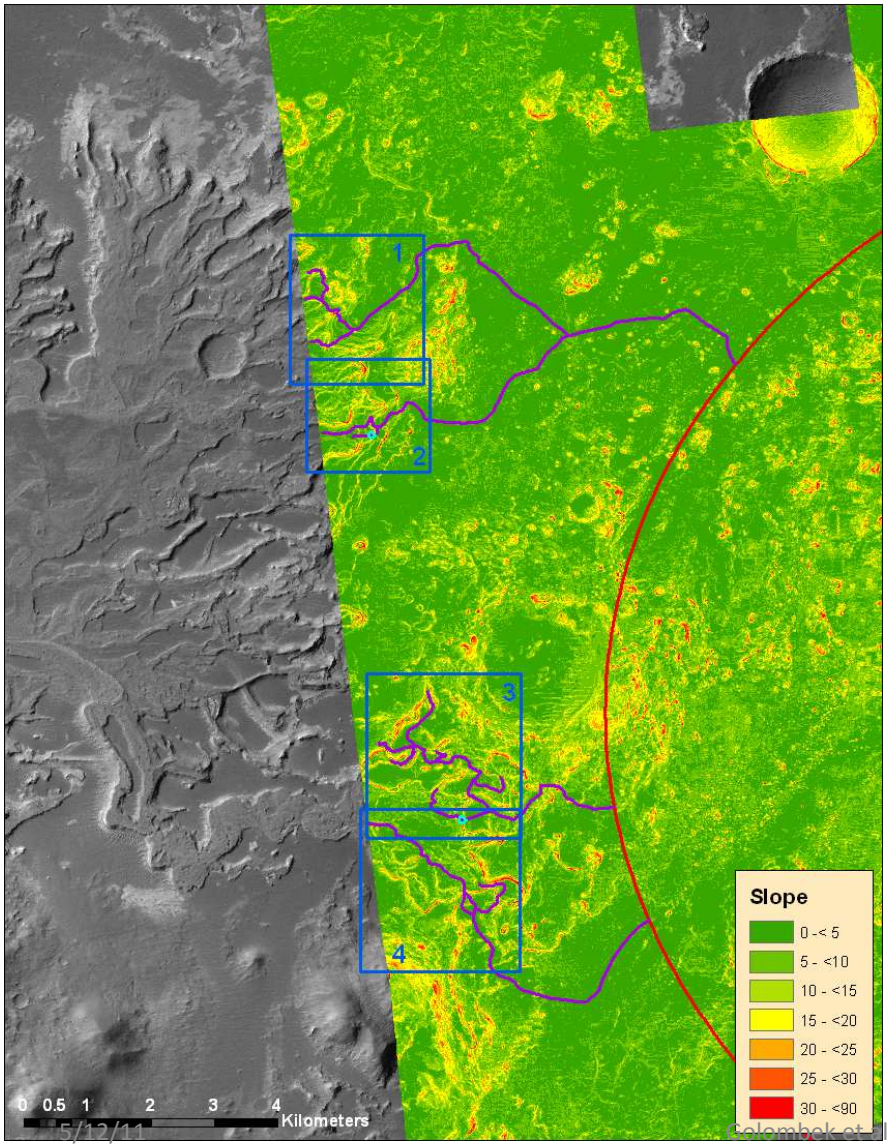
Eberswalde Orange Box 10

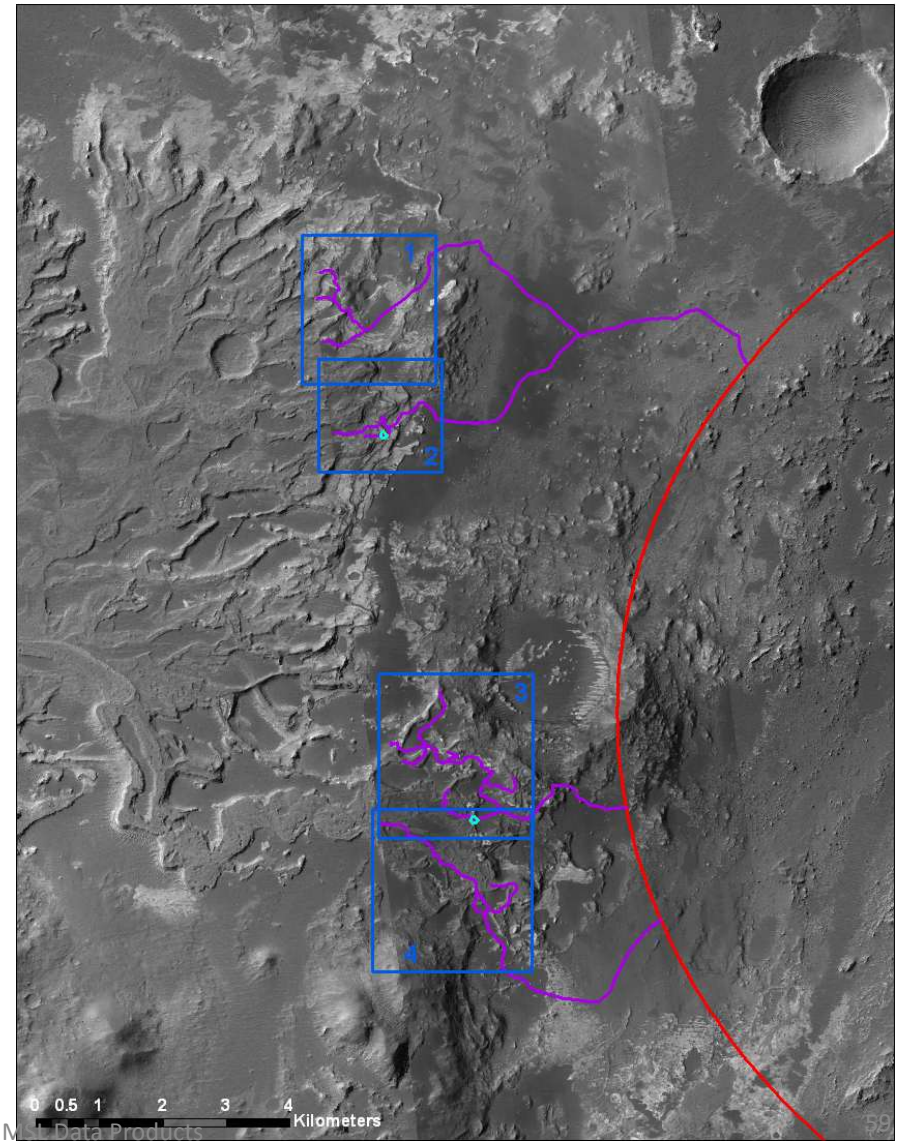




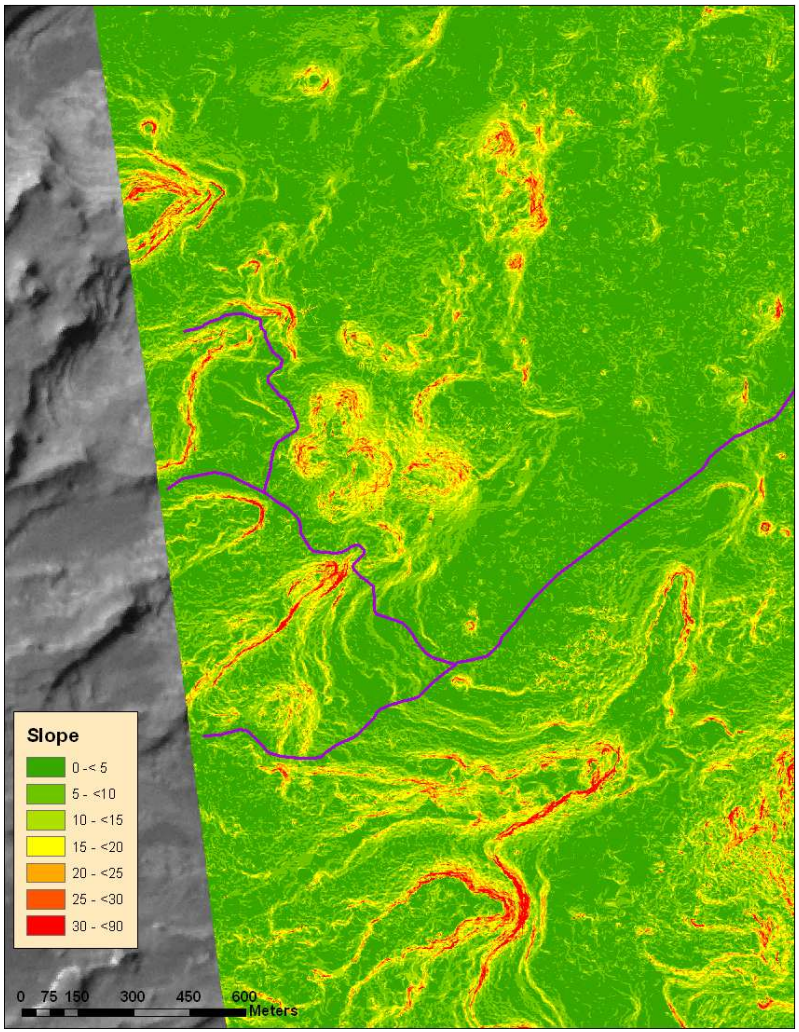
-This area is between the center of the ellipse and the delta
-Should be avoided when traversing across the ellipse
-Many small obstacles and high slopes, traversing would be required

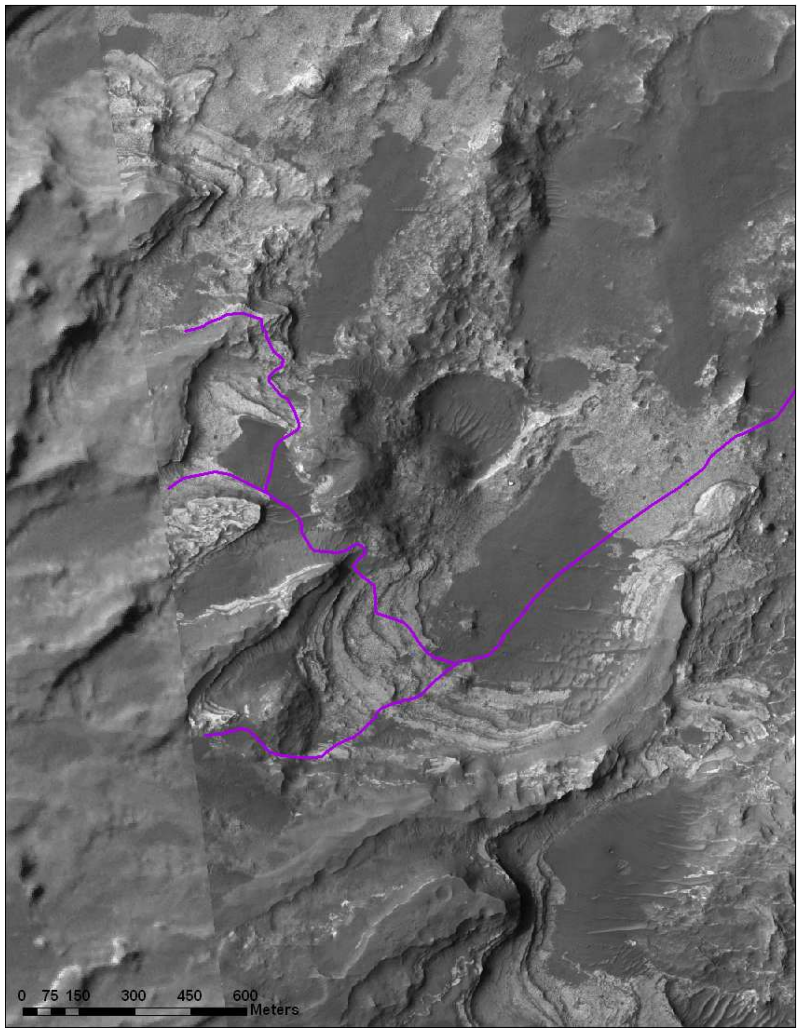
Eberswalde: Traverse to Delta Overview



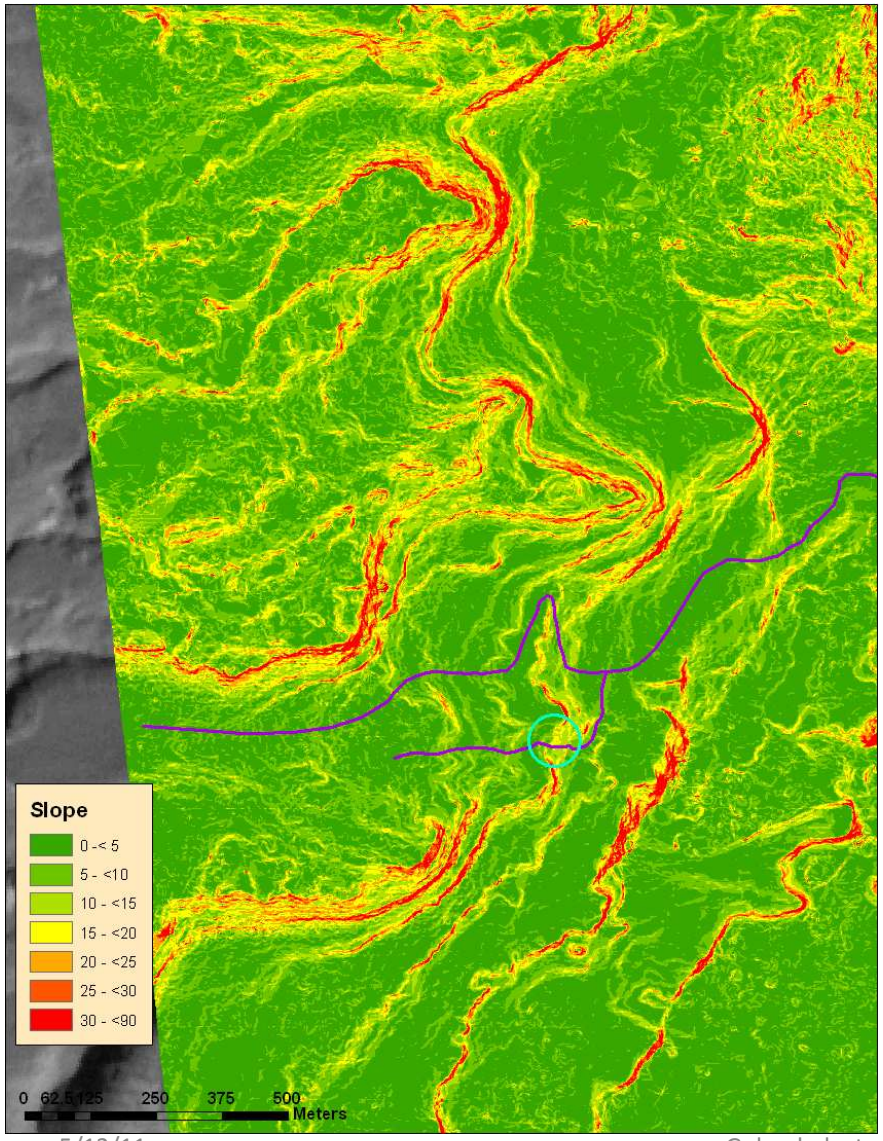


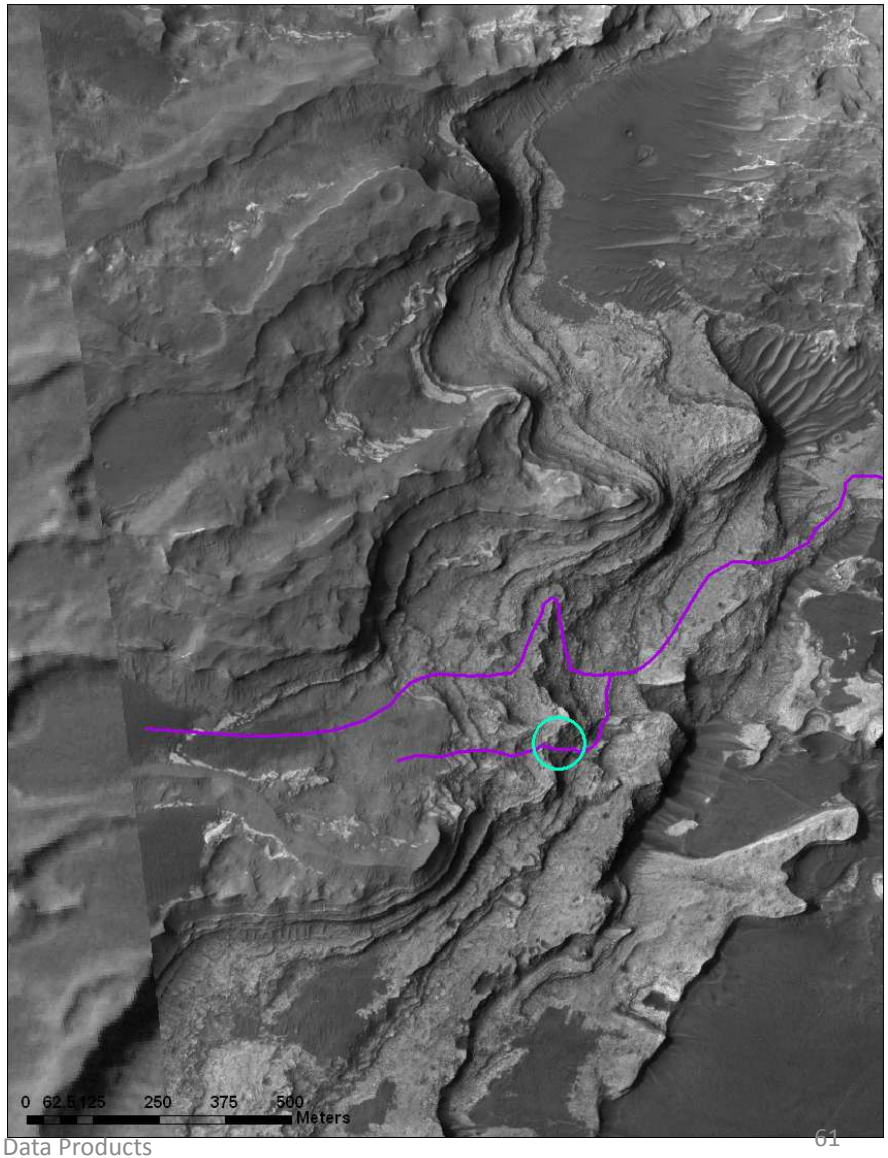
Eberswalde
Traverse Box 1



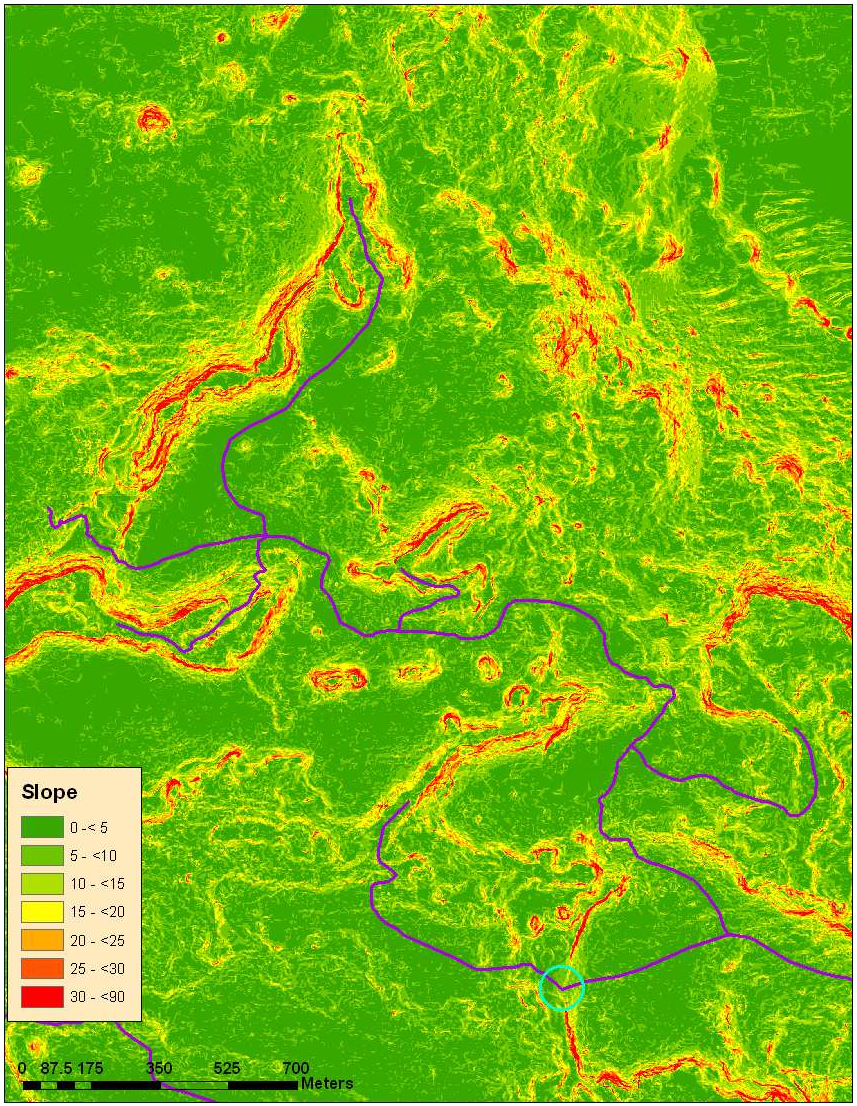


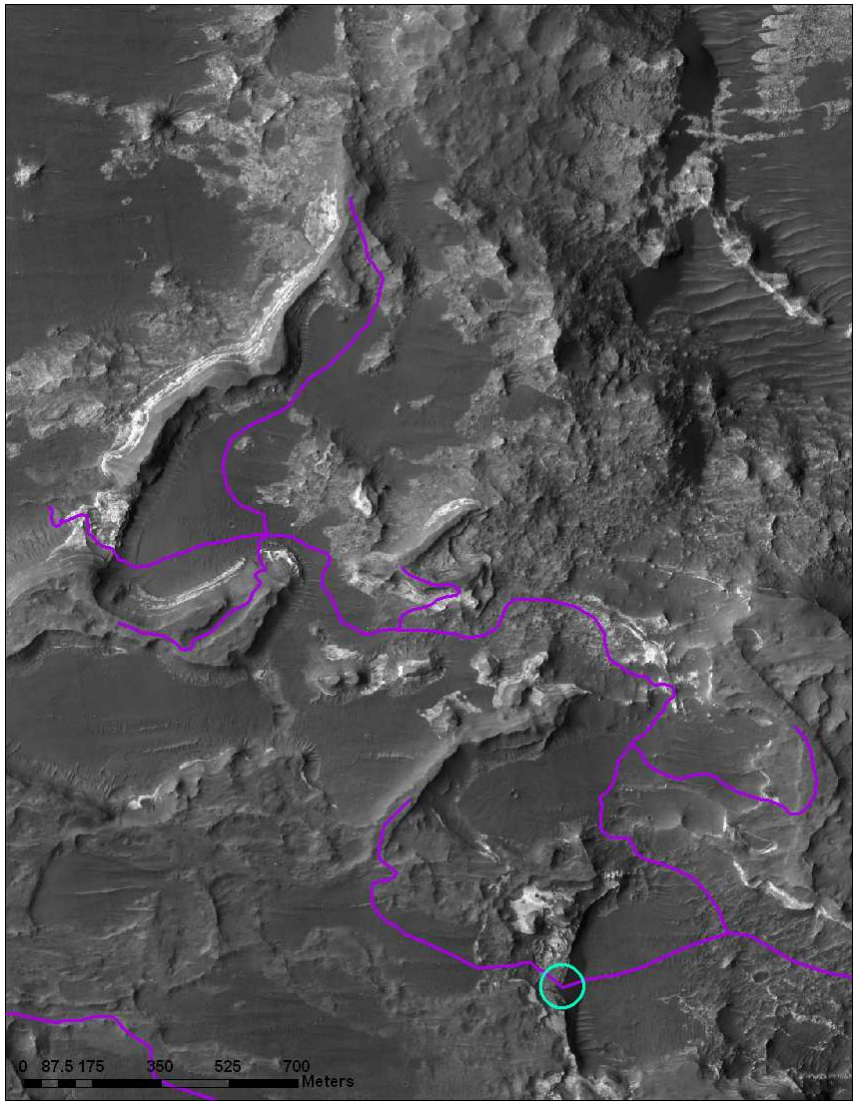
Eberswalde
Traverse Box 2



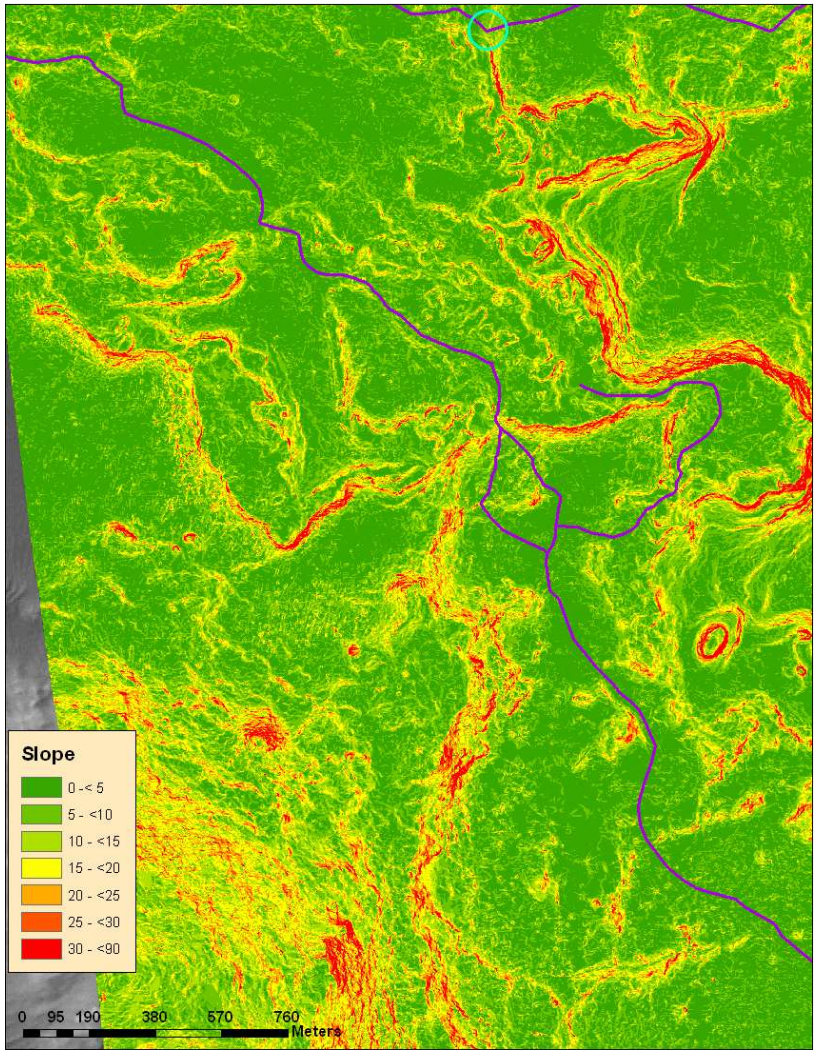


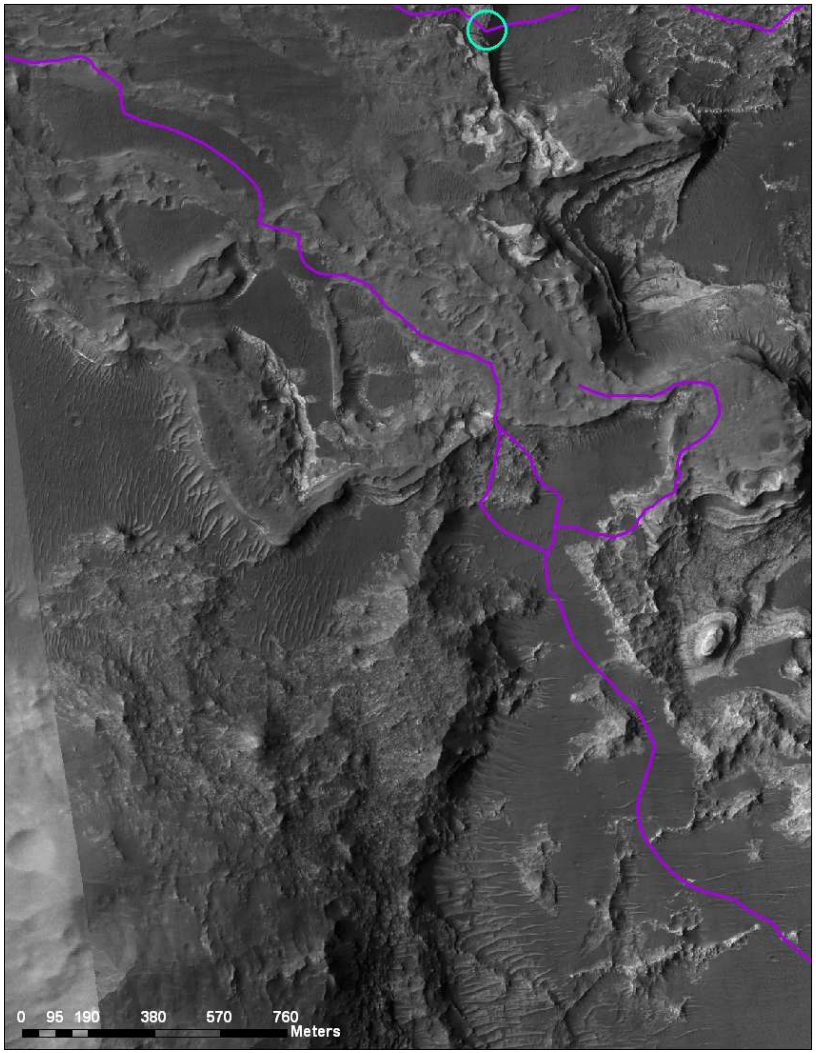
Eberswalde
Traverse Box 3





Eberswalde
Traverse Box 4





Eberswalde Summary

- Terrain throughout the ellipse is traversable, however routes must be carefully planned
  - Many small obstacles with high slopes throughout the ellipse
- The area outlined in orange should be avoided
- Several paths climb the delta

Traverse Routes at Gale Crater

Rachael Hoover, Matthew Golombek*,
Kenneth Herkenhoff*, Randy Kirk
Timothy Parker*, Ryan Anderson*,
Dawn Summer*, Fred Calef, Robert Sullivan*,
Paolo Bellutta

MSL Project Gale Ascent Review
JPL
April 19, 2011

*Gale Summit Team

History

- Gale Summit Team assembled 3/16-tasked with feasibility to ascend lower part of mound
- JPL team members sent around initial assessment on 3/21/11. The email was followed by comments and questions from other team members
- Paolo Bellutta expressed concerns about path width needing to be >10 meters wide
  - Initially paths were at least 5 meters wide and were re-examined.
  - Paths with a width <10 meters were identified
- Ryan Anderson provided more paths options, specifically paths to the west of the canyon
- Dawn Summer provided areas of scientific interest
  - Mapping stratigraphic sequence in Gale to determine which paths preferred [e.g., continuous exposure; Dawn's Valley identified]
- Rob Sullivan expressed concerns about slope criteria: rovers climb slopes <15° degrees on unconsolidated material and <30° on rock
  - Paolo Bellutta provided information that MSL Scarecrow can traverse up slopes as high as 20° in cohesive soils and if similar to MER (expected) 30° on rock
- Ken Herkenhoff & Randy Kirk evaluated uncertainties in DEMs and slope maps
  - Looked at stereo correlation at choke points and differences between hand edited and machine matched points
- Tim Parker evaluated choke points in anaglyphs and compared to DEMS
- Paolo Bellutta providing a separate evaluation of traversabilty

Gale Crater

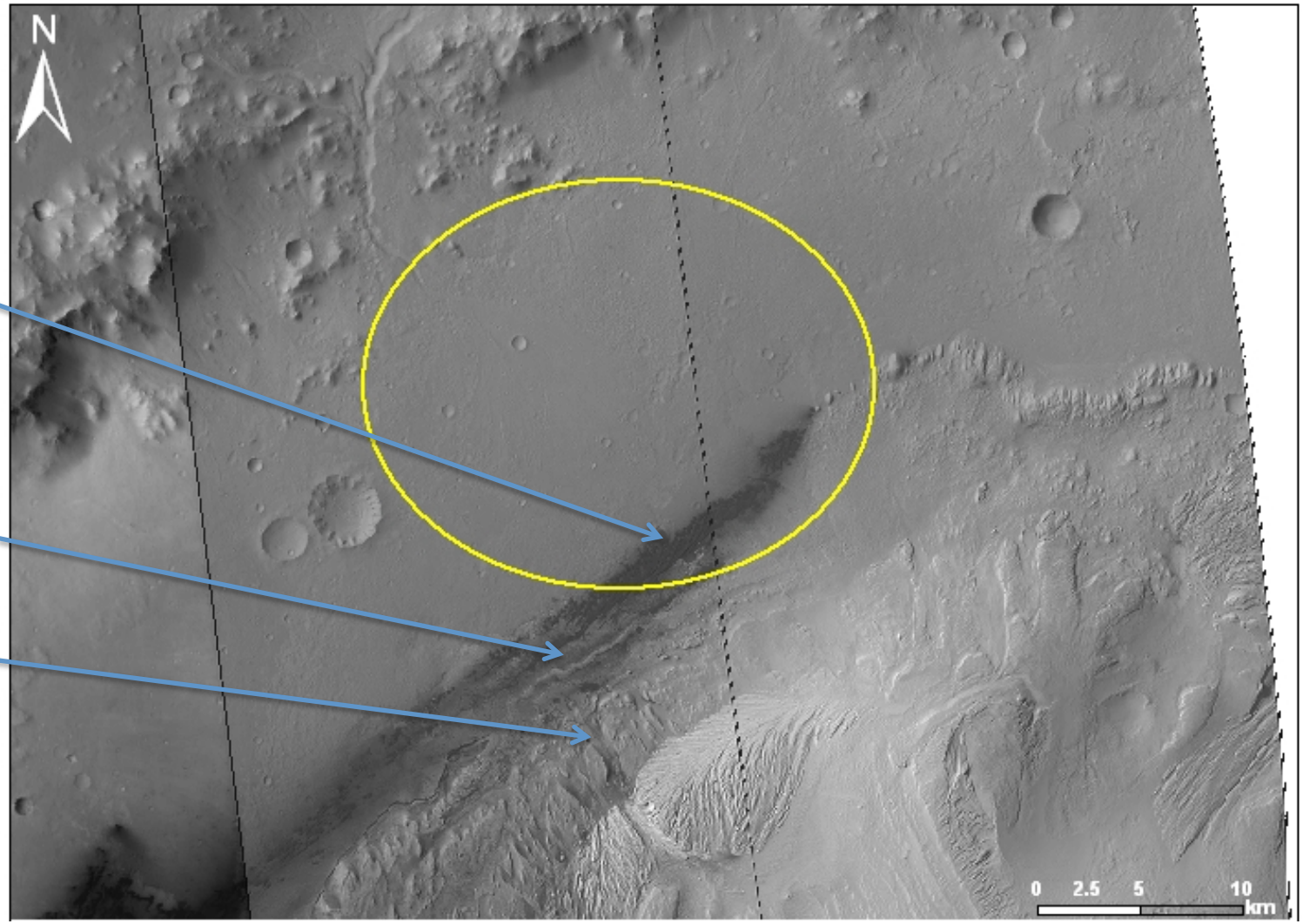
Cratered Plains –
No obvious Mobility
Concerns

Dark Dunes
Appear Fresh
Many Exceed 30°
Mobility
Impediment

Sample Strata Here

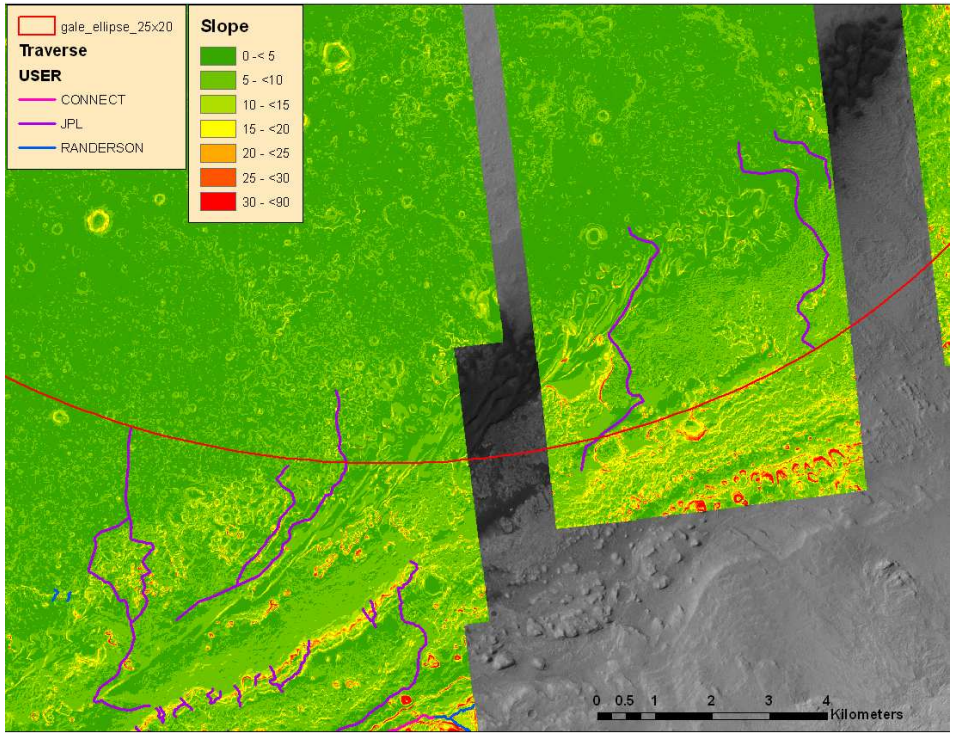
Drive up Canyon
Here

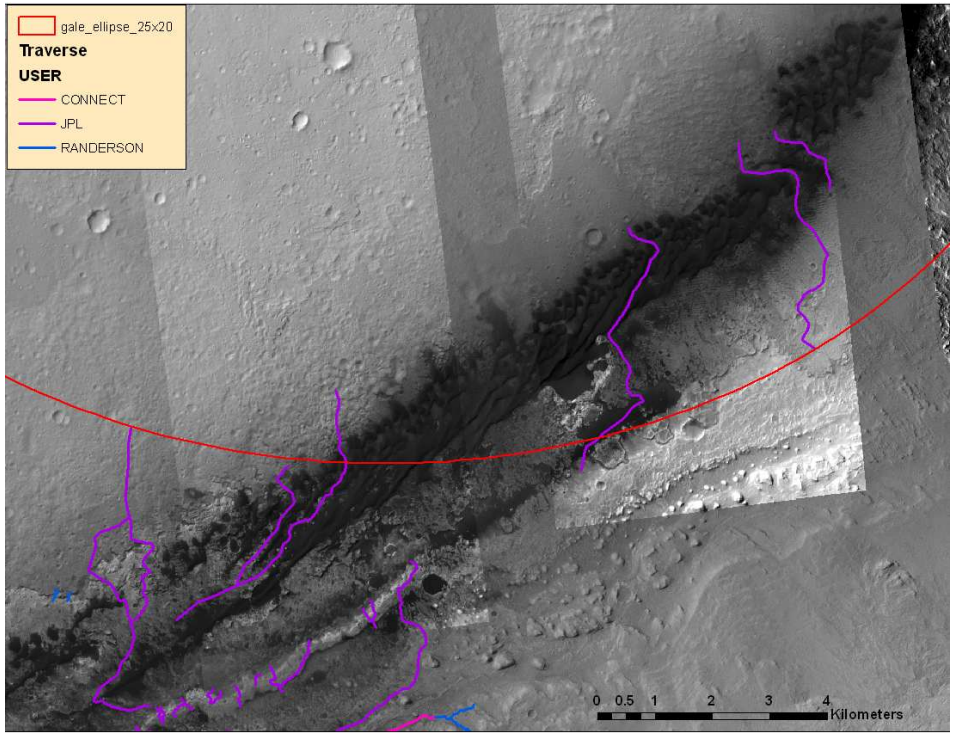
Can Access Mineral
Strata in CRISM
Can drive up mound



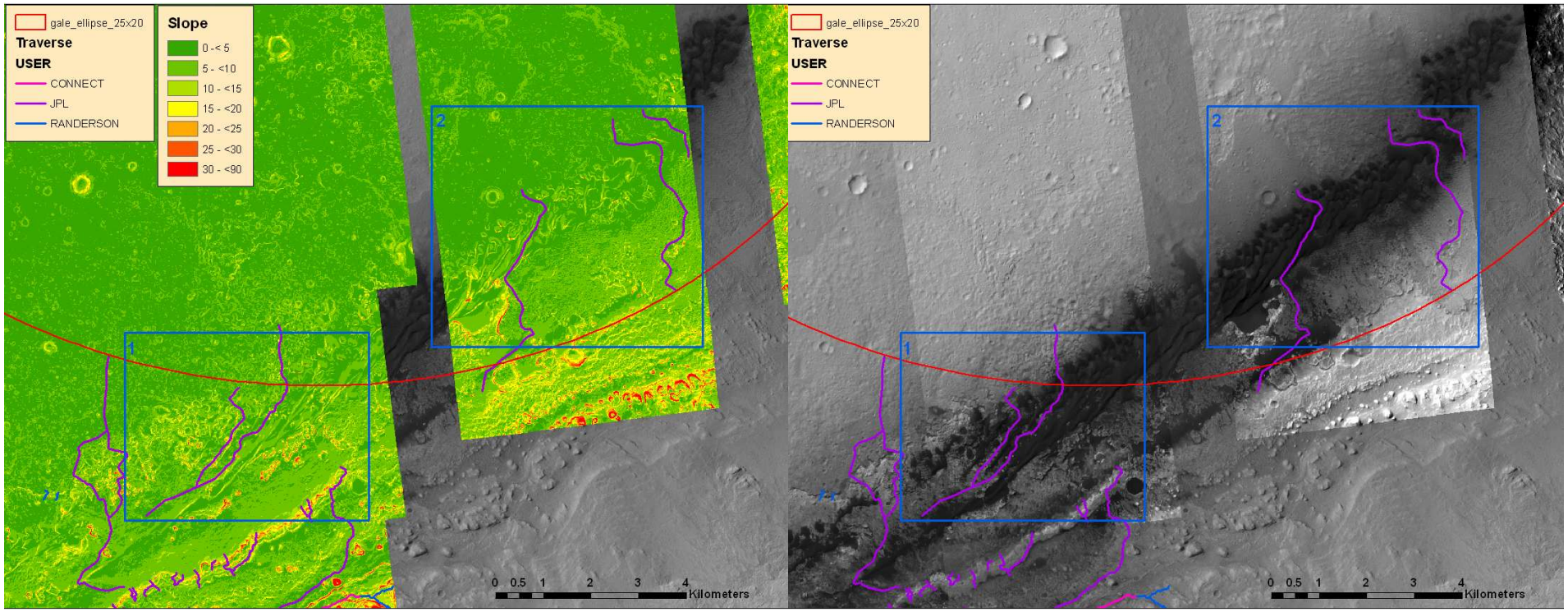
Golombek et al., MSL Data Products

Overview of Dunes



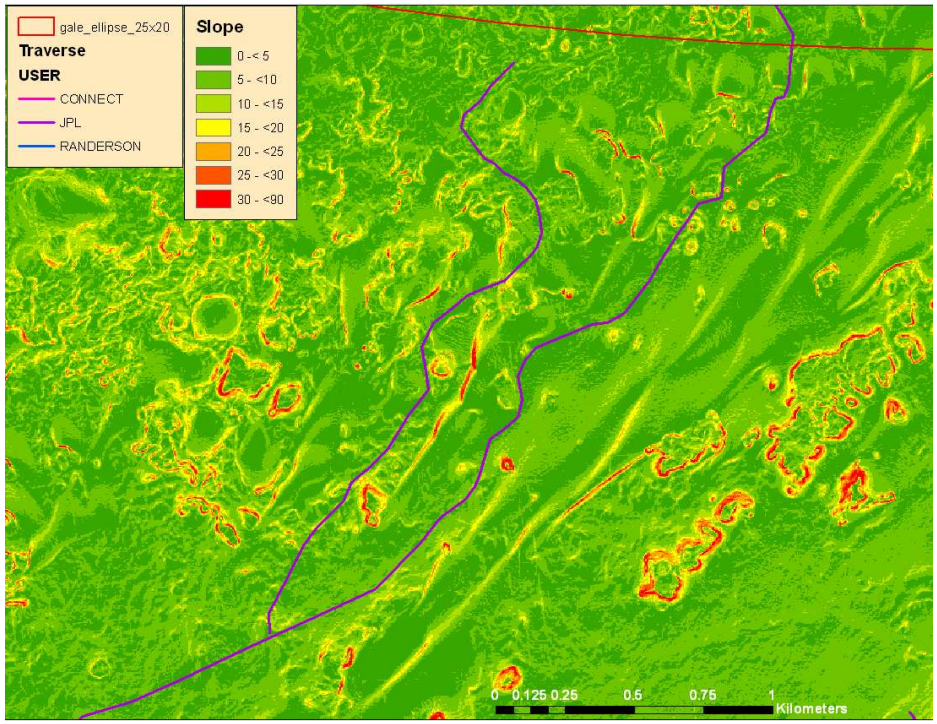


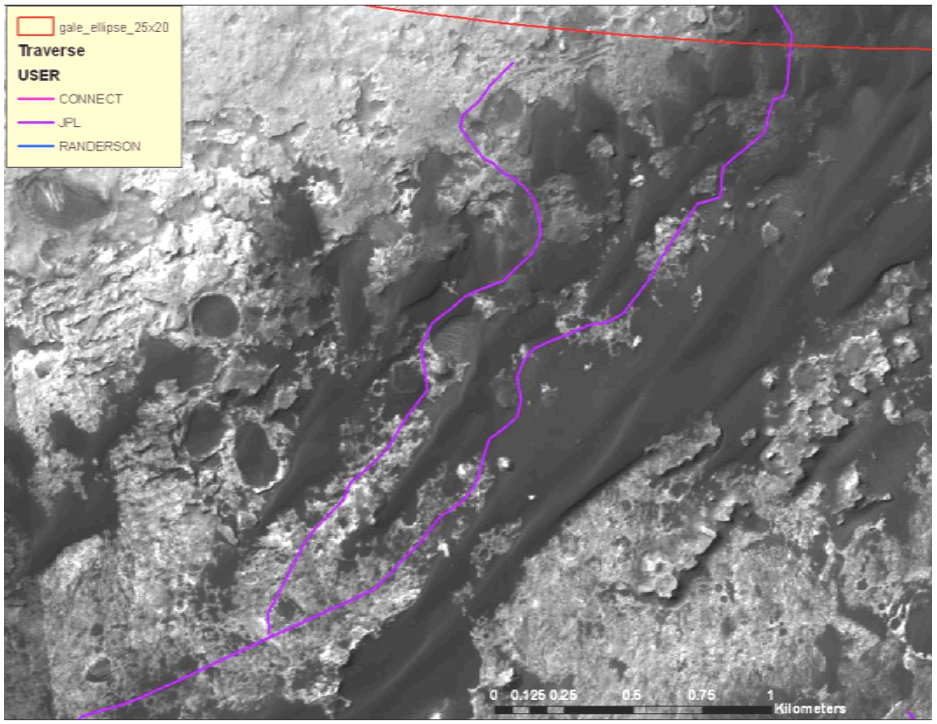
Overview



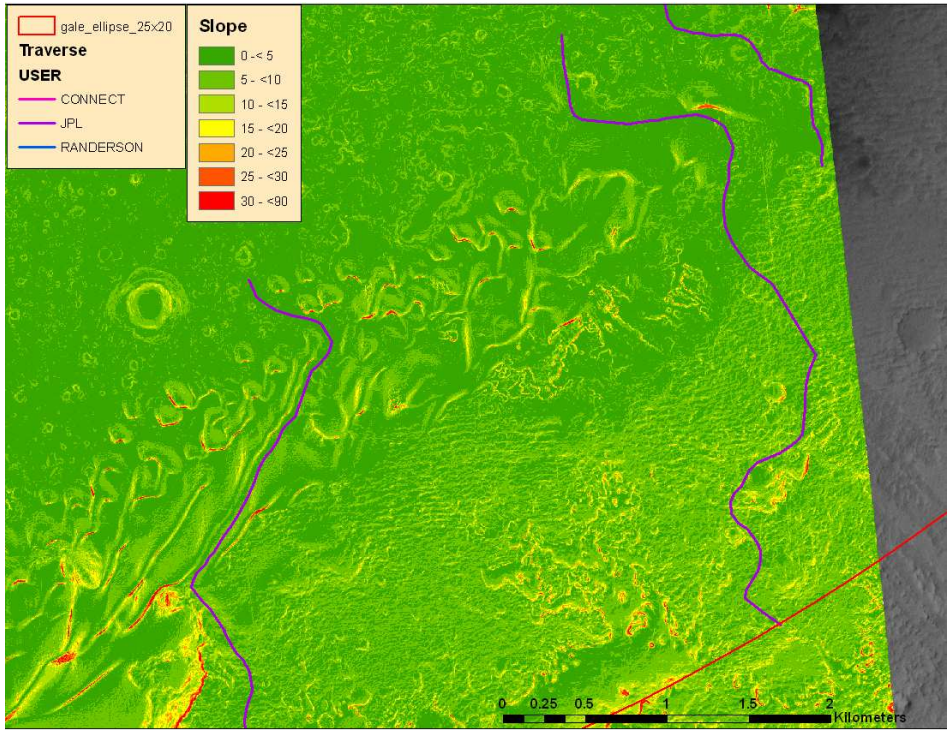
-Blue box 1 and 2 show the approximate location of the next slides

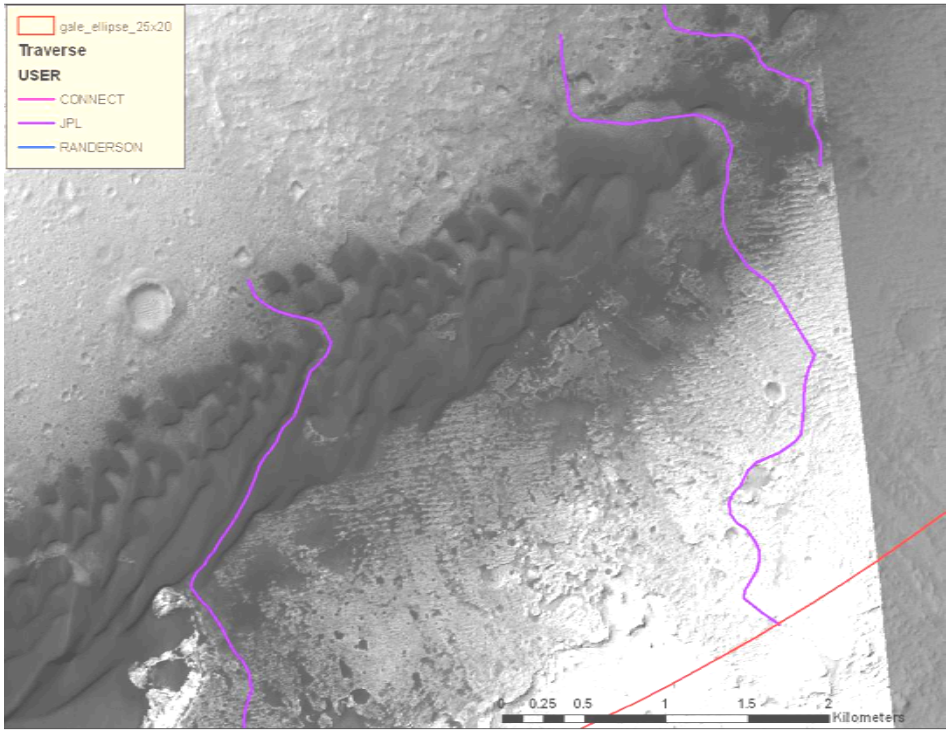
Box 1


gale_ellipse_25x20
Traverse
USER
CONNECT
JPL
RANDERSON
Slope
0 - < 5
5 - <10
10 - <15
15 - <20
20 - <25
25 - <30
30 - <90
0 0.125 0.25 0.5 0.75 1
Kilometers

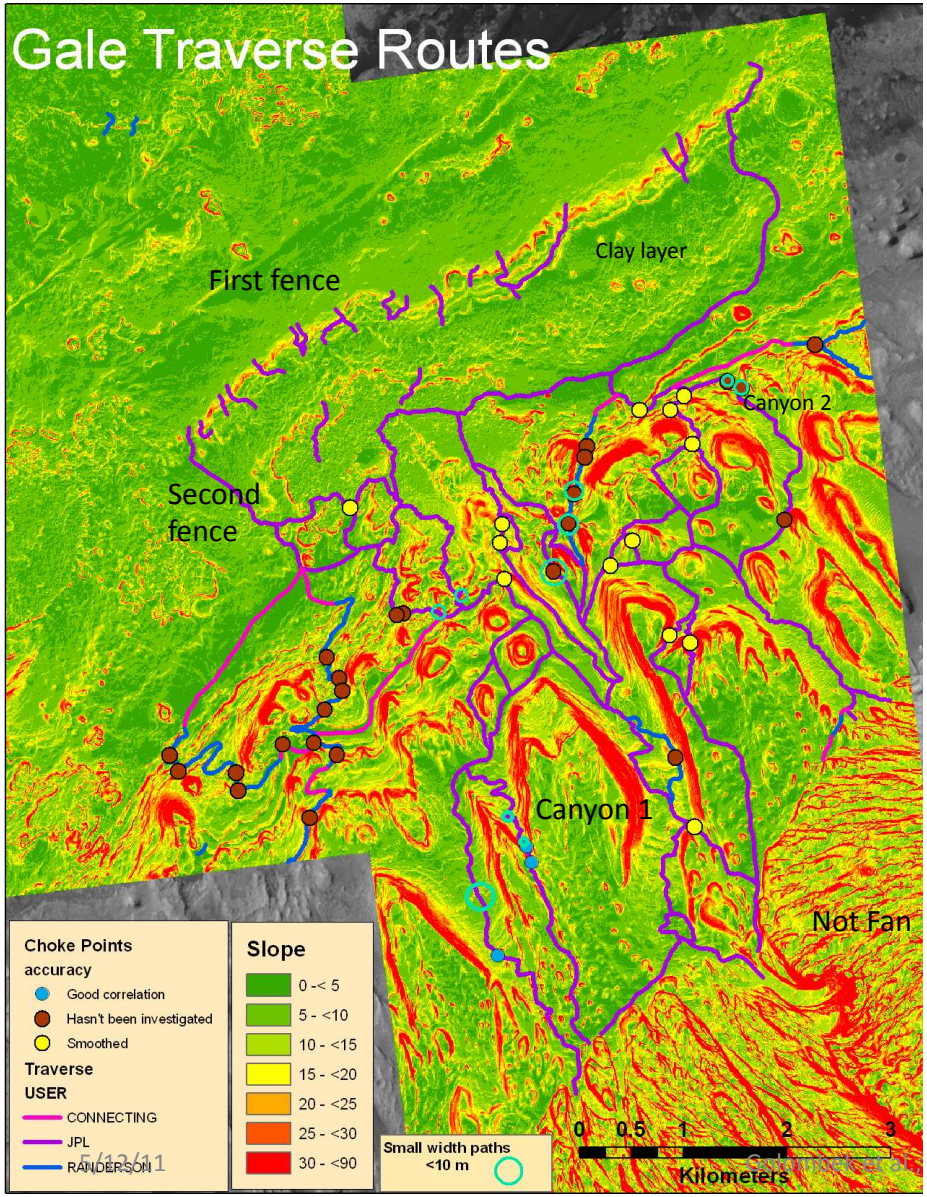

gale_ellipse_25x20
Traverse
USER
CONNECT
JPL
RANDERSON
0 0.125 0.25 0.5 0.75 1
Kilometers

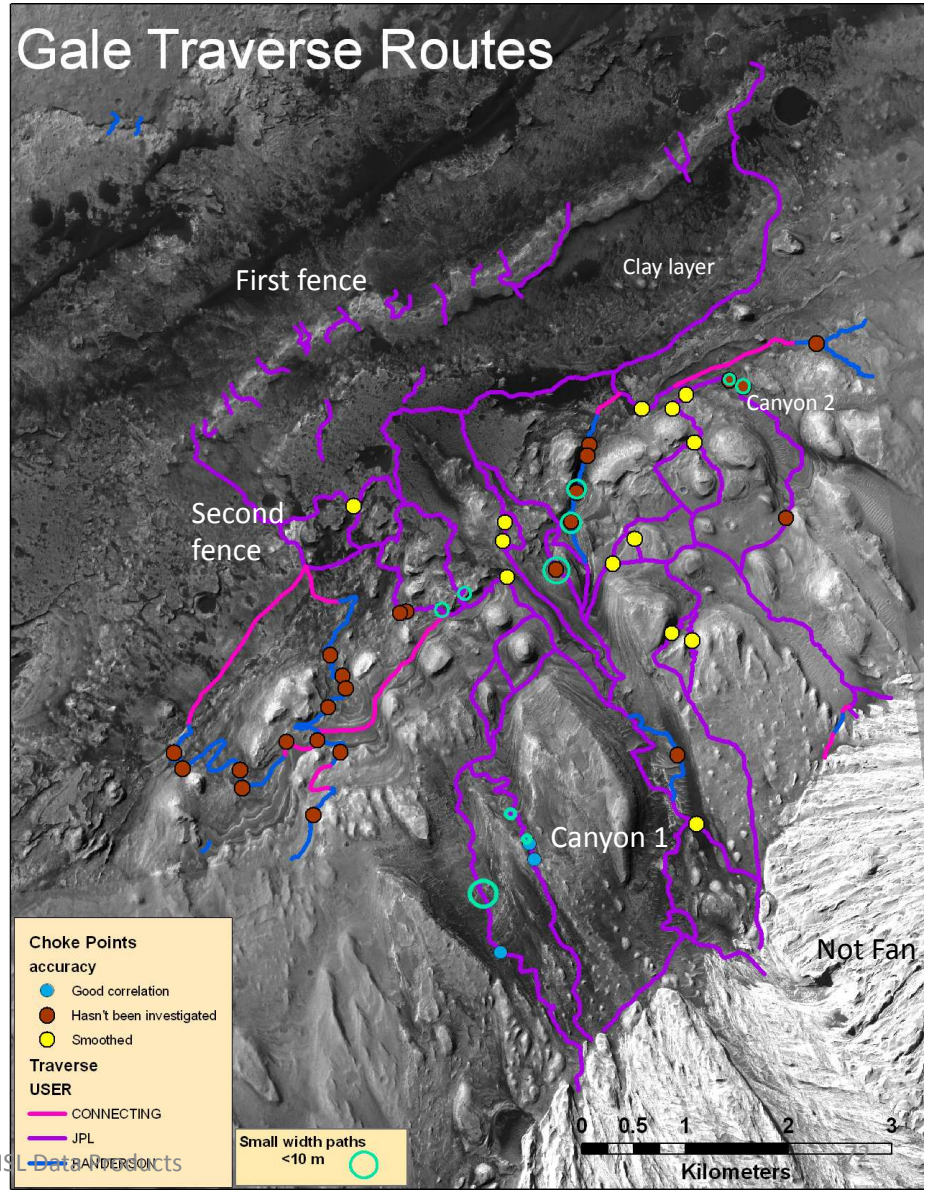
Box 2


gale_ellipse_25x20
Traverse
USER
CONNECT
JPL
RANDERSON
Slope
0 -< 5
5 - <10
10 - <15
15 - <20
20 - <25
25 - <30
30 - <90
0 0.25 0.5 1 1.5 2
Kilometers


gale_ellipse_25x20
Traverse
USER
CONNECT
JPL
RANDERSON
0 0.25 0.5 1 1.5 2
Kilometers

Overview


Gale Traverse Routes
First fence
Clay layer
Canyon 2
Second fence
Canyon 1
Not Fan
Choke Points
accuracy
Good correlation
Hasn't been investigated
Smoothed
Traverse
USER
CONNECTING
JPL
RANDERSON
Slope
0 -< 5
5 - <10
10 - <15
15 - <20
20 - <25
25 - <30
30 - <90
Small width paths
<10 m
0 0.5 1 2 3
Kilometers


Gale Traverse Routes
First fence
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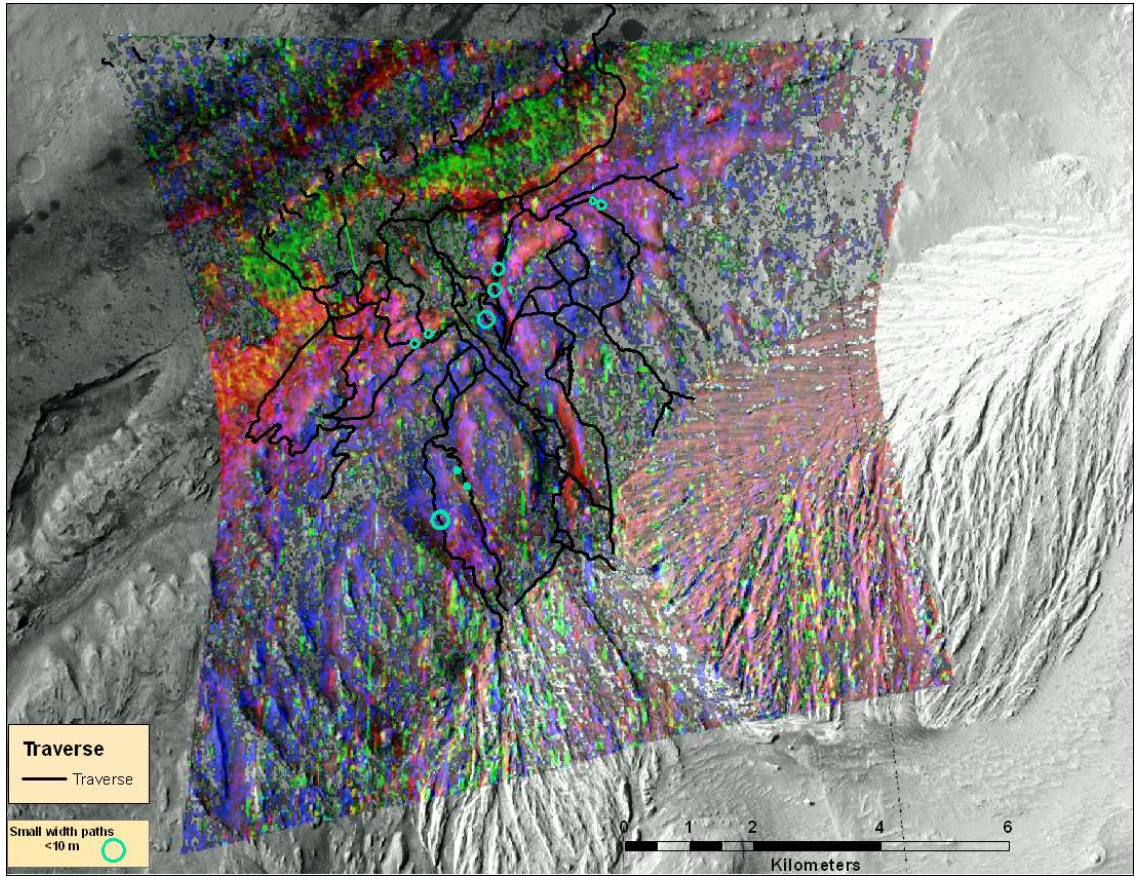
Choke Points
accuracy
Good correlation
Hasn't been investigated
Smoothed
Traverse
USER
CONNECTING
JPL
RANDERSON
Small width paths
<10 m
0 0.5 1 2 3
Kilometers

Mineralogy across traverse routes



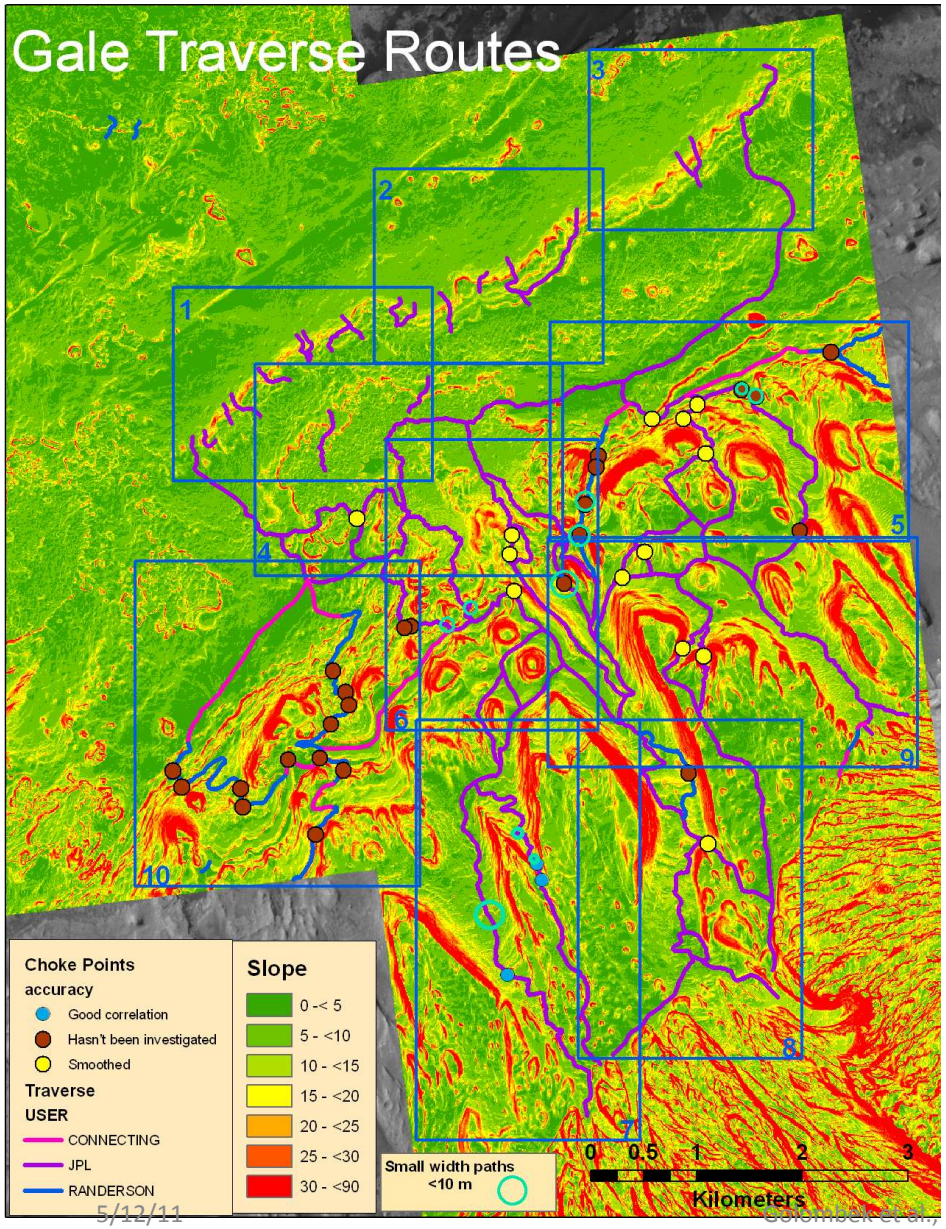
CRISM RGB mineral parameter maps overlain on CTX mosaic.
red = Fe-minerals,
green = Fe/Mg-clay minerals,
blue = sulfates)

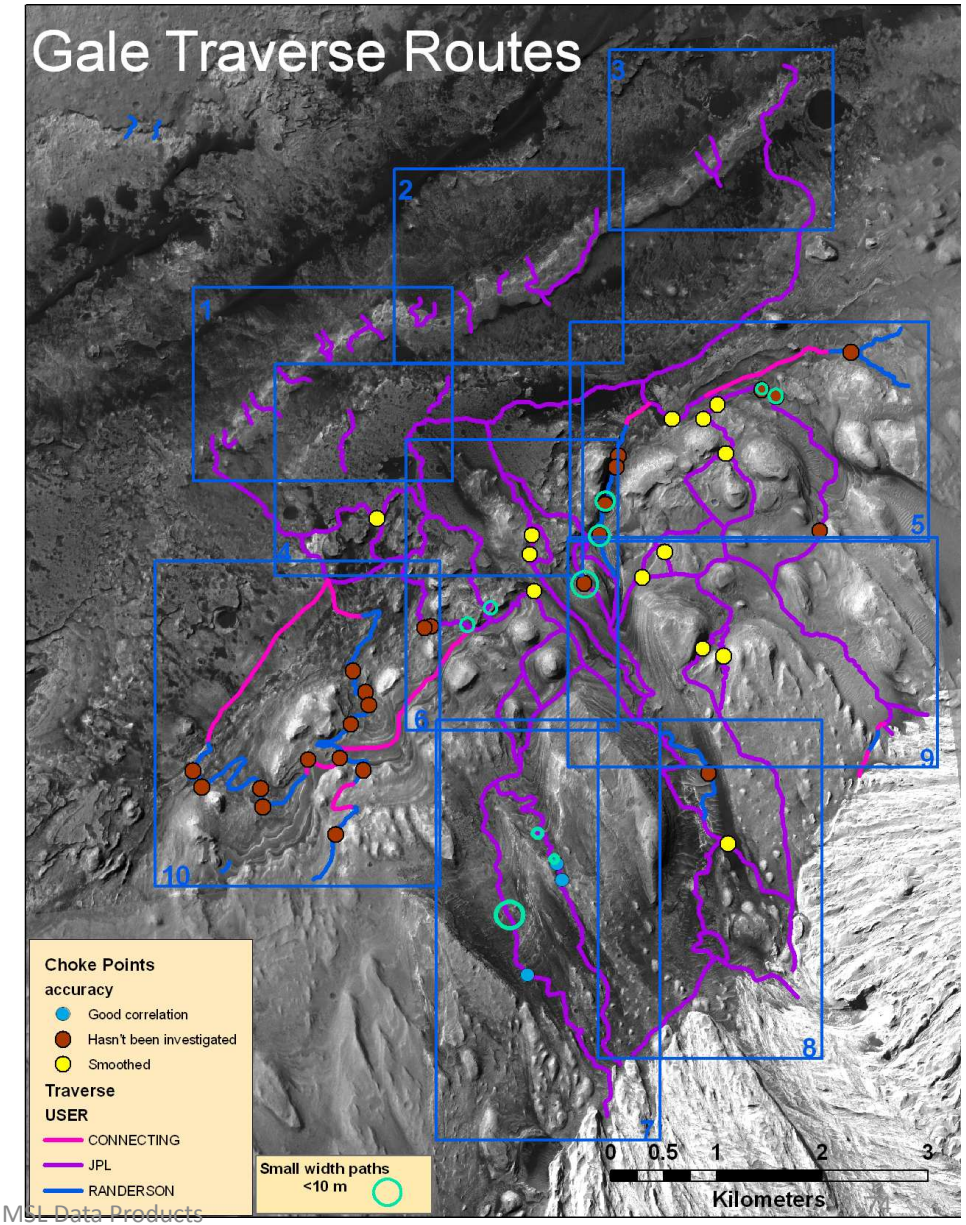
Bright red regions correspond to olivine-bearing dunes,
green regions contain nontronite,
dark blue regions contain sulfates.
Orange and magenta regions contain sulfates and clay minerals in variable proportions.

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.

Overview


Gale Traverse Routes
1
2
3
4
5
6
7
8
9
10
Choke Points
accuracy
Good correlation
Hasn't been investigated
Smoothed
Traverse
USER
CONNECTING
JPL
RANDERSON
Slope
0 -< 5
5 - <10
10 - <15
15 - <20
20 - <25
25 - <30
30 - <90
Small width paths
<10 m
0 0.5 1 2 3
Kilometers


Gale Traverse Routes
1
2
3
4
5
6
7
8
9
10
Choke Points
accuracy
Good correlation
Hasn't been investigated
Smoothed
Traverse
USER
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JPL
RANDERSON
Small width paths
<10 m
0 0.5 1 2 3
Kilometers

Gale Conclusions

- Mineral Strata Observed from Orbit Accessible at Gale; Paths through/around dunes
- Four major paths that cross through each mineral layer identified in the CRISM RGB mineral parameter maps (Milliken et al., 2010)
  - A northeast route, a southwest route, a west route and a route though the canyon
- If DTMs Reasonably Accurate Many paths are traversable
  - 18 paths crossing first fence; 8 paths crossing second fence
  - 1 path through the canyon and 4 paths around the canyon; 6 paths reaching the fan
- About 30 Choke Points in Paths
  - All but ~5 have <20° Slopes so may be traversable regardless of material properties if soil is cohesive
  - All but 9 are at least 10 m wide; 9 are >5 m wide
- Uncertainty in DTMs
  - Smoothing does not affect slope, but could have finer roughness elements
  - up to 0.3 m elevation
  - RMS at 1 m 1.4°, but individual slope uncertainty could be up to 5° or even 10°
- May always be some uncertainty in any given path
  - Scale of slope, finer roughness elements, material properties
  - Large number possible paths suggests some will be traversable
- If Gale Selected, acquire additional adjacent HiRISE stereo-additional paths
- Continue to evaluate best sections to explore to focus path planning
- Careful driving will be required for most of the identified paths
  - Level of difficulty much greater than previous traverses

Summary

- Can Access Stratigraphy in Gale Mound?
  - Yes
  - Number of paths higher in section
- Can Access Science Targets at Eberswalde?
  - Yes
- Can Access Science Targets at Holden?
  - Yes – but don't drive in canyon
- Are there Large Untraversable Areas in Ellipses?
  - Especially Mawrth – Targets in Ellipse – No
  - Eberswalde - Areas with High Slopes and Rocks difficult driving