# General Assessment of Safety of Prospective MSL Landing Sites

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Second MSL Landing Site Workshop

Pasadena, CA

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# Introduction

- Provide First Order Evaluation of Landing Ellipse Safety
- Establish Tools for Landing Site Evaluation
- Incorporate Data Sets
- Fill Out Fever Chart for Safety for 2nd Workshop
- Use in Evaluation and Downselection of Sites

**LANDING SITES FROM 1st MSL WORKSHOP DISCUSSED AT 2ND WORKSHOP**

| NAME | LOCATION | ELEVATION | TARGET | PROPOSER |
|---|---|---|---|---|
| Nili Fossae Trough | 20.93ºN, 74.35ºE | -0.6 km | Phyllosilicates | J. Mustard |
| Holden Crater Fan | 26.32ºS, 325.30ºE | -2.3 km | Layered Materials | Irwin, Grant, Malin, Edgett, Rice |
| Terby Crater | 27.7435°S, 74.1137°E | -5 km | Layered Material | S. Wilson, Cohen, Dobrea |
| Marwth Vallis | 24.65ºN, 340.1ºE | ~-3.1 km | Phyllosilicates | J-P Bibring, J. Michalski |
| Eberswalde Crater | 23.85°S, 326.75°E | -1.4 km | Delta | J. Schieber, J. Dickson, J. Rice |
| Gale Crater | 4.50°S, 137.35°E | -4.5 km | Interior Layered Deposits | J. Bell, N. Bridges |
| W Candor | 5.80°S, 284.17°E | 1.8 km | Sulfate Deposits | N. Mangold |
| N Meridiani | 2.37°N, 6.69°E | -1.5 km | Sedimentary Layers | Edgett/Malin |
| Juventae Chasma | 4.45°S, 298.09°E | -2.8 km | Layered Sulfates | J. Grotzinger |
| Nilo Syrtis | 29.16°N, 72.97°E | ~-0.5 | Phyllosilicates | J. Mustard |
| Melas Chasma | 9.81°S, 283.62°E | -1.9 km | Paleolake | C. Quantin |
| | | | | |
| E. Meridiani | 0.01N°, 3.66°E | ~-1.3 km | Sedimentary Layers | B. Hynek |
| Iani Chaos | 2.06°S , 342.41°E | Below -2 km | Hematite, Sulfate | T. Glotch |
| Nili Fossae Crater | 18.44ºN, 77.58ºE | -2.6 km | Valley Networks, Delta sediments | R. Harvey, J. Rice |
| Eos Chasma | 10.7°S, 322.05°E | ~-4 km | Chert | V. Hamilton |
| Meridiani Crater Lake | 5.72°N, 358.03°E | ~-1.5 km | Crater lake sediments | L. Posiolova |
| NE Syrtis Major | ~16.21°N, ~76.63°E | ~1 km | Volcanics | R. Harvey |
| Hellas/Dao Vallis | 39.5ºS, 82,7ºE | -6 km | Valley Terminus, Layered Deposits | L. Crumpler |
| Xanthe/Hypanis Vallis | 11.4ºN, 314.65ºE | -2.6 km | Layered Deposits | L. Crumpler |
| | | | | |
| SW Arabia Terra | 6.01°N, 355.60°E | -1 km | Sed. Rocks, Methane | C. Allen |
| W. Arabia Crater | 8.45°N, 359.09°E | -1.2 km | Sedimentary Rocks | E. Heydari |
| W. Meridiani | 1.7°S, 352.39°E | ~-1.0 to -1.5 km | Sediments, Hematite | H. Newsom |
| Elysium/Avernus Colles | 3.05ºS, 170.60ºE | -2.5 km | High iron abundance | L. Crumpler |
| Isidis Basin Escarp | 18.00ºN, 79.60ºE | –3.5 km | Volatile sink | L. Crumpler |
| Additional Sites Proposed After 1st Workshop | | | | |
| Samara Vallis | 23.55°S, 339.75°E | -1 km | Valley network channel | R. Kuzmin |
| Eos Alluvial | 13.6°S, 317.5°E | -3.5 km | Alluvial fan | R. Kuzmin |
| Aeolis fan delta | 5.05°S, 132.85°E | -2.2 km | Fan, delta | R. Kuzmin |
| | | | | |

# MSL Landing Sites to Be Discussed at the Second Landing Site Workshop, v. 4

## Landing Sites from 1st Workshop
## 27 Sites

## Dropped 9 Sites
Athabasca
Margaritifer basin
E Melas
Becquerel
Wirtz/Gullies
Argyre
NW Slope Valleys
Meridiani Bench
SML Craters

# MSL Landing Sites to Be Discussed at the Second Landing Site Workshop, v. 4

## Landing Sites before 2nd Workshop 24 Sites

**LANDING SITES ADDED BEFORE 2nd MSL WORKSHOP**

| Name | Location | Elevation (m) | Target | Proposer |
|---|---|---|---|---|
| Ariadnes Colles | 35.03 S, 174.17 E | -71 | Clay-bearing outcrops | E. Noe Dobrea |
| Ritchey Crater | 28.28 S, 308.93 E | -1178 | Clays, fan deposit | R. Milliken |
| Mawrth Vallis B1 | 24.5 N, 338.9 E | -3076 | layered clays | J-P. Bibring |
| Mawrth Vallis B2 | 23.95 N, 341.2 E | -2220 | layered clays | Bibring |
| Mawrth Vallis B3 | 23.2 N, 342.5 | -2104 | layered clays | Bibring |
| Nili Fossae | 21.8 N, 78.6 E | -1158 | Clays, mafics | Mangold |
| Terby alternate | 27.4 S, 73.5 E | -4509 | clays, possible paleolacustrine | E. Noe Dobrea, S. Wilson |
| Nili Fossae trough alternate | 21.73 N, 74.73 E | -695 | clays, mafics | Mustard, Elhman |
| S. Meridiani Clays | 3.35 S, 352.64 E | -1948 | clays, sulfates | Wiseman, Arvidson |
| W. Meridiani Alt | 3.01 S, 352.1 E | -1881 | clays, sultfates | Ollila, Newsome |
| Chloride site 1 | 11.4 S, 343.4 E | -1473 | chloride salts | Christensen |
| Chloride site 2 | 31.5 S, 180.8 E | 373 | chloride salts | Christensen |
| Chloride site 3 | 27.9 S, 339.1 E | -44 | chloride salts | Christensen |
| Chloride site 4 | 25.4 S, 346.6 E | -41 | chloride salts | Christensen |
| Chloride site 5 | 34.36 S, 177.76 E | 900 | chloride salts | Christensen |
| W. Candor Chasma alternate | 5.75 S, 285.19 E | -1517 | sulfates | Murchie |
| Tiu Valles | 22.9N, 32.25W | ~<-3000 | Chemolithotrophic habitat | F. Gomez |
| Gale alternate | 5.66 S, 137.53 E | -3385 | Interior Layered Deposits | N. Bridges, B. Thomson |
| Juventae alternate | 4.88 S, 297.01 E | -2600 | Layered sulfates | J. Bishop |
| Meridiani B1 | 3.84 N, 359.04 E | -2208 | | Bibring |
| Meridiani B2 | 1.60 N, 3.55 E | -1381 | | Bibring |
| Meridiani B3 | 3.19 S, 352.20 E | -1841 | Same as S, Meridiani Clays | Bibring |
| Meridiani B4 | 5.0 S, 354.52 E | -1180 | | Bibring |
| N. Meridiani Alternate | 1.5 N, 357.4 E | -1286 | Sedimentary Layers | Malin, Edgett |

# Summary MSL Landing Site Criteria

**Major Questions/ Criteria:**

**Landing Sites:**

| ***Science Criteria*** | ***Nili Fos*** | ***Hol den*** | ***Ter by*** | ***Maw rth*** | ***Gale*** | ***Ebers walde*** | ***W. Cand*** | ***N. Merid*** | ***Juven*** | ***Nilo Syrt*** | ***Mel as*** | ***E. Merid*** | ***Iani*** | ***Nili Crat*** | ***Eos*** | ***Merid Crat*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

Ability to Assess Biological
Potential w/MSL Payload
Evidence for Habitable
Environment (Environment of Formation and Deposition)
Aqueous Environment, Type of Habitable Environment
Preservation of Bio-
Signatures
Organic Material, (Pre) Biotic Materials,
Biologic Textures, Mineralogic Biosignatures

At Workshop

Ability to Characterize
Geology/Geochemistry
Context within Geologic
Timescale
Context within Geologic/
Geomorphic/
Stratigraphic Setting

At Workshop

Accessibility
Accessed by Rover/Arm
Go To
Distance/trafficability
to Materials of Interest
<1 km. <5 km, >10 km

Distance from Center of Ellipse to Material of Interest

Dust Obscuration

Albedo, Dust Cover Index

Reduced Performance
Thermal Constraints

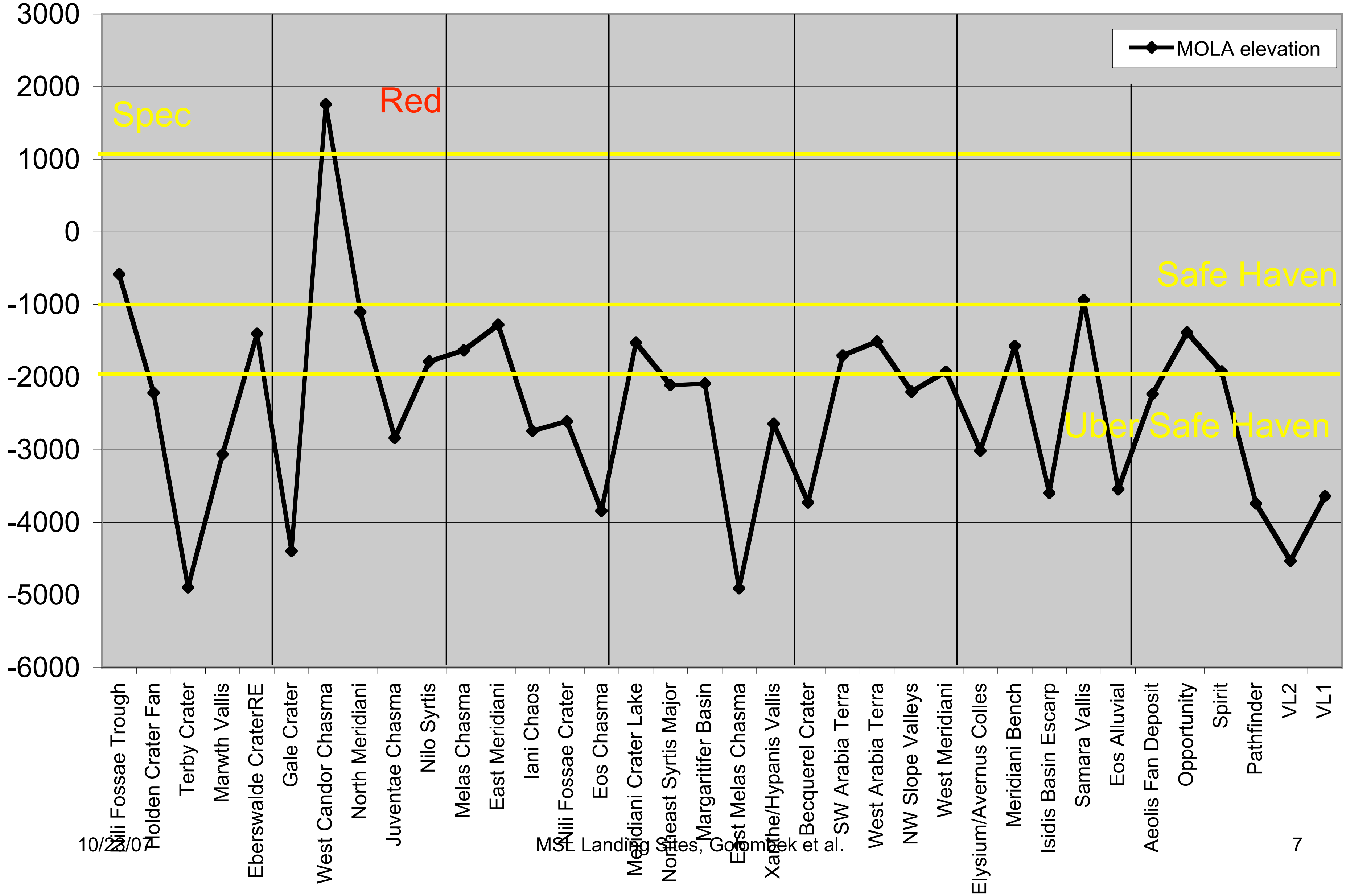
Mostly Latitude, Atmosphere, A. Vasavada

**<u>Major Questions/ Criteria:</u>**

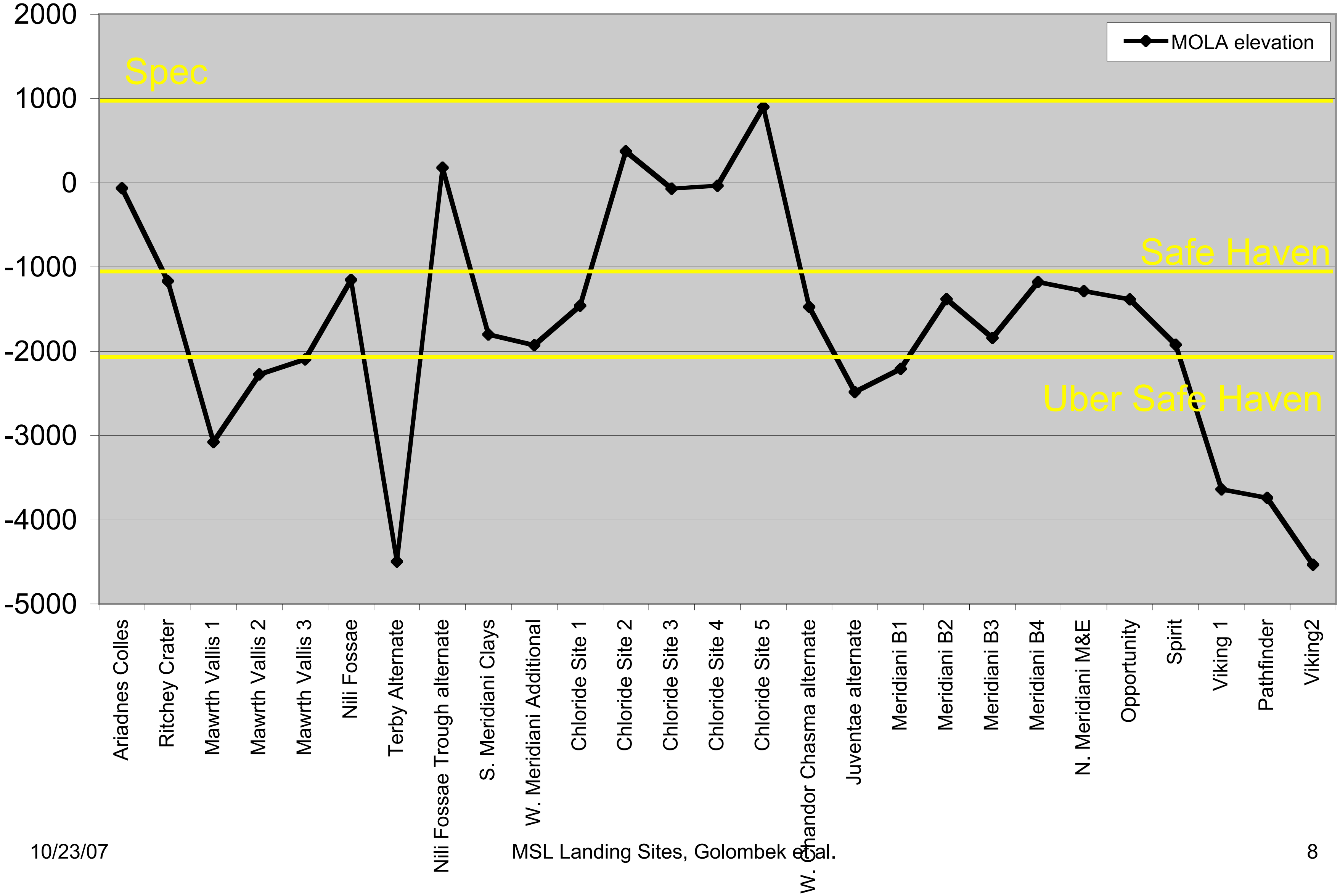
**<u>Landing Sites:</u>**

| ***Safety Criteria*** | ***Nili Fos*** | ***Hol den*** | ***Ter by*** | ***Maw rth*** | ***Gale*** | ***Ebers walde*** | ***W. Cand*** | ***N. Merid*** | ***Juven*** | ***Nilo Syrt*** | ***Mel as*** | ***E. Merid*** | ***Iani*** | ***Nili Crat*** | ***Eos*** | ***Merid Crat*** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surface Slope/Relief | | | | | | | | | | | | | | | | |
| 2-10 km Slope | MOLA | | | | | | | | | | | | | | | |
| 1-2 km Slope | | | | | | | | | | | | | | | | |
| 200-1000 m Slope | | | | | | | | | | | | | | | | |
| 2-5 m Slope | HiRISE; HiRISE Photoclinometry [Beyer]; If no HiRISE - Relief in MOC | | | | | | | | | | | | | | | |
| Relief in HiRISE | | | | | | | | | | | | | | | | |
| Warning Track Slope | MOLA | | | | | | | | | | | | | | | |
| 2-10 km Slope | | | | | | | | | | | | | | | | |
| Flexibility Ellipse Placement | MOLA | | | | | | | | | | | | | | | |
| Safe Haven? (non go to) | MOLA | | | | | | | | | | | | | | | |
| Rock Abundance | | | | | | | | | | | | | | | | |
| IRTM | IRTM, TES Thermal Differencing | | | | | | | | | | | | | | | |
| TES | | | | | | | | | | | | | | | | |
| Rocks Present in HiRISE | Rocks in HiRISE | | | | | | | | | | | | | | | |
| Load Bearing Surface | Thermal Inertia, Albedo Surfaces for Mars | | | | | | | | | | | | | | | |
| Dust (DCI, Albedo) | Albedo, Dust Cover Index, Thermal Inertia | | | | | | | | | | | | | | | |
| Cold Temperatures | Atmosphere, thermal inertia & albedo, A. Vasavada | | | | | | | | | | | | | | | |
| Trafficability | | | | | | | | | | | | | | | | |
| Atmospherically Challenging Site | Atmosphere Council, A. Vasavada | | | | | | | | | | | | | | | |

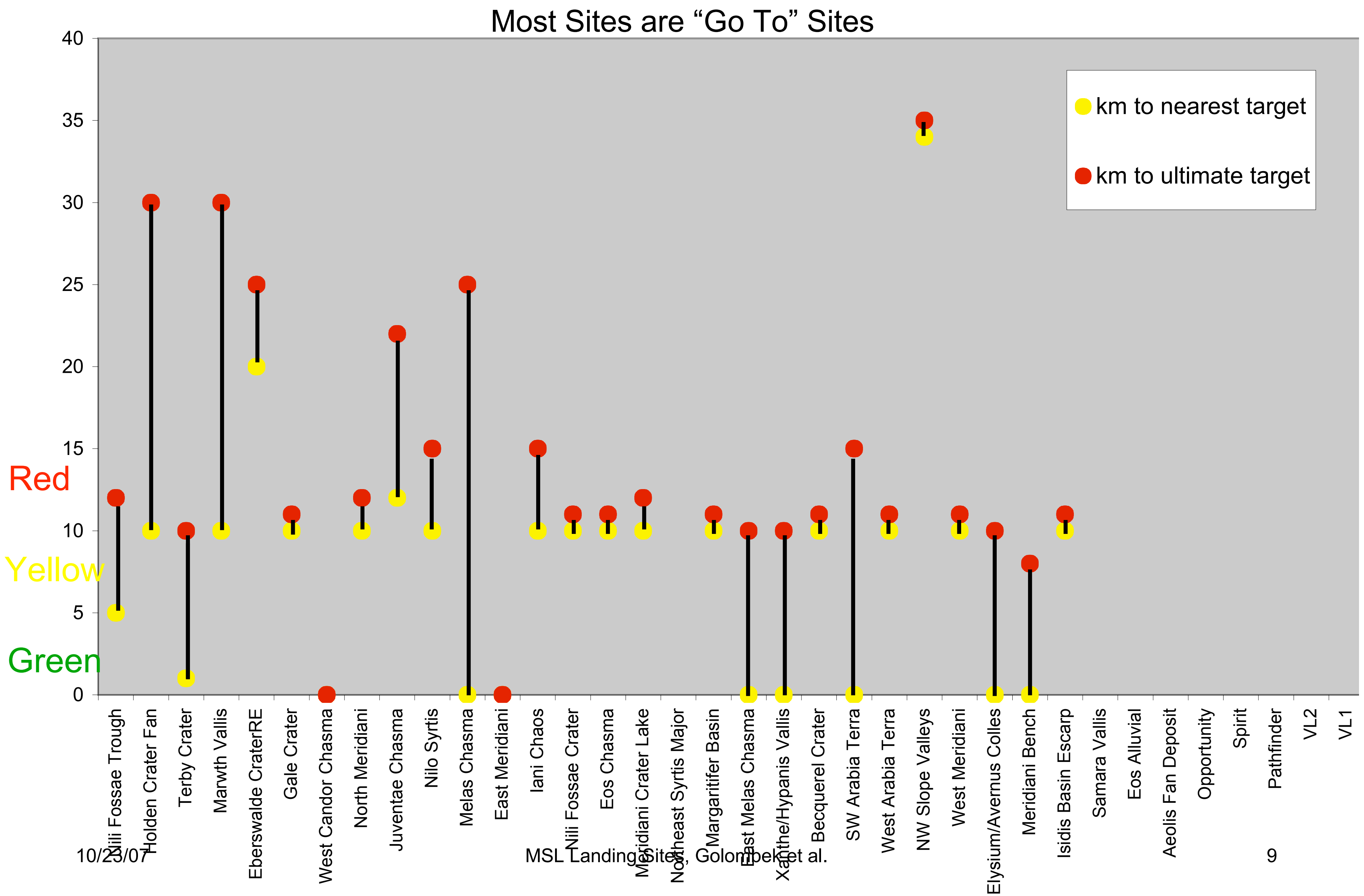
# Average elevation of ellipses



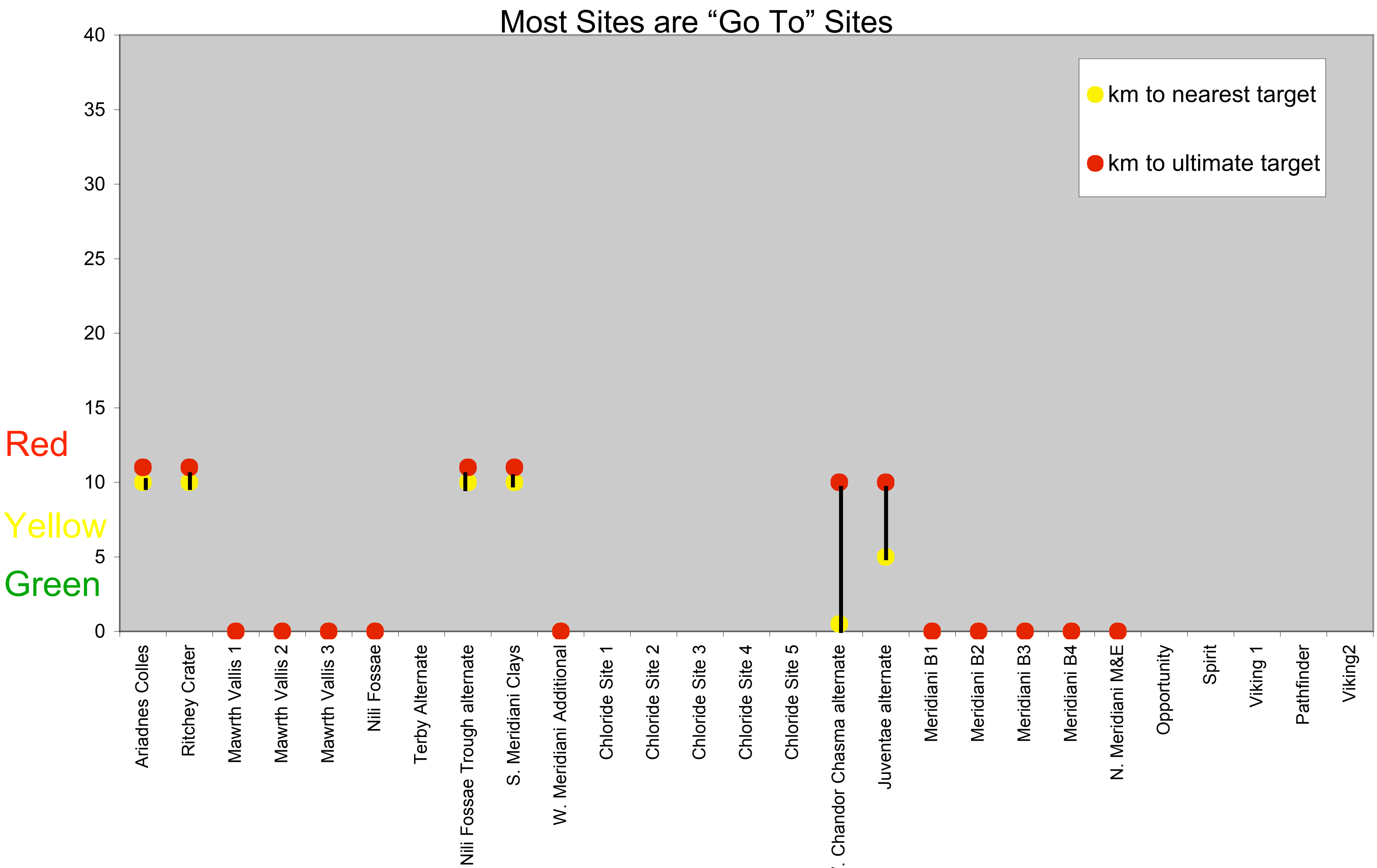
# Average MOLA elevation in ellipse

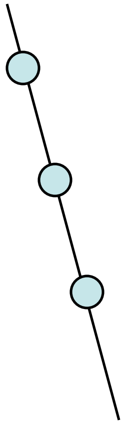


# Distance to Materials of Interest



# Distance to Materials of Interest





Orbit Track

300 m Shot Spacing

Spot Size 75 m

Average Elevation of Spot

Footprint Slope & RMS Roughness of Spot

# MOLA Data

## Individual Data Along Track

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

Technique from Anderson et al. [2003]

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

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

## Binned Data 463 m/pixel

In GIS System - Easily Modified for Quick Evaluation

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

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

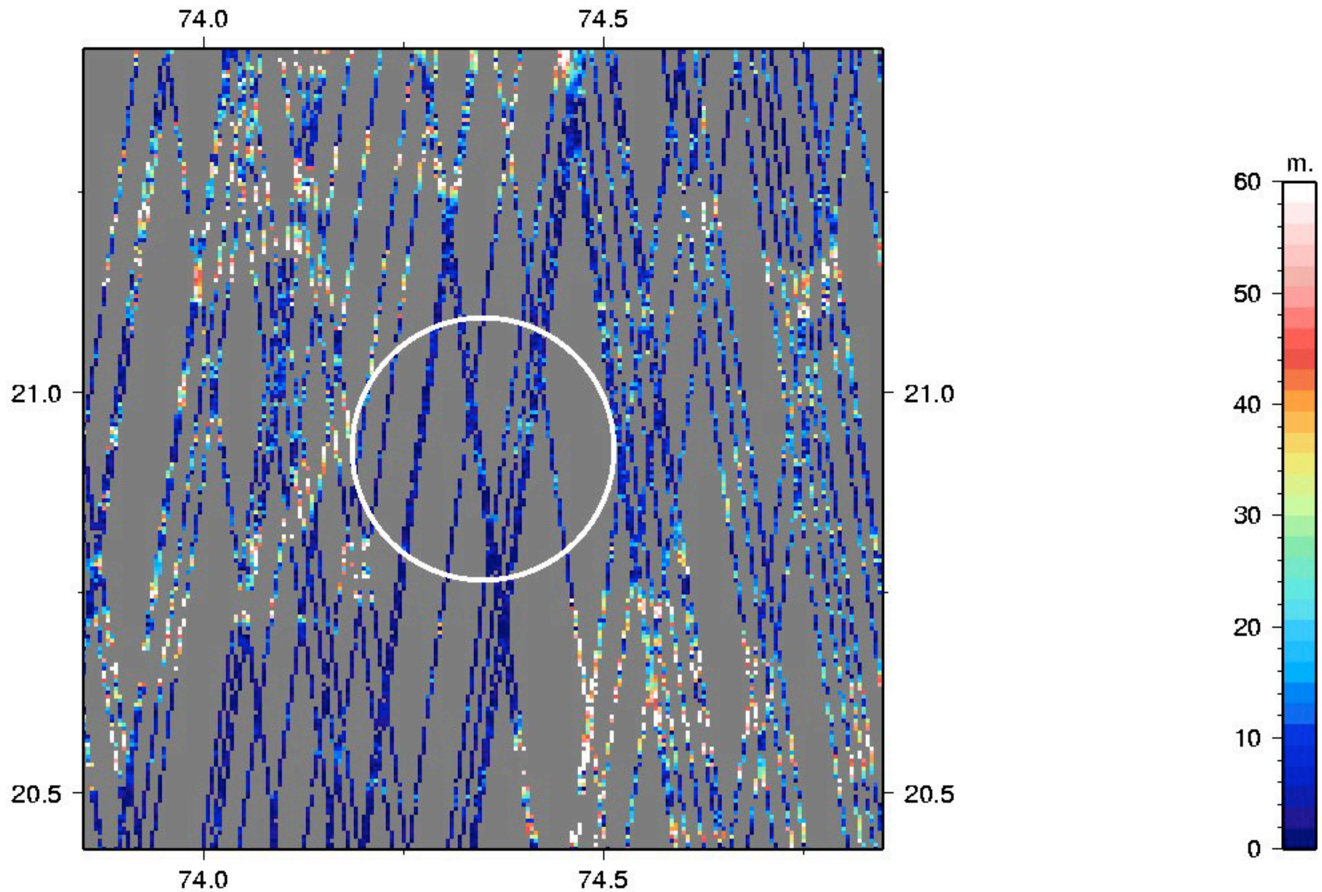
c) 2 km <20° over 25 km Circle and 35 km Circle (warning track)

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

Safe Haven Used a and b over 35 km Circle

# Nili Fossae: 300 m relief

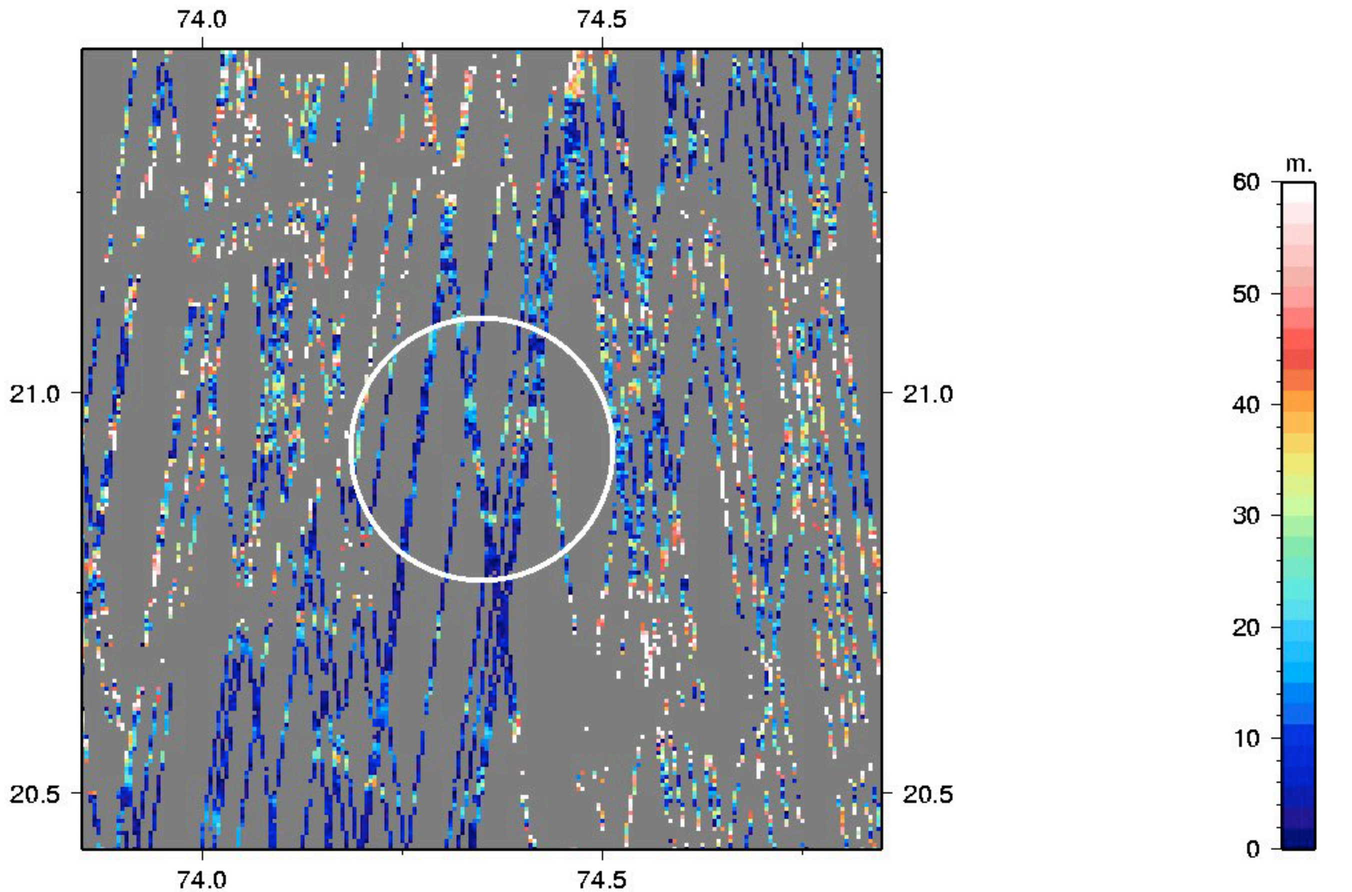
bidirectional



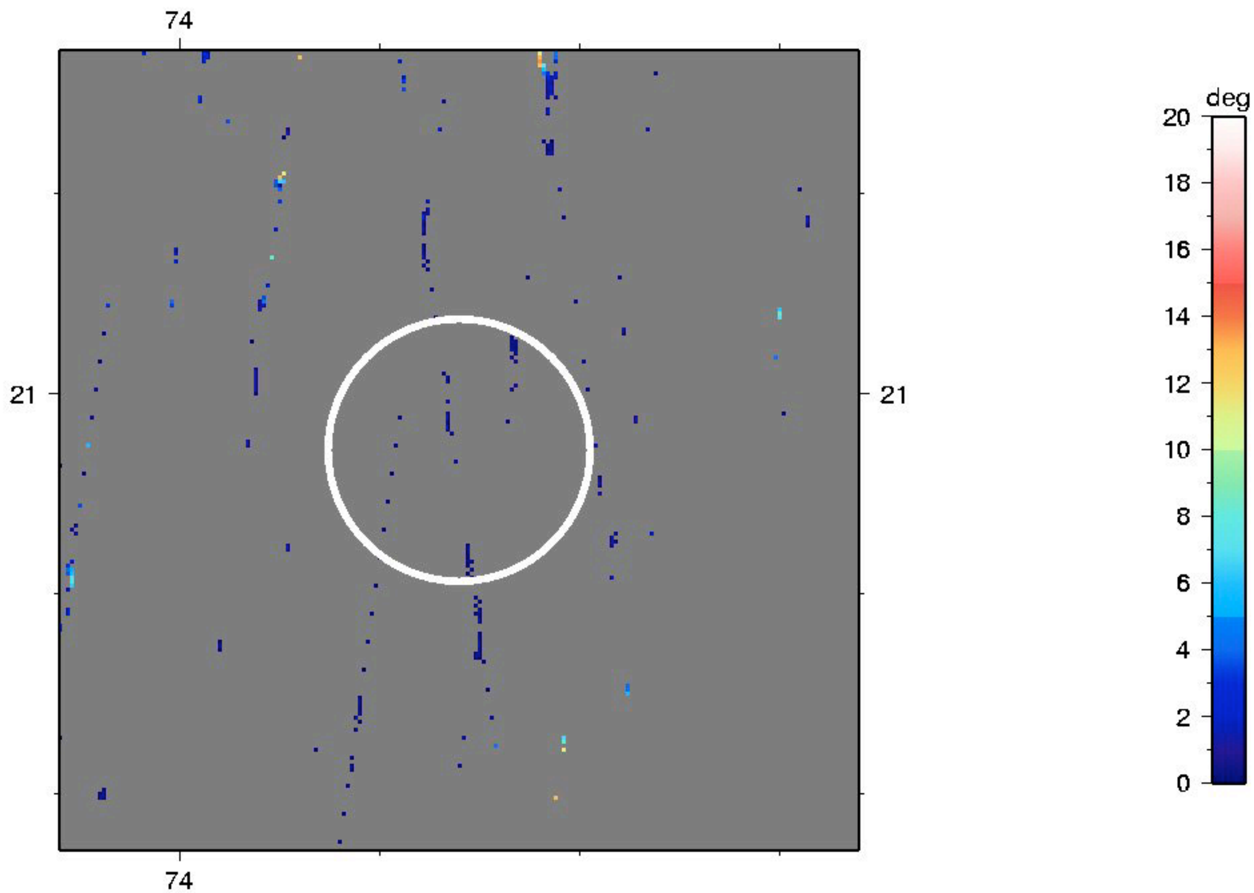

20 km
Circle

# Nili Fossae: 900 m relief

bidirectional

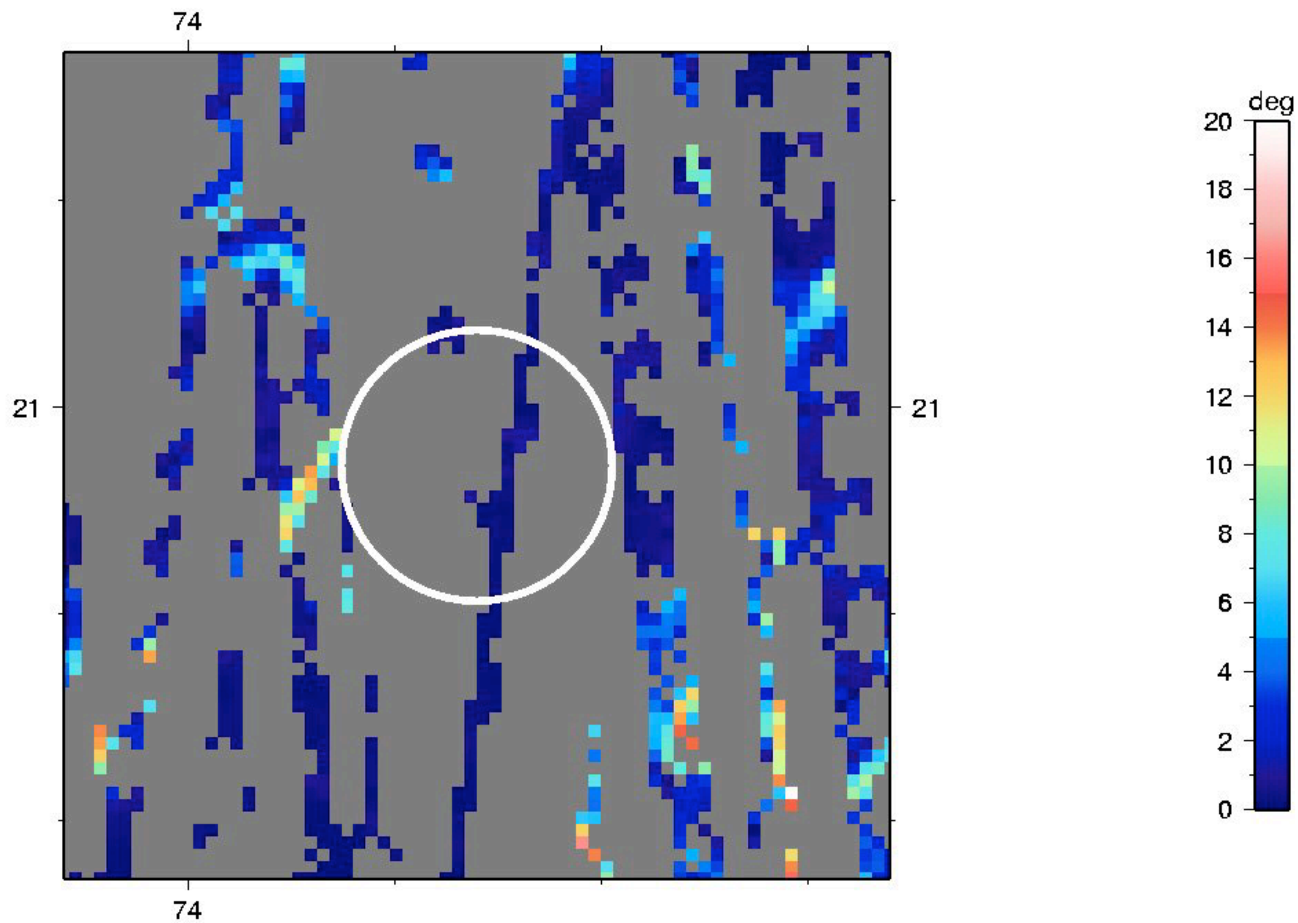


# Nili Fossae: 300 m
## adirectional slope
## only if adjacent area has MOLA shot

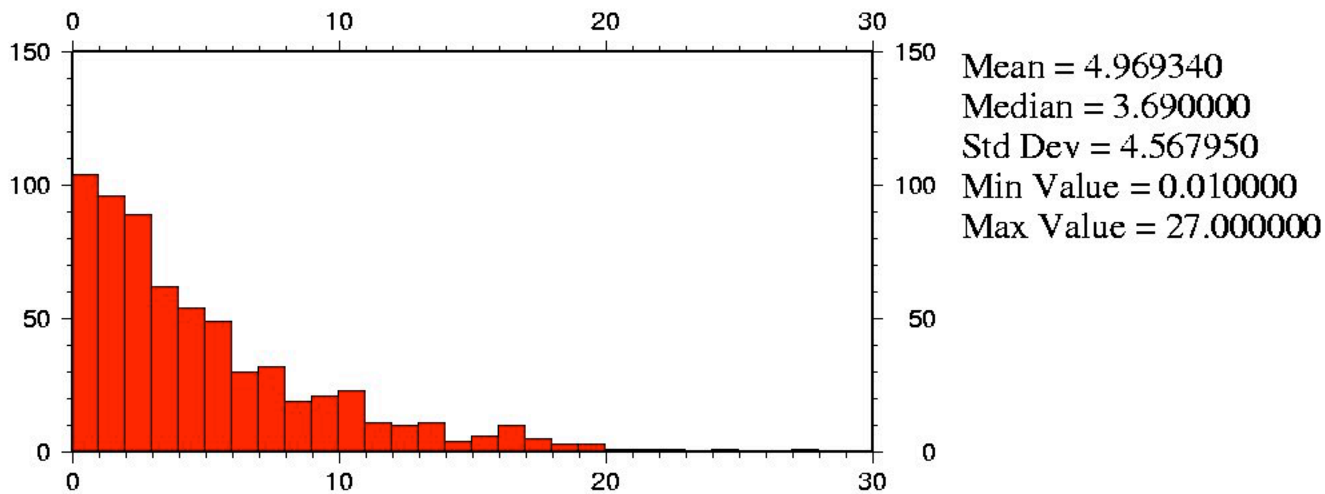


# Nili Fossae: 900 m adirectional slope

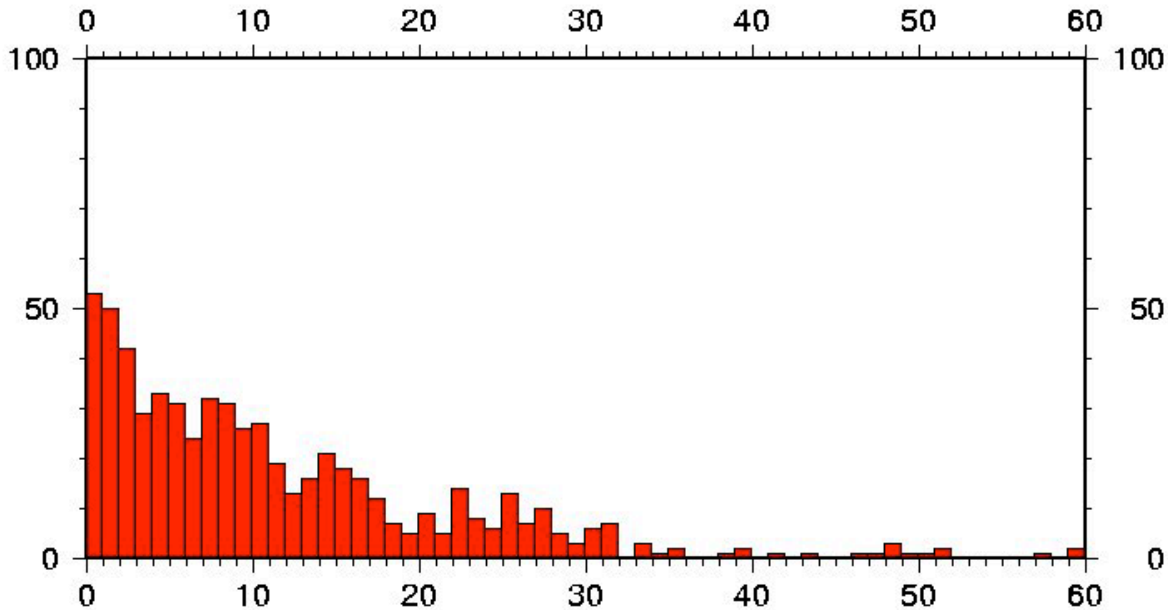
## only if adjacent area has MOLA shot



# Nili Fossae: 300 m relief

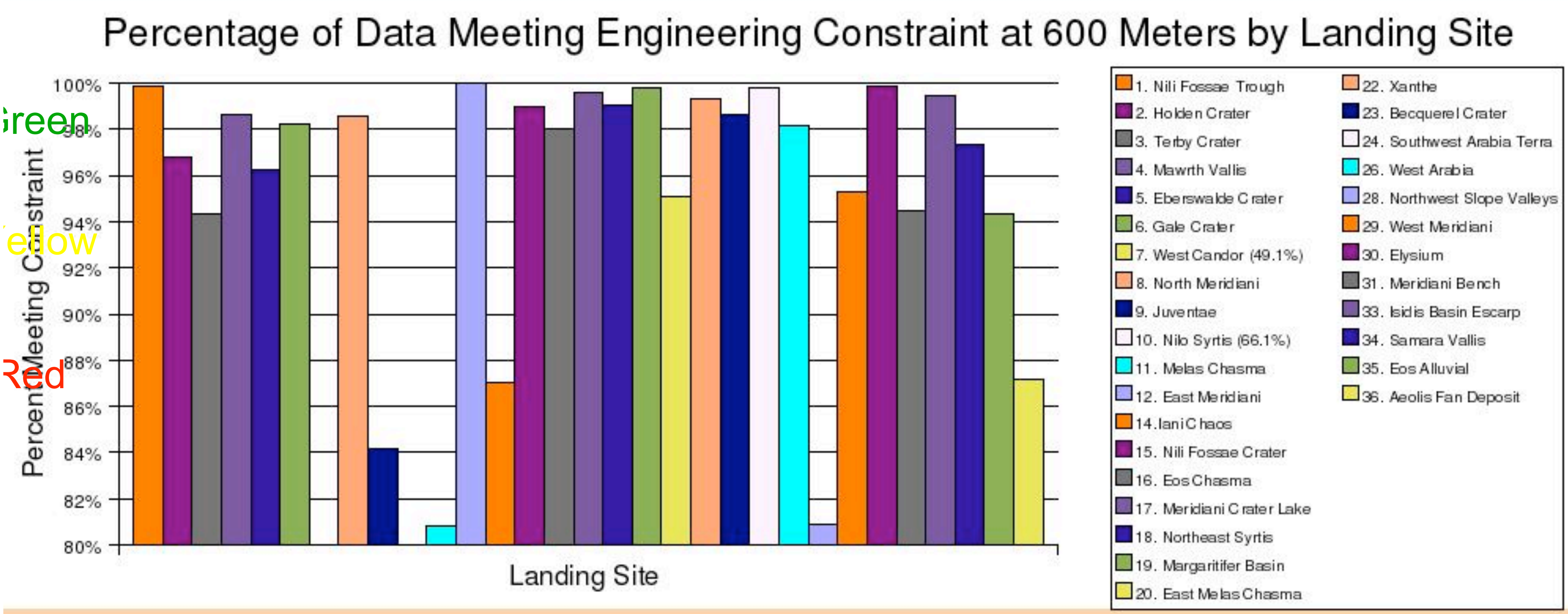


# Nili Fossae: 900 m relief



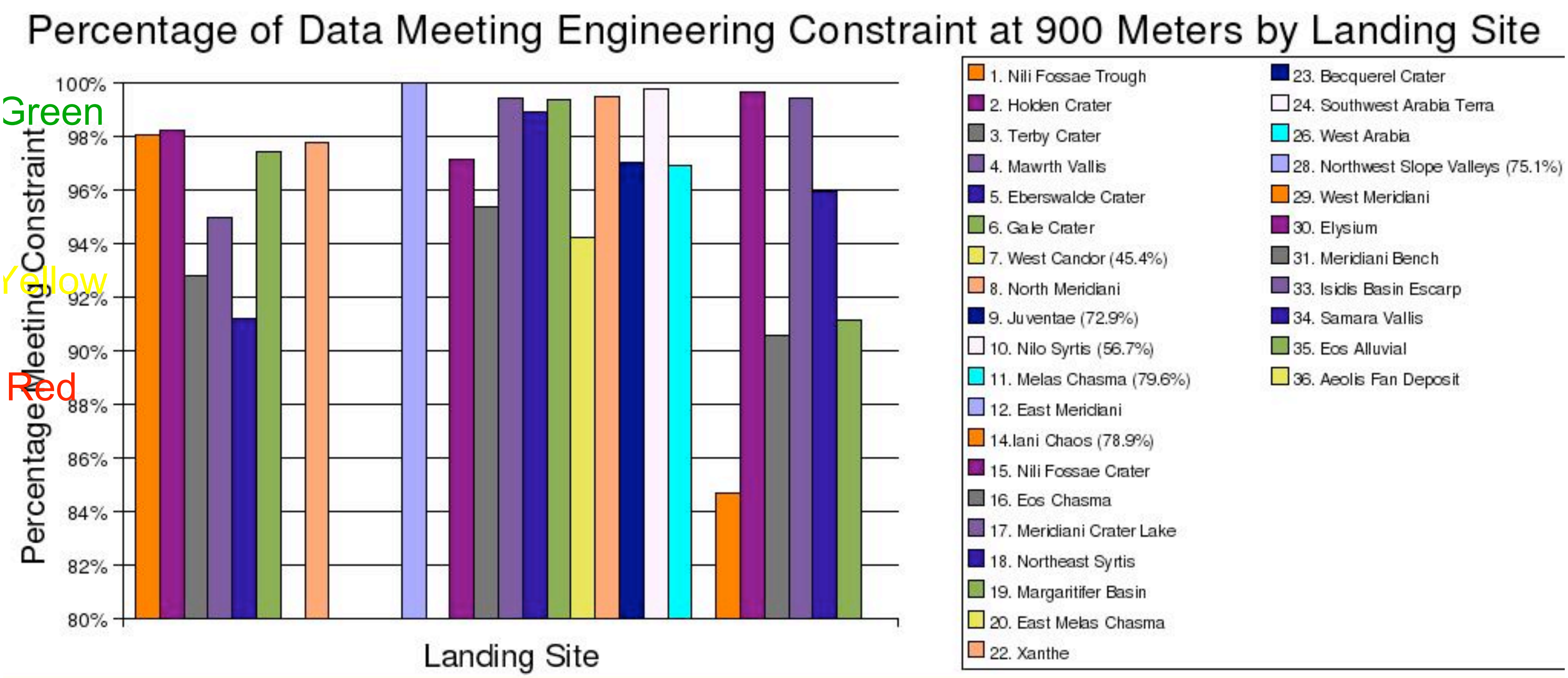

Mean = 11.401800
Median = 8.305000
StdDev = 10.545000
Min Value = 0.030000
Max Value = 59.560000

# 600 meters

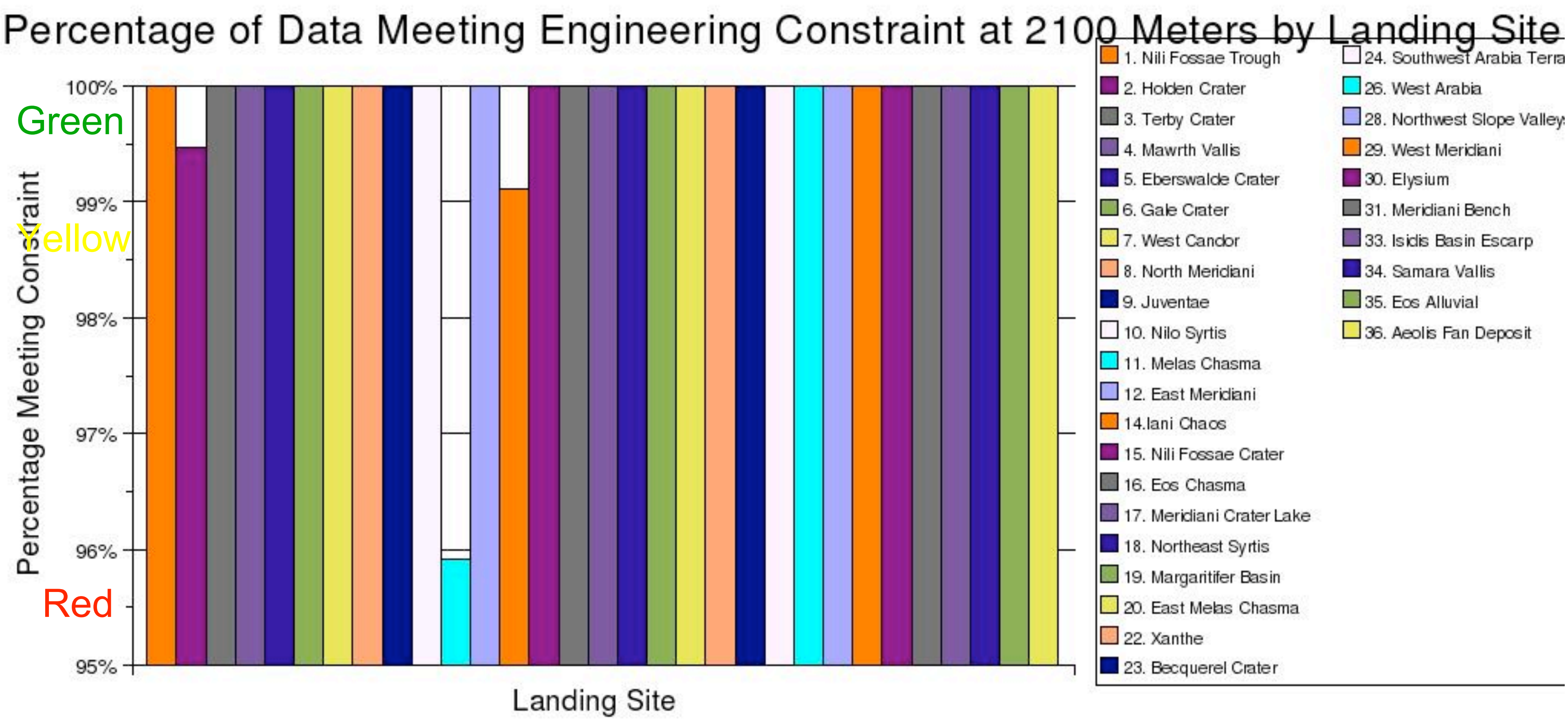


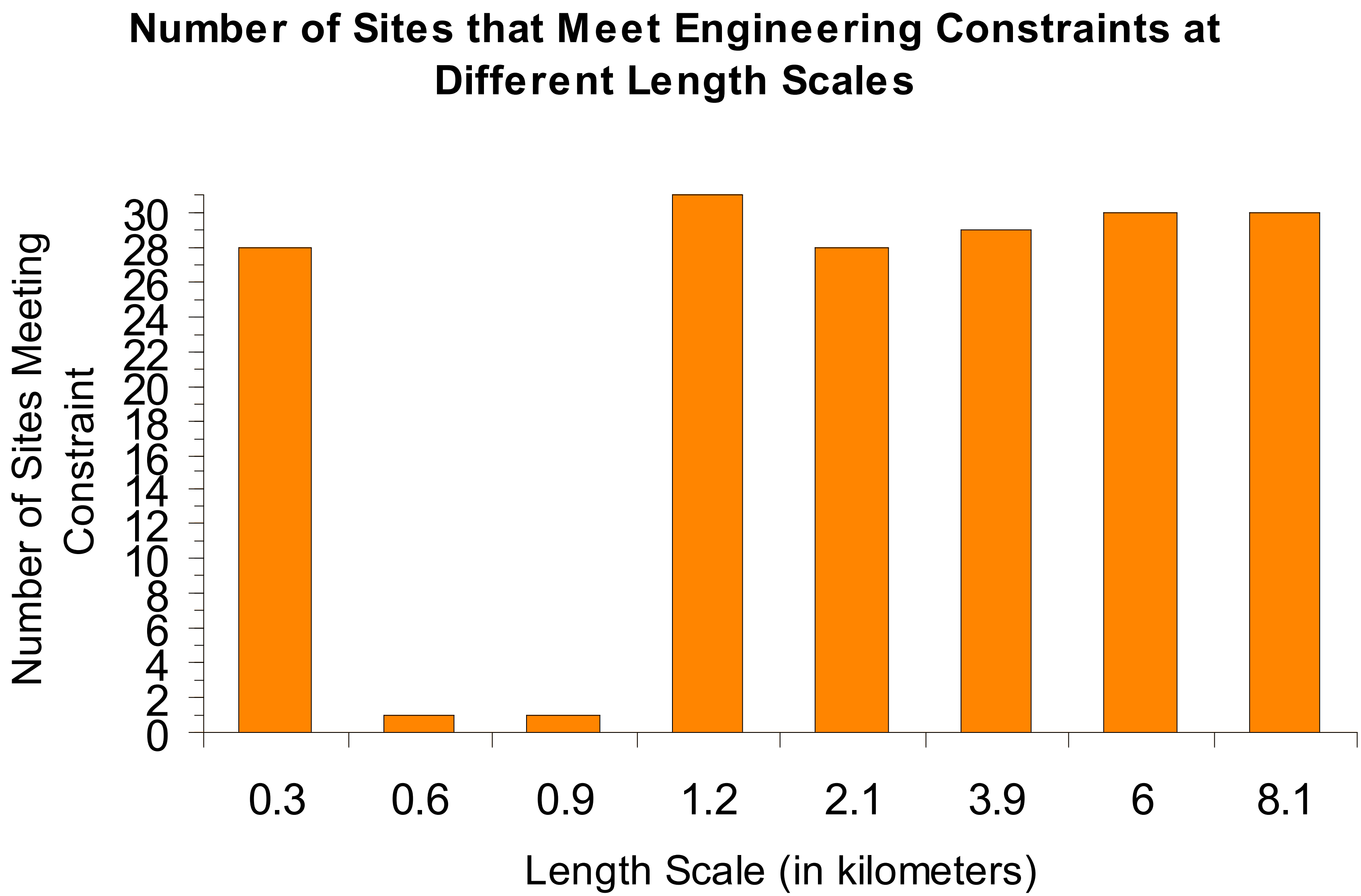
Percentage of Data Meeting Engineering Constraint at 600 Meters by Landing Site
Percent Meeting Constraint
Green
Yellow
Red
100%
98%
96%
94%
92%
90%
88%
86%
84%
82%
80%
Landing Site
1. Nili Fossae Trough
2. Holden Crater
3. Terby Crater
4. Mawrth Vallis
5. Eberswalde Crater
6. Gale Crater
7. West Candor (49.1%)
8. North Meridiani
9. Juventae
10. Nilo Syrtis (66.1%)
11. Melas Chasma
12. East Meridiani
14. Iani Chaos
15. Nili Fossae Crater
16. Eos Chasma
17. Meridiani Crater Lake
18. Northeast Syrtis
19. Margaritifer Basin
20. East Melas Chasma
22. Xanthe
23. Becquerel Crater
24. Southwest Arabia Terra
26. West Arabia
28. Northwest Slope Valleys
29. West Meridiani
30. Elysium
31. Meridiani Bench
33. Isidis Basin Escarp
34. Samara Vallis
35. Eos Alluvial
36. Aeolis Fan Deposit

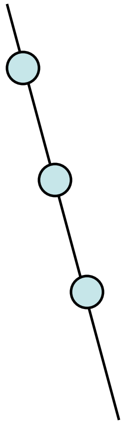
# 900 meters


Percentage of Data Meeting Engineering Constraint at 900 Meters by Landing Site
Green
Yellow
Red
Percentage Meeting Constraint
100%
98%
96%
94%
92%
90%
88%
86%
84%
82%
80%
Landing Site
1. Nili Fossae Trough
2. Holden Crater
3. Terby Crater
4. Mawrth Vallis
5. Eberswalde Crater
6. Gale Crater
7. West Candor (45.4%)
8. North Meridiani
9. Juventae (72.9%)
10. Nilo Syrtis (56.7%)
11. Melas Chasma (79.6%)
12. East Meridiani
14.Iani Chaos (78.9%)
15. Nili Fossae Crater
16. Eos Chasma
17. Meridiani Crater Lake
18. Northeast Syrtis
19. Margaritifer Basin
20. East Melas Chasma
22. Xanthe
23. Becquerel Crater
24. Southwest Arabia Terra
26. West Arabia
28. Northwest Slope Valleys (75.1%)
29. West Meridiani
30. Elysium
31. Meridiani Bench
33. Isidis Basin Escarp
34. Samara Vallis
35. Eos Alluvial
36. Aeolis Fan Deposit

# 2100 meters


Percentage of Data Meeting Engineering Constraint at 2100 Meters by Landing Site
100%
99%
98%
97%
96%
95%
Green
Yellow
Red
Percentage Meeting Constraint
Landing Site
1. Nili Fossae Trough
2. Holden Crater
3. Terby Crater
4. Mawrth Vallis
5. Eberswalde Crater
6. Gale Crater
7. West Candor
8. North Meridiani
9. Juventae
10. Nilo Syrtis
11. Melas Chasma
12. East Meridiani
14.Iani Chaos
15. Nili Fossae Crater
16. Eos Chasma
17. Meridiani Crater Lake
18. Northeast Syrtis
19. Margaritifer Basin
20. East Melas Chasma
22. Xanthe
23. Becquerel Crater
24. Southwest Arabia Terra
26. West Arabia
28. Northwest Slope Valley
29. West Meridiani
30. Elysium
31. Meridiani Bench
33. Isidis Basin Escarp
34. Samara Vallis
35. Eos Alluvial
36. Aeolis Fan Deposit


Number of Sites that Meet Engineering Constraints at Different Length Scales
Number of Sites Meeting Constraint
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
0.3
0.6
0.9
1.2
2.1
3.9
6
8.1
Length Scale (in kilometers)



Orbit Track

300 m Shot Spacing

Spot Size 75 m

Average Elevation of Spot

Footprint Slope & RMS Roughness of Spot

# MOLA Data

## Individual Data Along Track

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

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

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

## Binned Data 463 m/pixel

In GIS System - Easily Modified for Quick Evaluation

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

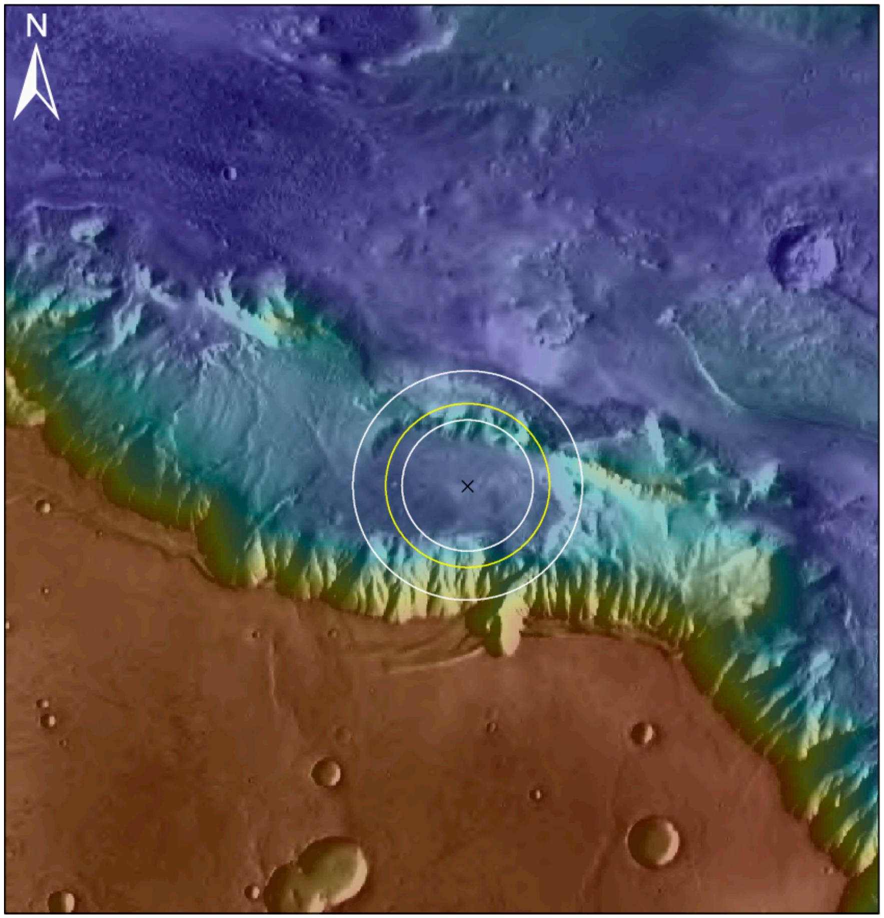
b) 1389 m Slope <12.56° over 25 km Circle, equivalent to 200-1000 m constraint

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

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

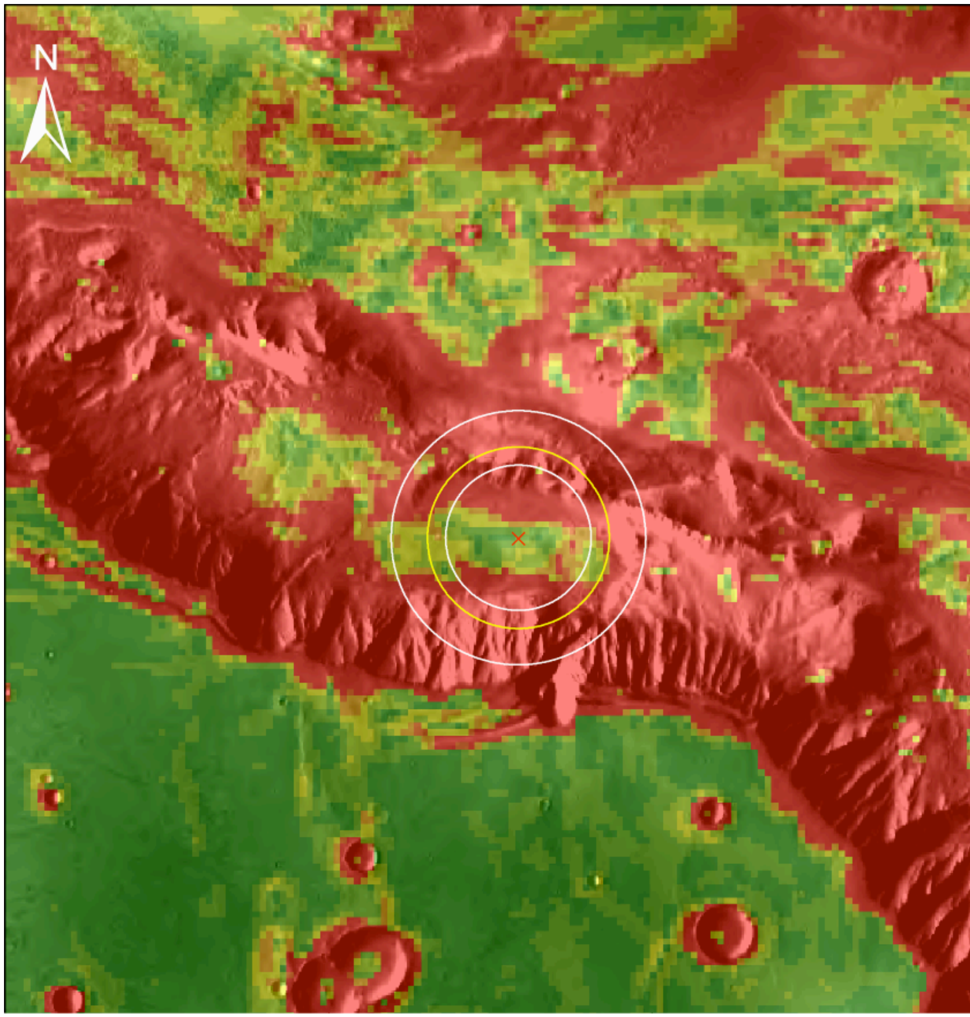
Safe Haven Used a and b over 35 km Circle

# Melas MOLA topography




Binned MOLA Data
463 m/pixel
-Includes Pixels with Interpolated Data
20, 25, 35 km Circles

# Melas Chasma: 926 m slope



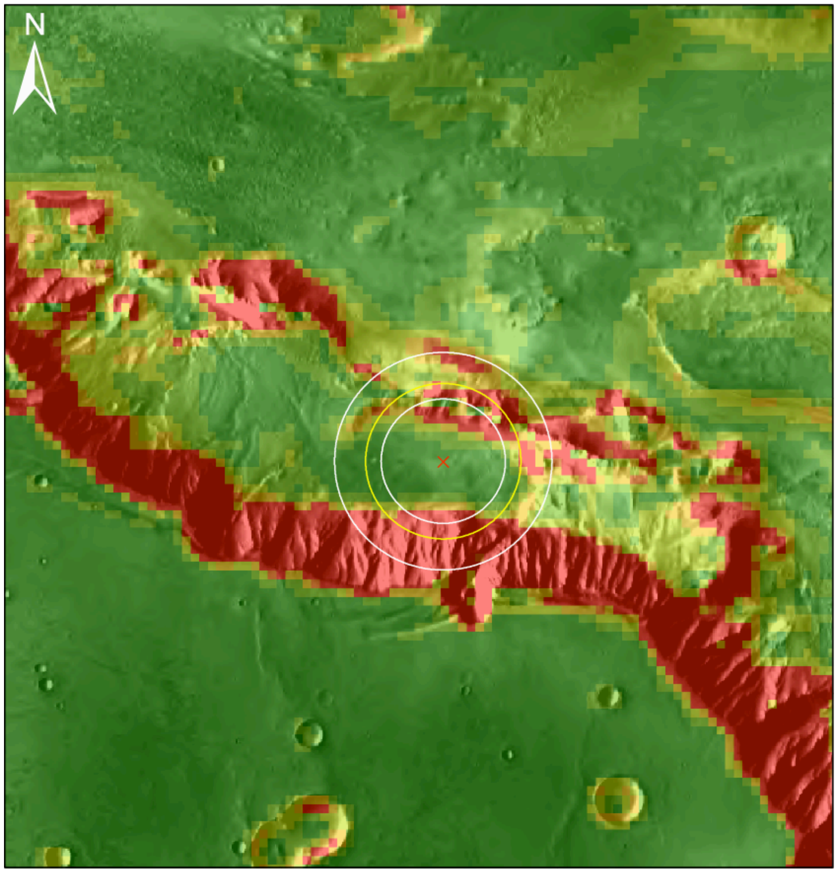

Slope btw 2 MOLA Binned
463 m/pixels
-Each Pixels Average of Data

20, 25, 35 km Circles

2.66° Over 926 m is 43 m

Example of Red - Much of Ellipse Fails Criterion

# Melas Chasma: 1389 m slopes



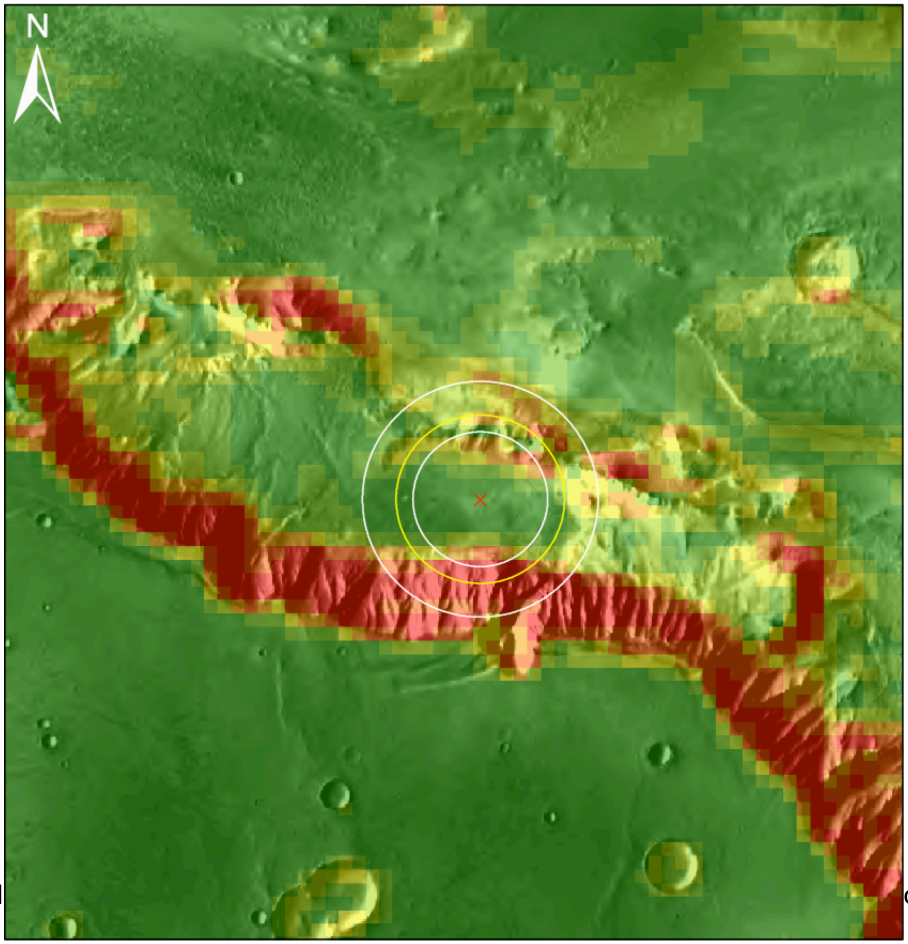

Slope btw 3 MOLA Binned 463 m/pixels
-Each Pixels Average of Data

20, 25, 35 km Circles

1389 m Slope <12.56° is the 1-2 km Relief Criterion at this length scale
-Linear fit of 43 m at 1 km to 720 m at 2 km

Example of Red - Signficant Portions of Ellipse Fails Criterion

# Melas Chasma 2 km slope



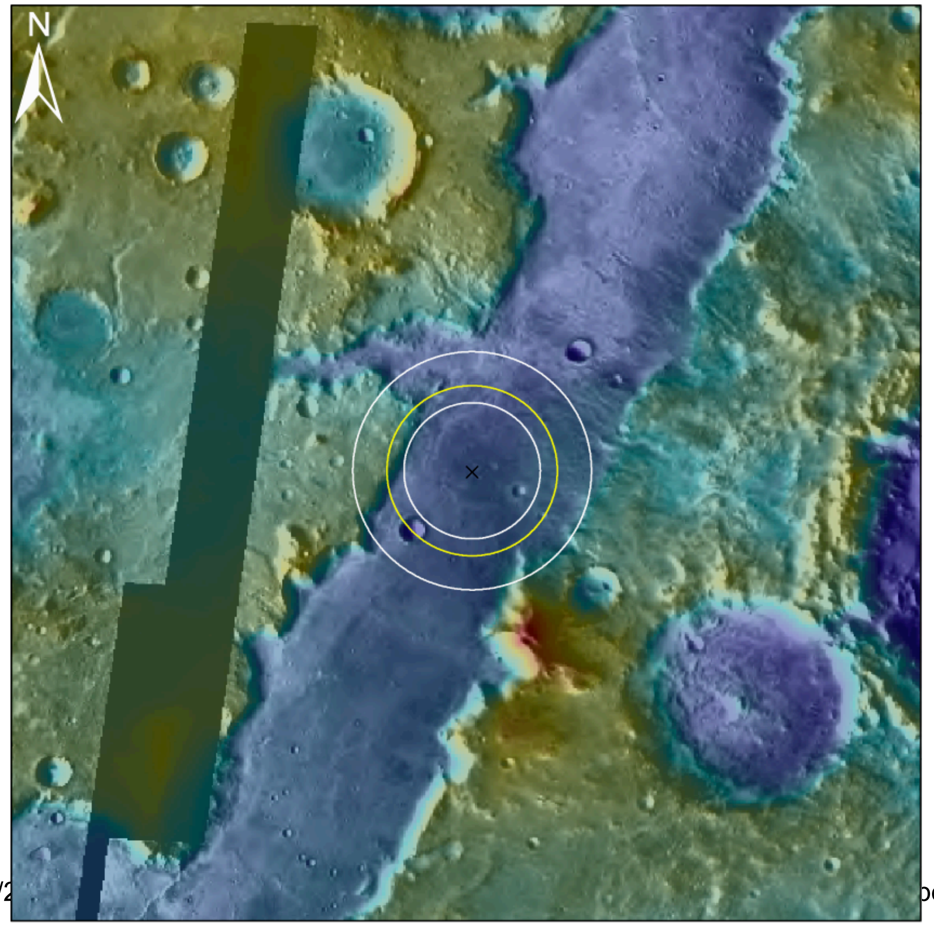

Slope btw 4 MOLA Binned
463 m/pixels
-Each Pixels Average of Data

20, 25, 35 km Circles

2 km Slope <20° is the 2-10 km Relief Criterion at this length scale (most stringent of 2-10 km slope criteria)

Example of Red - Portions of Ellipse and Much of Warning Track Fails Criterion

# Nili Fossae Trough: MOLA topography

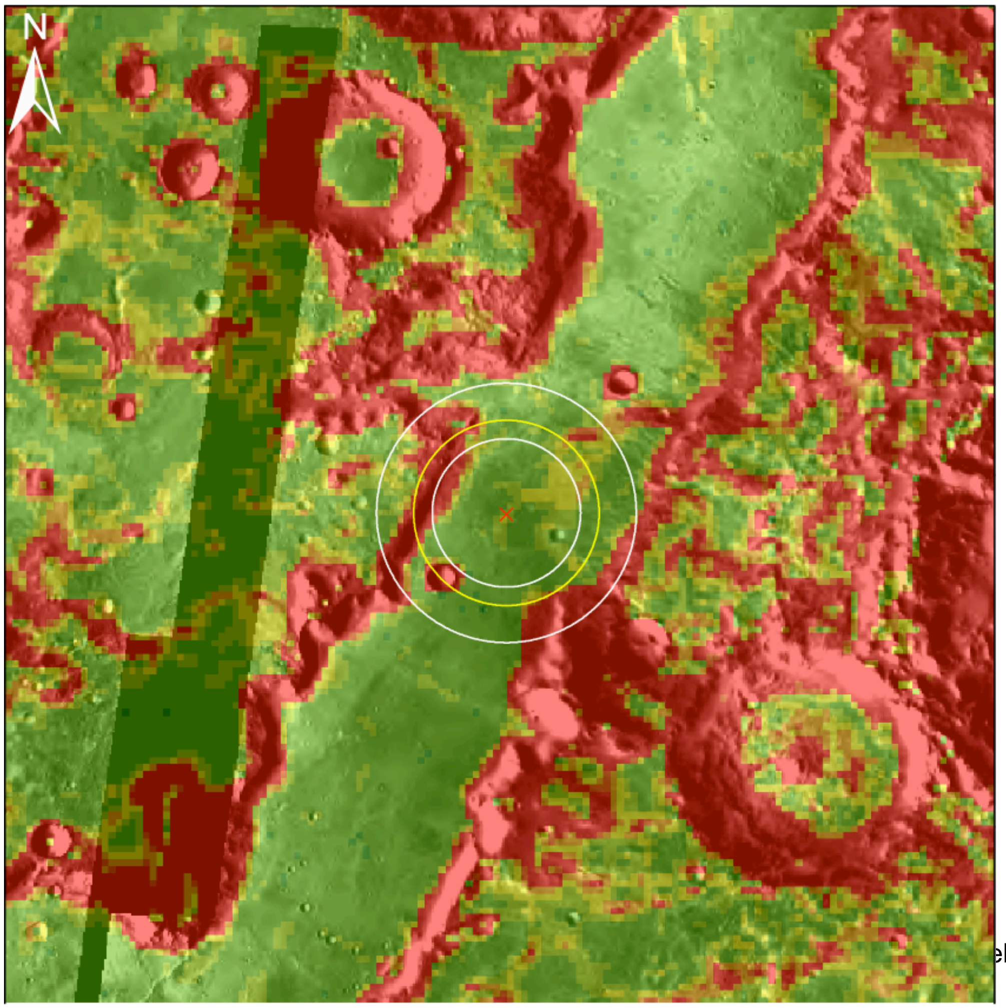



Binned MOLA Data
463 m/pixel
-Includes Pixels with

-Interpolated Data

20, 25, 35 km Circles

# Nili Fossae Trough: 926 m slope



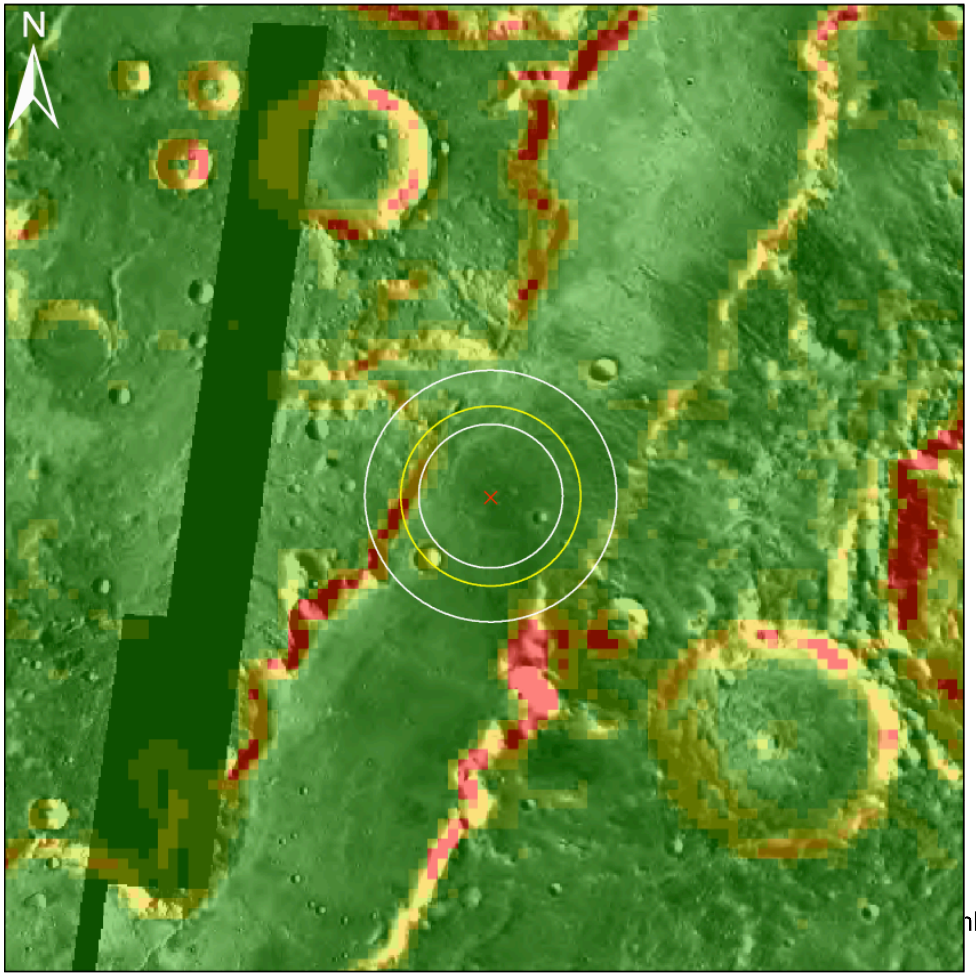

Slope btw 2 MOLA Binned
463 m/pixels
-Each Pixels Average of Data

20, 25, 35 km Circles

2.66° Over 926 m is 43 m

Example of Yellow - Some of
Edge of Ellipse Fails Criterion

# Nili Fossae Trough: 1389 m slope



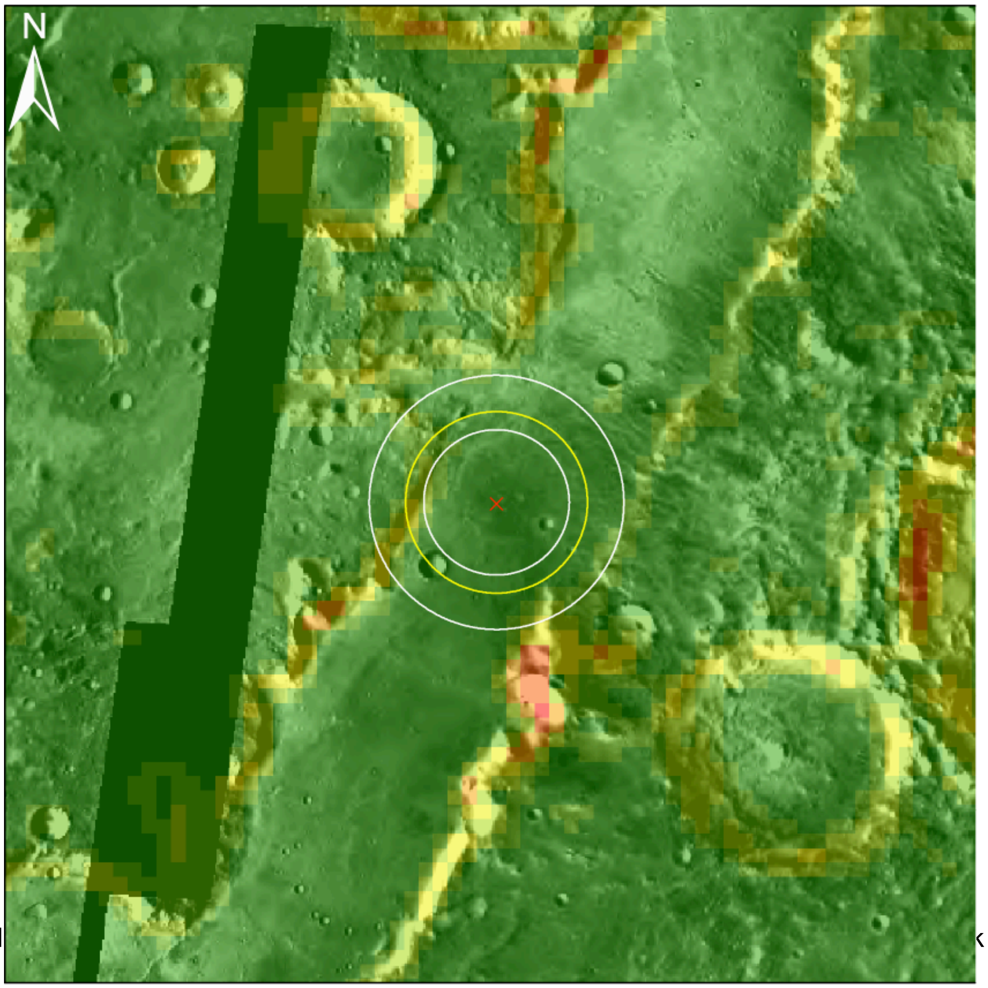

Slope btw 3 MOLA Binned
463 m/pixels
-Each Pixels Average of Data

20, 25, 35 km Circles

1389 m Slope <12.56° is the
1-2 km Relief Criterion at this
length scale

Example of Green - Almost All
of Ellipse Meets Criterion

# Nili Fossae Trough: 2 km slope




Slope btw 4 MOLA Binned
463 m/pixels
-Each Pixels Average of Data

20, 25, 35 km Circles

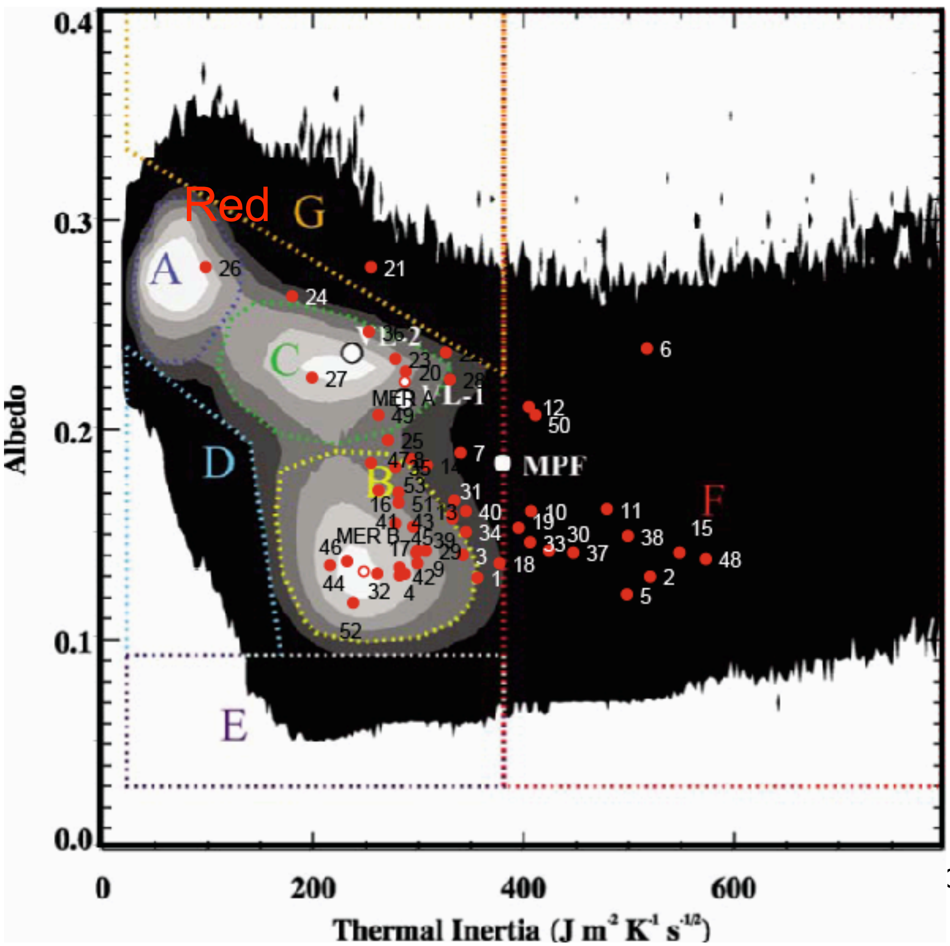
2 km Slope <20° is the 2-10 km Relief Criterion at this length scale (most stringent of 2-10 km slope criteria)

Example of Green - All of Ellipse and Warning Track Meets Criterion

# Thermophysical Properties

- Dust Obscuration
  - Dust Covers Materials of Interest
  - More Difficult to Recognize Materials of Interest Remotely
  - More Difficult to Access Materials of Interest
  - Albedo and Dust Cover Index
- Load Bearing Surface
  - Used Thermal Inertia vs Albedo Plot
  - Comparison to Surface Types
  - Excluded Very Low Thermal Inertia Very High Albedo
- Dust
  - Enough Dust to Impact Trafficability and Operations
  - Albedo, Dust Cover Index and Thermal Inertia
- Rock Abundance
  - IRTM, TES
  - Rocks in HiRISE

# Comparison of MSL candidate sites with Mars terrain types [After Putzig et al., 2005]



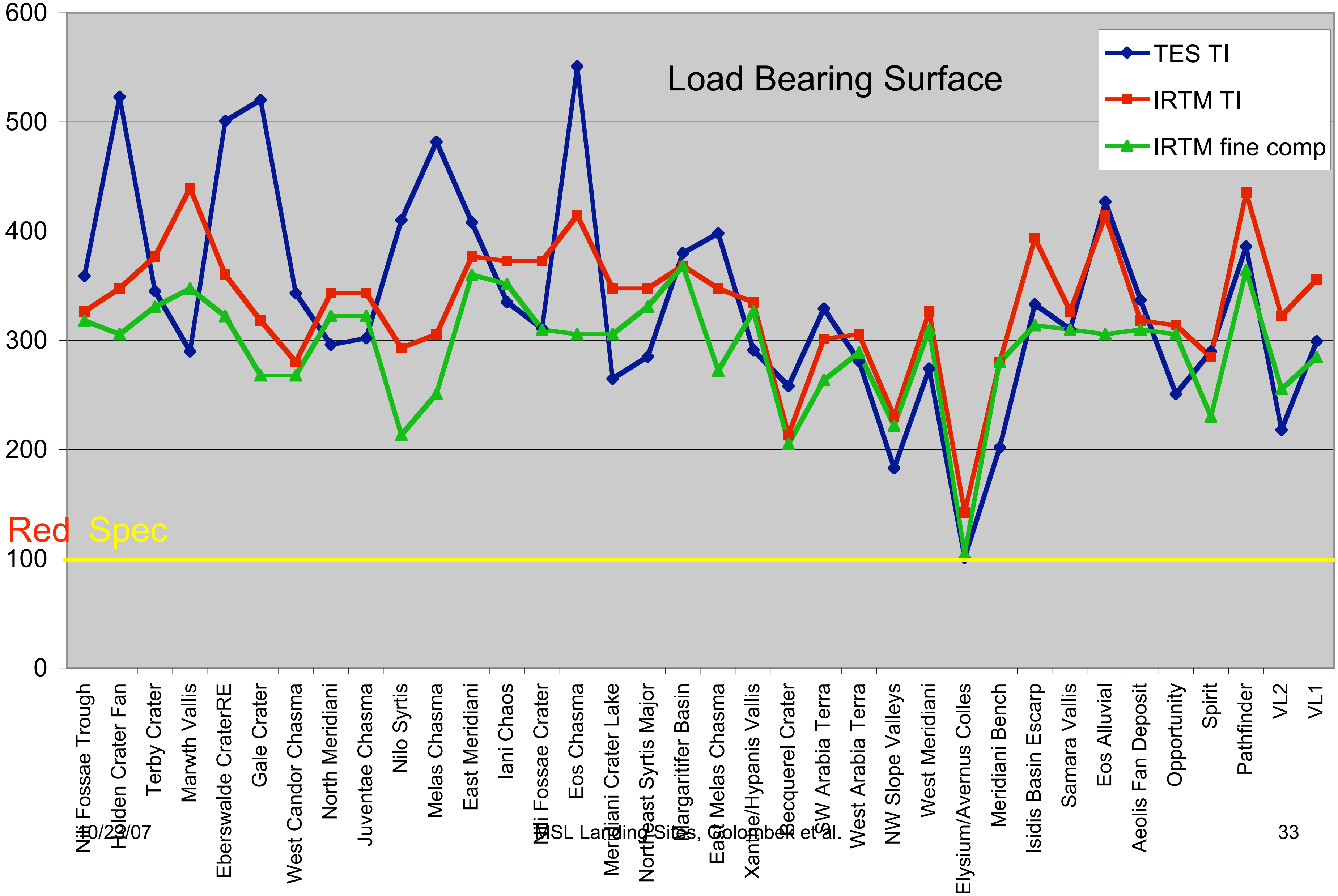

| | | | |
|---|---|---|---|
| 1 | Nili Fossae Trough | 28 | Isidis Basin Escarp |
| 2 | Holden Crater Fan | 29 | Samara Vallis |
| 3 | Terby Crater | 30 | Eos Alluvial |
| 4 | Marwth Vallis | 31 | Aeolis Fan Deposit |
| 5 | Eberswalde Crater | 32 | Ariadnes Colles |
| 6 | Gale Crater | 33 | Ritchey Crater |
| 7 | West Candor Chasma | 34 | Mawrth Vallis 1 |
| 8 | North Meridiani | 35 | Mawrth Vallis 2 |
| 9 | Juventae Chasma | 36 | Mawrth Vallis 3 |
| 10 | Nilo Syrtis | 37 | Nili Fossae |
| 11 | Melas Chasma | 38 | Terby Alternate |
| 12 | East Meridiani | 39 | Nili Fossae Trough alter |
| 13 | Iani Chaos | 40 | S. Meridiani Clays |
| 14 | Nili Fossae Crater | 41 | W. Meridiani Additional |
| 15 | Eos Chasma | 42 | Chloride Site 1 |
| 16 | Meridiani Crater Lake | 43 | Chloride Site 2 |
| 17 | Northeast Syrtis Major | 44 | Chloride Site 3 |
| 18 | Margaritifer Basin | 45 | Chloride Site 4 |
| 19 | East Melas Chasma | 46 | Chloride Site 5 |
| 20 | Xanthe/Hypanis Vallis | 47 | W. Chandor Chasma alt |
| 21 | Becquerel Crater | 48 | Juventae alternate |
| 22 | SW Arabia Terra | 49 | Meridiani B1 |
| 23 | West Arabia Terra | 50 | Meridiani B2 |
| 24 | NW Slope Valleys | 51 | Meridiani B3 |
| 25 | West Meridiani | 52 | Meridiani B4 |
| 26 | Elysium/Avernus Colles | 53 | N. Meridiani M&E |
| 27 | Meridiani Bench | | |

Golombek et al.

# Thermal inertia from TES and IRTM

TES data are from ASU 8 ppd maps [Christensen et al. 2001]

IRTM TI data are selected from 2 ppd maps by Palluconi and Kieffer [1981] and fine component IRTM TI is from Christensen [1986] 1 ppd maps



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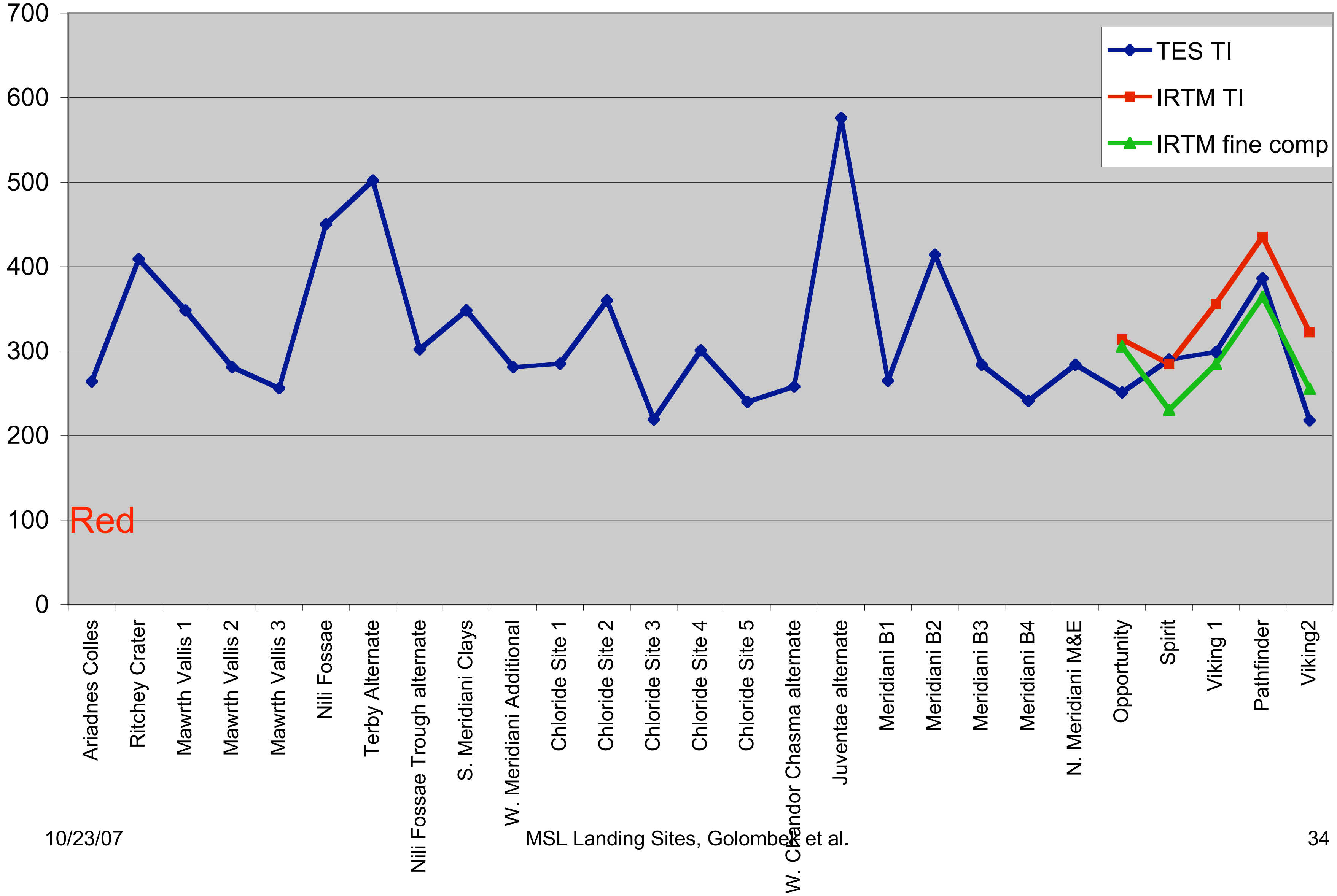
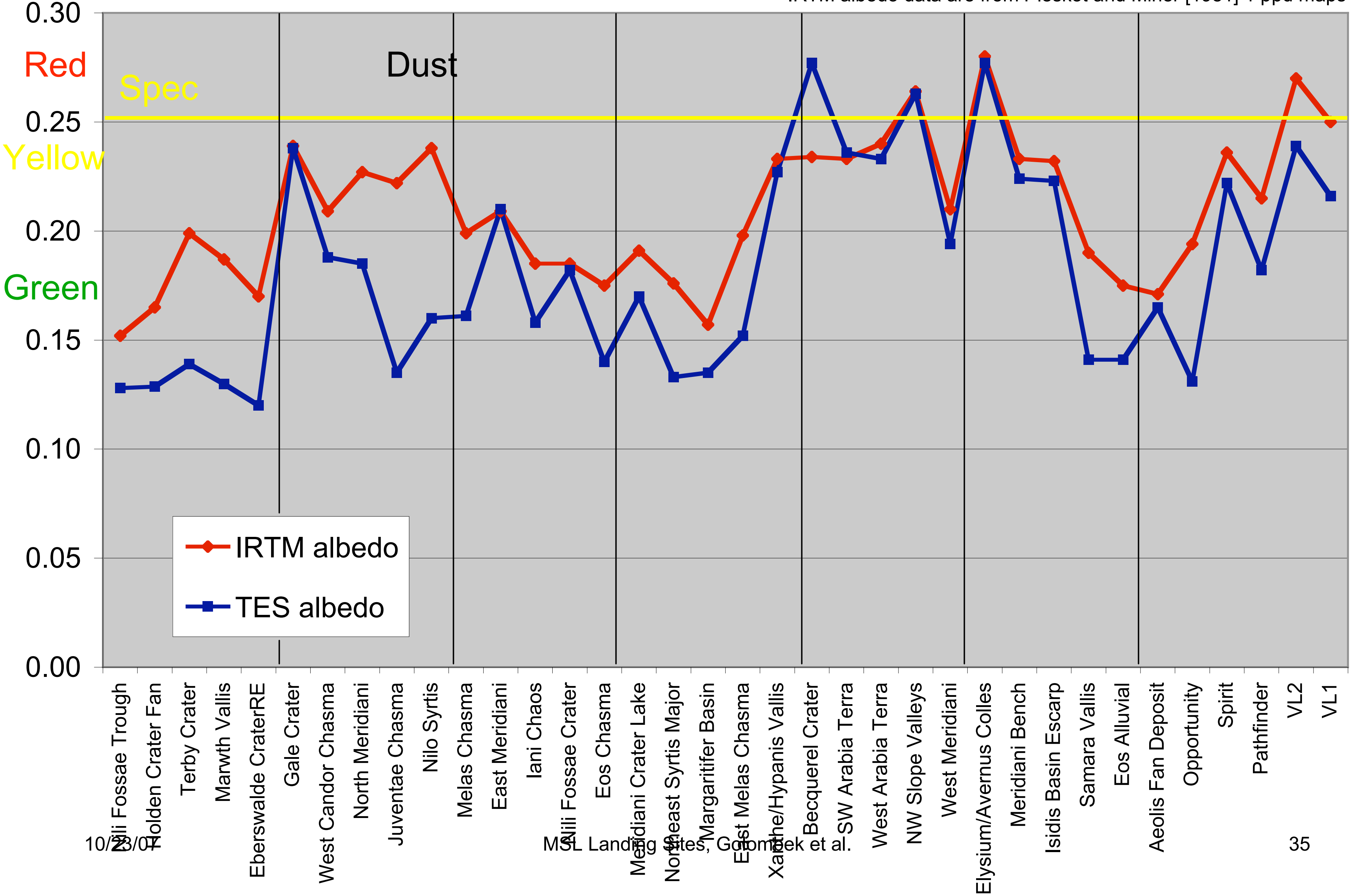


# TES and IRTM Albedo

TES data are from ASU 8 ppd maps [Christensen et al. 2001]

IRTM albedo data are from Pleskot and Miner [1981] 1 ppd maps



# TES and IRTM Albedo

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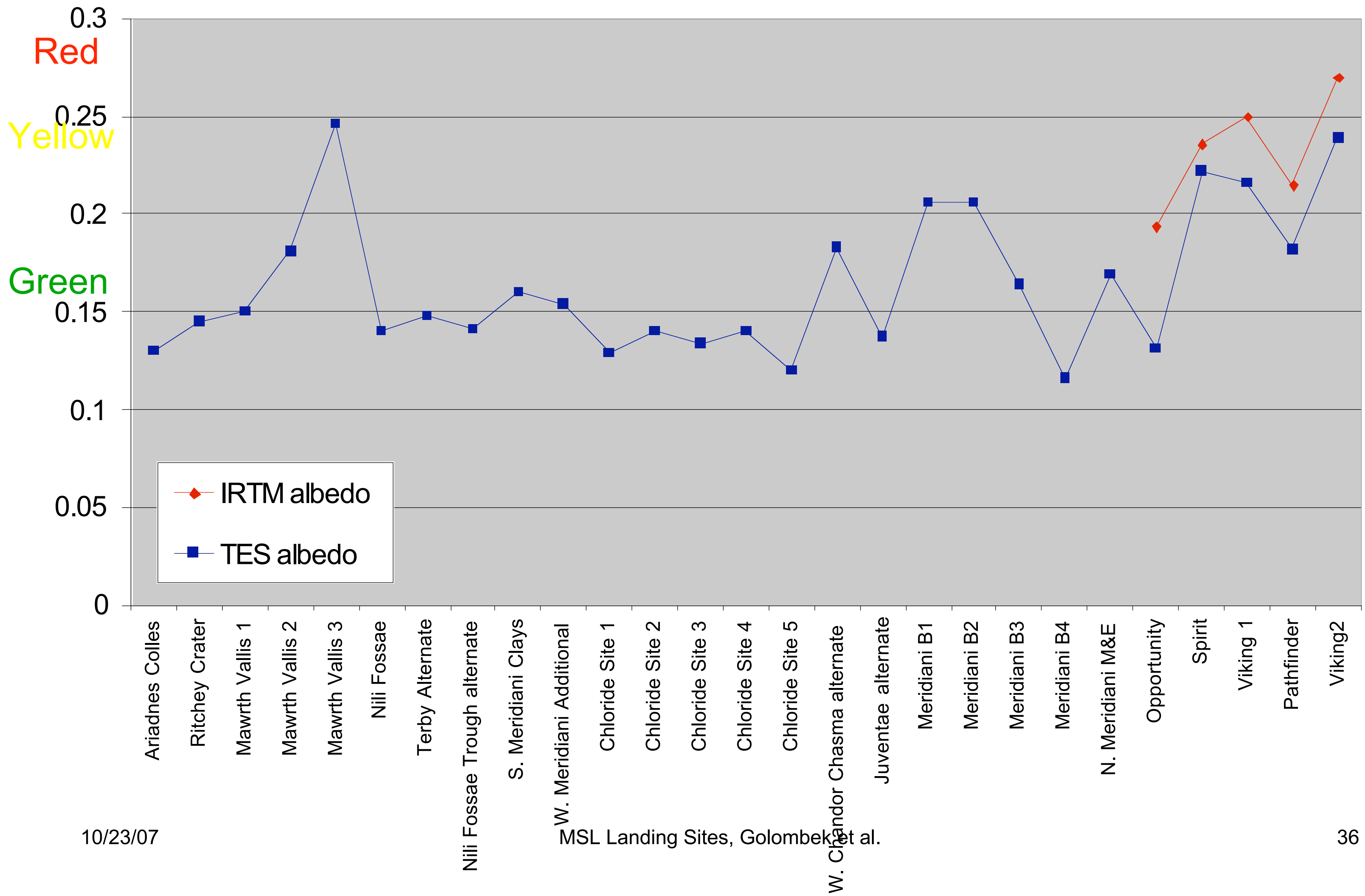
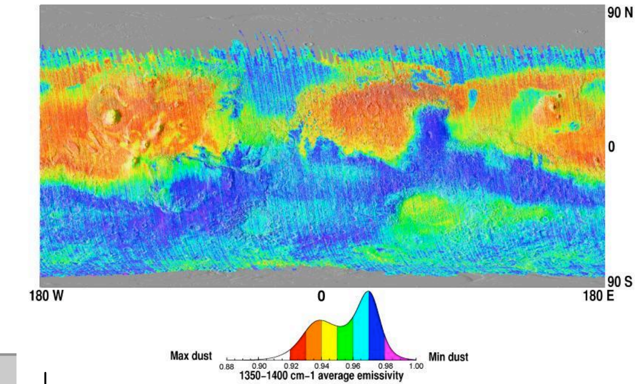
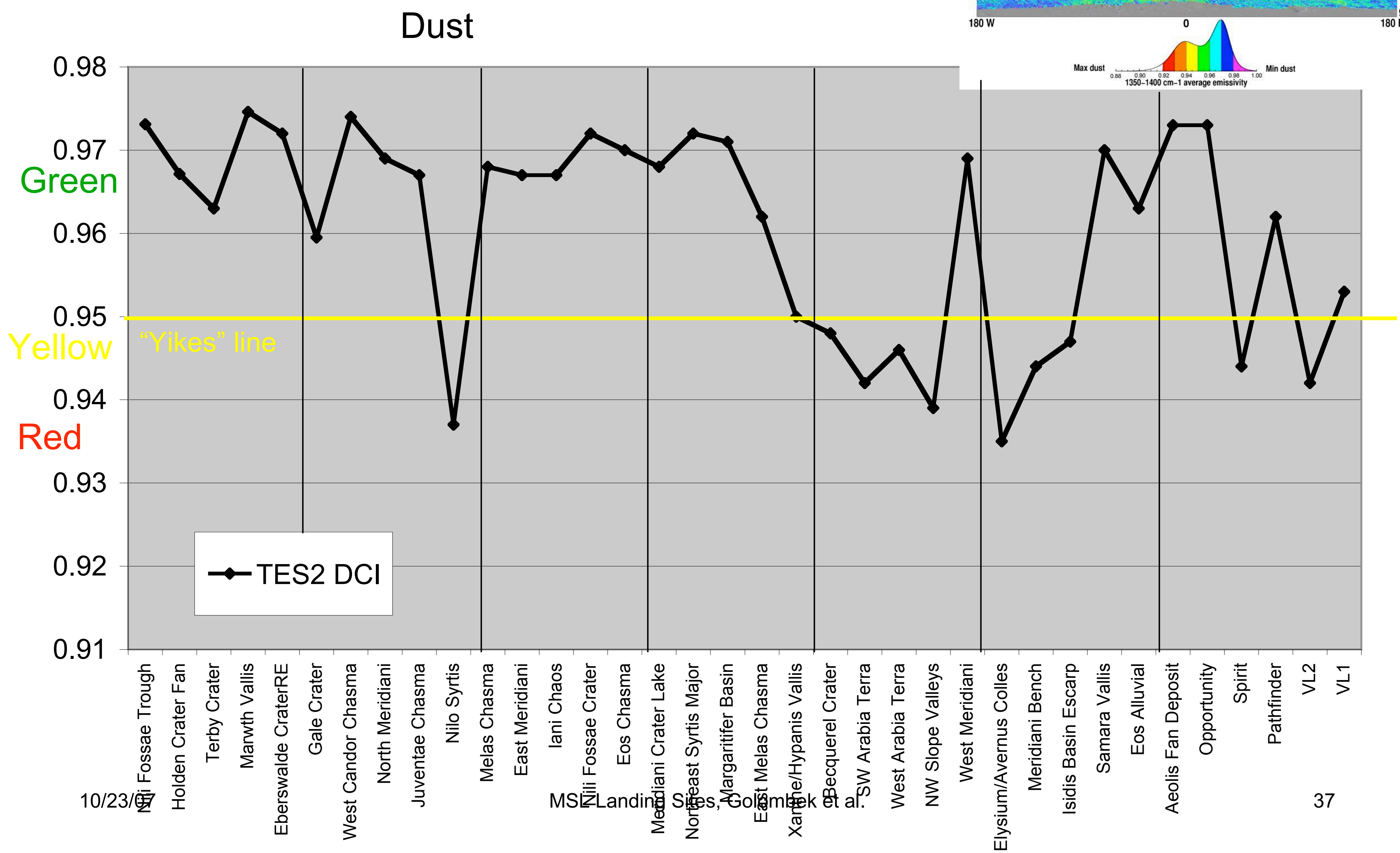


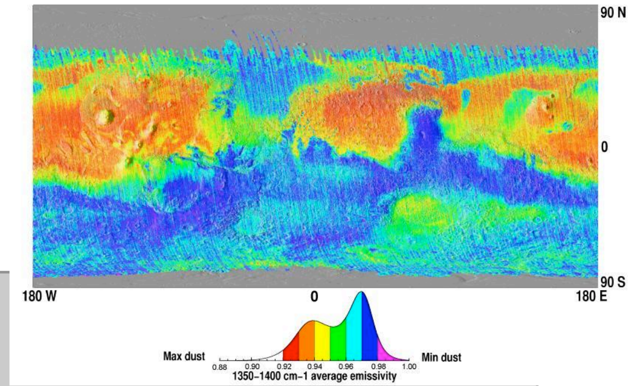
# TES Dust Cover Index

From Ruff and Christensen, 2002

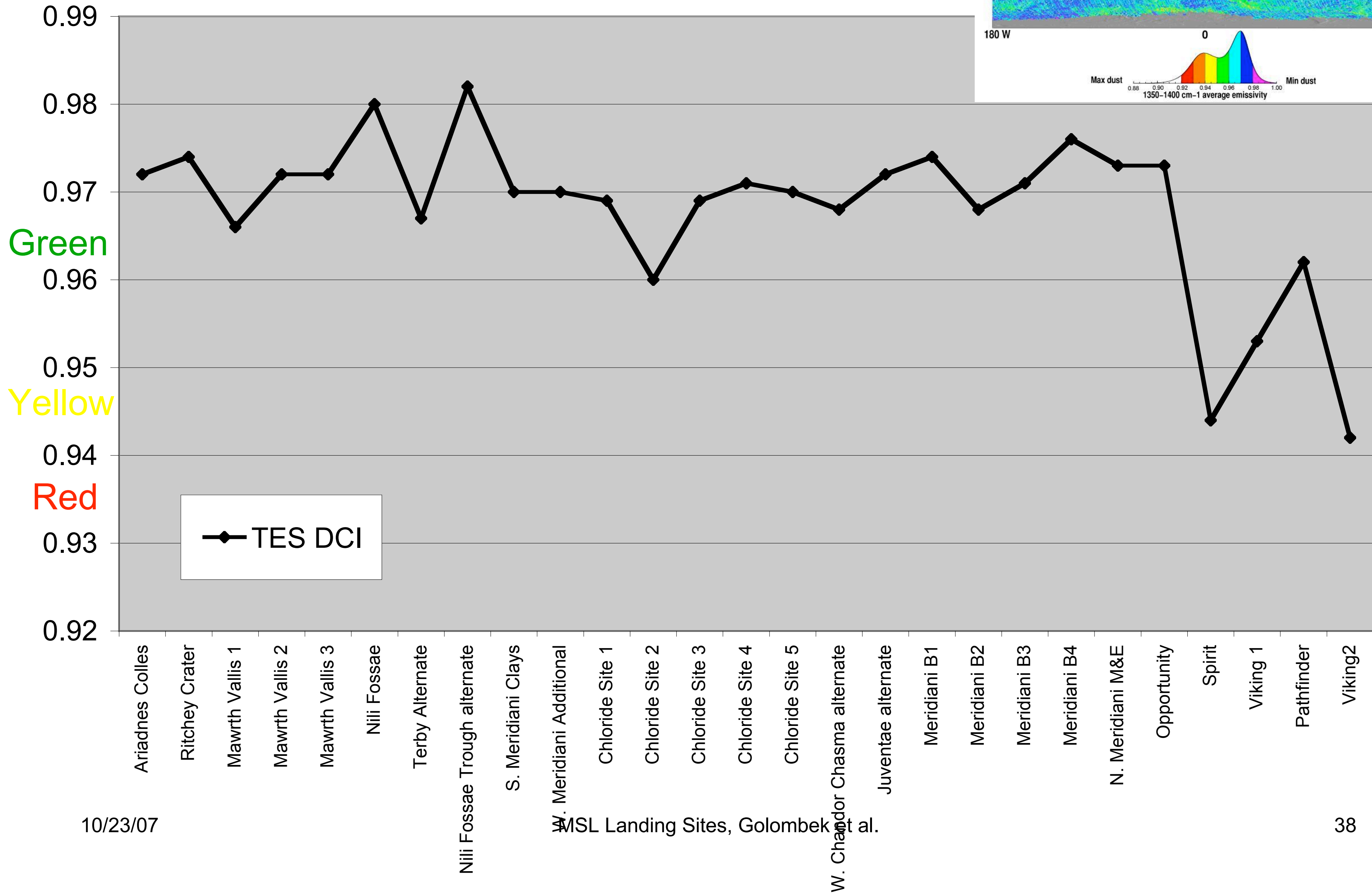


# TES Dust Cover Index



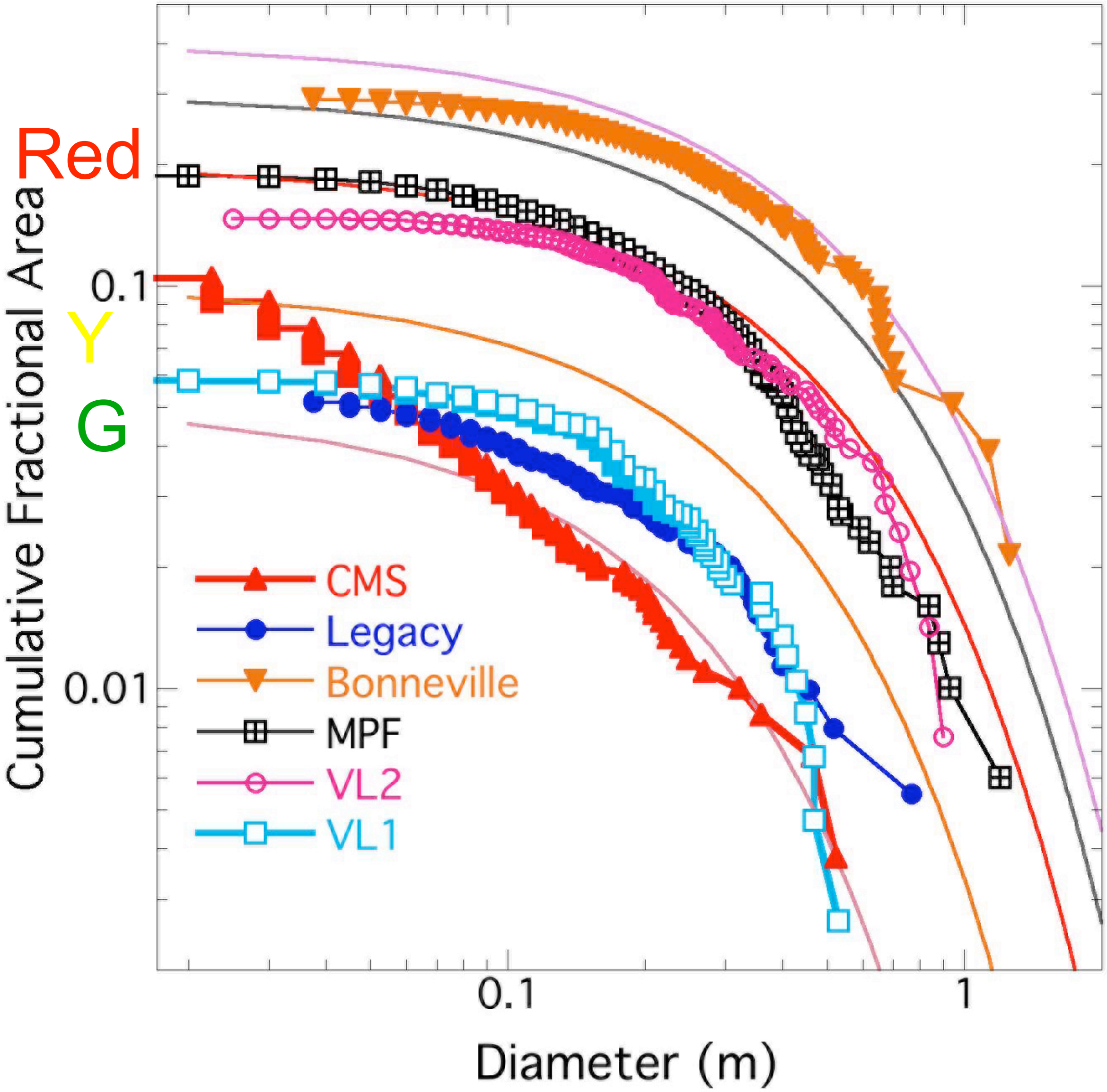

From Ruff and Christensen, 2002



# Rock Abundance

- Derivation of Engineering Criterion
  - 0.5% Probability Encountering 0.55 m High (1.1 m Diameter) Rock During Landing - 4 $m^2$ Area
  - Using Model Rock Size-Frequency Distributions Corresponds to 8% Rock Abundance/Coverage
  - <8% Green, <15% Yellow, >15% Red
- Rock Abundance
  - IRTM, TES
  - Presence of Rocks in HiRISE
- Relationship Rocks in HiRISE to Surface Distributions
  - Extrapolation to Size of Concern

# Rock Size-Frequency Distributions




Model Distribution for Based on VL, Rocky Locations on Earth
[Golombek & Rapp, 1977]

Distributions from Exponential - Fracture/Fragmentation Theory

Correctly Predicted Distributions at MPF and Spirit from IRTM Rock Abundance

$F_k(D) = k \exp[-q(k)\,D]$

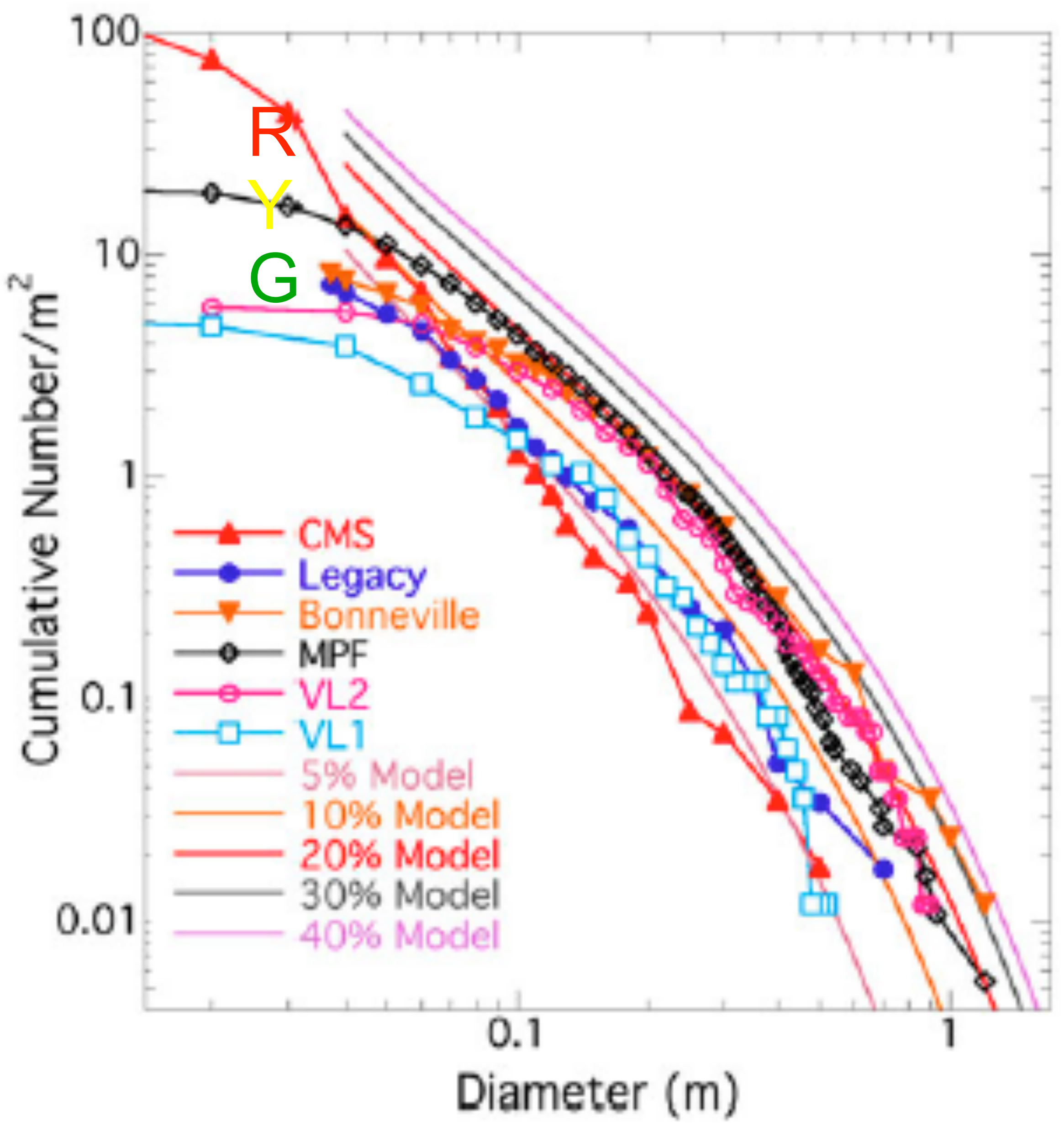
$F_k(D)$ Cum. Frac. Area

k is Total Rock Abundance Relate to IRTM Rock Abundance



Golombek et al. [2005, 2006]

# Cumulative Number Distributions



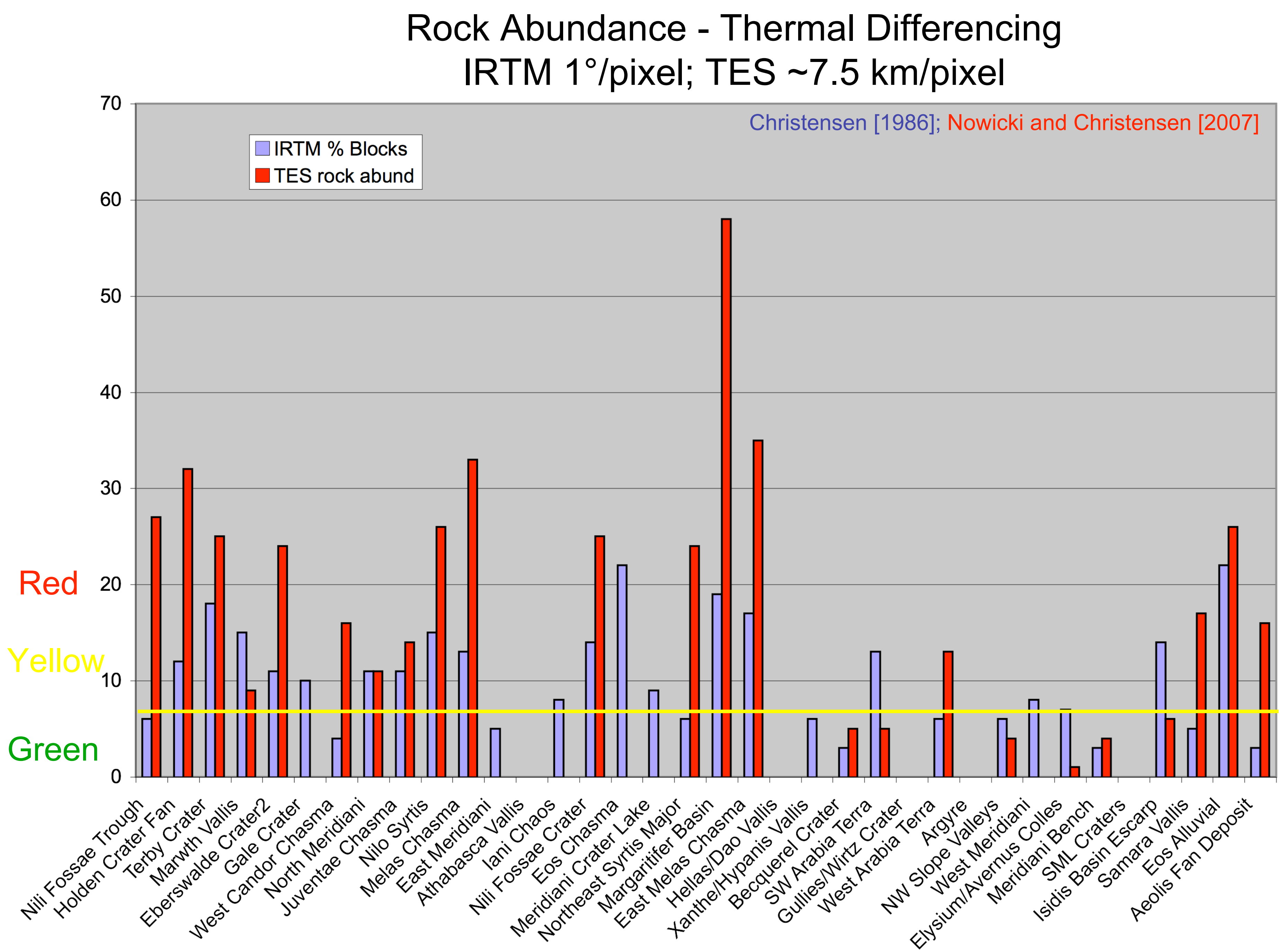

Cumulative Number Model Distributions

Measured Distributions Follow Model for D>0.1 m

Derive Cumulative Number for Rock of any Size and Derive Probability of Impact Over Area of Concern

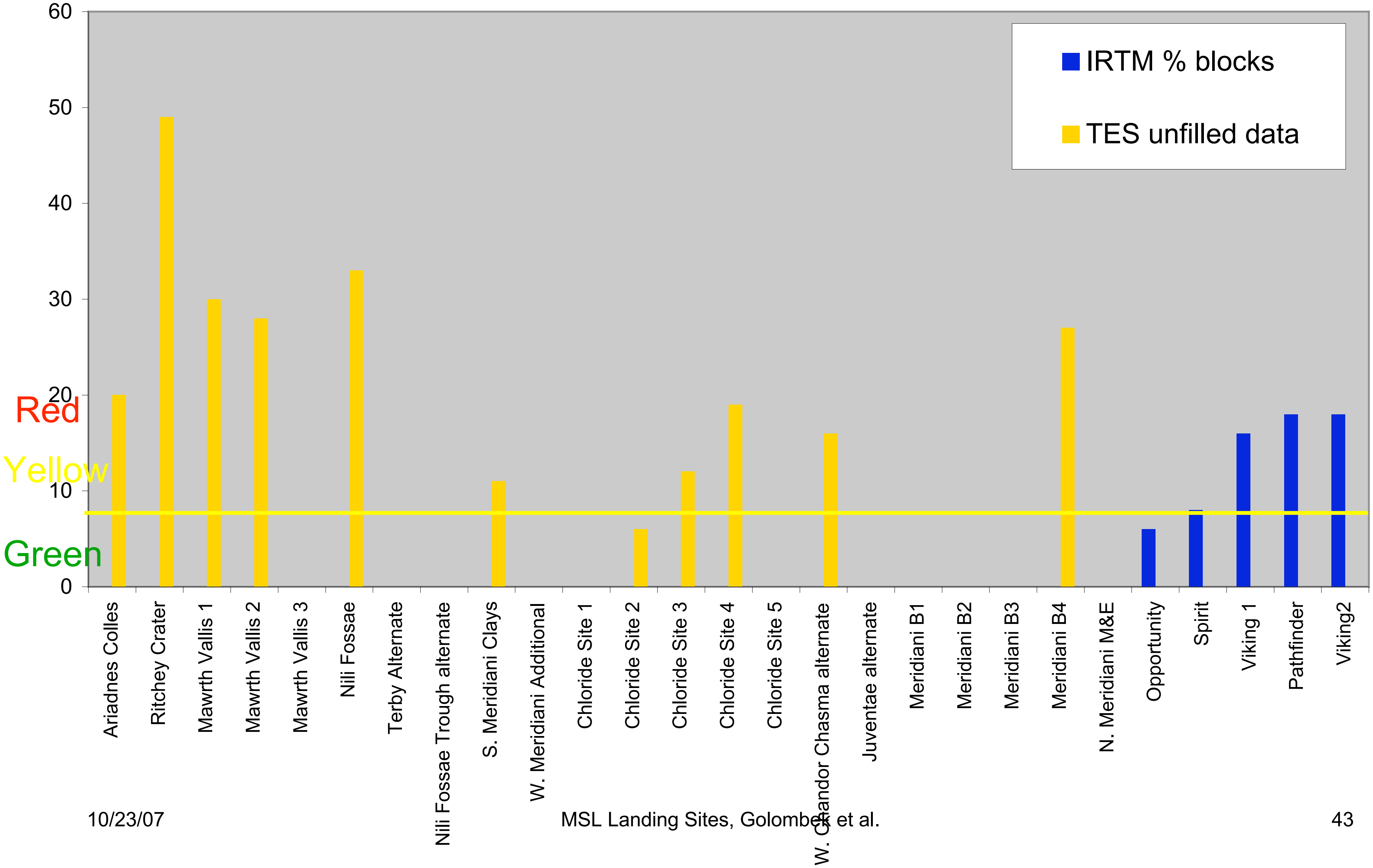
8% = 0.5% 1.1 m D rock over 4 $m^2$

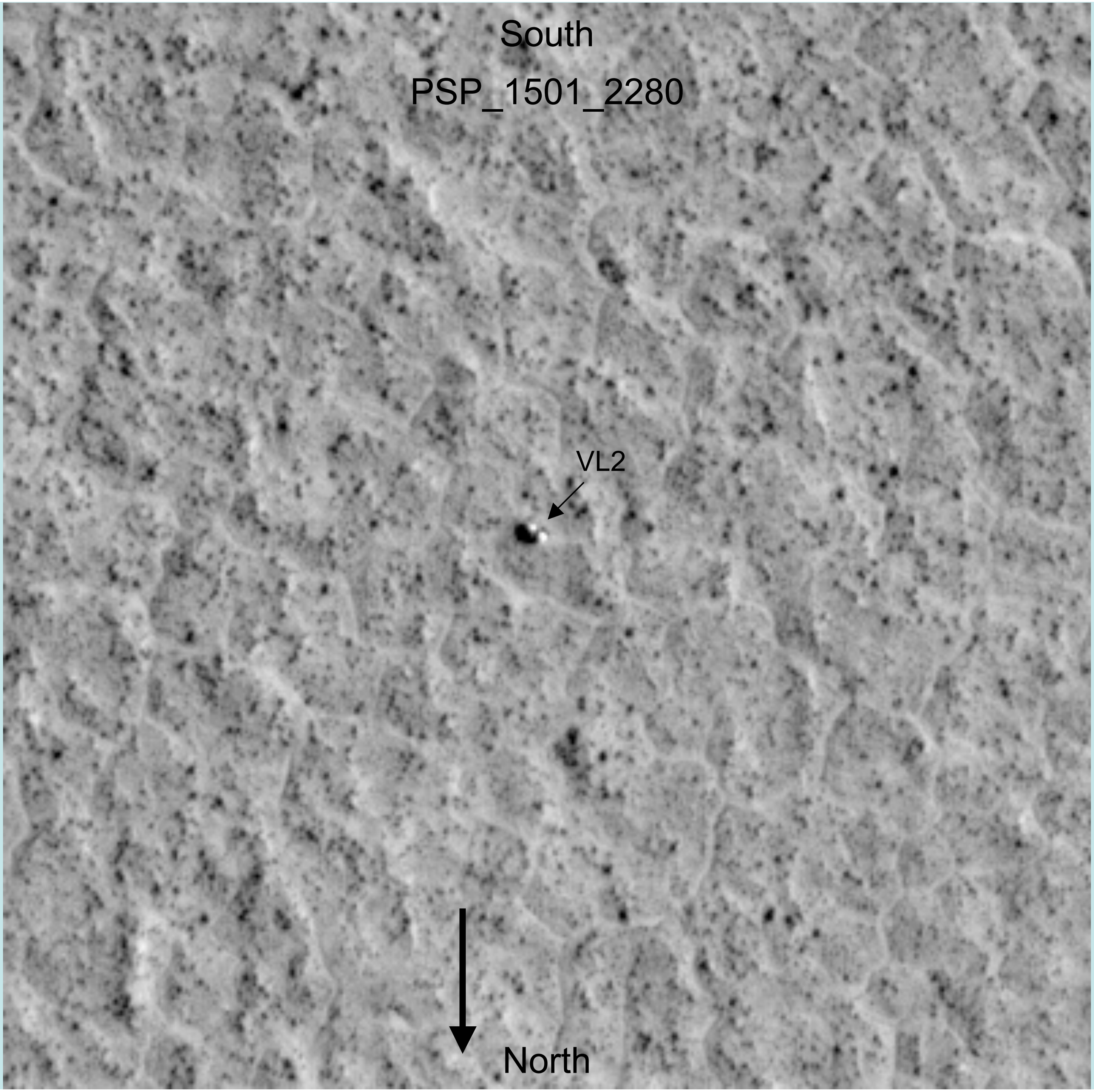
Golombek et al. [2006]


Rock Abundance - Thermal Differencing
IRTM 1°/pixel; TES ~7.5 km/pixel
Christensen [1986]; Nowicki and Christensen [2007]
IRTM % Blocks
TES rock abund
70
60
50
40
30
20
10
0
Red
Yellow
Green
Nili Fossae Trough
Holden Crater Fan
Terby Crater
Marwth Vallis
Eberswalde Crater2
Gale Crater
West Candor Chasma
North Meridiani
Juventae Chasma
Nilo Syrtis
Melas Chasma
East Meridiani
Athabasca Vallis
Iani Chaos
Nili Fossae Crater
Eos Chasma
Meridiani Crater Lake
Northeast Syrtis Major
Margaritifer Basin
East Melas Chasma
Hellas/Dao Vallis
Xanthe/Hypanis Vallis
Becquerel Crater
SW Arabia Terra
Gullies/Wirtz Crater
West Arabia Terra
Argyre
NW Slope Valleys
West Meridiani
Elysium/Avernus Colles
Meridiani Bench
SML Craters
Isidis Basin Escarp
Samara Vallis
Eos Alluvial
Aeolis Fan Deposit

# IRTM % blocks and TES rock abundance

From Christensen [1986] 1 ppd maps; Nowicki and Christensen, 2007





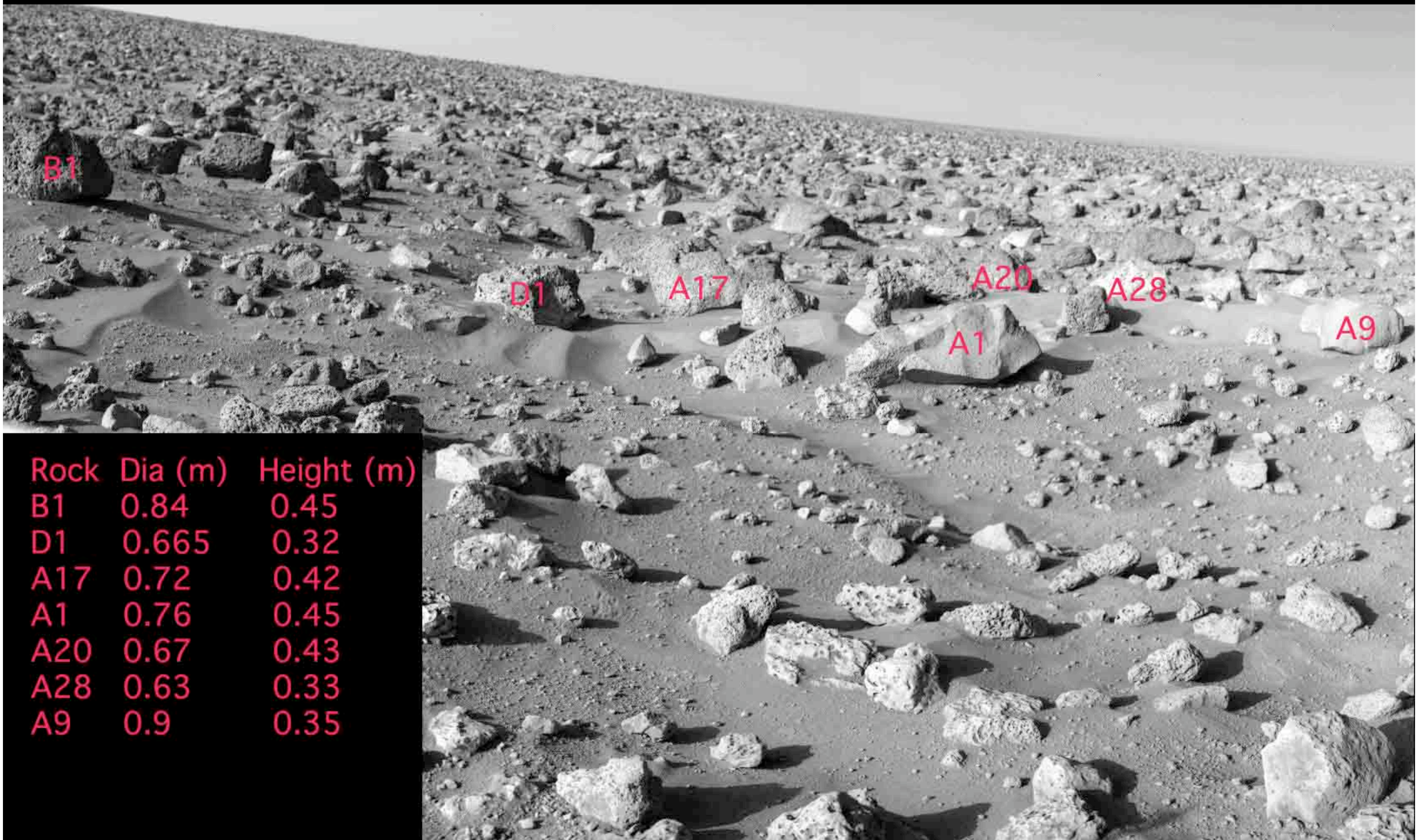

# VL2

Can See Rocks Directly in HiRISE

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

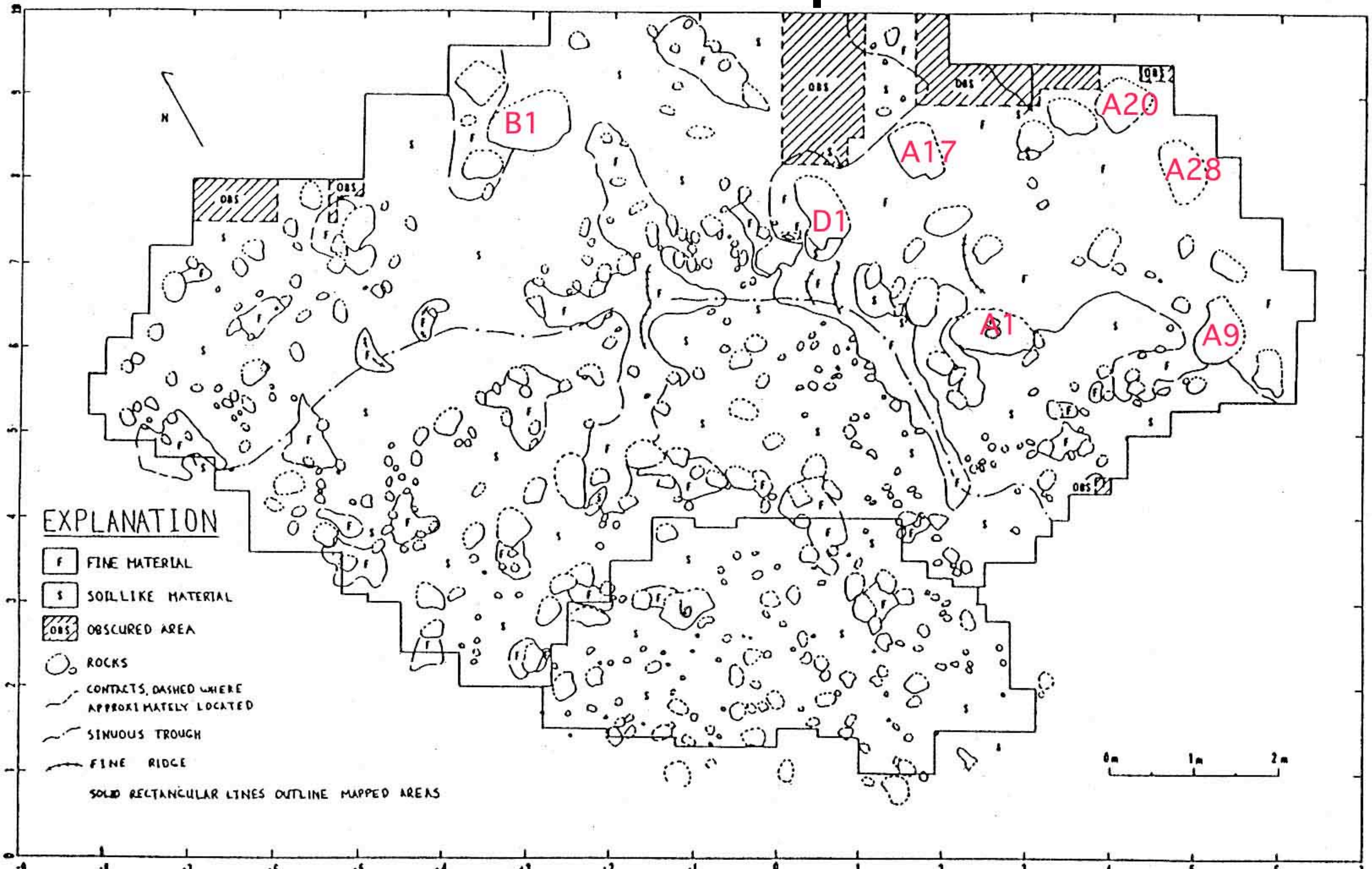
400x400 pixels
124x124 meters
1.5 hectares

# VL2 Large Rocks




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

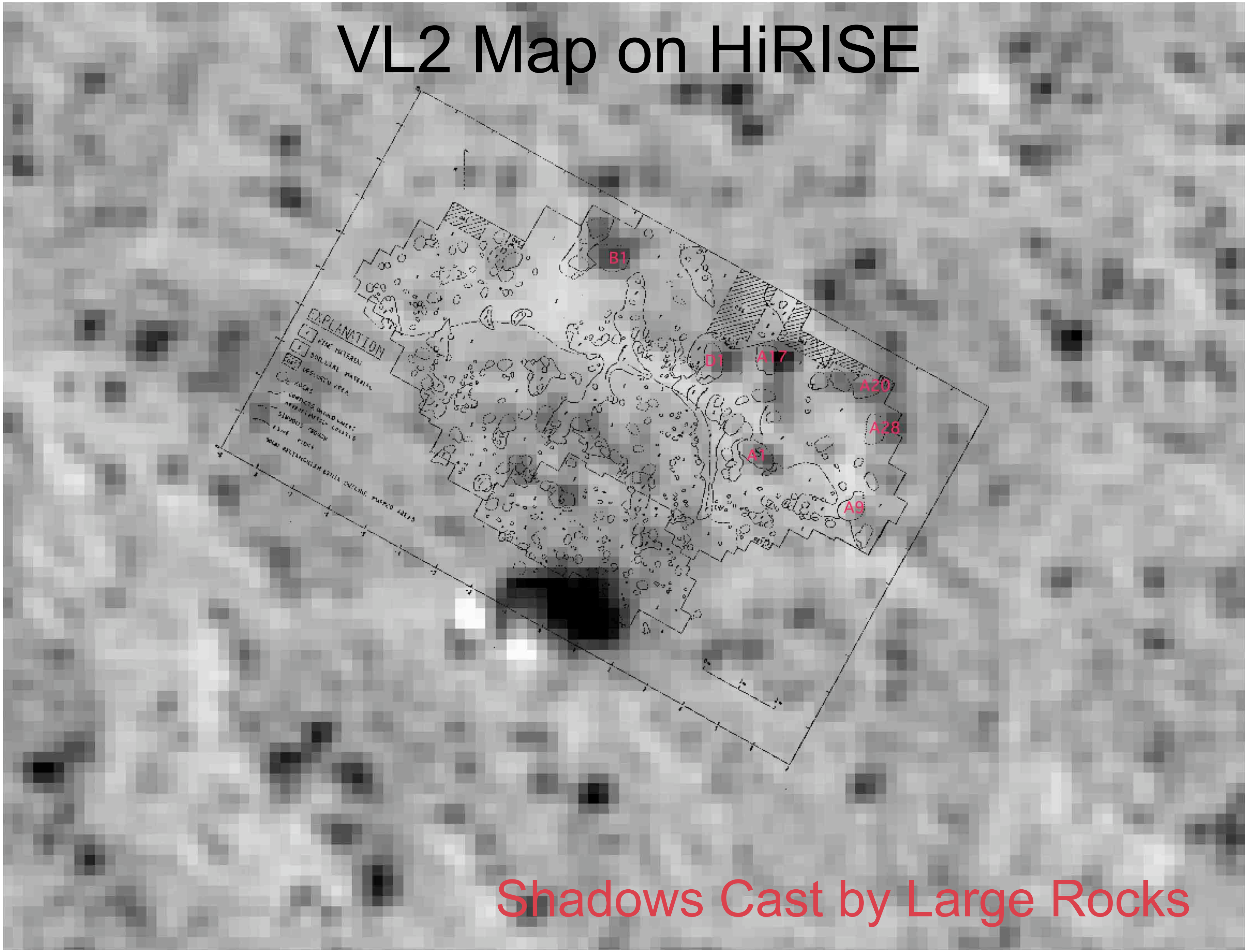
# VL2 Map



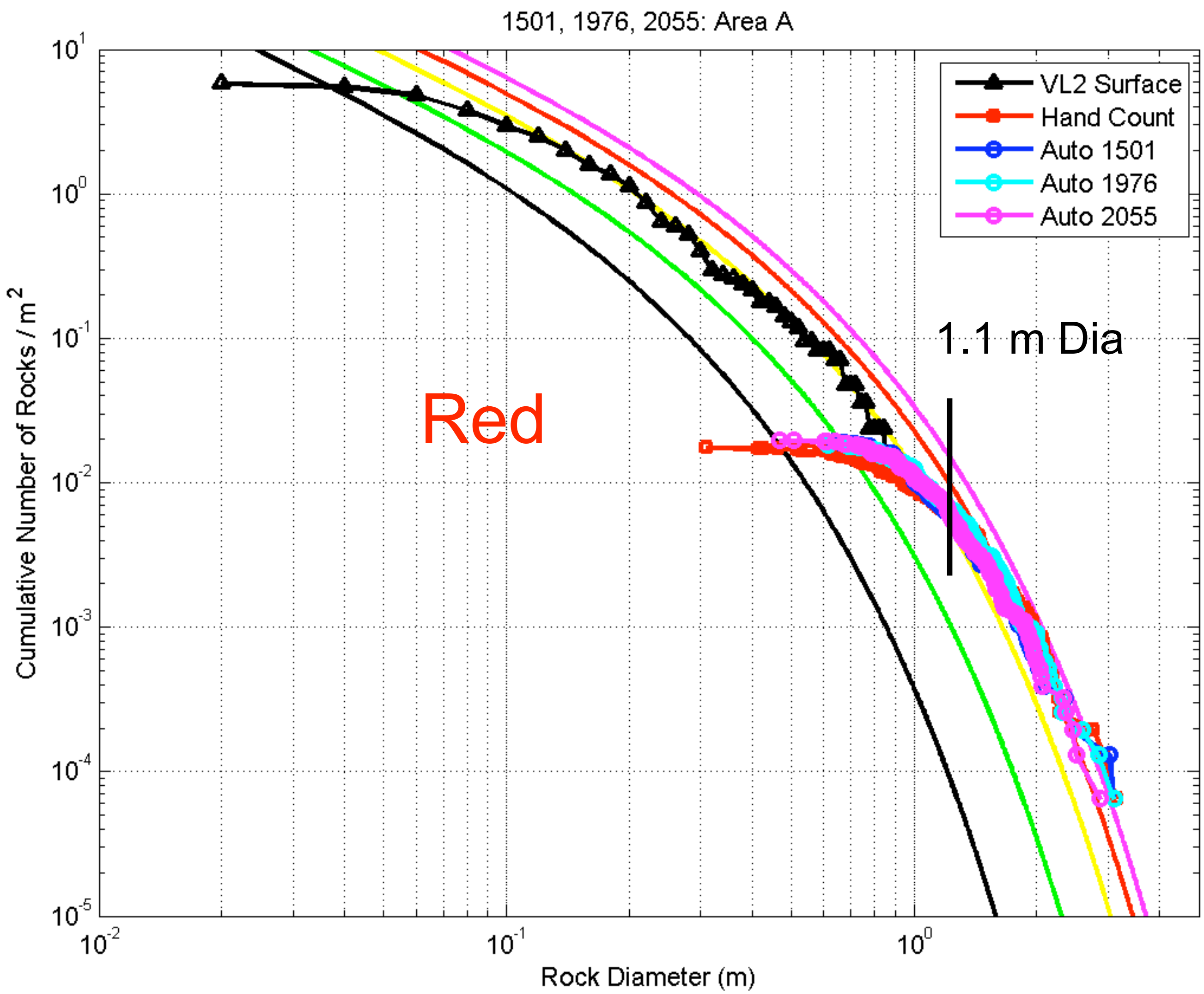

7 Largest Rocks

Moore & Keller

# VL2 Map on HiRISE



# VL2 Surface to HiRISE Comparison




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

Validated on Landers/Rovers and Matches Hand Counts

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

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



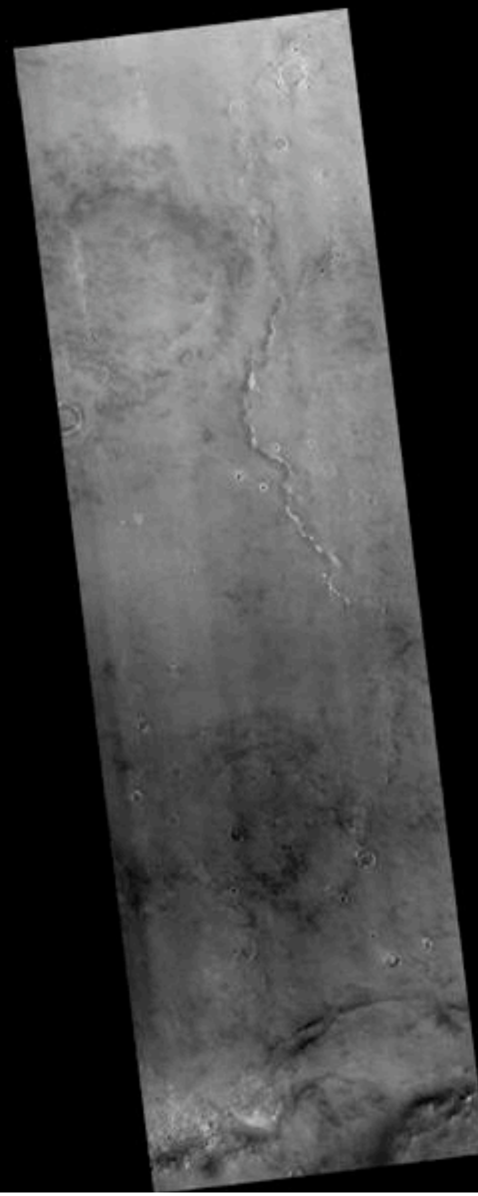
Cheng et al. [2001], Huertas et al. [2007], Golombek et al. [2007]

# Relief/Rocks in HiRISE

- Systematic Visual Examination of HiRISE
  – Images in Ellipse Only
- Qualitative Estimate of Relief and Rocks
  – 2 Observers [Jen Griffes, Tim Parker]
    - Blind Test, Comparison at End
  – Consistent Results, Maps of Surfaces
    - Green - Low Relief, Safe for Landing, No/Few Rocks
    - Yellow - Moderate Relief, Possibly Hazardous, Some Rocks
    - Red - High Relief, Certainly Hazardous, Many Rocks
  – Dominant Relief/Rocks Used in Criteria
- If No HiRISE - Relief in MOC [not rocks]
- Comparison with 19 PC Results of Beyer
  – 10 Same, 6 Qualitative Worse, 3 Quantitative Worse
  – Qualitative +One Color, Eye Conservative Filter

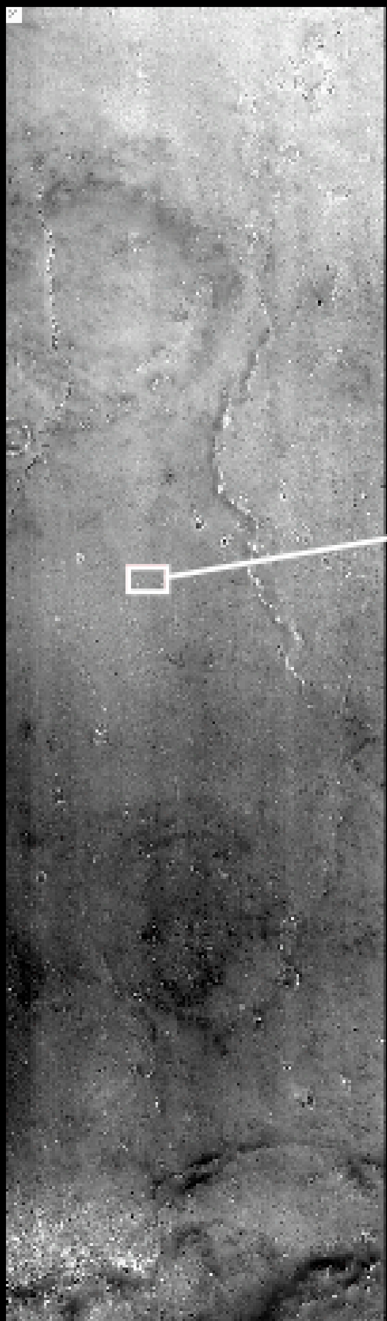
# N Meridiani: PSP_003405_1825

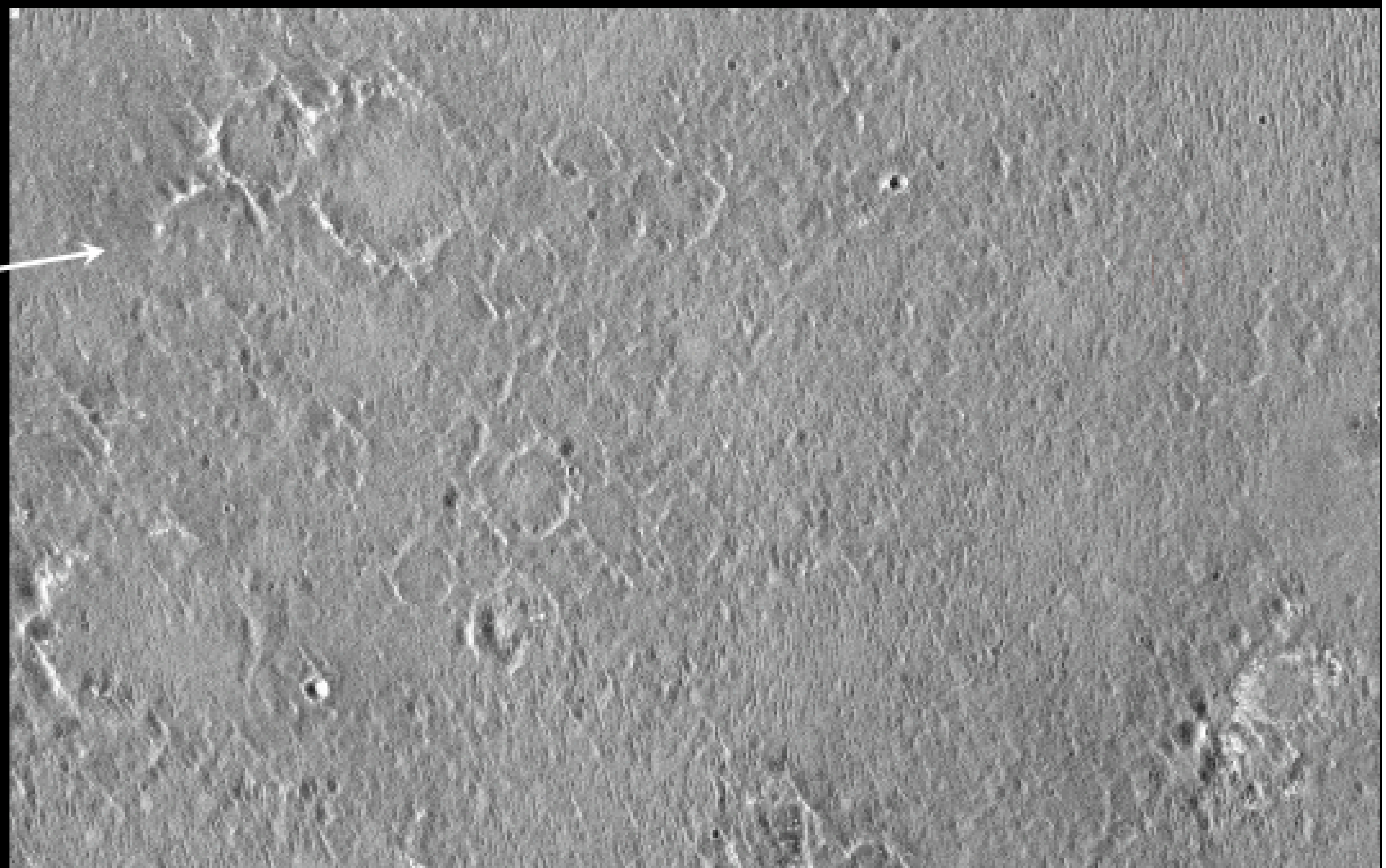
- Some outcrop, few rocks
- Lots of aeolian features (dunes/ripples)
- Lots of old degraded craters



J. Griffes

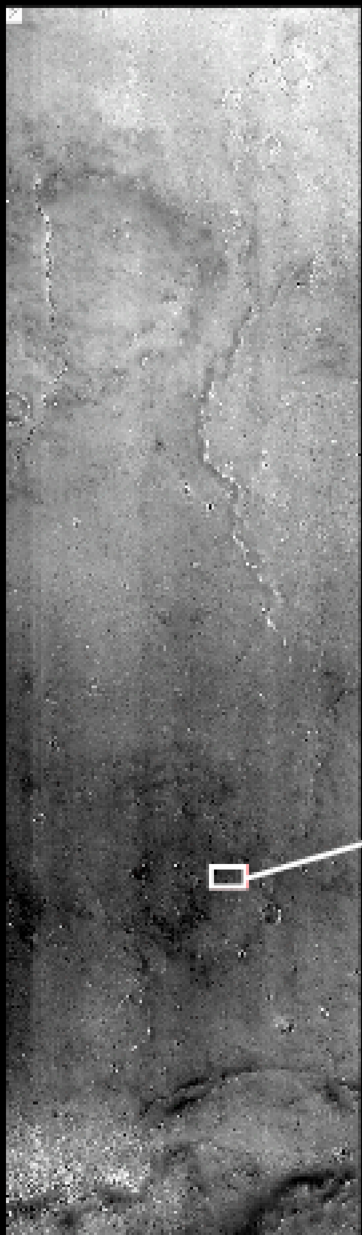
# N Meridiani - green

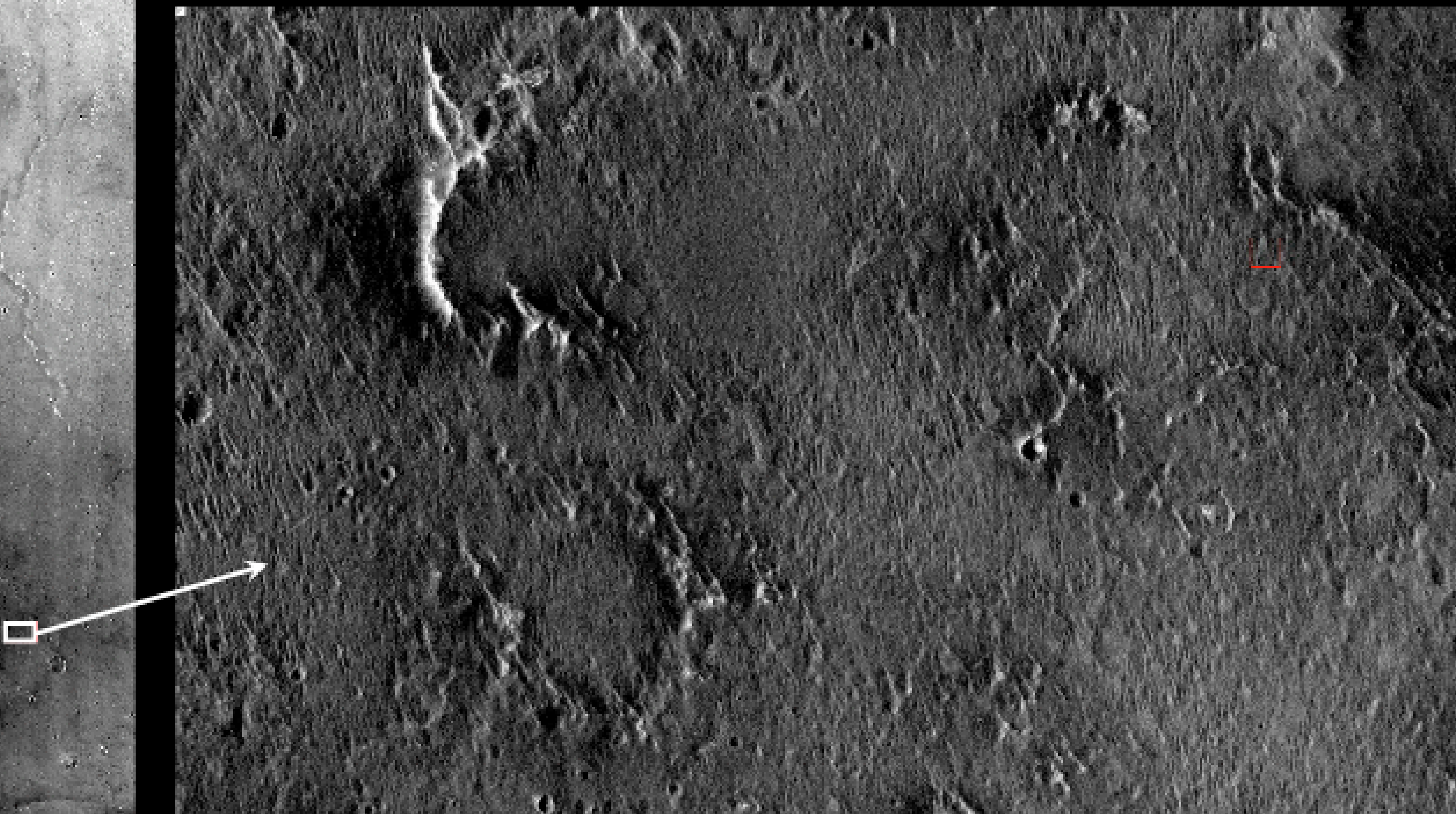




J. Griffes

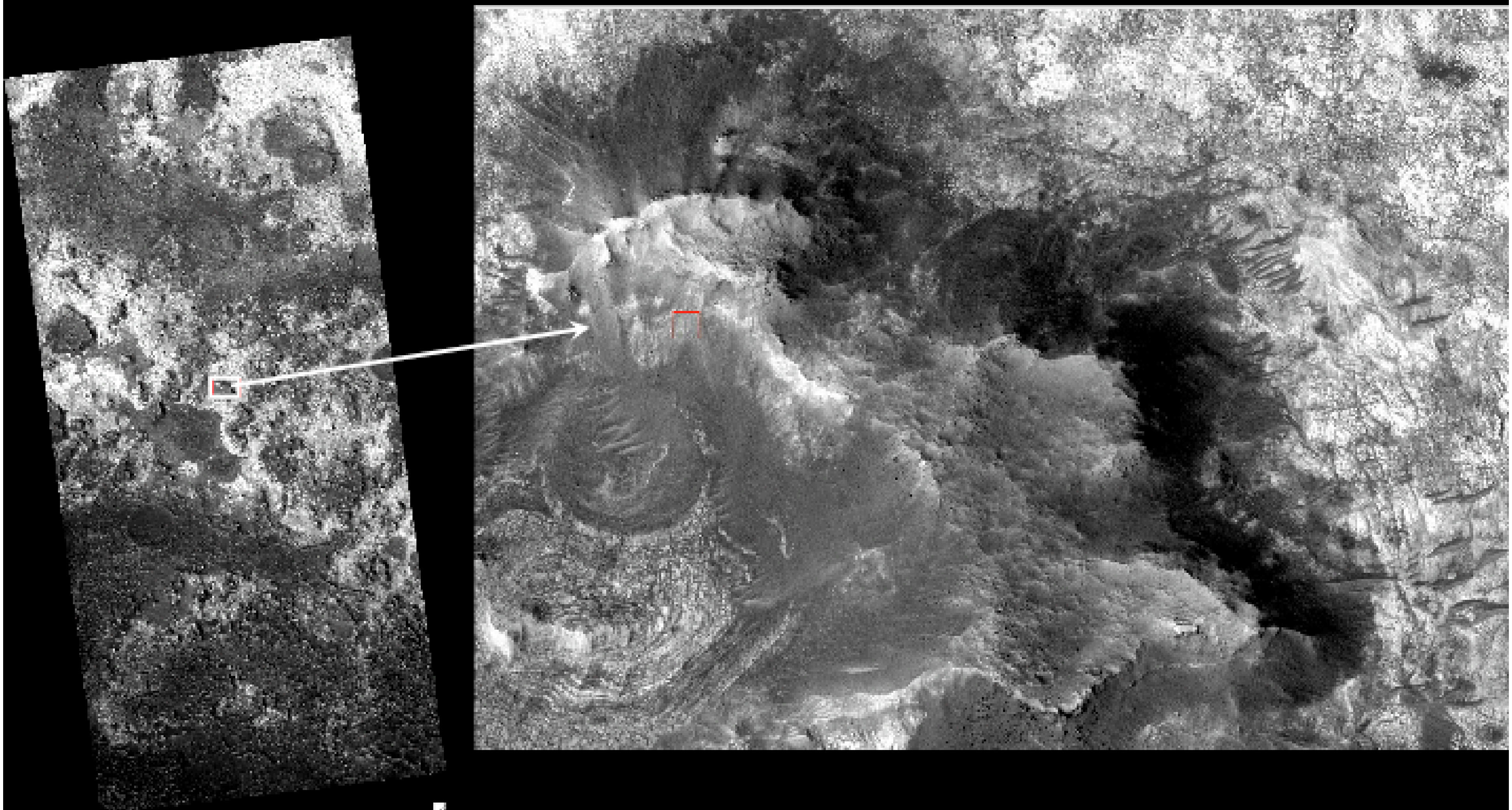
# N Meridiani - yellow





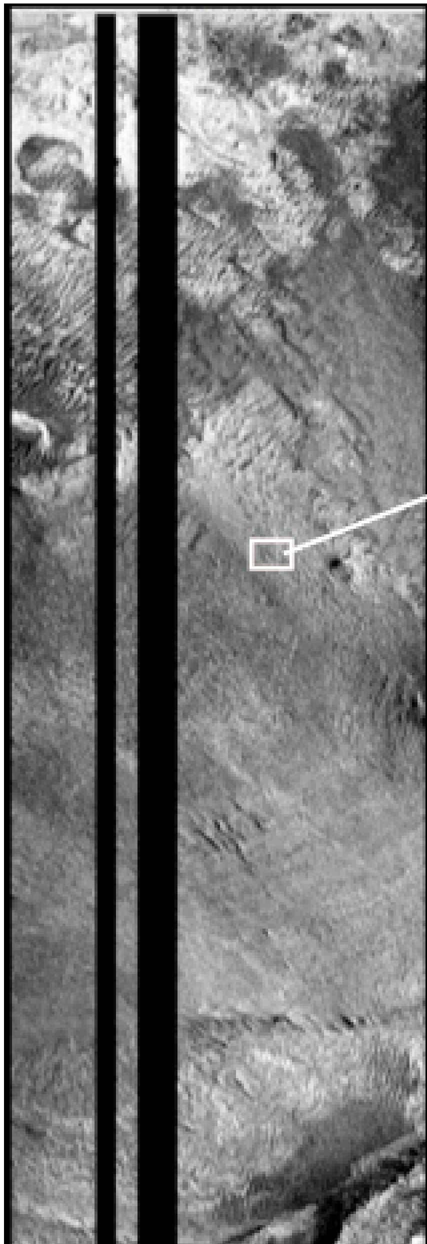
J. Griffes

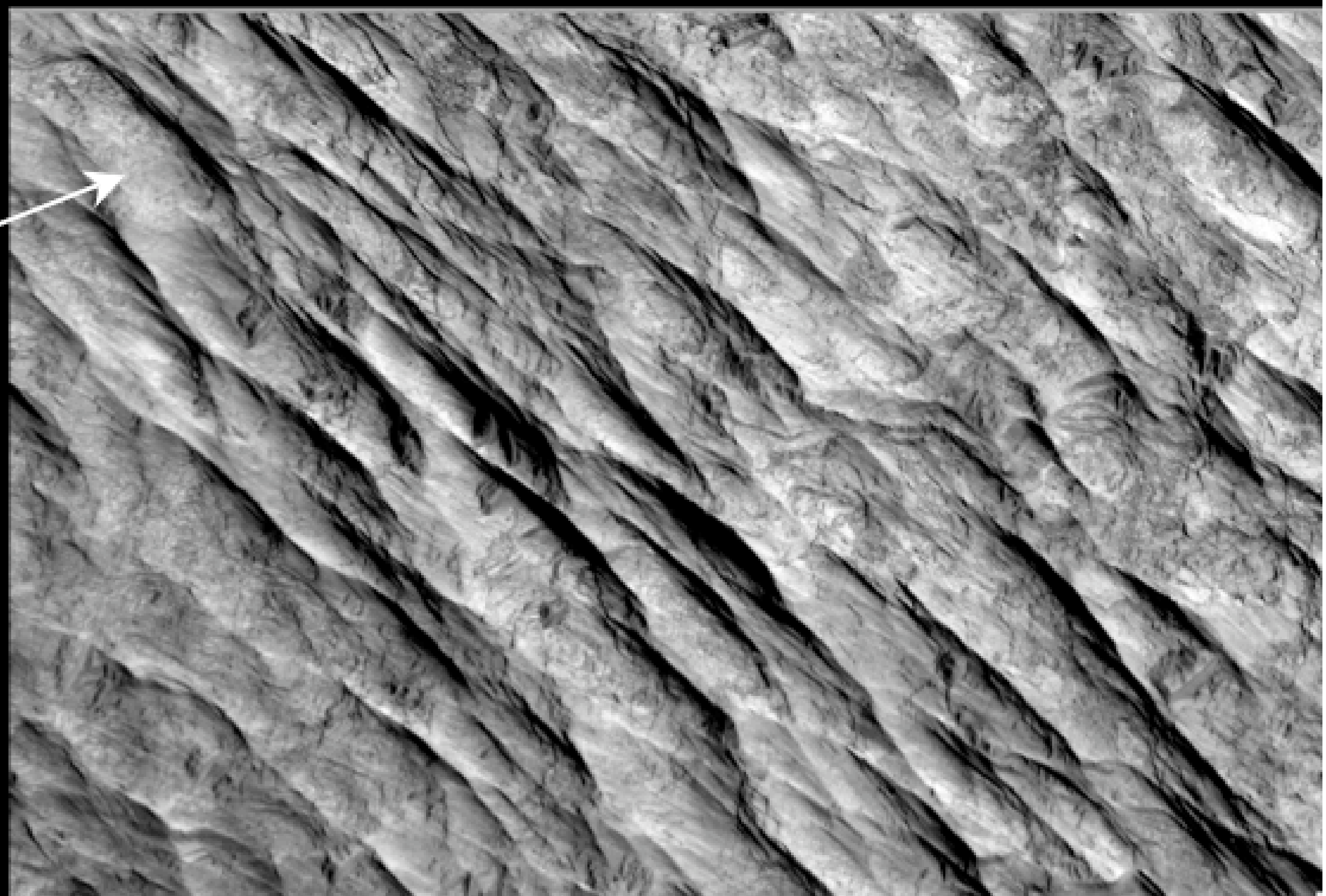
# Mawrth Vallis - red



J. Griffes

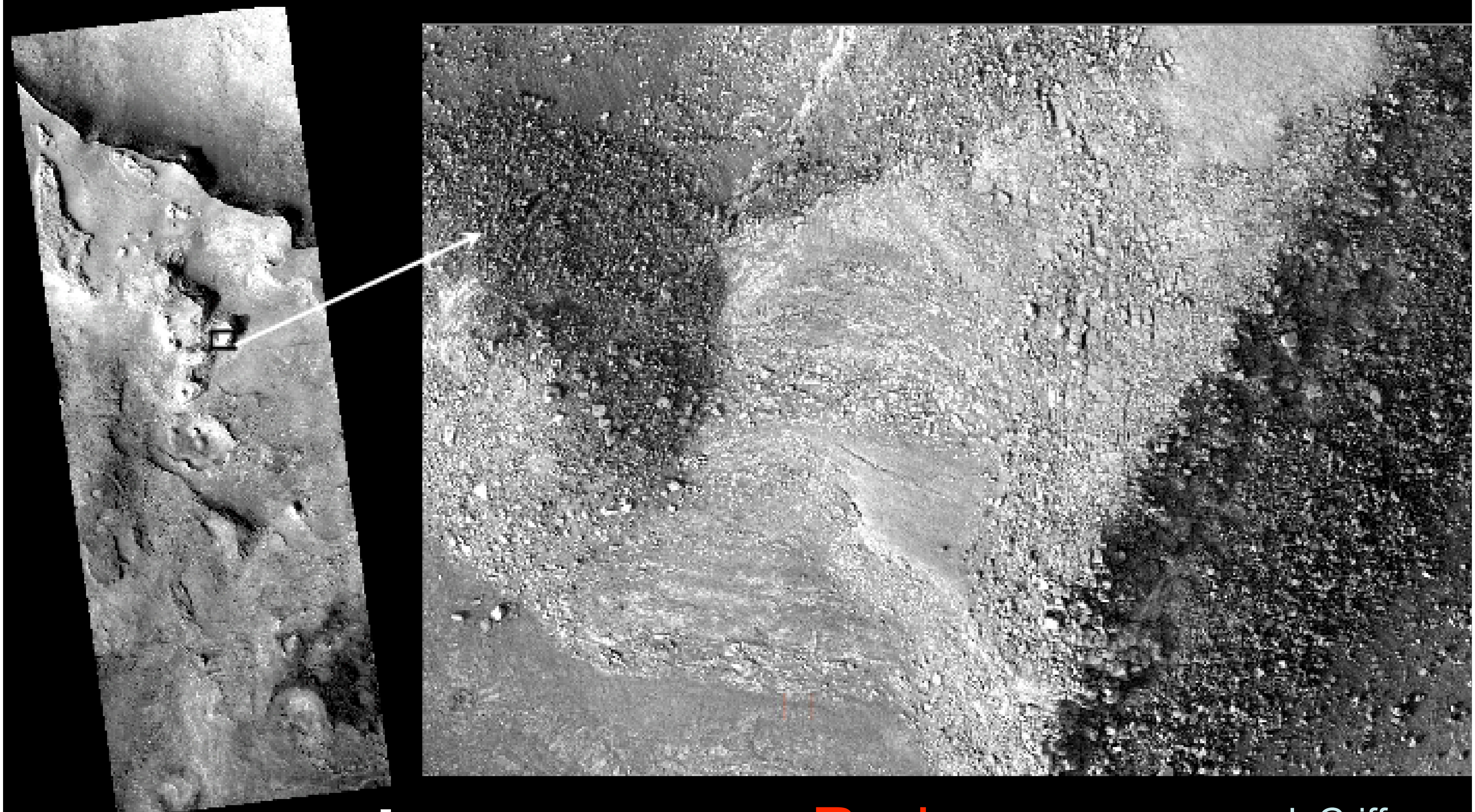
# W Candor - “Red”





J. Griffes

# Nilo Syrtis - rocks



Red

J. Griffes

# Summary MSL Landing Site Criteria

**Major Questions/ Criteria:**

**Landing Sites: (Workshop 1 Top Half)**

*Science Criteria*

| | *Nili Fos* | *Hol den* | *Ter by* | *Maw rth* | *Ebers walde* | *Gale* | *W. Cand* | *N. Merid* | *Juven* | *Nilo Syrt* | *Mel as* | *E. Merid* | *Iani* | *Nili Crat* | *Eos* | *Merid Crat* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|

Ability to Assess Biological
Potential w/MSL Payload
Evidence for Habitable
Environment (Environment of Formation and Deposition)
Aqueous Environment, Type of Habitable Environment
Preservation of Bio-
Signatures
Organic Material, (Pre) Biotic Materials,
Biologic Textures, Mineralogic Biosignatures

Ability to Characterize
Geology/Geochemistry
Context within Geologic
Timescale
Context within Geologic/
Geomorphic/
Stratigraphic Setting

Accessibility
Accessed by Rover/Arm
Go To
Distance/trafficability
to Materials of Interest
<1 km, <5 km, >10 km
Dust Obscuration

Reduced Performance
Thermal Constraints

**Major Questions/ Criteria:**

## Landing Sites: (Workshop 1 Top Half)

| *Safety Criteria* | *Nili Fos* | *Hol den* | *Ter by* | *Maw rth* | *Ebers walde* | *Gale* | *W. Cand* | *N. Merid* | *Juven* | *Nilo Syrt* | *Mel as* | *E. Merid* | *Iani* | *Nili Crat* | *Eos* | *Merid Crat* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surface Slope/Relief | | | | | | | | | | | | | | | | |
| 2-10 km Slope | green | yellow | green | green | yellow | green | green | green | green | green | red | green | yellow | green | green | green |
| 1-2 km Slope | green | green | yellow | green | green | yellow | red | green | yellow | yellow | red | green | yellow | green | yellow | green |
| 200-1000 m Slope | yellow | green | red | yellow | yellow | orange | red | yellow | red | red | red | green | red | yellow | yellow | yellow |
| 2-5 m Slope | | green | yellow | yellow | green | yellow | | green | green | green | | | | green | red | |
| Relief in HiRISE | green | yellow | yellow | yellow | orange | yellow | red | green | green | orange | red | yellow | orange | orange | orange | green |
| Warning Track Slope | | | | | | | | | | | | | | | | |
| 2-10 km Slope | green | green | green | green | green | green | green | green | green | green | red | green | green | green | green | green |
| Flexibility Ellipse Placement | yellow | green | red | yellow | yellow | yellow | red | red | red | red | red | green | red | green | yellow | yellow |
| Safe Haven? (non go to) | red | red | red | red | red | red | red | red | red | red | red | green | red | red | red | red |
| Uber Safe Haven | | | | | | | | | | | | red | | | | |
| Rock Abundance | | | | | | | | | | | | | | | | |
| IRTM | green | yellow | red | yellow | red | yellow | yellow | yellow | yellow | red | red | green | yellow | yellow | red | yellow |
| TES | red | red | red | yellow | red | | red | yellow | yellow | red | red | | | red | | |
| Rocks Present in HiRISE | | yellow | | green | | green | green | green | | red | green | green | red | red | red | |
| Load Bearing Surface | green | green | green | green | green | green | green | green | green | green | green | green | green | green | green | green |
| Dust (DCI, Albedo) | green | green | green | green | green | green | green | green | green | yellow | green | green | green | green | green | green |
| Atmospherically Challenging Site | | | | | | | | | | | | | | | | |

# Summary MSL Landing Site Criteria

**Landing Sites: (Workshop 1 Lower Half)**

| Major Questions/ Criteria: *Science Criteria* | *NE Syrt* | *Hellas Dao* | *Xan the* | *SW Arab* | *W Arab* | *W Merid* | *Elys AvCol* | *Isid Bas* | *Samra Valles* | *Eos Alluv* | *Aeolis Fan* | *VL1* | *VL2* | *MPF* | *Spir it* | *Opp* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ability to Assess Biological Potential w/MSL Payload | | | | | | | | | | | | | | | | |
| Evidence for Habitable | | | | | | | | | | | | | | | | |
| Environment Environment (Environment of Formation and Deposition) | | | | | | | | | | | | | | | | |
| Aqueous Environment, Type Habitable Environment | | | | | | | | | | | | | | | | |
| Preservation of Bio-Signatures | | | | | | | | | | | | | | | | |
| Organic Material, (Pre) Biotic Materials, Biologic Textures, Mineralogic Biosignatures | | | | | | | | | | | | | | | | |
| Ability to Characterize | | | | | | | | | | | | | | | | |
| Geology/Geochemistry | | | | | | | | | | | | | | | | |
| Context within Geologic/ Timescale | | | | | | | | | | | | | | | | |
| Context within Geologic/ Geomorphic/ Stratigraphic Setting | | | | | | | | | | | | | | | | |
| Accessibility | | | | | | | | | | | | | | | | |
| Accessed by Rover/Arm | | | | | | | | | | | | | | | | |
| Go To | | | | | | | | | | | | | | | | |
| Distance/trafficability to Materials of Interest <1 km, <5 km, >10 km | | | 🟢 | 🟢 | 🟡 | 🟡 | 🟢 | 🟡 | | | | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 |
| Dust Obscuration | 🟢 | | 🟡 | 🟡 | 🟡 | 🟢 | 🔴 | 🟡 | 🟢 | 🟢 | 🟢 | 🟢 | 🟡 | 🟢 | 🟡 | 🟢 |
| Reduced Performance | | | | | | | | | | | | | | | | |
| Thermal Constraints | | | | | | | | | | | | | | | | |

# Summary MSL Landing Site Criteria

**Major Questions/ Criteria:**
*Safety Criteria*

**Landing Sites: (Workshop 1 Bottom Half)**

| Major Questions/ Criteria: Safety Criteria | *NE Syrt* | *Hellas Dao* | *Xan the* | *SW Arab* | *W Arab* | *W Merid* | *Elys AvCol* | *Isid Bas* | *Samra Valles* | *Eos Alluv* | *Aeolis Fan* | *VL1* | *VL2* | *MPF* | *Spir it* | *Opp* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surface Slope/Relief | | | | | | | | | | | | | | | | |
| 2-10 km Slope | green | | green | green | green | green | green | green | | | | | | | | |
| 1-2 km Slope | green | | green | green | yellow | yellow | green | green | | | | | | | | |
| 200-1000 m Slope | yellow | | green | green | yellow | red | green | green | | | | | | | | |
| 2-5 m Slope | green | | green | | | green | green | yellow | | | | | | | | |
| Relief in HiRISE | yellow | orange | orange | orange | | green | orange | yellow | | | yellow | yellow | green | yellow | green | green |
| Warning Track Slope | | | | | | | | | | | | | | | | |
| 2-10 km Slope | green | | green | green | green | green | green | green | | | | | | | | |
| Flexibility Ellipse Placement | green | | green | green | green | yellow | green | green | | | | | | | | |
| Safe Haven? (non go to) | red | | yellow | yellow | red | red | yellow | red | | | | | | | | |
| Uber Safe Haven | | | yellow | red | | | yellow | | | | | | | | | |
| Rock Abundance | | | | | | | | | | | | | | | | |
| IRTM | green | | green | yellow | green | yellow | green | yellow | red | red | green | red | red | red | green | green |
| TES | red | | | green | yellow | | green | green | red | red | red | green | yellow | yellow | yellow | green |
| Rocks Present in HiRISE | red | red | | | | green | yellow | yellow | | | | yellow | red | red | green | green |
| Load Bearing Surface | green | | green | green | green | green | red | green | green | green | green | green | green | green | green | green |
| Dust (DCI, Albedo) | green | | green | green | green | green | red | green | green | green | green | green | yellow | green | green | green |
| Atmospherically Challenging Site | | | | | | | | | | | | | | | | |

# Summary MSL Landing Site Criteria

| Major Questions/ Criteria: | Landing Sites: (Workshop 2 New) | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Science Criteria* | *Adrian Colles* | *Richy Crat* | *Maw rth(1)* | *Maw rth(2)* | *Maw rth(3)* | *Nili. Foss* | *Terby. Alt* | *Nili Fs Tr alt* | *S Mer Clays* | *Chl Salt(1)* | *Chl Salt(2)* | *Chl Salt(3)* | *Chl Salt(4)* | *Chl Salt(5)* | *W Mer Alt* | *W Cndr Alt* | *Tiu Valles* |
| Ability to Assess Biological Potential w/MSL Payload | | | | | | | | | | | | | | | | | |
| Evidence for Habitable Environment (Environment of Formation and Deposition) | | | | | | | | | | | | | | | | | |
| Aqueous Environment, Type of Habitable Environment | | | | | | | | | | | | | | | | | |
| Preservation of Bio-Signatures | | | | | | | | | | | | | | | | | |
| Organic Material, (Pre) Biotic Materials, Biologic Textures, Mineralogic Biosignatures | | | | | | | | | | | | | | | | | |
| Ability to Characterize | | | | | | | | | | | | | | | | | |
| Geology/Geochemistry | | | | | | | | | | | | | | | | | |
| Context within Geologic Timescale | | | | | | | | | | | | | | | | | |
| Context within Geologic/ Geomorphic/ Stratigraphic Setting | | | | | | | | | | | | | | | | | |
| Accessibility | | | | | | | | | | | | | | | | | |
| Accessed by Rover/Arm | | | | | | | | | | | | | | | | | |
| Go To | | | | | | | | | | | | | | | | | |
| Distance/trafficability to Materials of Interest <1 km. <5 km, >10 km | 🔴 | 🔴 | 🟢 | 🟢 | 🟢 | 🟢 | | 🔴 | 🔴 | | | | | | 🟢 | 🟢 | |
| Dust Obscuration | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | |
| Reduced Performance | | | | | | | | | | | | | | | | | |
| Thermal Constraints | | | | | | | | | | | | | | | | | |

**Major Questions/**
**Criteria:**

**Landing Sites: (Workshop 2 New)**

| *Safety Criteria* | *Adrian Colles* | *Rbchy Crat* | *Mawrth(1)* | *Mawrth(2)* | *Mawrth(3)* | *Nili. Foss* | *Terby. Alt* | *Nili Fs Tr alt* | *S Mer Clays* | *Chl Salt(1)* | *Chl Salt(2)* | *Chl Salt(3)* | *Chl Salt(4)* | *Chl Salt(5)* | *W Mer Alt* | *W Cndr Alt* | *Tiu Valles* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Surface Slope/Relief | | | | | | | | | | | | | | | | | |
| 2-10 km Slope | green | green | green | green | green | green | green | green | green | green | green | green | green | green | green | green | |
| 1-2 km Slope | green | green | green | green | green | green | green | green | green | green | green | green | green | green | green | green | |
| 200-1000 m Slope | green | yellow | green | yellow | green | red | green | green | green | green | green | green | green | yellow | green | red | |
| 2-5 m Slope | yellow | | | | | | yellow | yellow | | | | | | | red | | |
| Relief in MOC | green | green | orange | red | yellow | yellow | orange H | yellow | orange | green | | | | | yellow H | green | |
| Warning Track Slope | | | | | | | | | | | | | | | | | |
| 2-10 km Slope | green | green | green | green | green | red | green | green | green | green | green | green | green | green | green | green | |
| Flexibility Ellipse Placement | green | red | green | yellow | yellow | red | green | yellow | yellow | green | red | green | green | yellow | yellow | red | |
| Safe Haven? (non go to) | red | red | yellow | yellow | orange | red | yellow | red | red | yellow | red | red | red | red | yellow | red | |
| Uber Safe Haven | | | yellow | yellow | orange | | yellow | | | red | | | | | yellow | | |
| Rock Abundance | | | | | | | | | | | | | | | | | |
| IRTM | | | | | | | | | | | | | | | | | |
| TES | red | red | red | red | | red | | | | | green | yellow | red | | | red | |
| Rocks Present in HiRISE | | | | | | | | | | | | | | | | red | |
| Load Bearing Surface | green | green | green | green | green | green | green | green | green | green | green | green | green | green | green | green | |
| Dust (DCI, Albedo) | green | green | green | green | green | green | green | green | green | green | green | green | green | green | green | green | |
| Atmospherically Challenging Site | | | | | | | | | | | | | | | | | |

# Summary MSL Landing Site Criteria

| **Major Questions/ Criteria:** | **Landing Sites: (Workshop 2 New)** | | | | | | |
|---|---|---|---|---|---|---|---|
| *Science Criteria* | *Gale Alt* | *Juv Alt* | *Mer B1* | *Mer B2* | *Mer B3* | *Mer B4* | *N Mer. M&E Alt* |
| Ability to Assess Biological Potential w/MSL Payload | | | | | | | |
| Evidence for Habitable Environment (Environment of Formation and Deposition) Aqueous Environment, Type of Habitable Environment | | | | | | | |
| Preservation of Bio-Signatures Organic Material, (Pre) Biotic Materials, Biologic Textures, Mineralogic Biosignatures | | | | | | | |
| Ability to Characterize | | | | | | | |
| Geology/Geochemistry | | | | | | | |
| Context within Geologic Timescale | | | | | | | |
| Context within Geologic/ Geomorphic/ Stratigraphic Setting | | | | | | | |
| Accessibility | | | | | | | |
| Accessed by Rover/Arm | | | | | | | |
| Go To | | | | | | | |
| Distance/trafficability to Materials of Interest <1 km, <5 km, >10 km | | 🟡 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 |
| Dust Obscuration | | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 | 🟢 |
| Reduced Performance | | | | | | | |
| Thermal Constraints | | | | | | | |

**Major Questions/ Criteria:**

**Landing Sites: (Workshop 2 New)**

| *Safety Criteria* | *Gale Alt.* | *Juv Alt* | *Mer B1* | *Mer B2* | *Mer B3* | *Mer B4* | *N Mer. Alt* |
|---|---|---|---|---|---|---|---|
| Surface Slope/Relief | | | | | | | |
| 2-10 km Slope | green | green | green | green | green | green | green |
| 1-2 km Slope | green | green | green | green | green | green | green |
| 200-1000 m Slope | yellow | red | green | green | green | green | yellow |
| 2-5 m Slope | | | | | | | |
| Relief in MOC/HiRISE | yellow | yellow | orange | orange | orange | orange | yellow |
| Warning Track Slope | | | | | | | |
| 2-10 km Slope | green | yellow | green | green | green | green | green |
| Flexibility Ellipse Placement | yellow | red | red | green | green | red | green |
| Safe Haven? (non go to) | yellow | red | yellow | green | green | red | green |
| Uber Safe Haven | yellow | | red | red | yellow | | red |
| Rock Abundance | | | | | | | |
| IRTM | | | | | | | |
| TES | | | | | | red | |
| Rocks Present in HiRISE | | | | | | | |
| Load Bearing Surface | | green | green | green | green | green | green |
| Dust (DCI, Albedo) | | green | green | green | green | green | green |
| Atmospherically Challenging Site | | | | | | | |

# Summary

- Most Sites Require Traverse >5 km to Materials of Interest (Most “Go To” Sites)
- Candor Chasma Fails Elevation Constraint
- Melas Chasma, Terby, Juventae & Juventae Alt, Nilo Syrtis, Iani, W. Meridiani, Nili Fossae, Candor & Candor Alt Fail >0.2 km Slope Constraints
  - Most Sites Strictly Fail 43 m at 1 km Constraint (high 90s%)
- Few Sites Have Flexibility in Ellipse Placement
- Elysium Fails Load Bearing and/or Dust Constraint
- Most Sites Fail ROCK Constraint -
  - Taken Directly from IRTM and TES - HiRISE Observations
- Almost All Sites Have Some Concerns
- Possible Safe Havens -
  - E. Meridiani, N. Meridiani Alt, Meridiani B2, SW Arab
- Possible Uber Safe Havens
  - Terby Alt, Mawrth B1&3, W. Merid Alt, Merid B3, Xanthe, Gale Alt?