Rocks at the MSL Landing Sites

Engineer's Definition of a Rock
Something that Could Damage Rover when Landing
Something to Avoid while Driving

M. Golombek, A. Huertas, D. Kipp, V. Hanus & Y. Sun
Jet Propulsion Laboratory, California Institute of Technology

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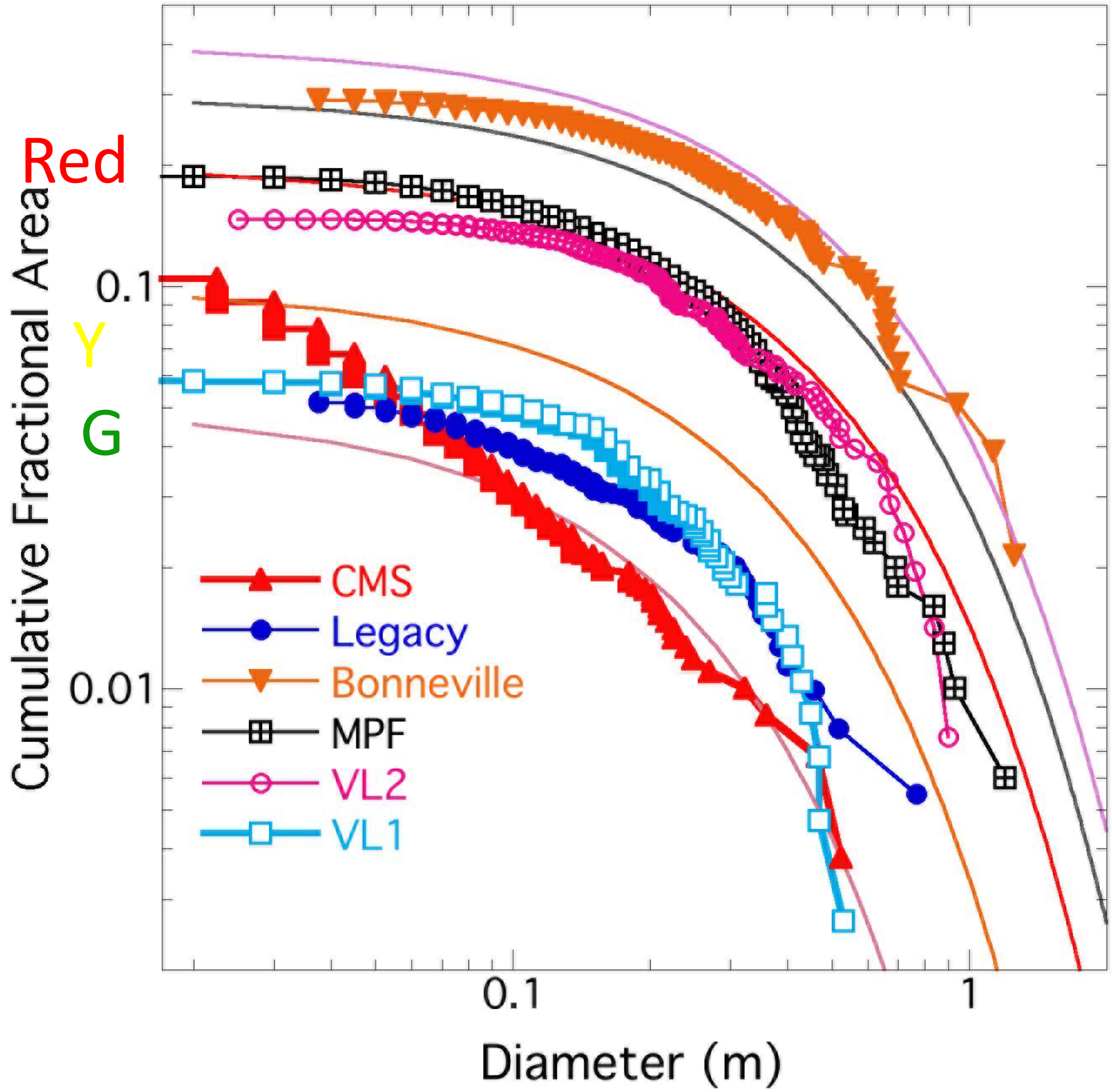
Outline

- Background
  - Model Based on VL1, VL2
  - Successfully Predicted MPF, MER RA based on IRTM, TES RA
- Phoenix
  - "What you can't see (without HiRISE) can hurt you"
  - See Same Rocks in HiRISE as See on Ground
  - Automated Rock Counting Software
  - Counts & Extrapolation from Model Predicted PHX Rocks
- Improvements Made for MSL
  - Automated Deconvolution Sharpens Image, Rocks 3 pixels
  - Non Rocks & Editing
  - Automated Removal of Non Rocks, Model Fit, Extrapolation
  - Assessment of Rock Hazard at Sites

Rock Size-Frequency Distributions



Model Distribution 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

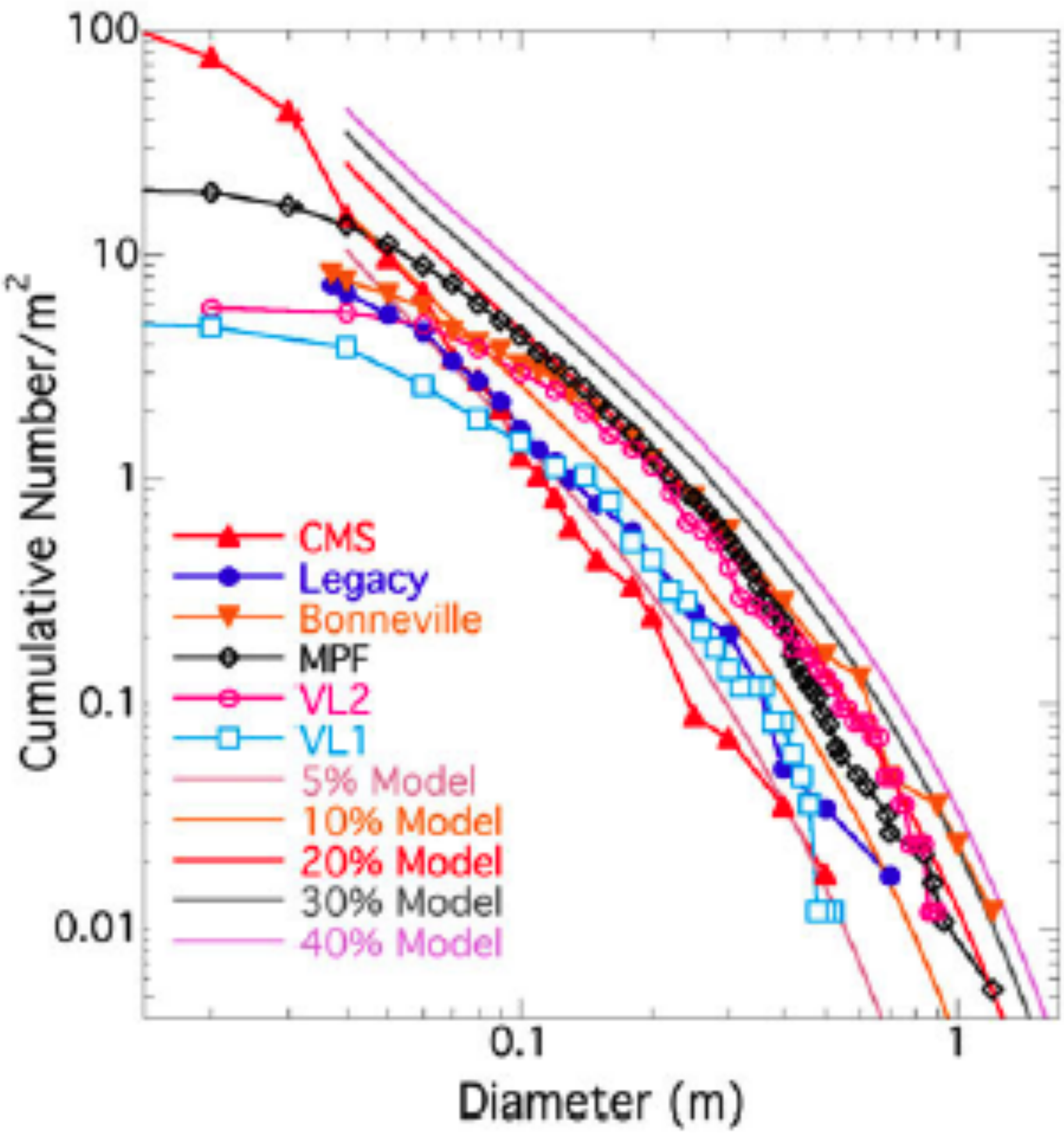
$F_k(D) = k \exp[-q(k) D]$

$F_k(D)$ Cum. Frac. Area

k is Total Rock Abundance Relate to IRTM Rock Abundance

Golombek et al. [2005, 2006]

Cumulative Number Distributions

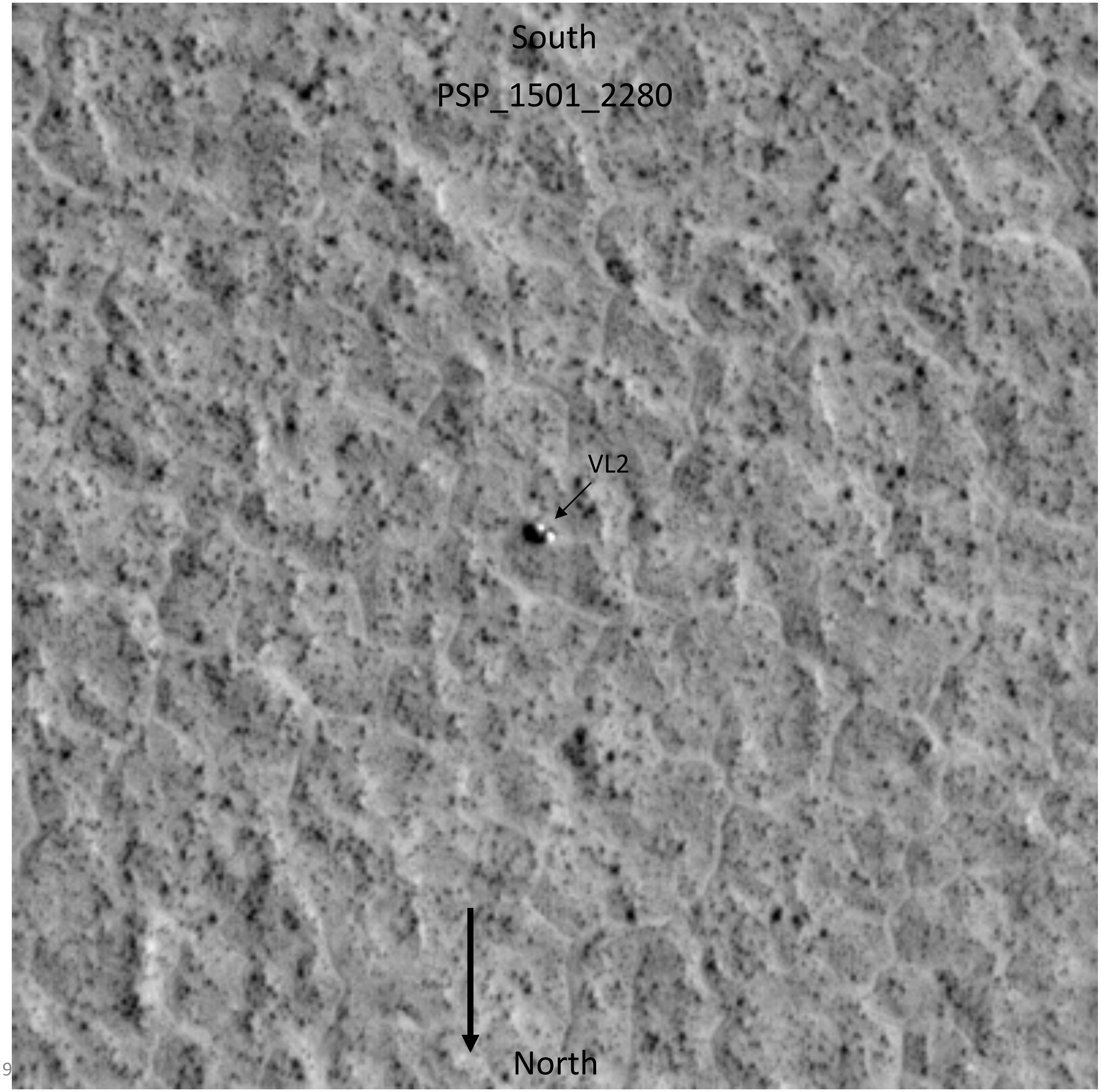


Cumulative Number Model Distributions

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

Golombek et al. [2003, 2006]



VL2

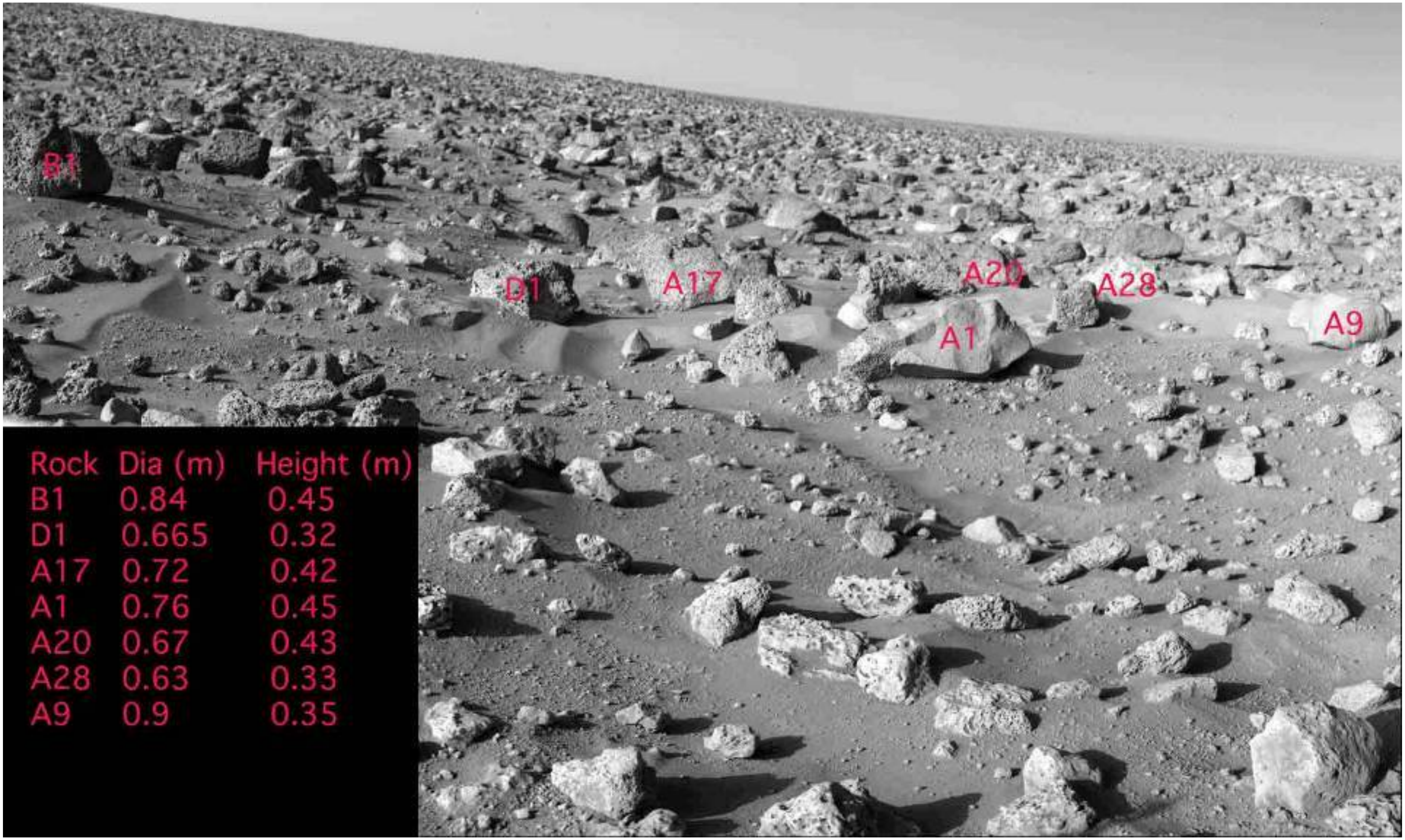
HiRISE Search for PHX Landing Site Changed Everything

Can See Rocks Directly in HiRISE

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

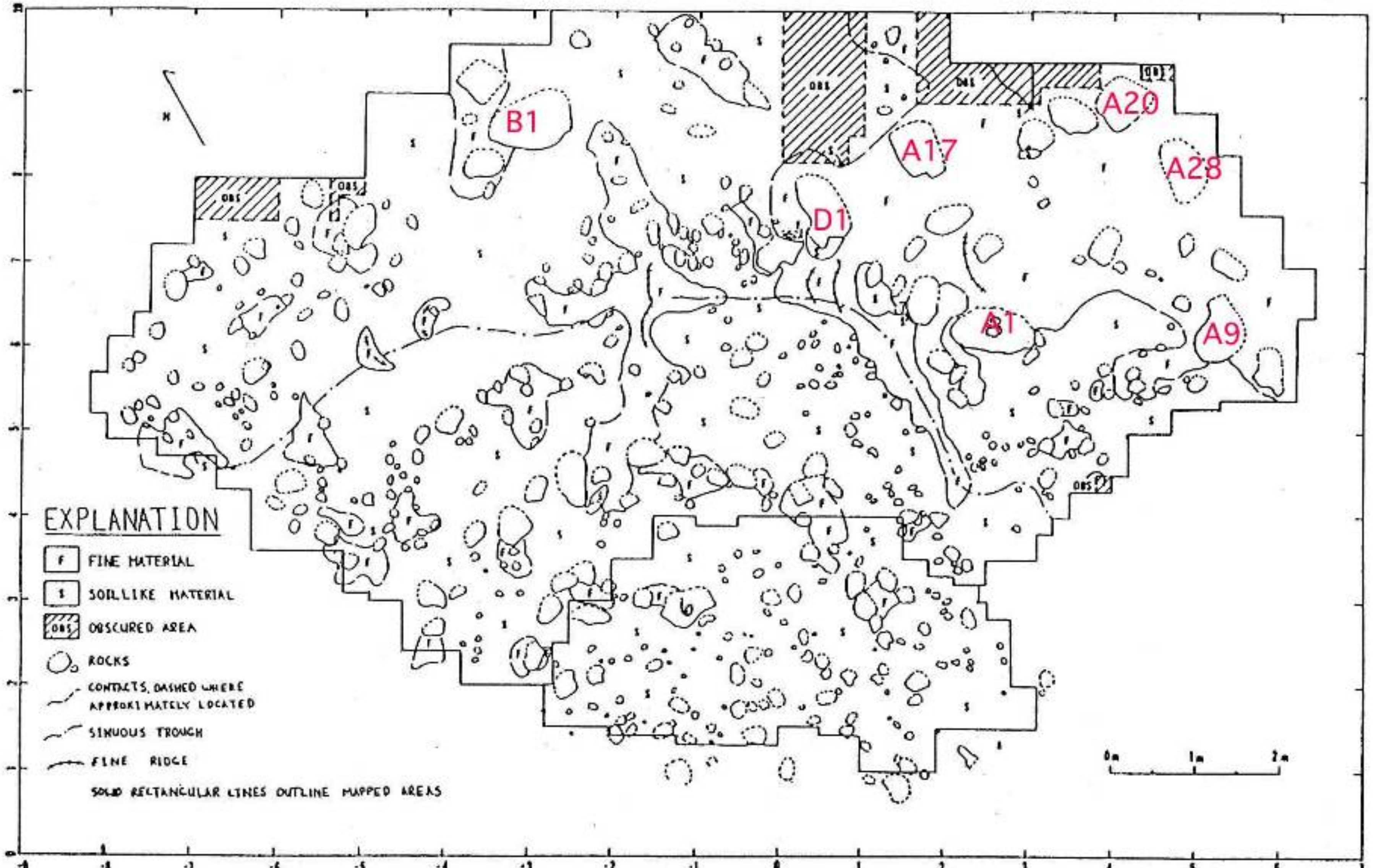
400x400 pixels
124x124 meters
1.5 hectares

VL2 Large Rocks



Moore & Keller

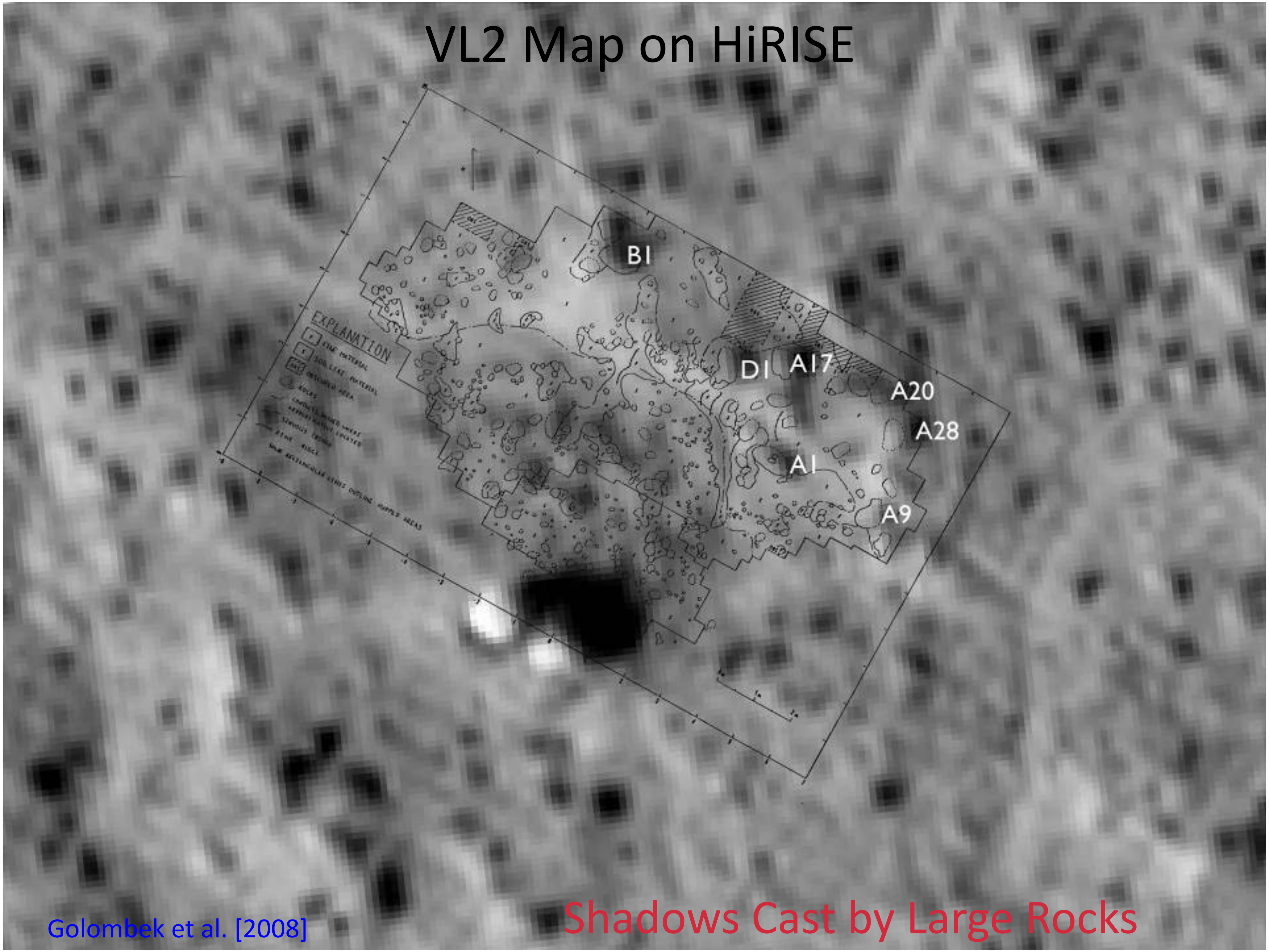
VL2 Map



7 Largest Rocks

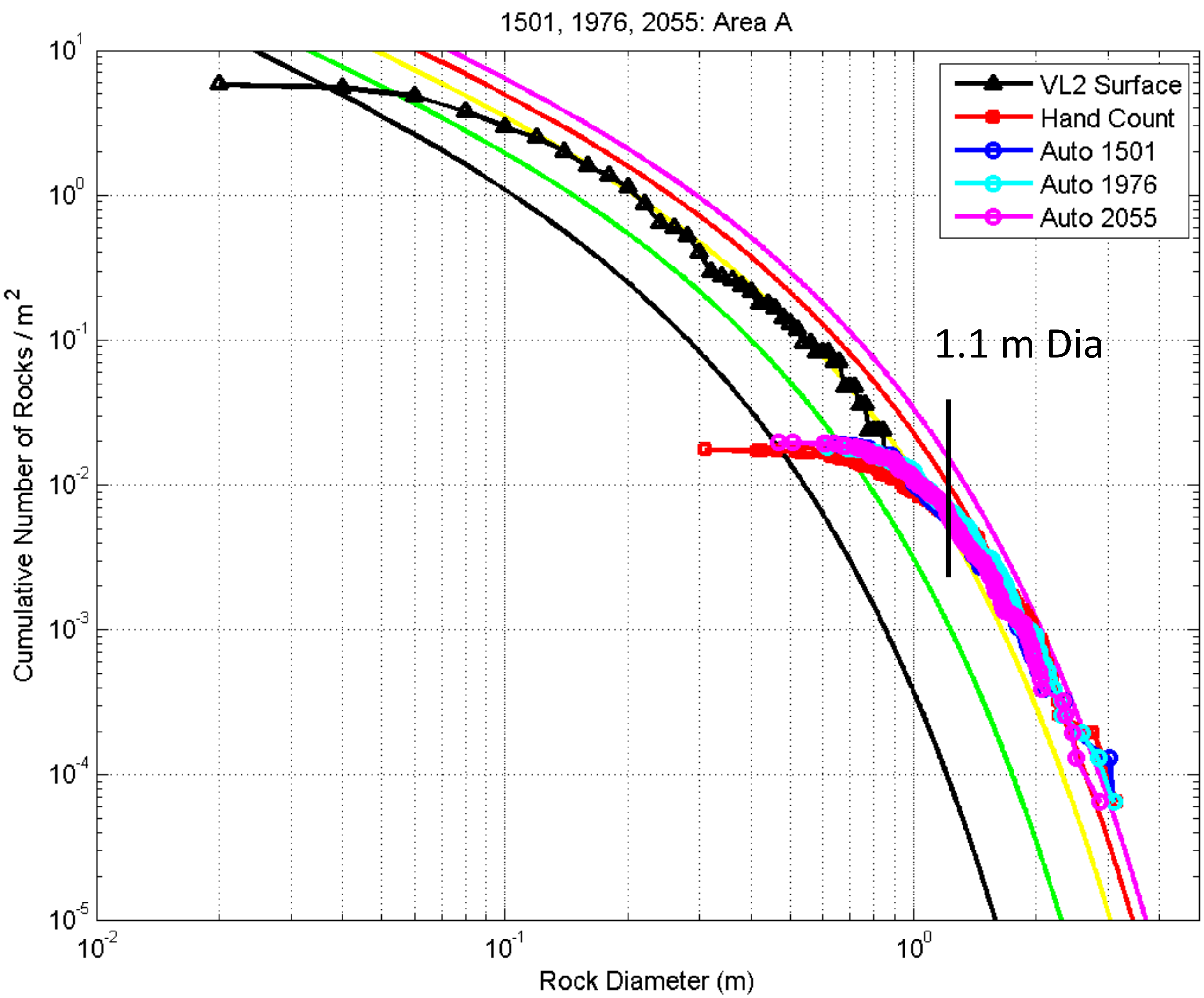
Moore & Keller

VL2 Map on HiRISE



Golombek et al. [2008]

VL2 Surface to HiRISE Comparison



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

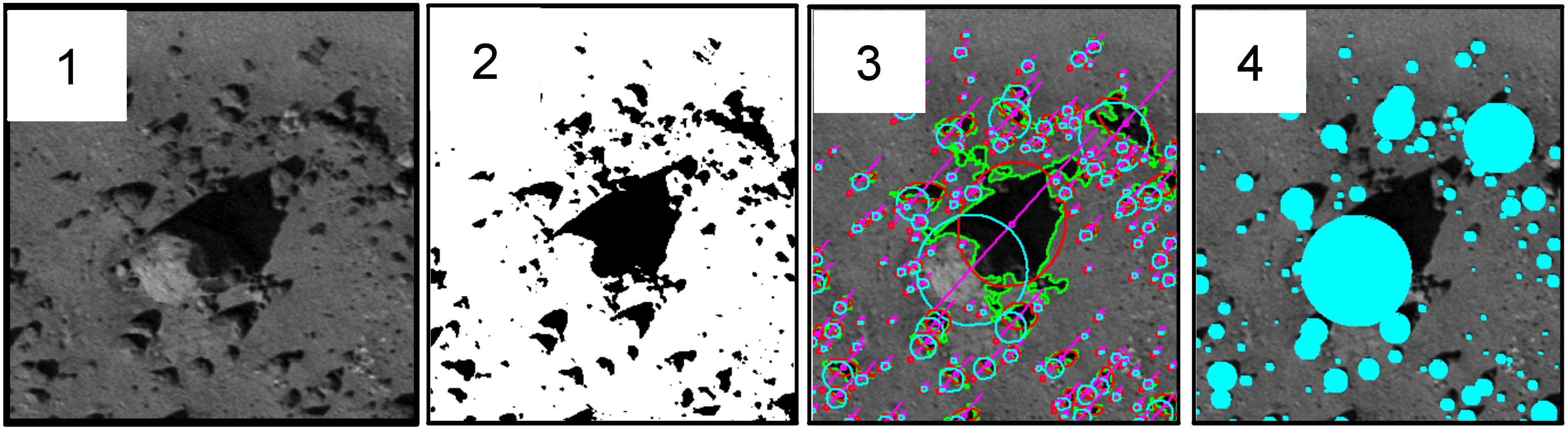
Do Not See All Rocks in HiRISE <1.5 m Diameter - Resolution Roll Off

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

VL2 ~20-30% Rock Coverage

Golombek et al. [2008]

Automated Rock Counting



1) Image Huertas et al.
2) Software Segments Shadow [>5 pixels]
3) Fits Ellipse to Shadow - Width is Rock Width
4) Fits Cylinder to Rock - Diameter is Rock Diameter

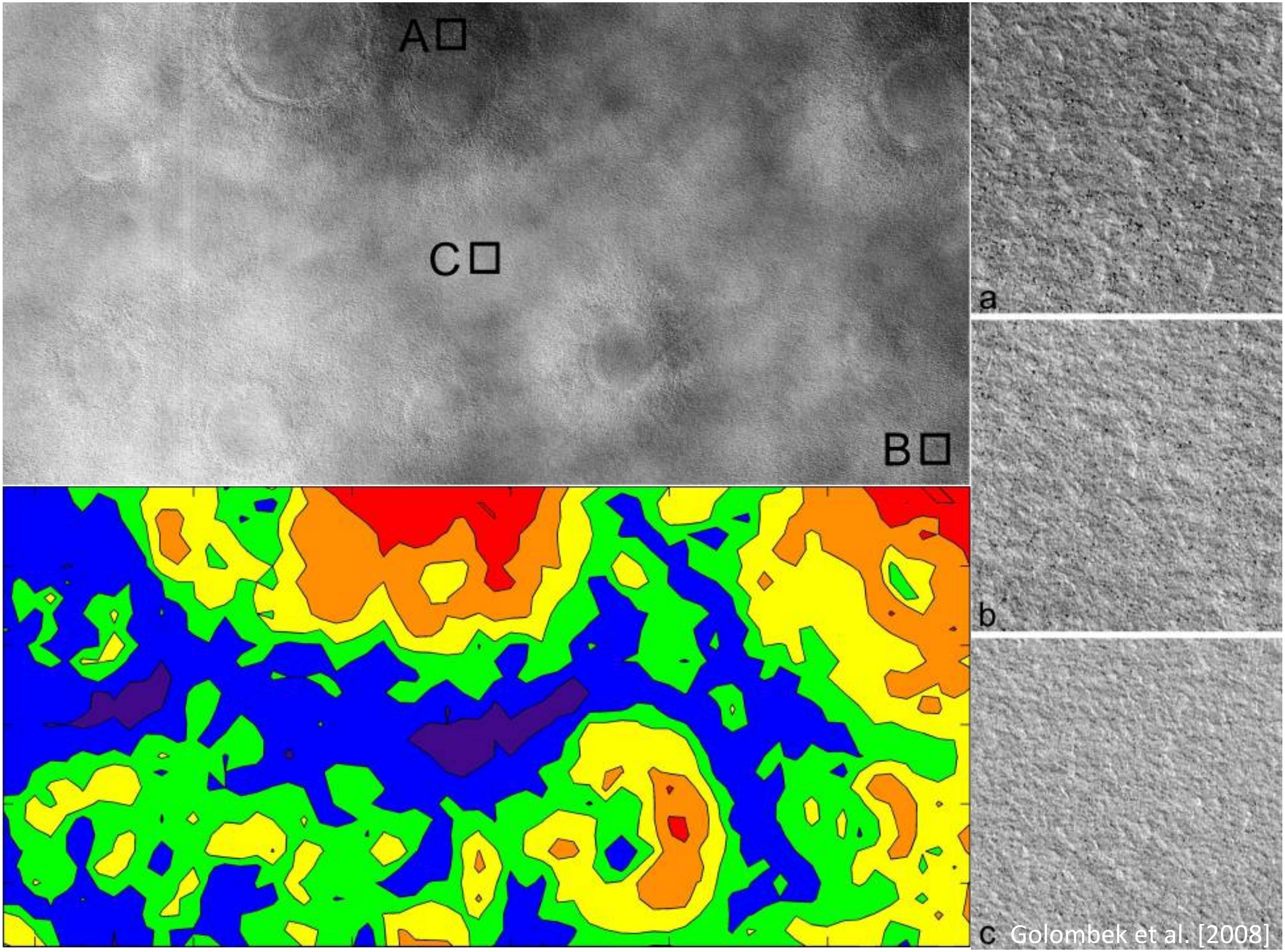
Height is Rock Height from Shadow Length

Results Match Hand Counts Golombek et al. [2008]

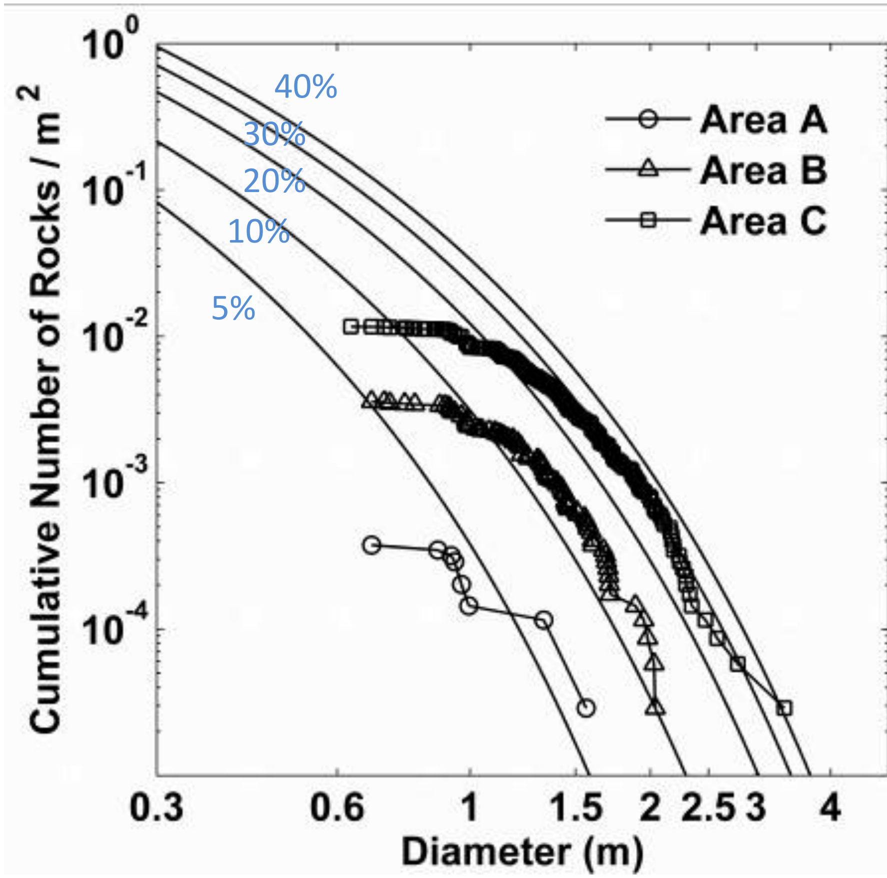
Results for Lander and Rovers of Known Size Generally ±1 pixel

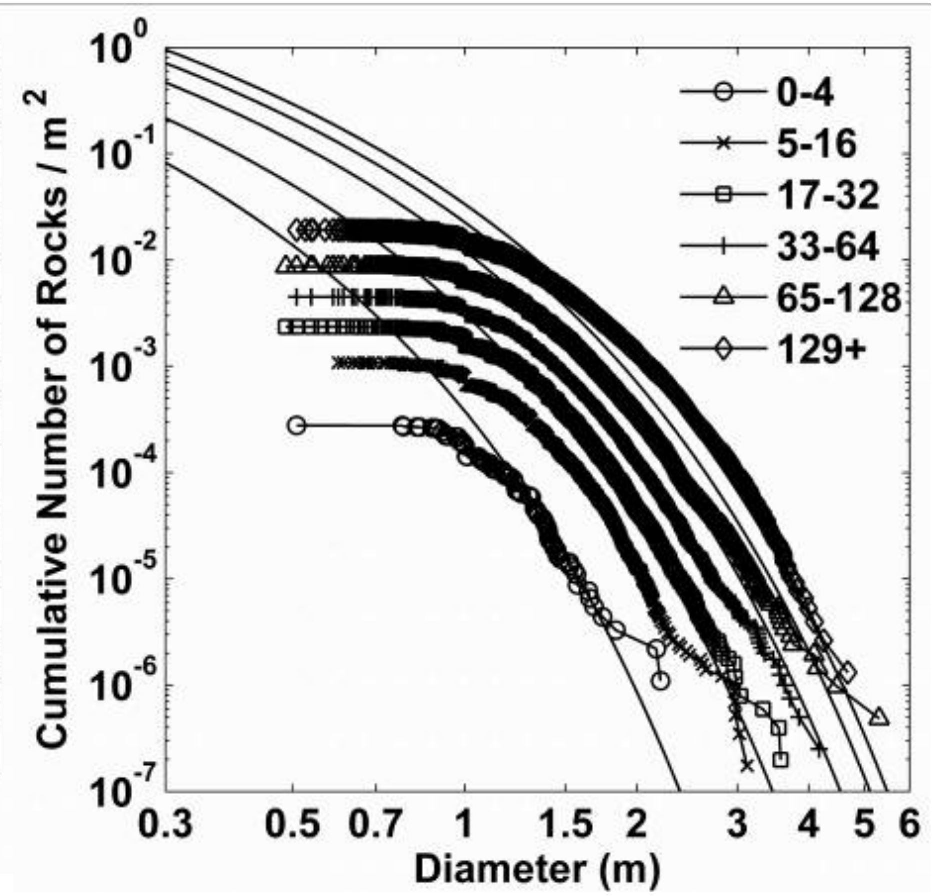
Used to Map ~10 million rocks >1500 km^2 of the Northern Plains

Certified Phoenix Landing Site, Accurately predicted surface rocks


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

Cumulative Number Rocks/m^2





541 rocks counted

65,470 rocks counted

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

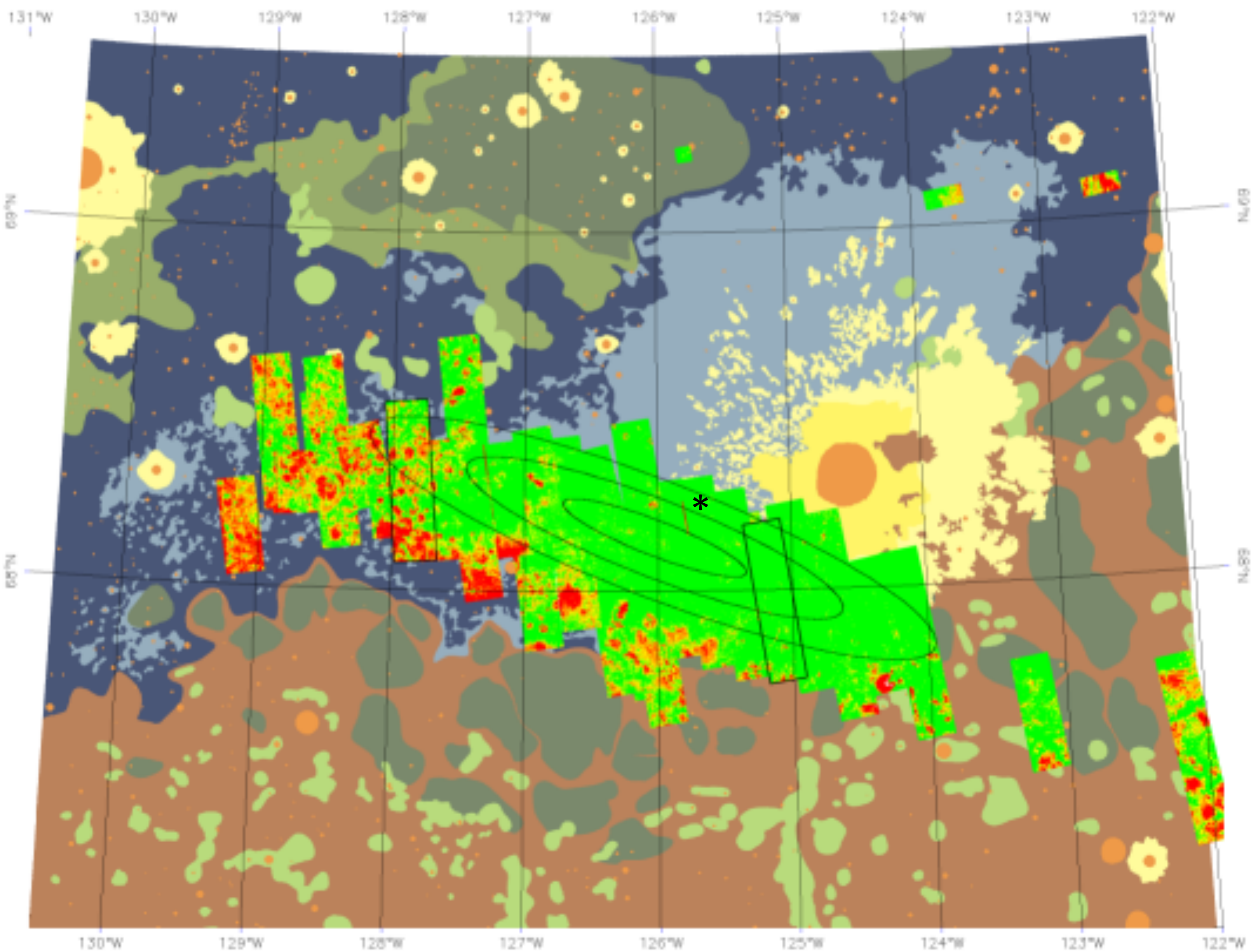
Golombek et al. [2008]

Cumulative Number Rocks; Cumulative Fractional Area; Risk

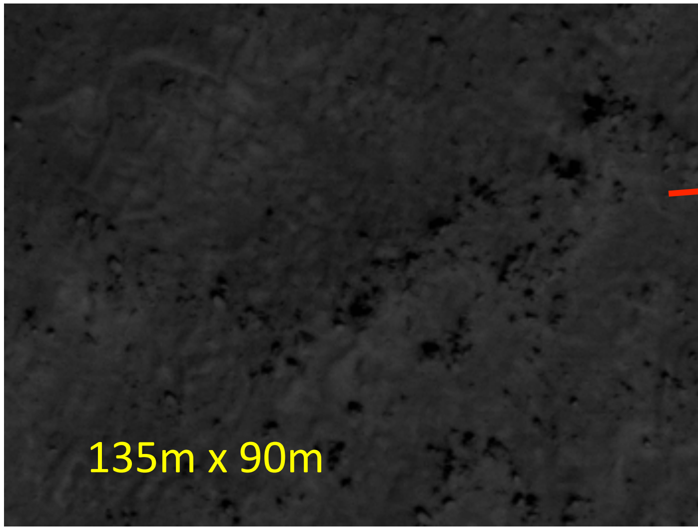
- Rock density maps: cumulative number of rocks per hectare with diameter $\geq$ 1.5 m.
- Rock hazard thematic maps: color-coded CFA

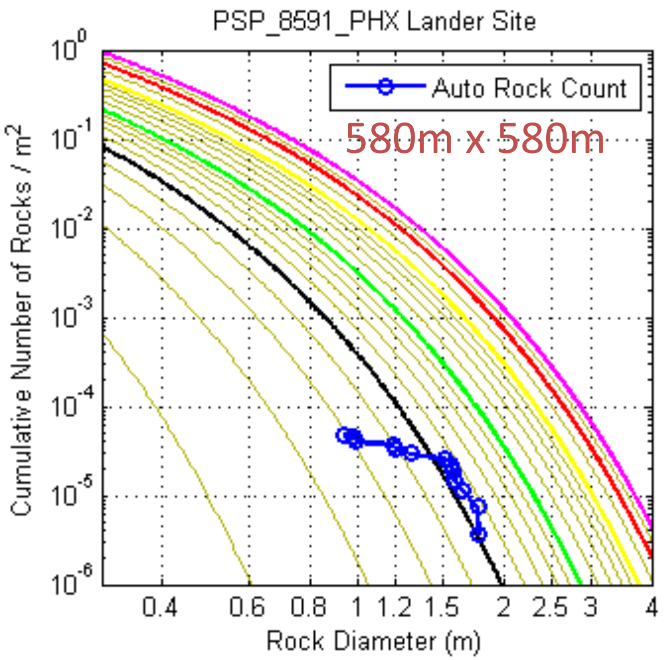
Color	Rocks ³ 1.5 m Wide/Hectare	Cumulative Fractional Area Covered by Rocks	Total Probability of Rock Impact (H/D=0.5)
Green	0 - 3	0 - 10%	0.000 - 0.019
Yellow	4 - 8	10 - 14%	0.019 - 0.034
Orange	9 - 19	14 - 21%	0.034 - 0.070
Red	> 19	> 21%	> 0.070

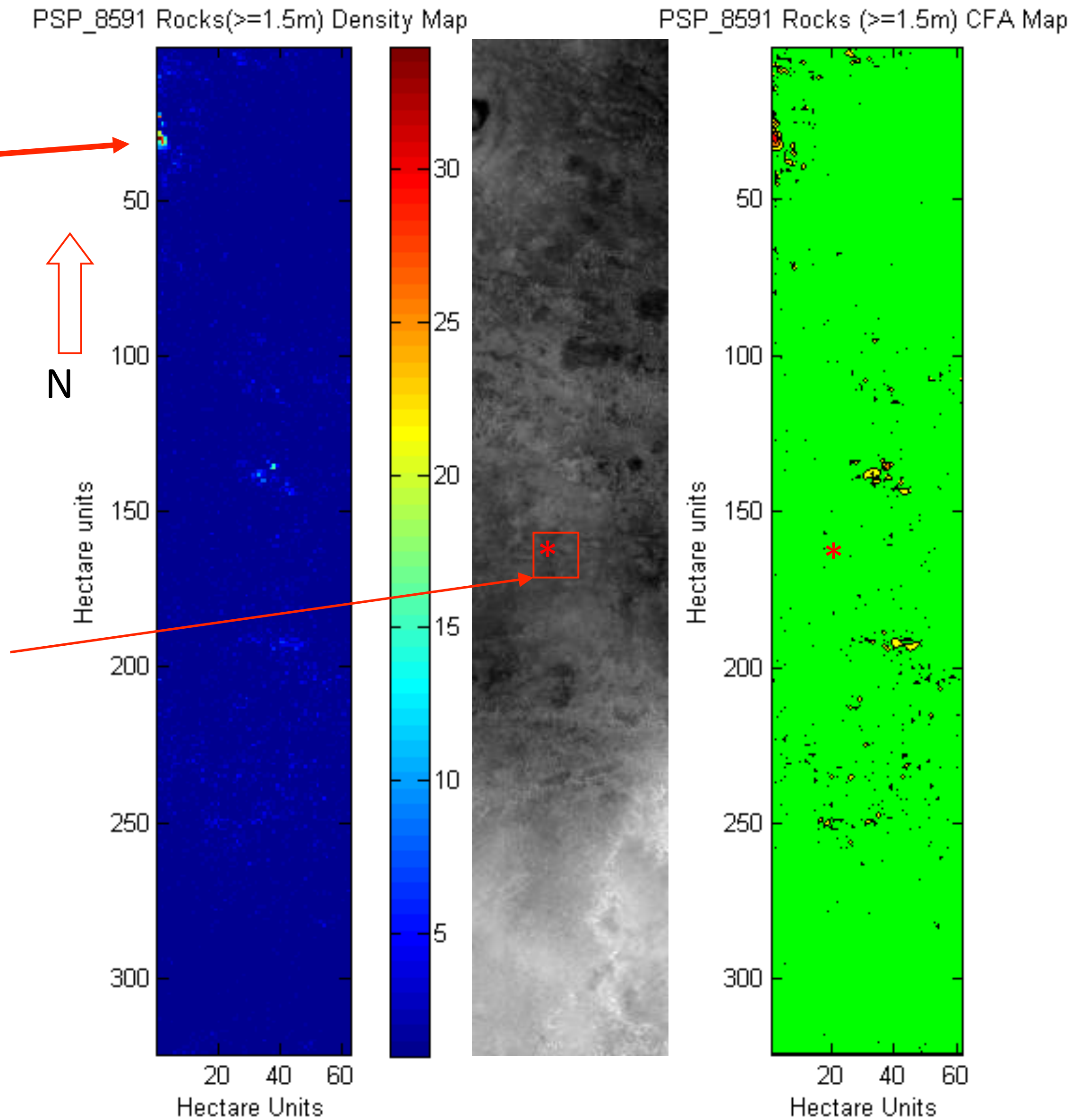
Phoenix Rock Map



PSP_8591: 4,027 Rocks with Diameter ≥ 1.5 m

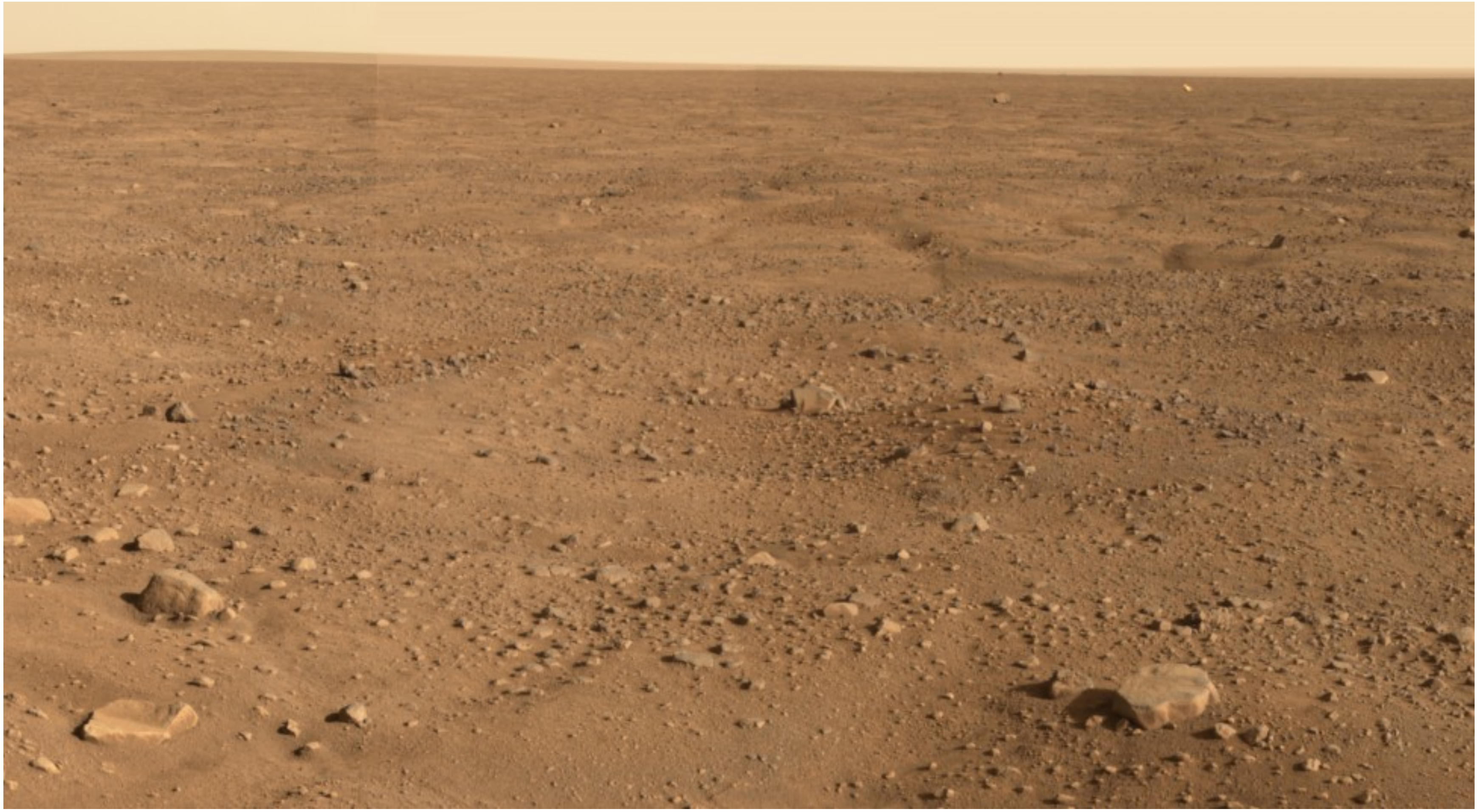






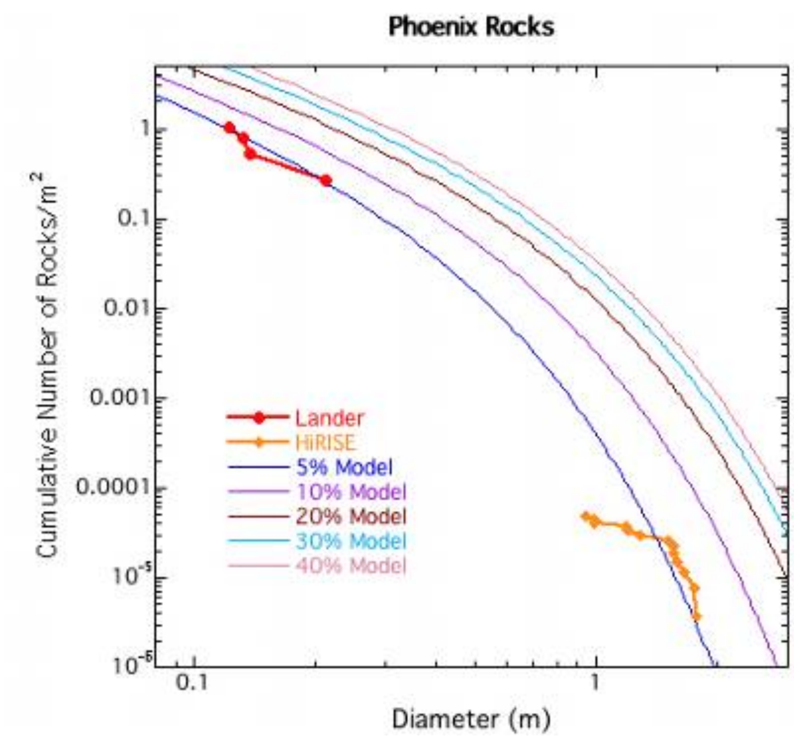
* Phoenix Landing site

TEST - Phoenix Landed in Green
No Large Rocks!

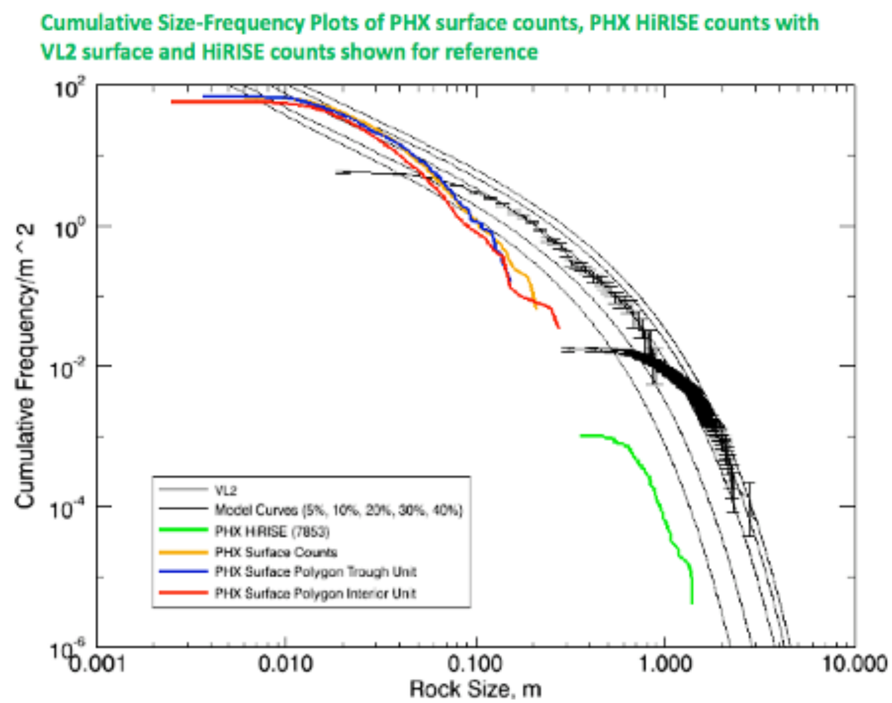


Surface – HiRISE Rock Distributions

Same Population from HiRISE and Surface
Method Works Can Accurately Extrapolate along Model



Auto HiRISE Count
vs Largest Rocks
Near Lander



Hand HiRISE Count Near Lander
vs All Rocks in Work Area

Huertas & Golombek

T. Heet et al.

Enhancements/Limitations for MSL

- HiRISE image restoration
  - High quality (SNR) Images
  - Blind deconvolution using small gaussian PSF in four iterations
  - Allows robust detection and modeling of rocks casting 3-pixel shadows
  - Improves full rock resolvability down to ~1.2 m diameter
- Sectional image processing
  - Detection parameters optionally adjusted for 8 image sections to conform better to more complex terrain in MSL landing site candidates
  - Refined measurement of shadow width and length
- Detects non-rocks. Individual rock-like fragments. Rock clump shadow separation also breaks narrow scarp shadows and thus detects rock-size scarp fragments.
- Interactive graphical re-classification tool assists humans to re-classify non-rock detections.
  - Needed for extrapolating rock abundance to smaller, still hazardous, rocks using M. Golombek's rock abundance model
  - See D. Kipp presentation for systematic, automated, re-classification approach

Huertas & Golombek

Rock Detection Process

1. Break non-Mapped HiRise image into 16 sections (matlab limit) and restore sharpness by deconvolution. Use 7x7 Gaussian PSF,σ=1, 4 iterations.
2. Assemble into 8 image sections.
3. Run detector with test parameters (sun angles and filters) on 10% of image tiles (~ 150m x 150m)
4. Adjust parameters for each section and repeat 3. until best observed detection result.
5. Run entire image (save tiles)
6. Assemble full image rock list
7. Generate SFD/CFA plots and binned (e.g. hectare) maps and thematic maps

- Algorithm detects all shadow regions and fits ellipse to each separate region for fast sizing.
- Select shadow regions between 3 and n pixels (< 9m rock diam.)
- Shadow terminator >= contrast threshold (e.g. not smooth)
- Shadow ellipse l:w ratio < 4.0
- Min shadow size to try separate.
- And Gamma (1< γ < 10): non-linear shadow enhancement to deal with varying:
  – Image contrast (shadow to soil), blur, noise, shadow effects (umbra/penumbra).

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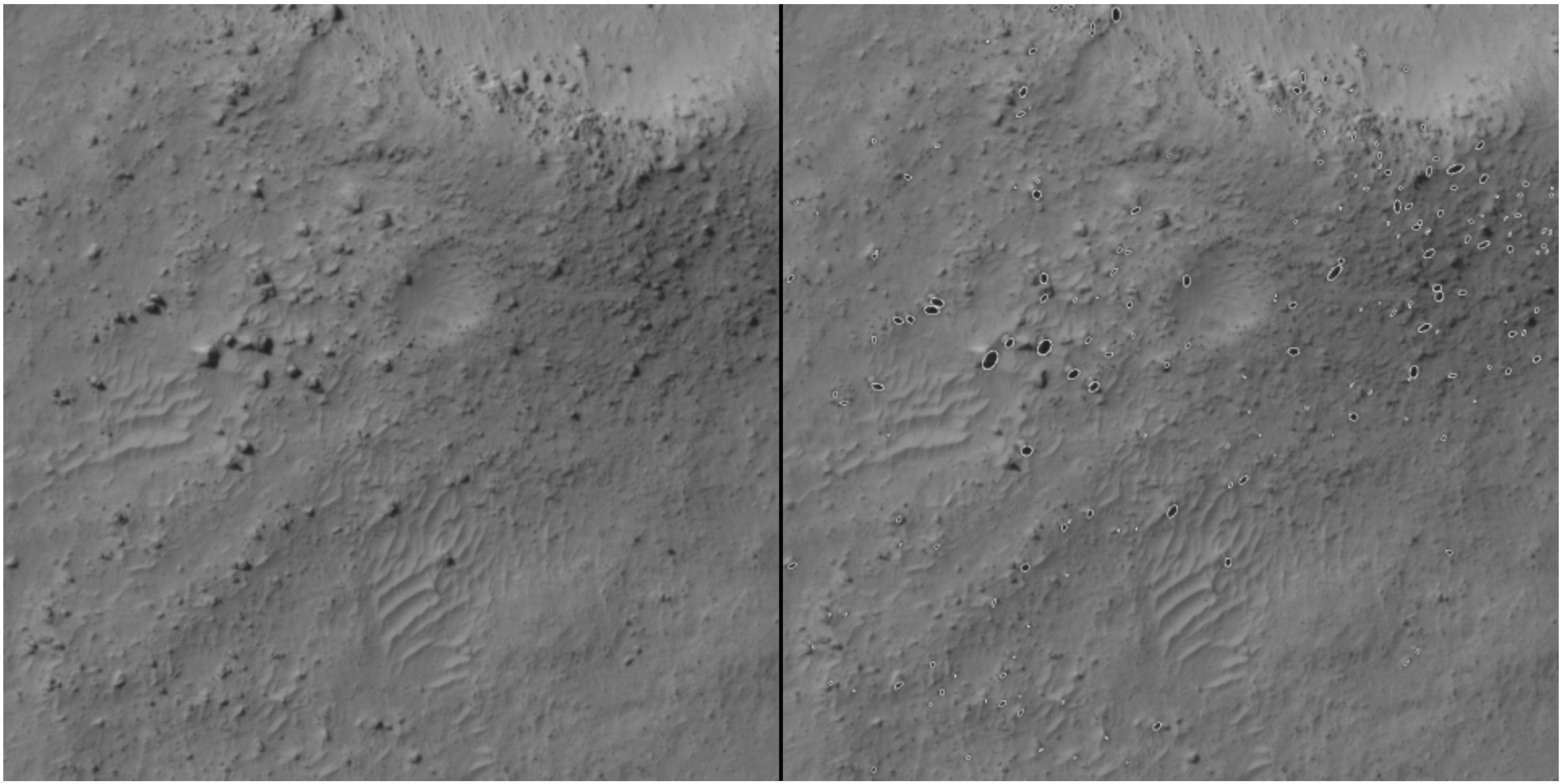
Original

265m x 265m sub image from original Gale image. Detected shadows >= 5 pixels represented by ellipses (right)

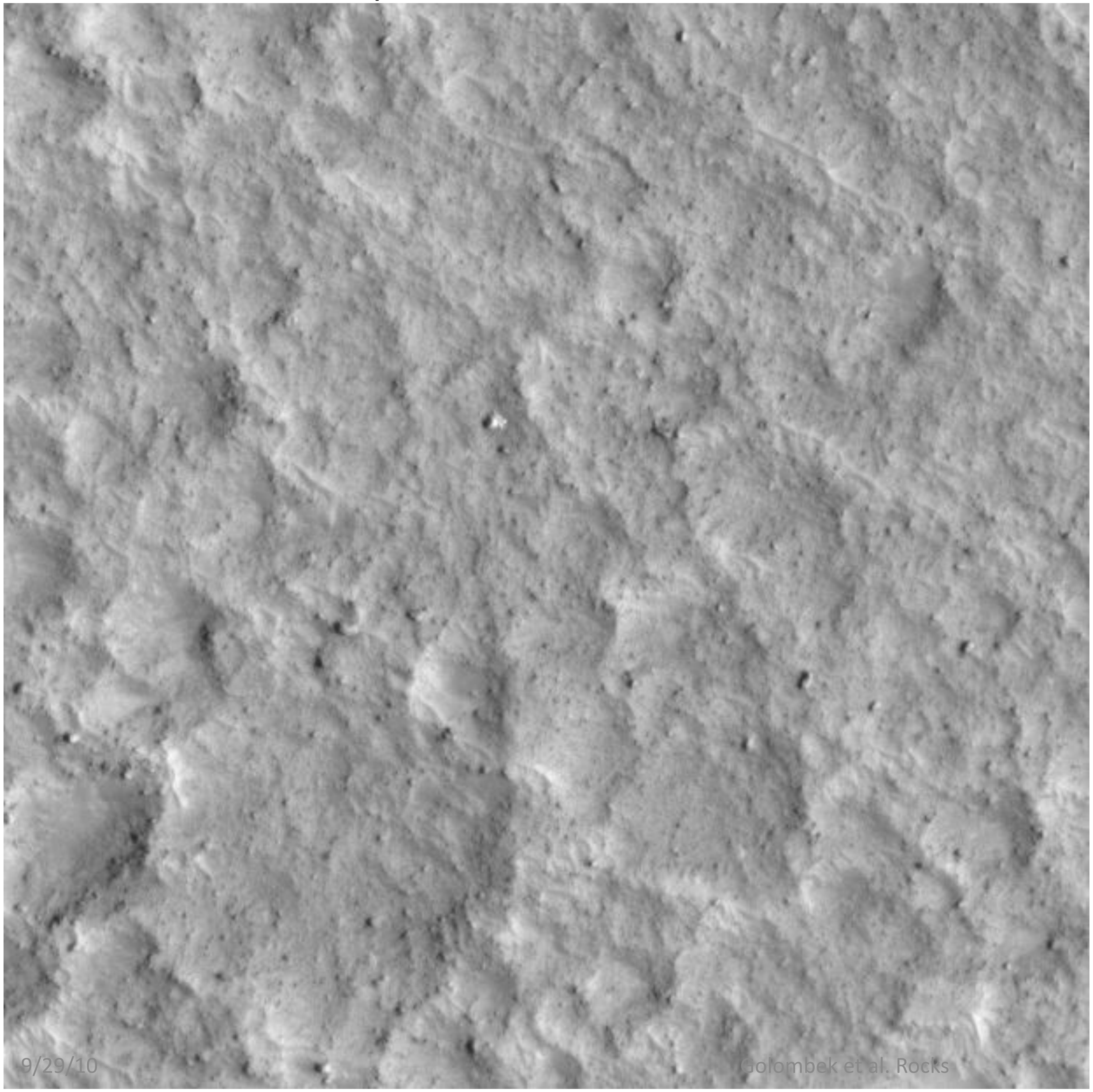


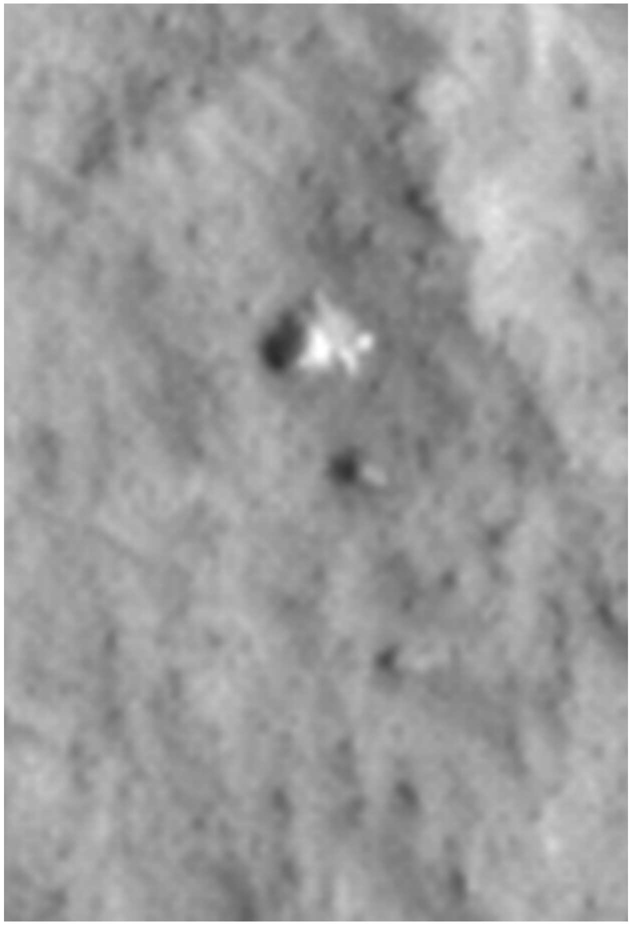
Sharpened - Decovolution

265m x 265m sub image from restored Gale image. Detected shadows
>= 3 pixels represented by ellipses (right)

MPF - PSP_1890 - Original

620x620 pixels ~ 185m x 185m





Lander Detail

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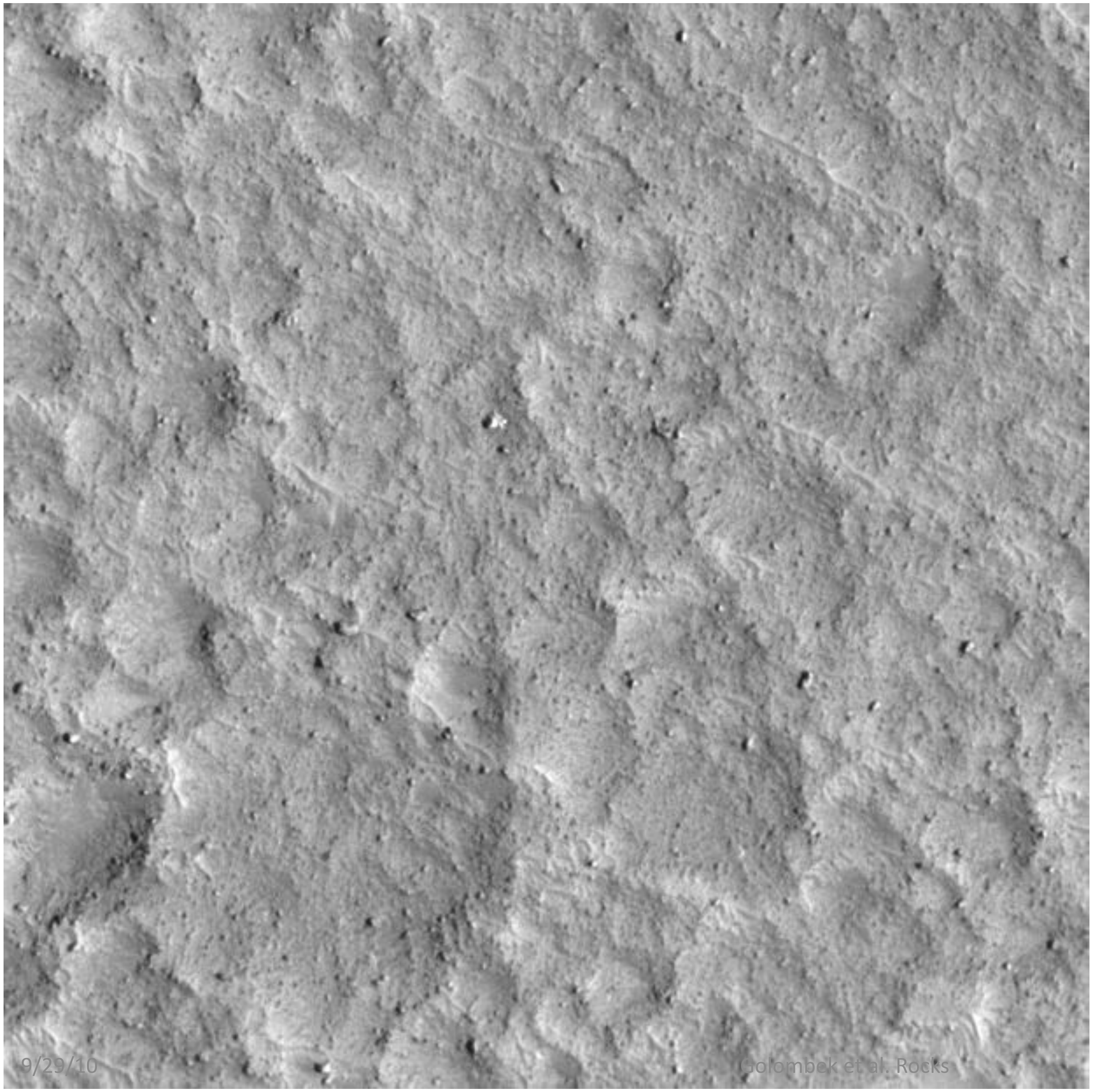
MPF PSP_1890 Blind Deconvolution



Lander Detail

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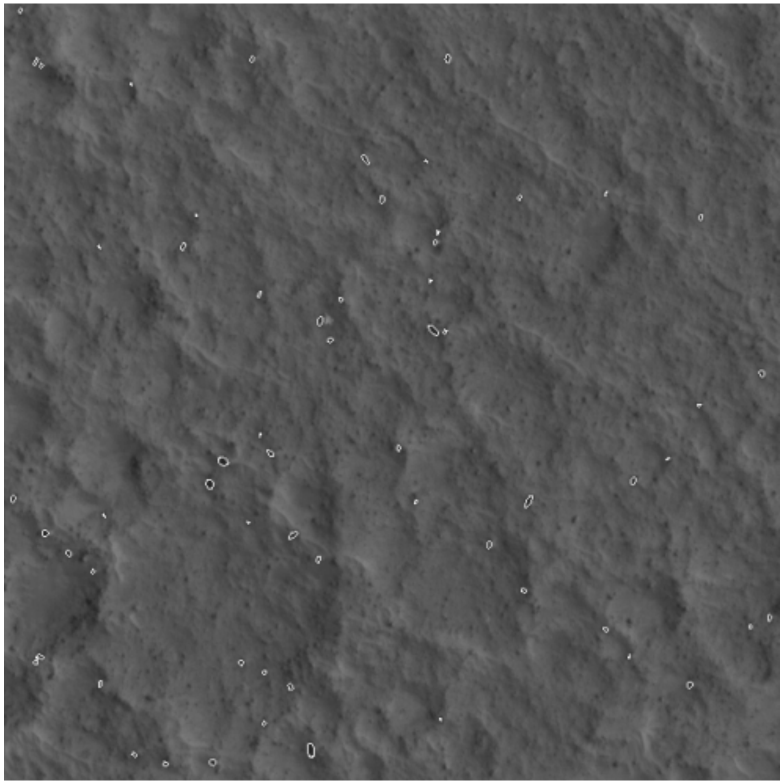
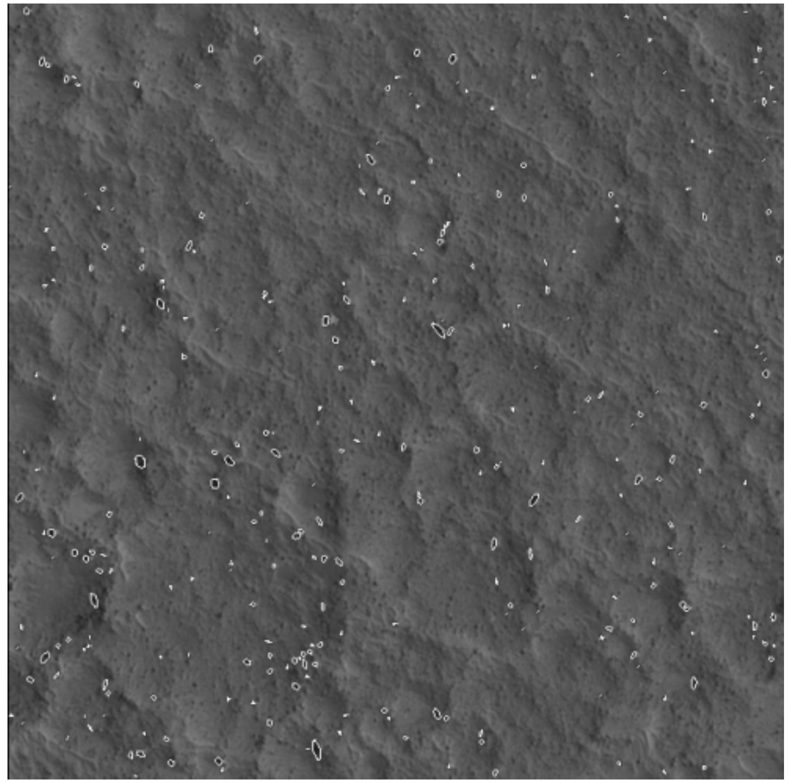
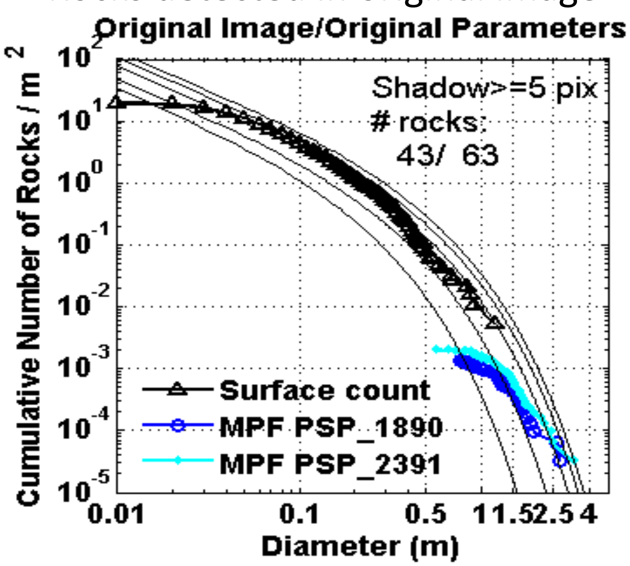
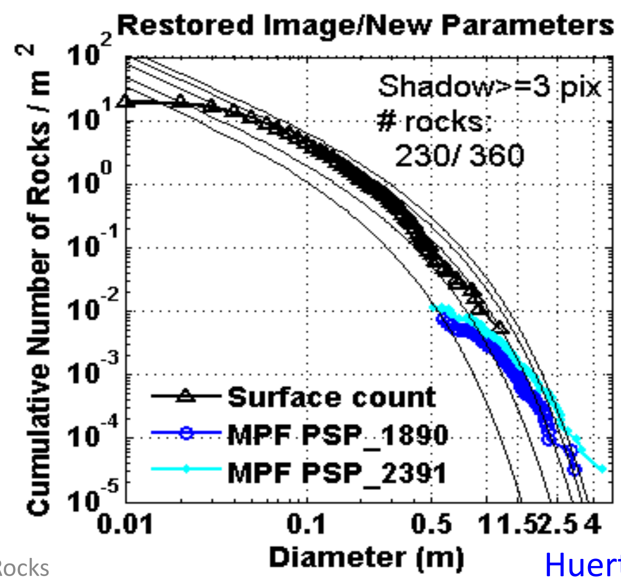




Rocks detected in original image

Rocks detected in restored image





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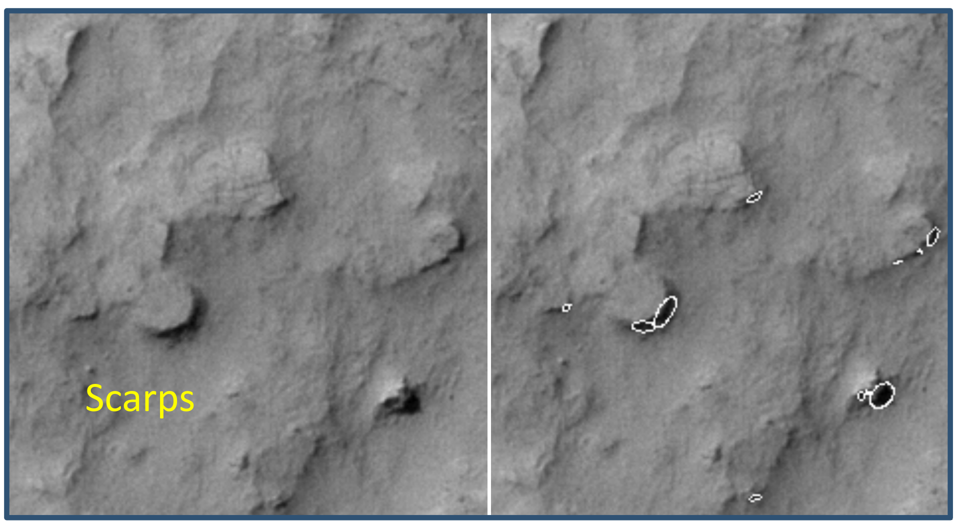
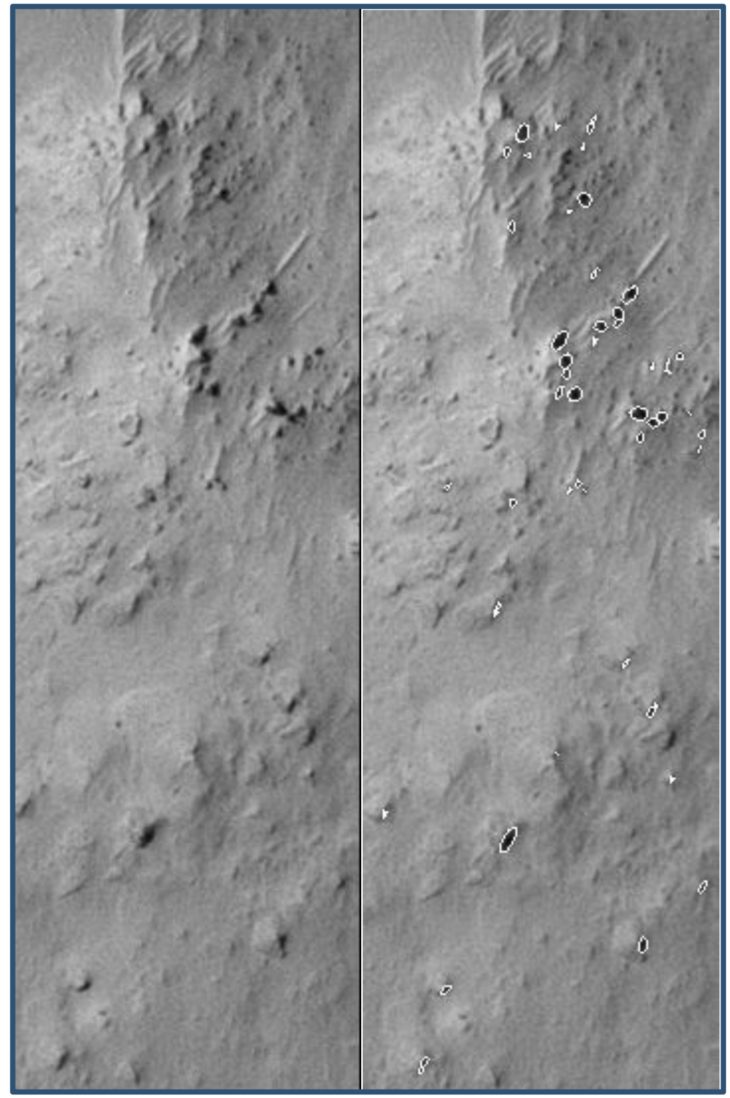
Gale Non-rocks

Rocks and fragmented Scarps





Rocks and Scarps

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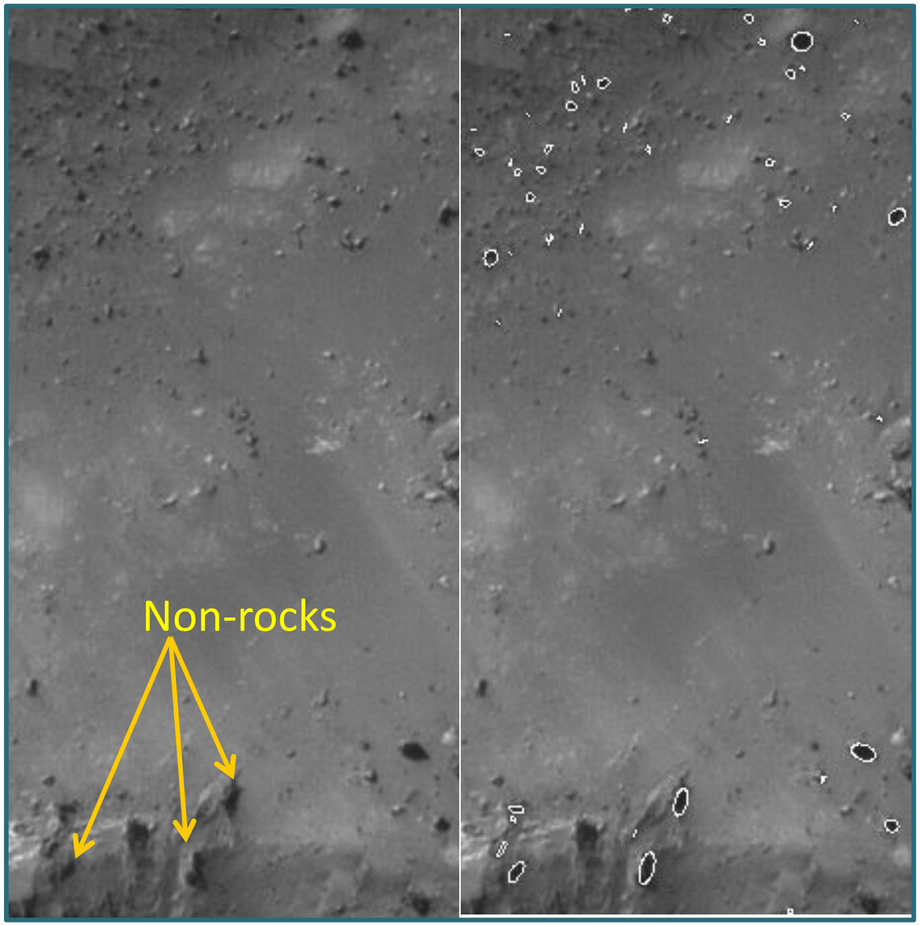
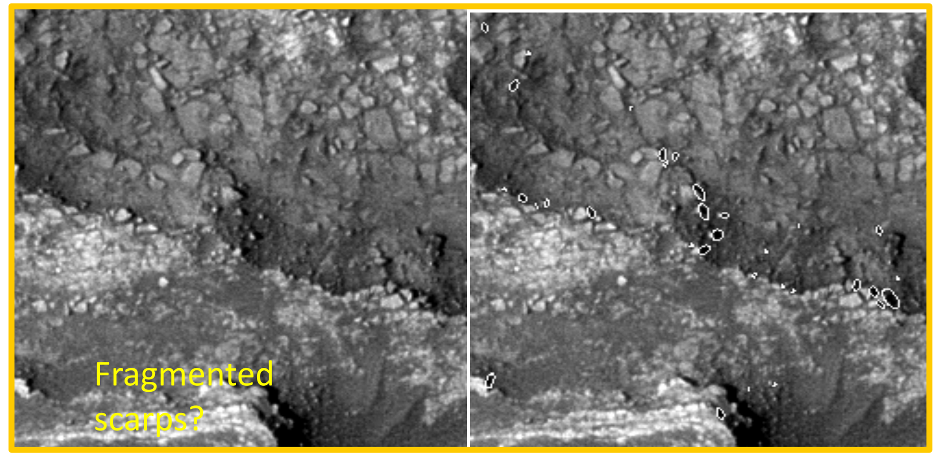
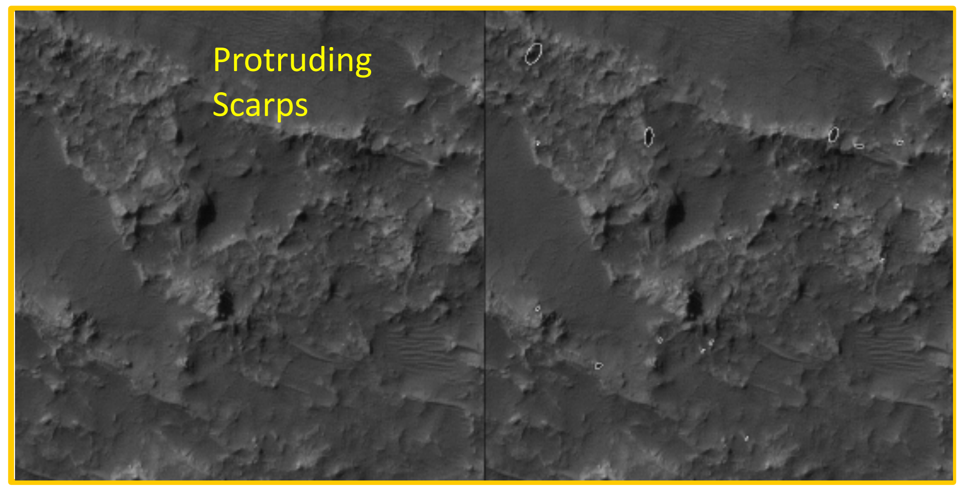
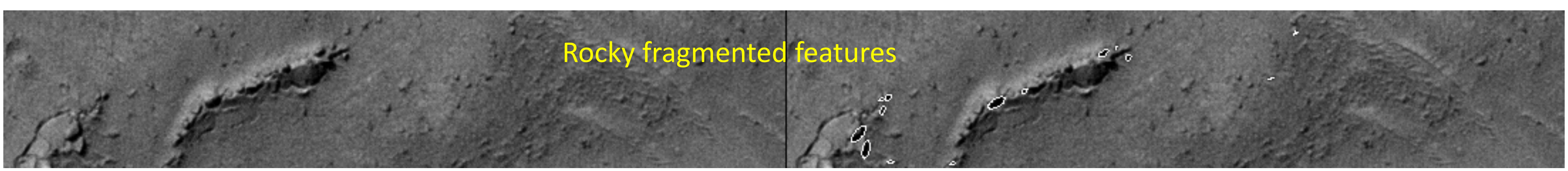
Eberswalde Non-rocks









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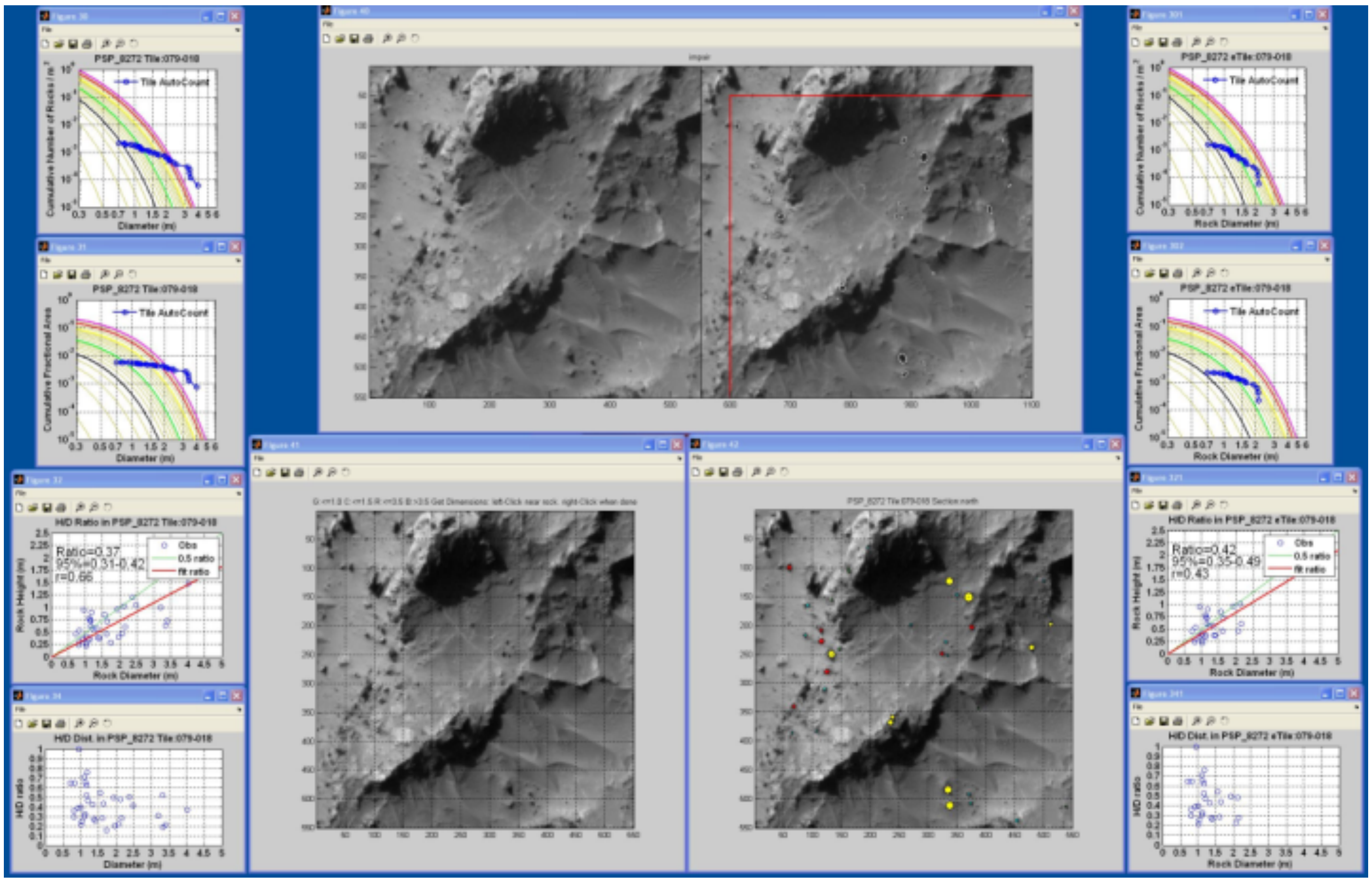
Rock/Non-Rock

Detector identifies non-rocks by examining contrast across shadow terminator for sharpness. Many scarp fragments have similar contrast as rocks. Larger shadows are examined and split to handle rock clumps and the shadows of some surface scarps become separated and identified as clumped rocks. Filters are turned on/off depending on the image content.

Eberswalde is worst case with filtering reasonably successful but at the expense of a moderate number of rocks not mapped.



Rock Detector processes a HiRISE image in 500x500 pixel tiles. Interns used these tiles to interactively indicate a non-rocks (yellow) by one click.

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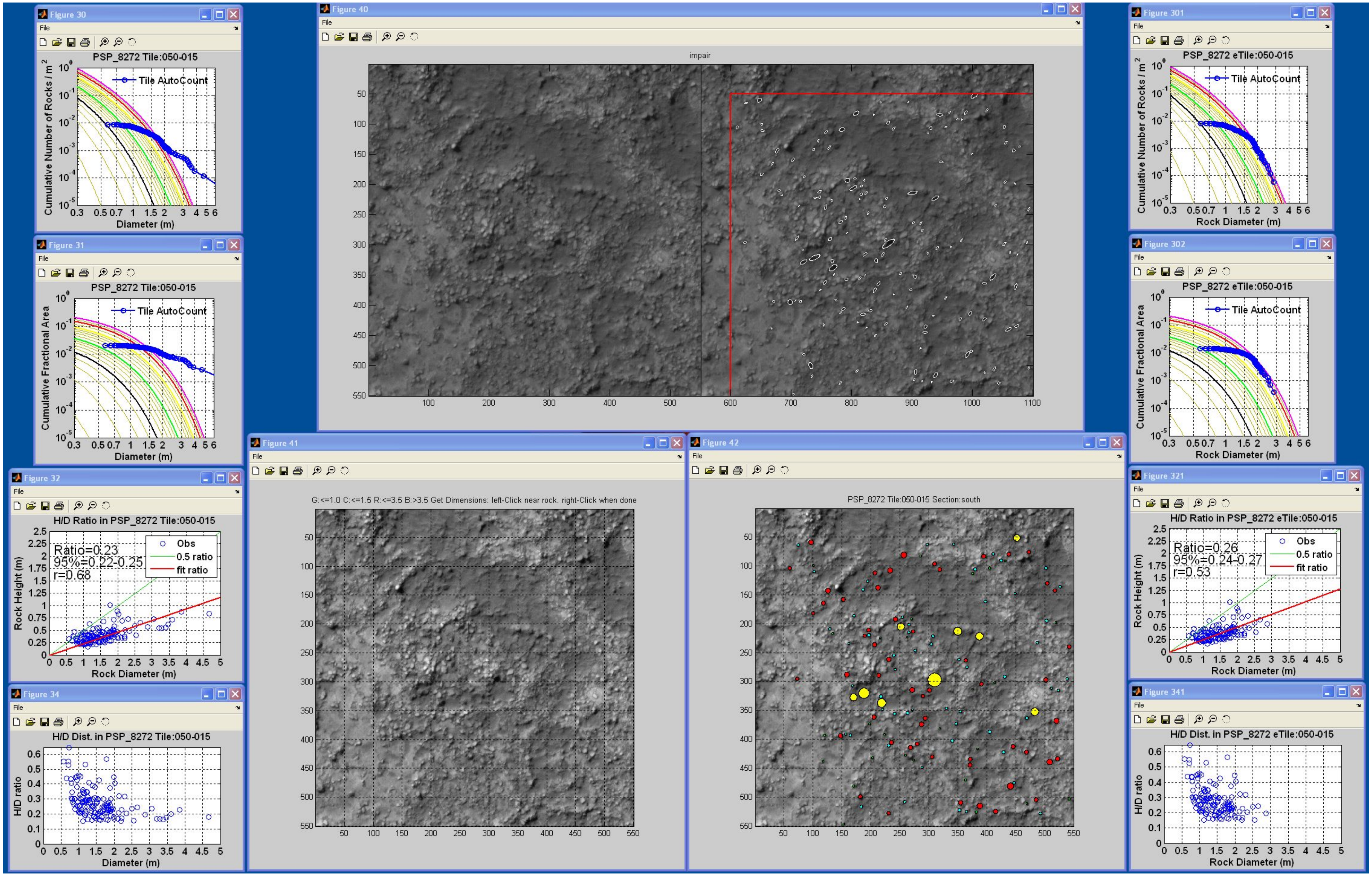
Interactive Editing Example



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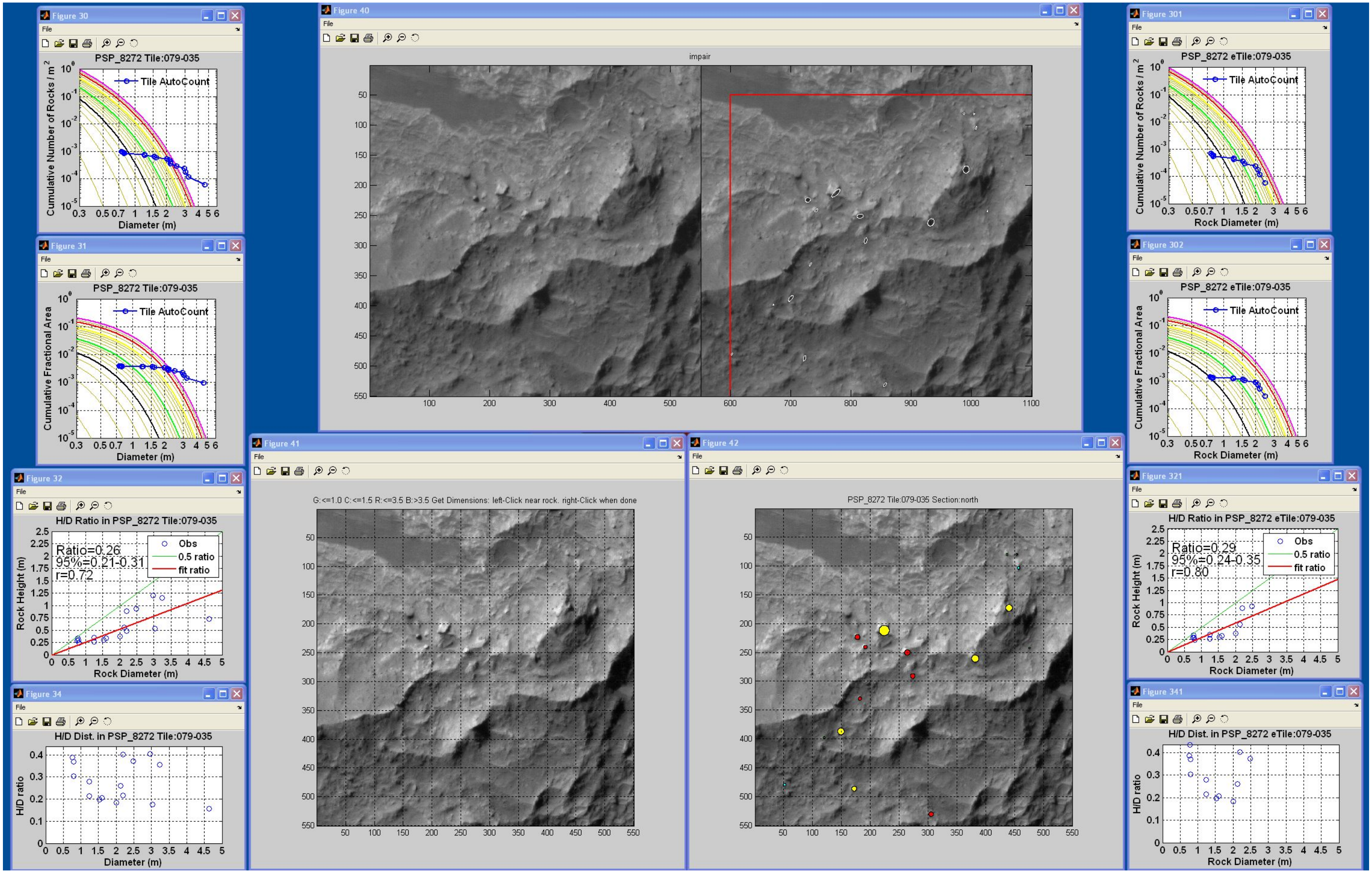
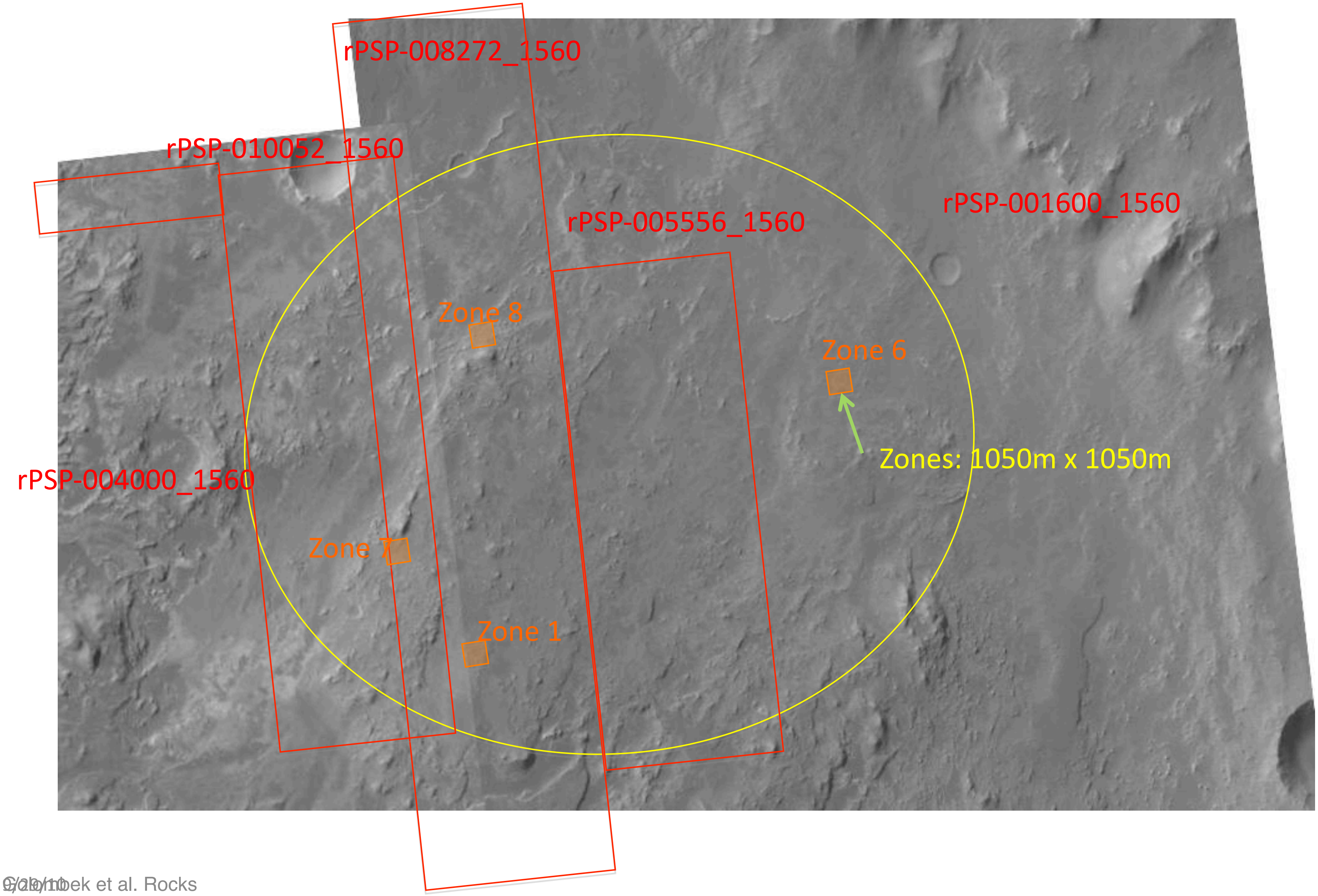
Interactive Editing Example



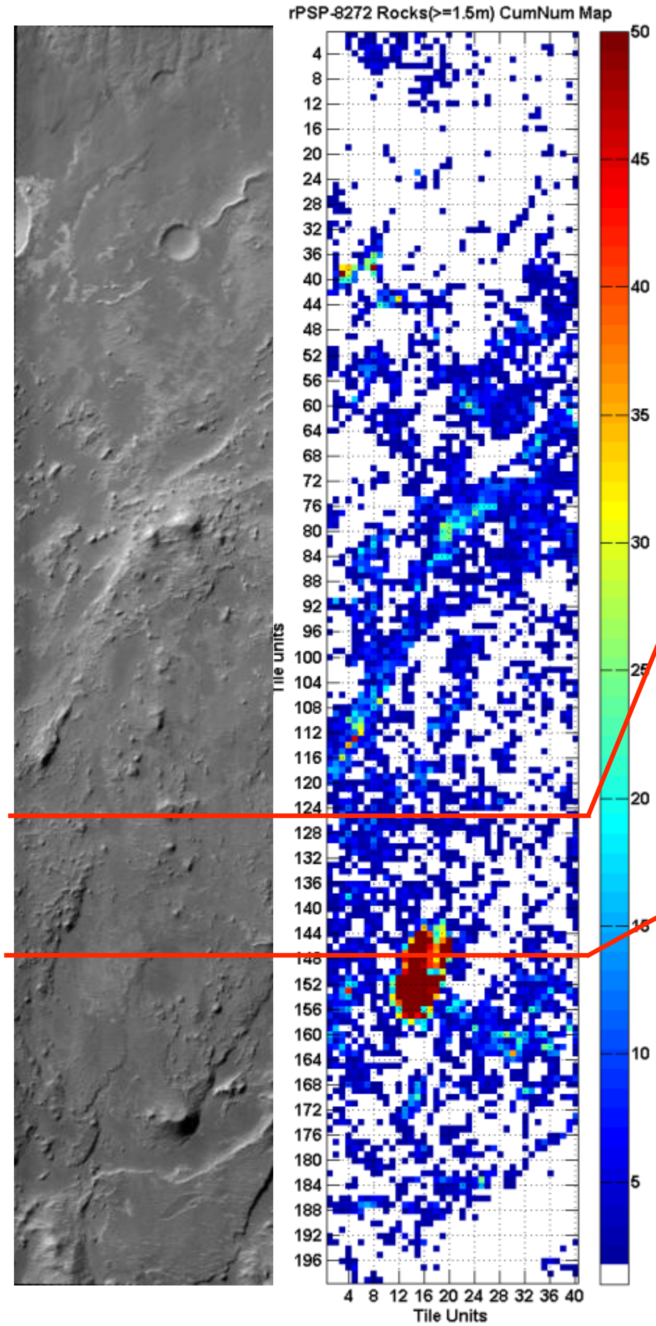
So Just Edit All Rock Maps

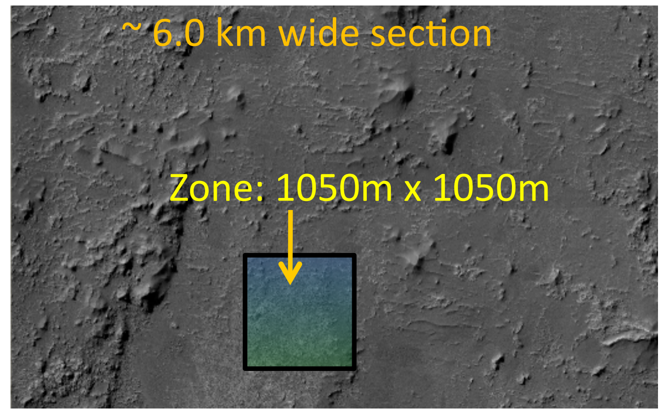
- Except >17,000 Tiles [150 m by 150 m Area]
- Edit File, Record Data ~10-15 min/tile
- Would Take >1 year
  - 8 hrs/day, 5 days a week
  - Probably Impossible
- So Need Automated Way to Edit Out Non Rocks
- All of the Non Rocks are >2.25 m Diameter
- Resolution Roll Off <1.5 m Diameter
- Took Total # Rocks/m^2 btw 1.5-2.25 m Diameter
- Sampled Over 450 m x 450 m Area
- Matched to Closest Model
- Compared to Interactively Edited Result
  - Pilot Study of four 7x7 Tile Areas in Eberswalde, Gale, Mawrth

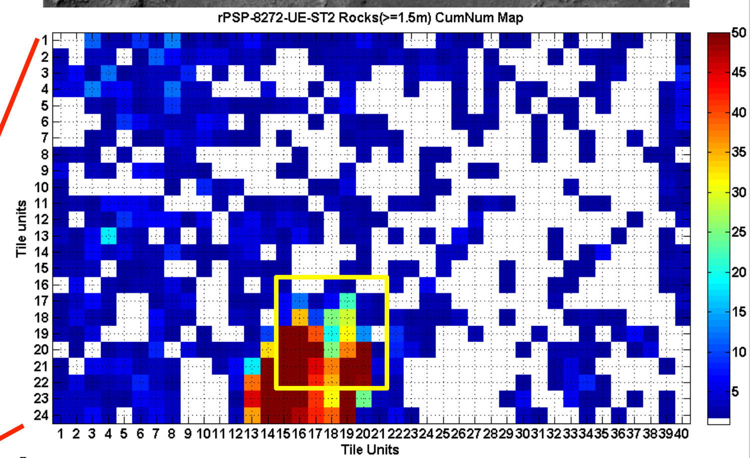
Eberswalde Zone Overview

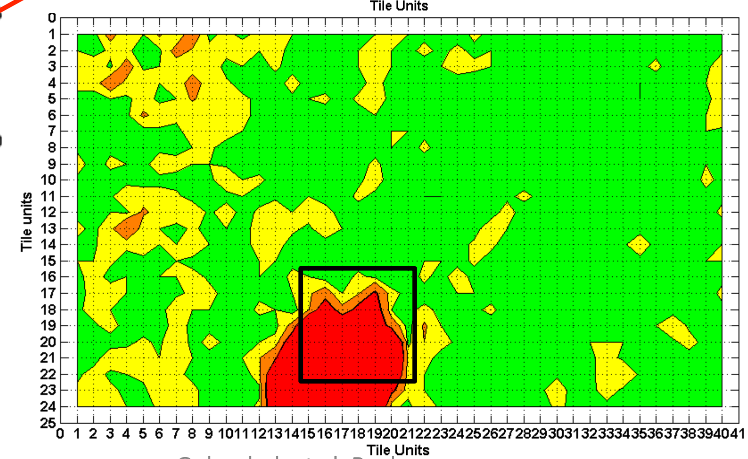


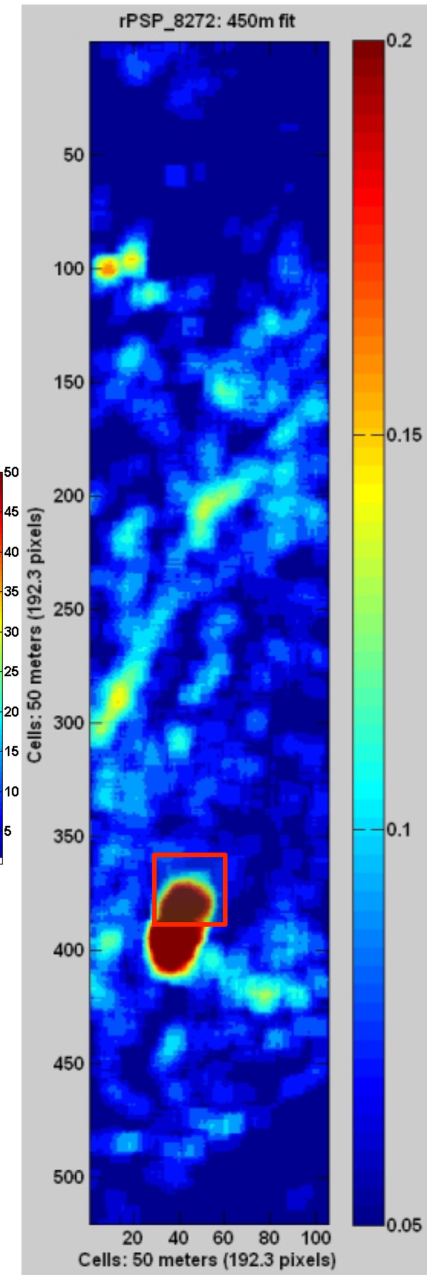
Eberswalde Zone 1











~ 6.0 km wide, Tiles: 150m

Abundance estimate

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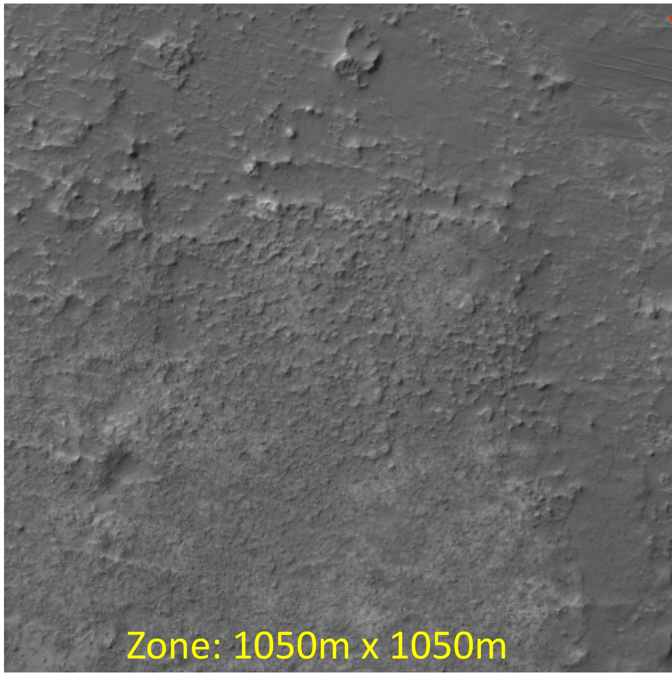
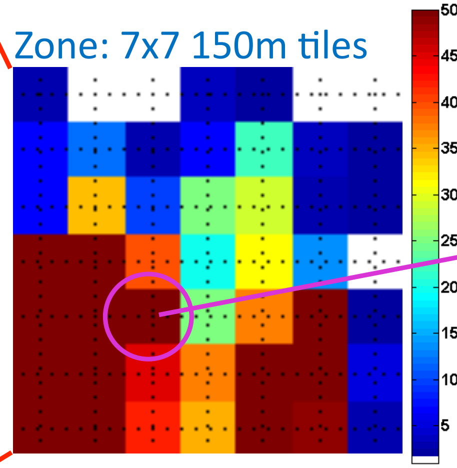
Eberswalde Zone 1

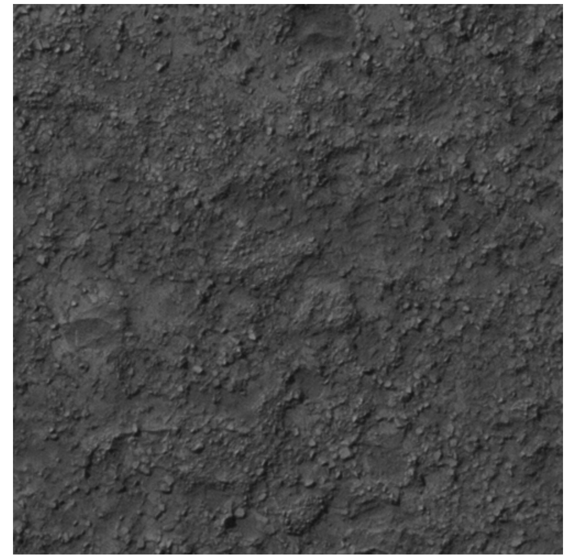


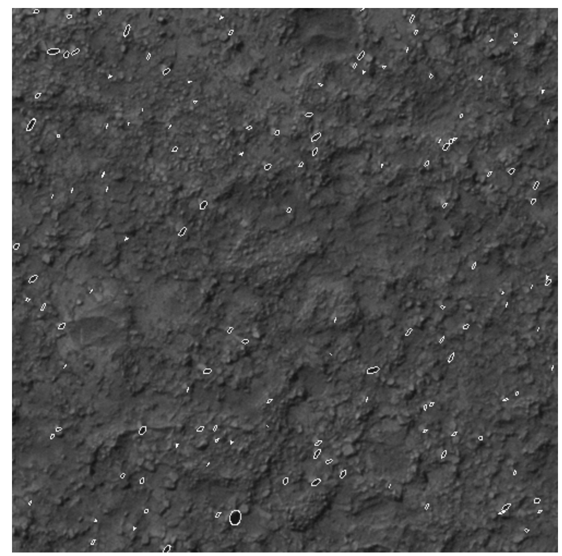
Zone: 7x7 150m tiles



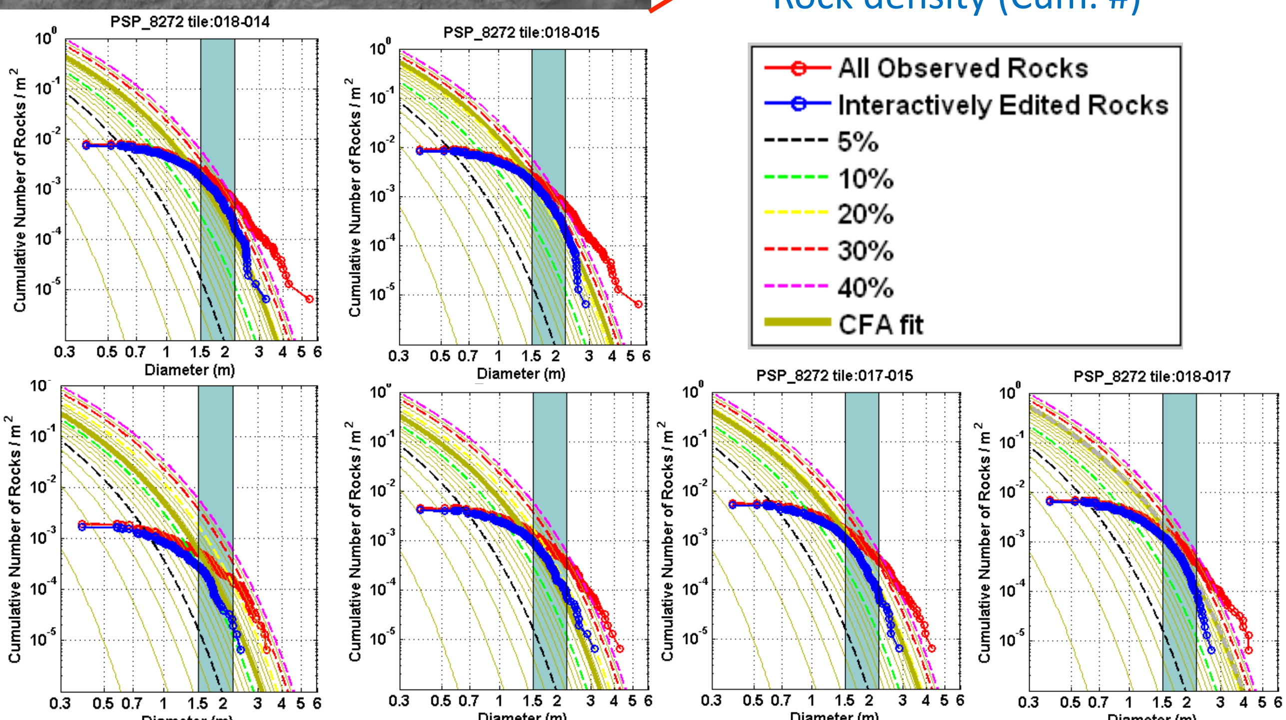
Rock density (Cum. #)

Tile: 150m x 150m





Detected shadows of rocks



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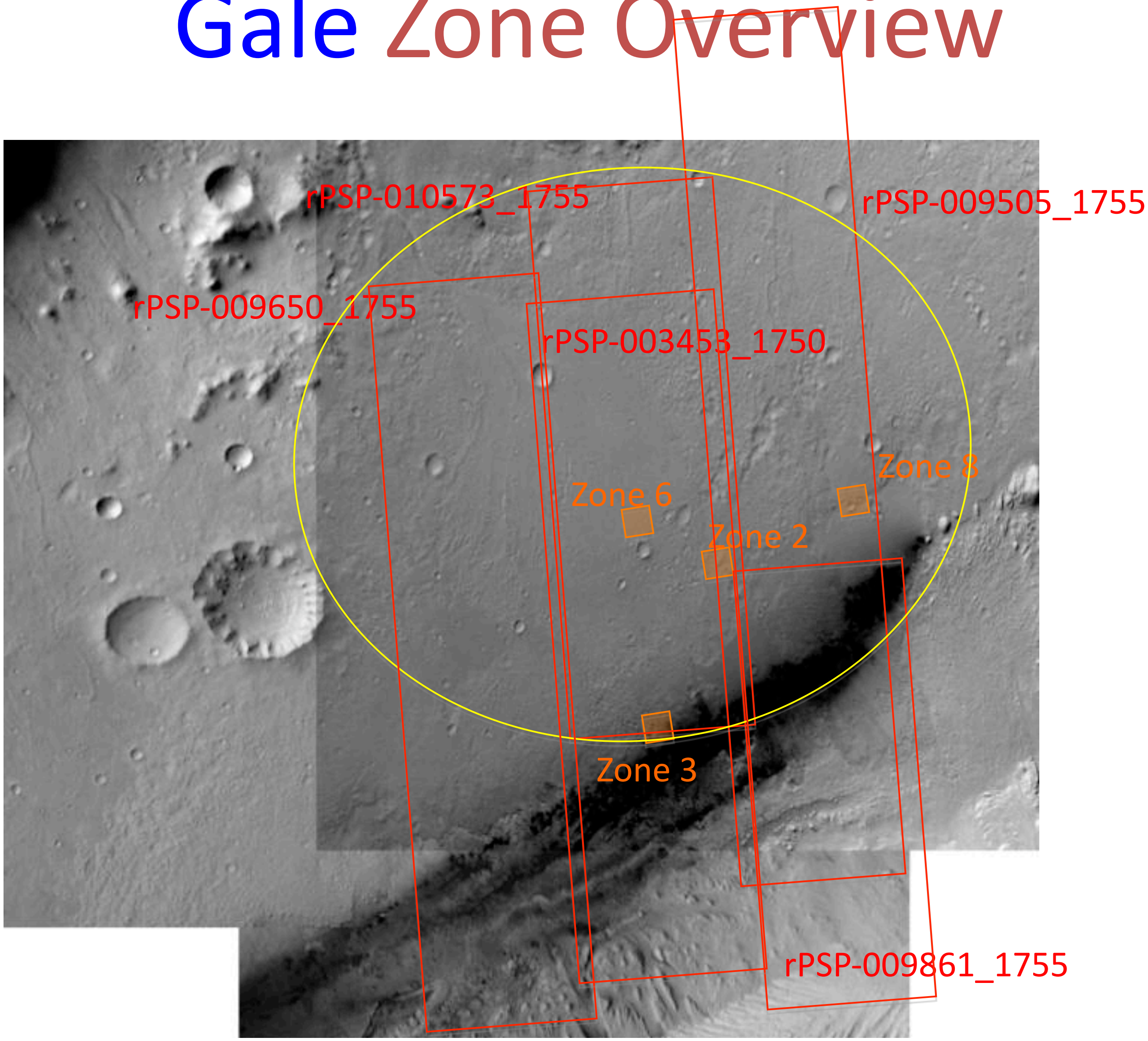
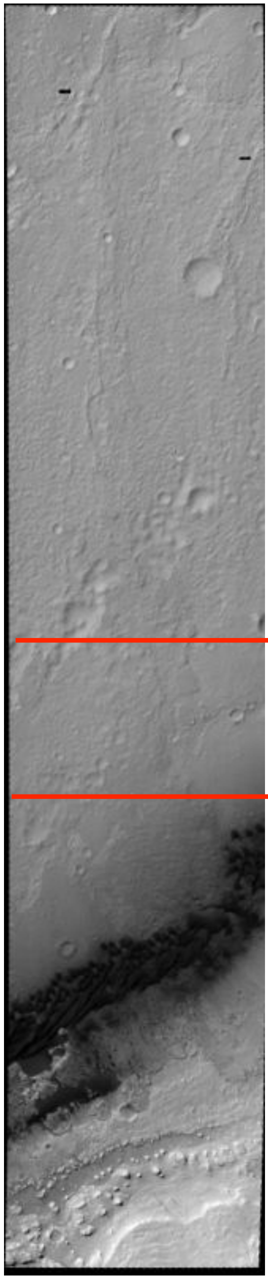
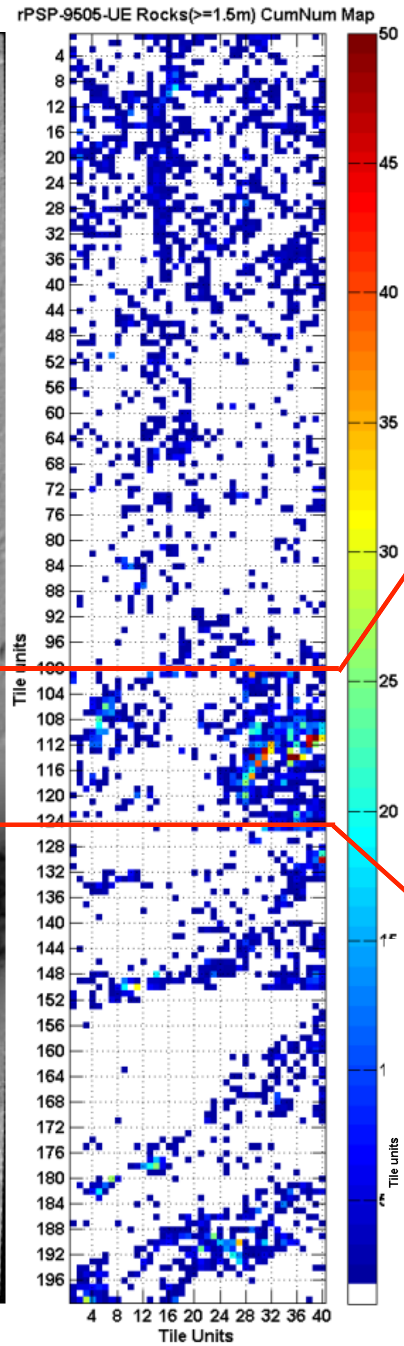
Gale Zone Overview



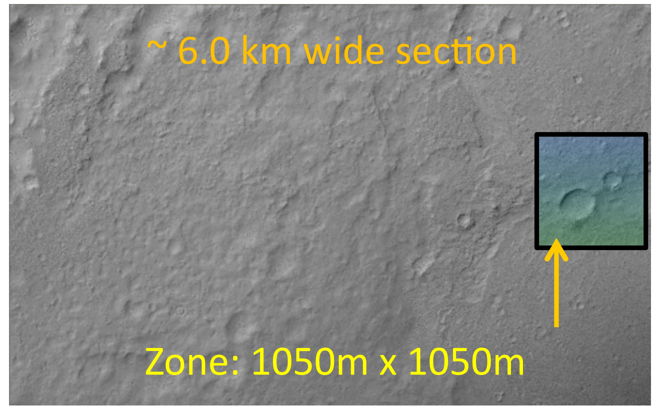
Golombek et al. Rocks

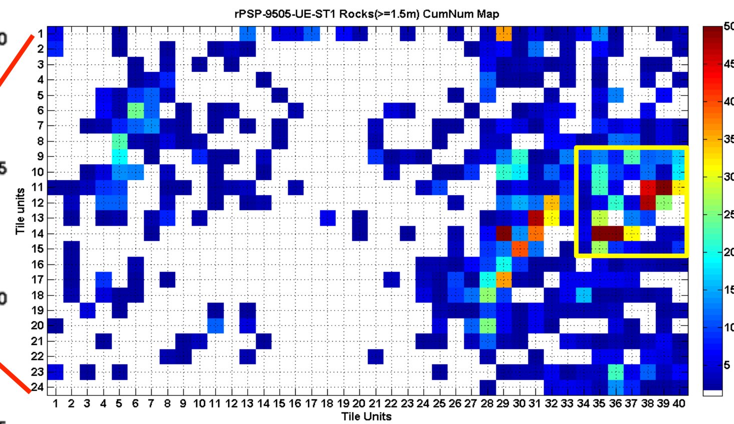
Gale Zone 8

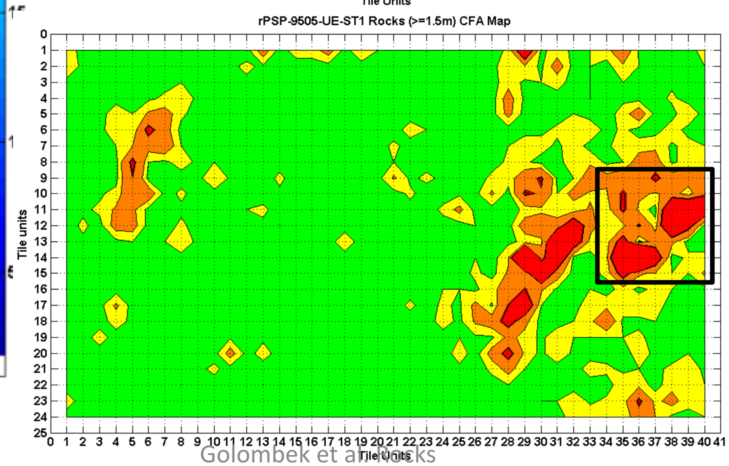


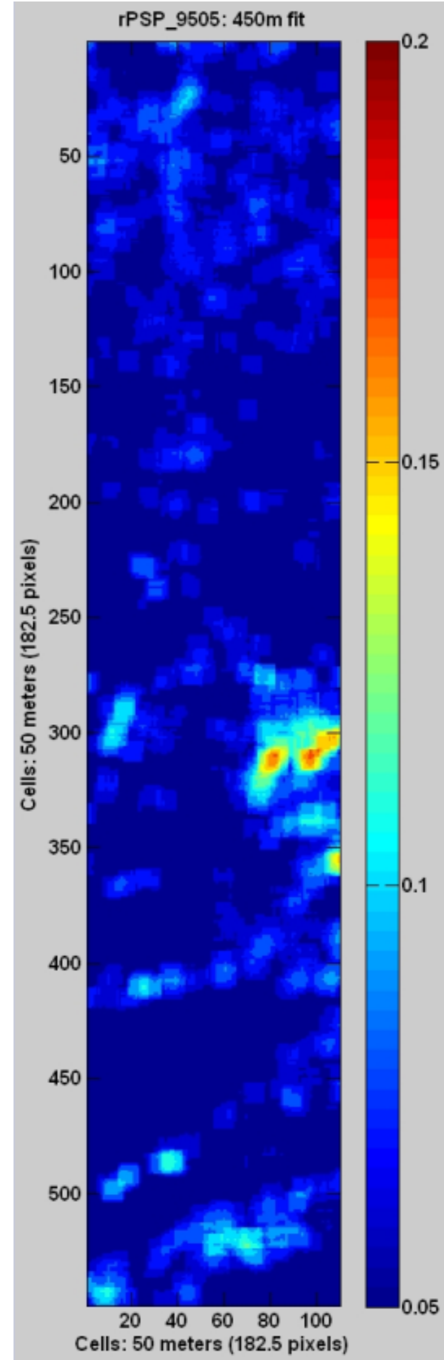


~6.0 km wide, Tiles: 150m









Abundance estimate

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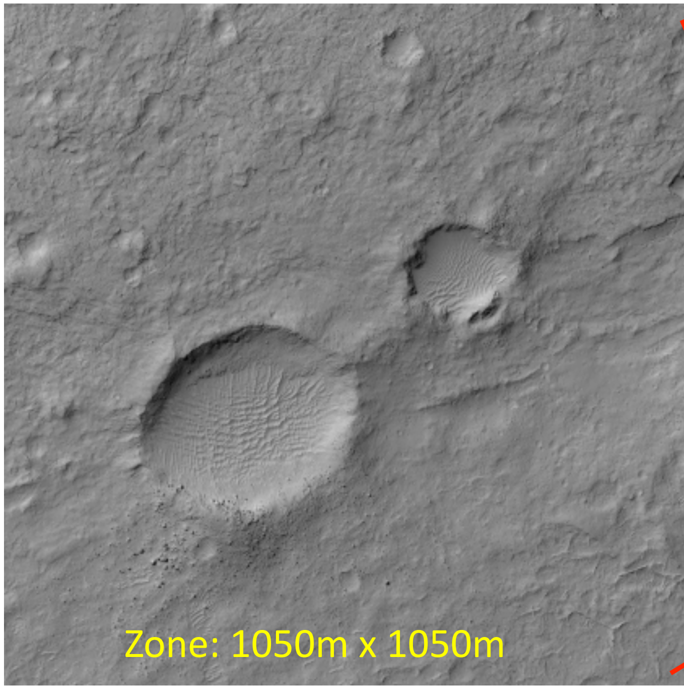
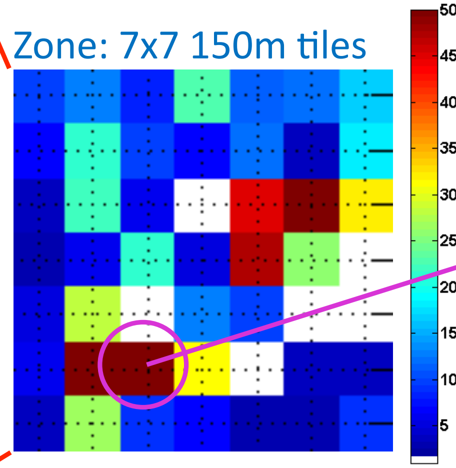
Gale Zone 8

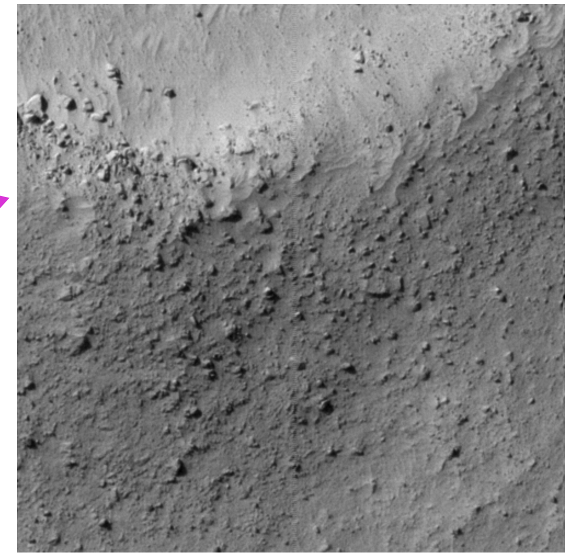


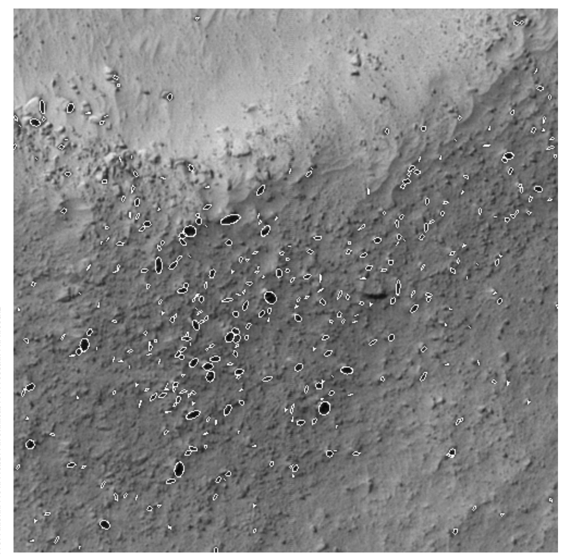
Zone: 7x7 150m tiles



Rock density (Cum. #)

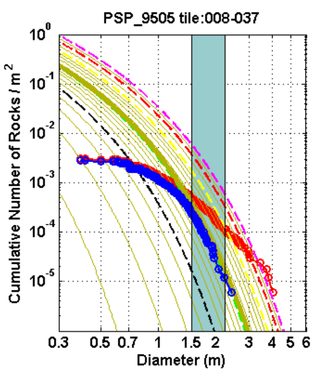
Tile: 150m x 150m

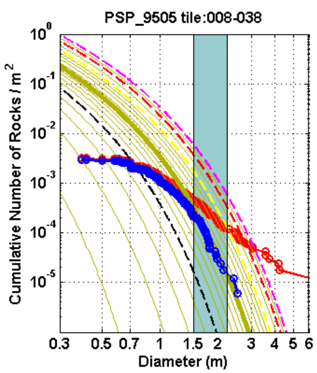


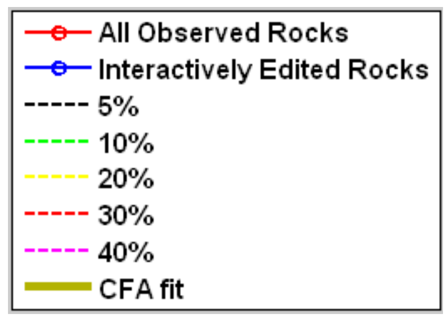


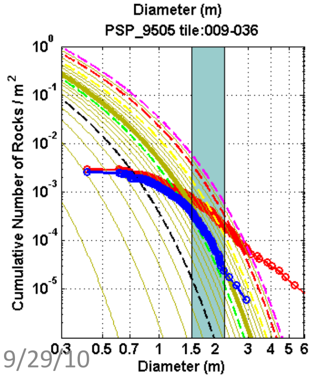
Detected shadows of rocks

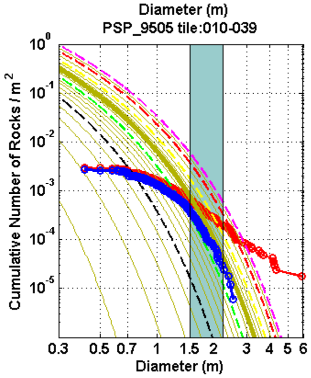
Huertas, Kipp, Golombek

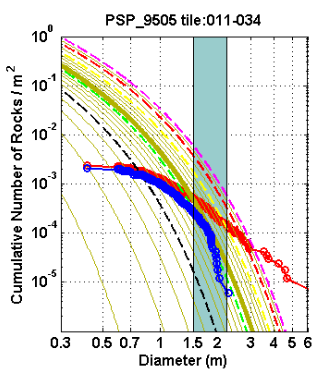


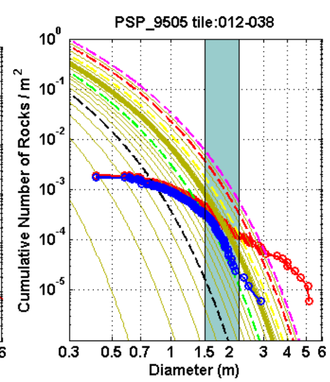












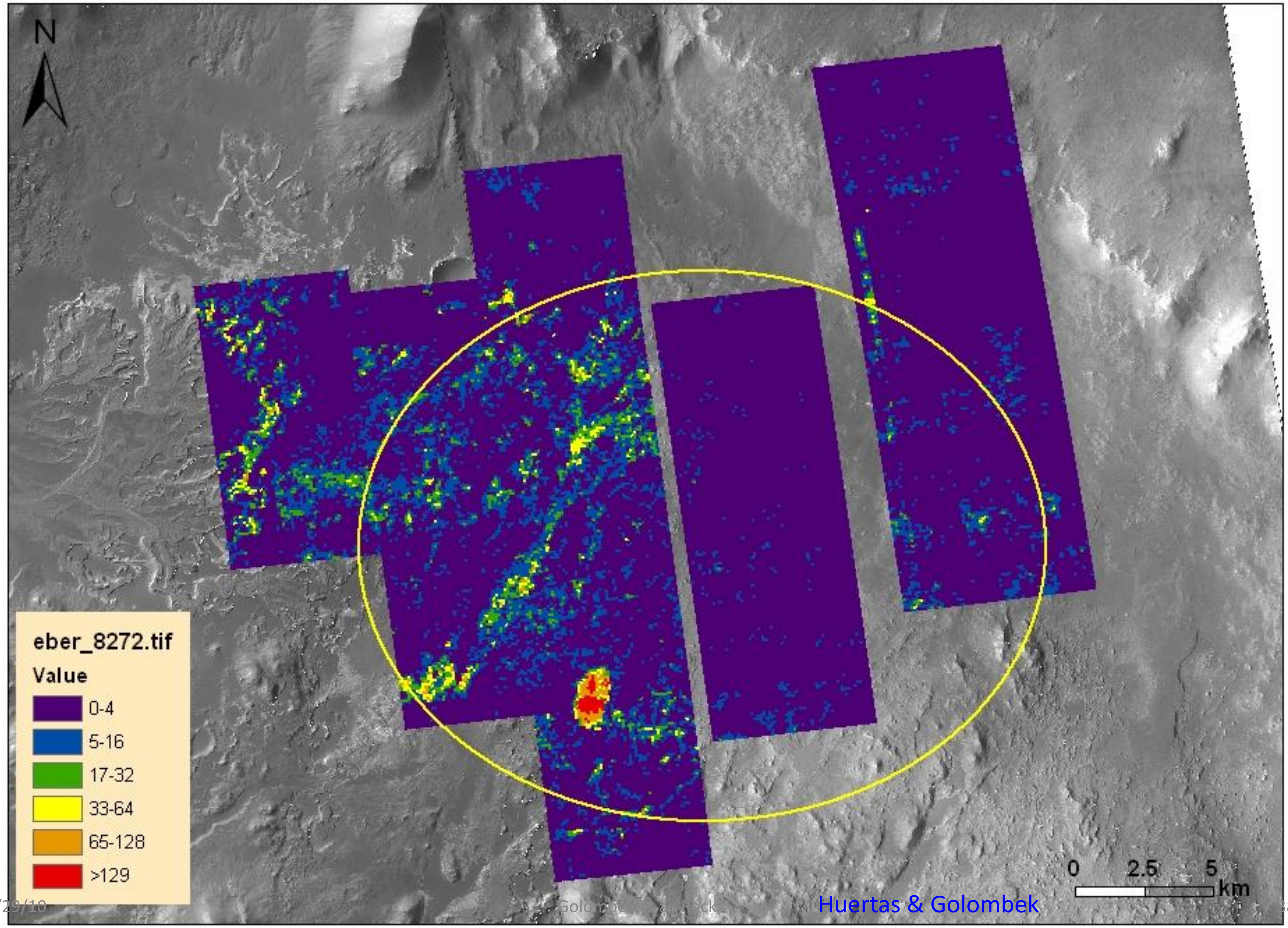
MSL Rock Density & Risk

Rock Density	Total Number of Rocks ~Rocks >1.5 m^2 Dia per Tile*	Cumulative Fractional Area Covered by All Rocks (%)	Cumulative Number of Rocks >1.5 m Dia per m^2	Probability of Encountering 1 Rock Higher than 0.6 m in 7.58 m2 Area of Rover During Touchdown (%)
Low	<1	5	0.00002	0.1
Medium Low	1-6	6-10	0.0003	0.9
Medium High	7-19	11-15	0.0009	2.3
High	20-35	16-20	0.0017	4.0
Very High	36-54	21-25	0.0026	5.8
Extremely High	55-74	26-30	0.0036	7.7
Extreme	>75	>30	>0.0036	9.6

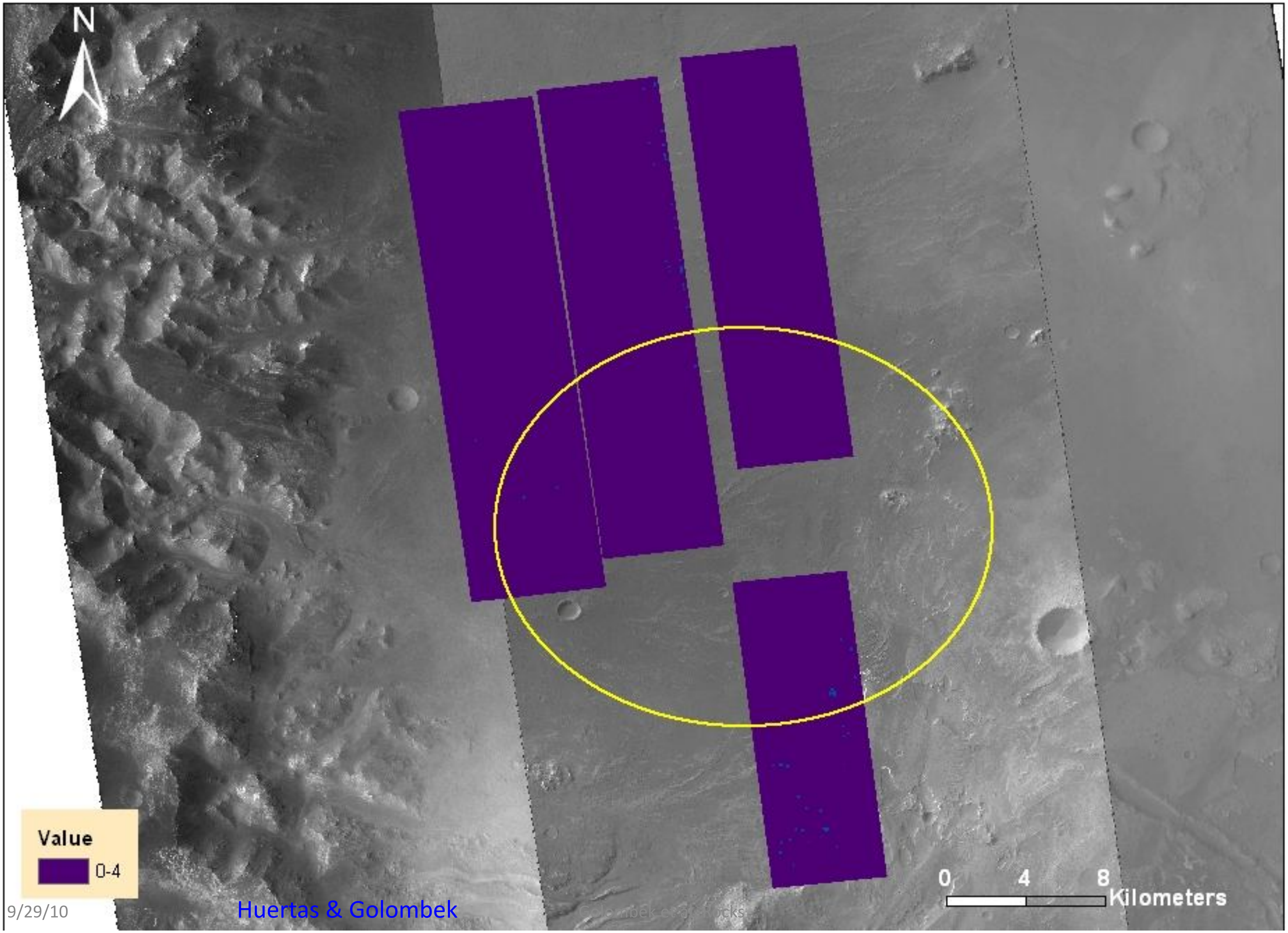
*Tile 150 m by 150 m

Kipp, Golombek & Huertas

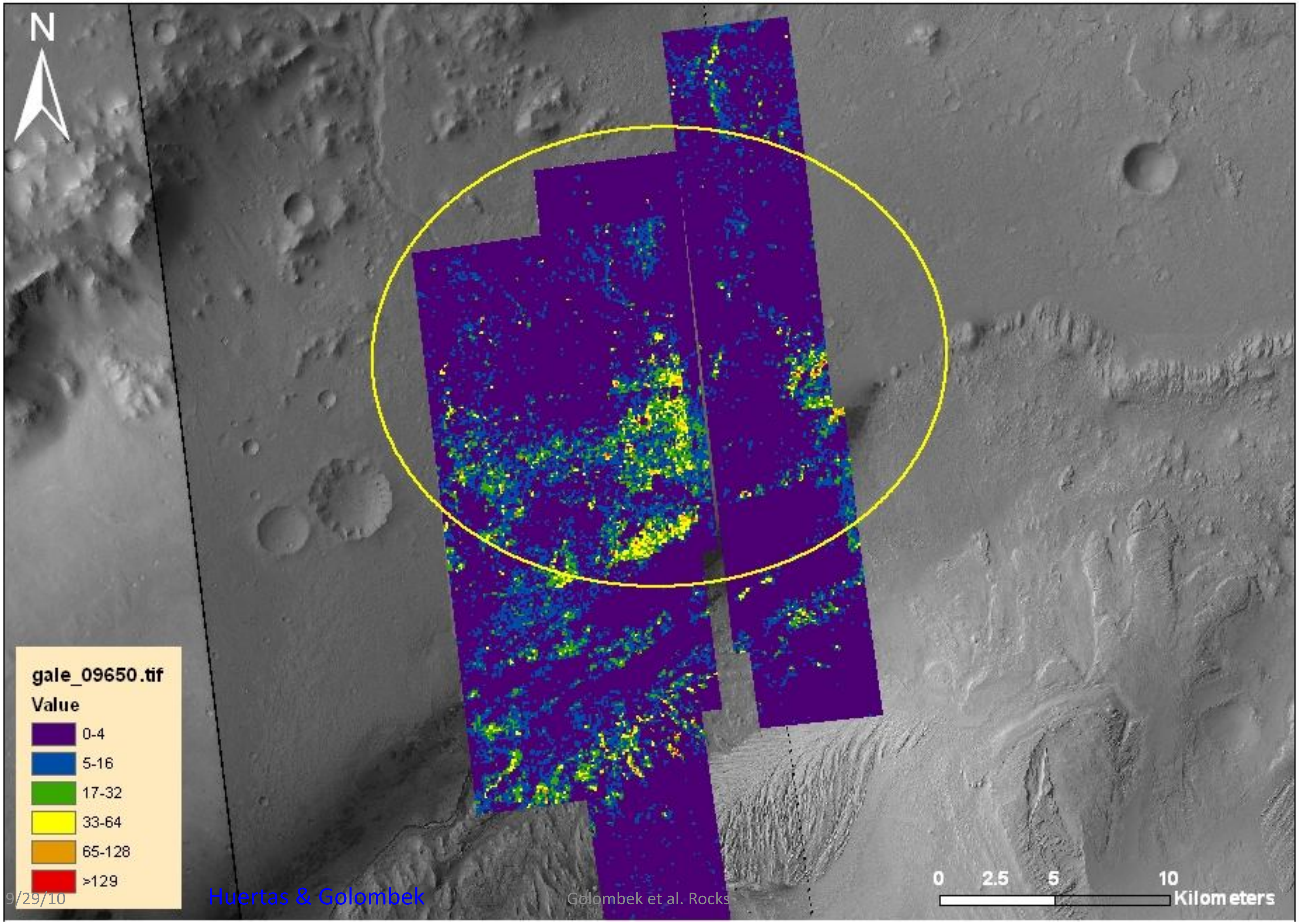
Eberswalde Crater Rock Density



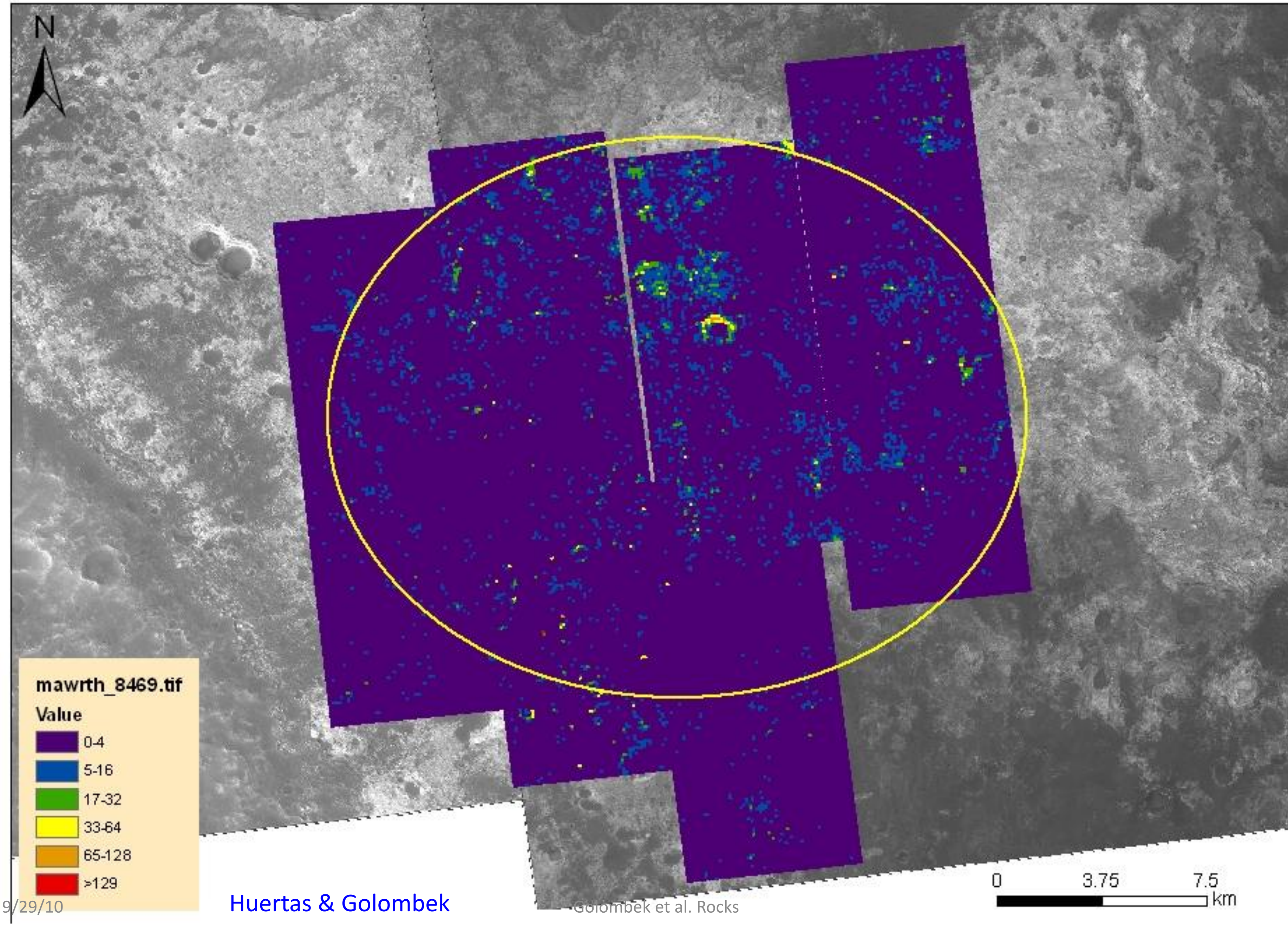
Holden Crater Rock Density



Gale Crater Rock Density



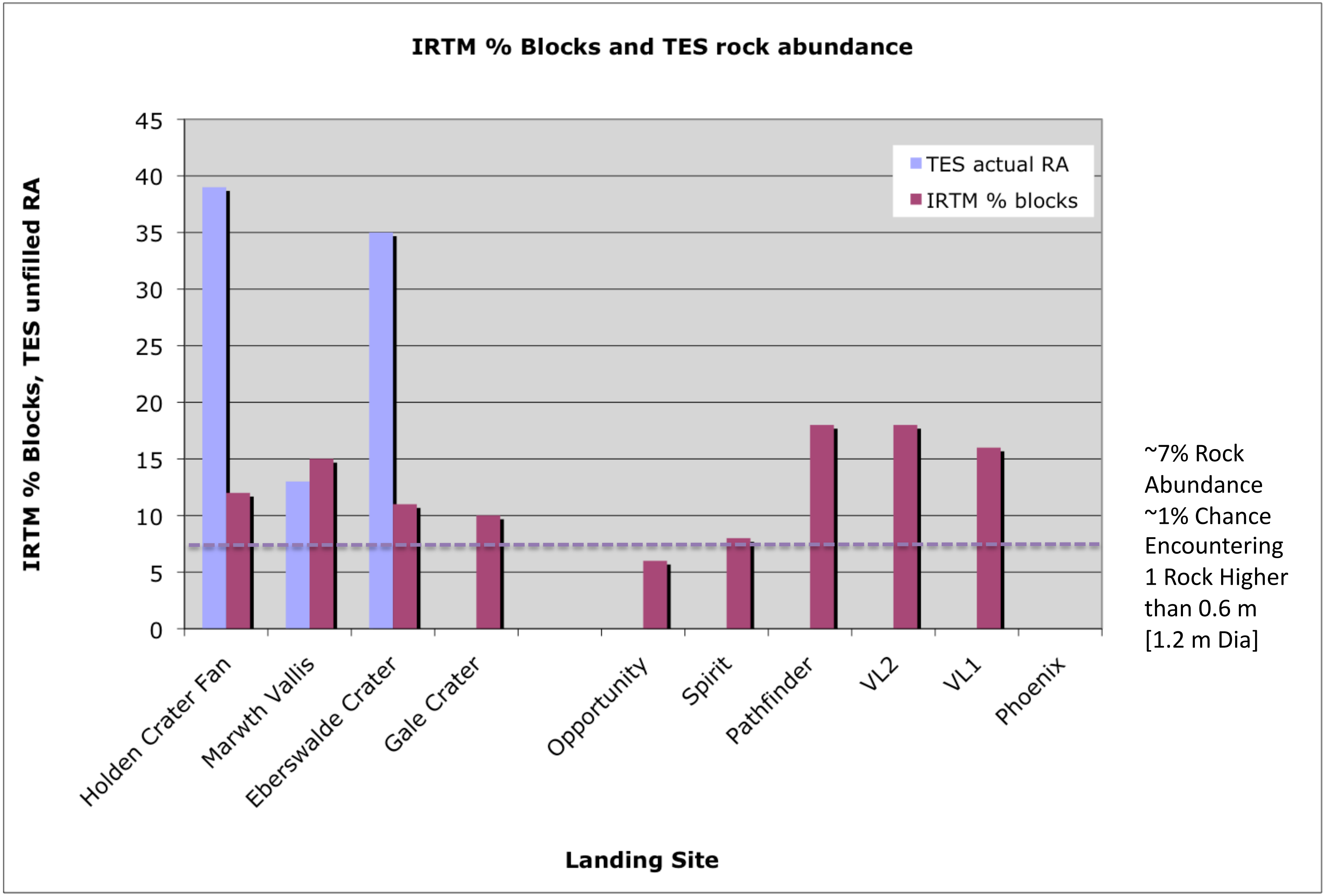
Mawrth Vallis Rock Density



Huertas & Golombek

Maps & Data Provided

- Diameter, Height and Location of All Rocks Detected
  - In 150 m by 150 m Tiles of Image
- Summary Size-Frequency Distribution in 450 m by 450 m Super Tiles [9 by 9 Tiles] Spaced Every 150 m
  - Measured Cumulative # Rocks/m2 >1.5 m Diameter for Probability Calculation
- Best Fit Model from Rocks btw 1.5-2.25 m Diameter
  - Model CFA Provided for Extrapolation to Rocks <1.5 m Diameter
- Maps of Total Number of Rocks per Tile and Best Fit Model Distribution [CFA]
  - Carefully Geoferenced onto Landing Site Map & Ellipse using Non Map Projected Images from which Rocks were measured
  - Location of Maps and Rocks in Ellipse



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

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

Christensen [1986]; Nowicki and Christensen [2007]

Rock Abundance

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