Rock Statistics Calculations for the MER Landing Sites

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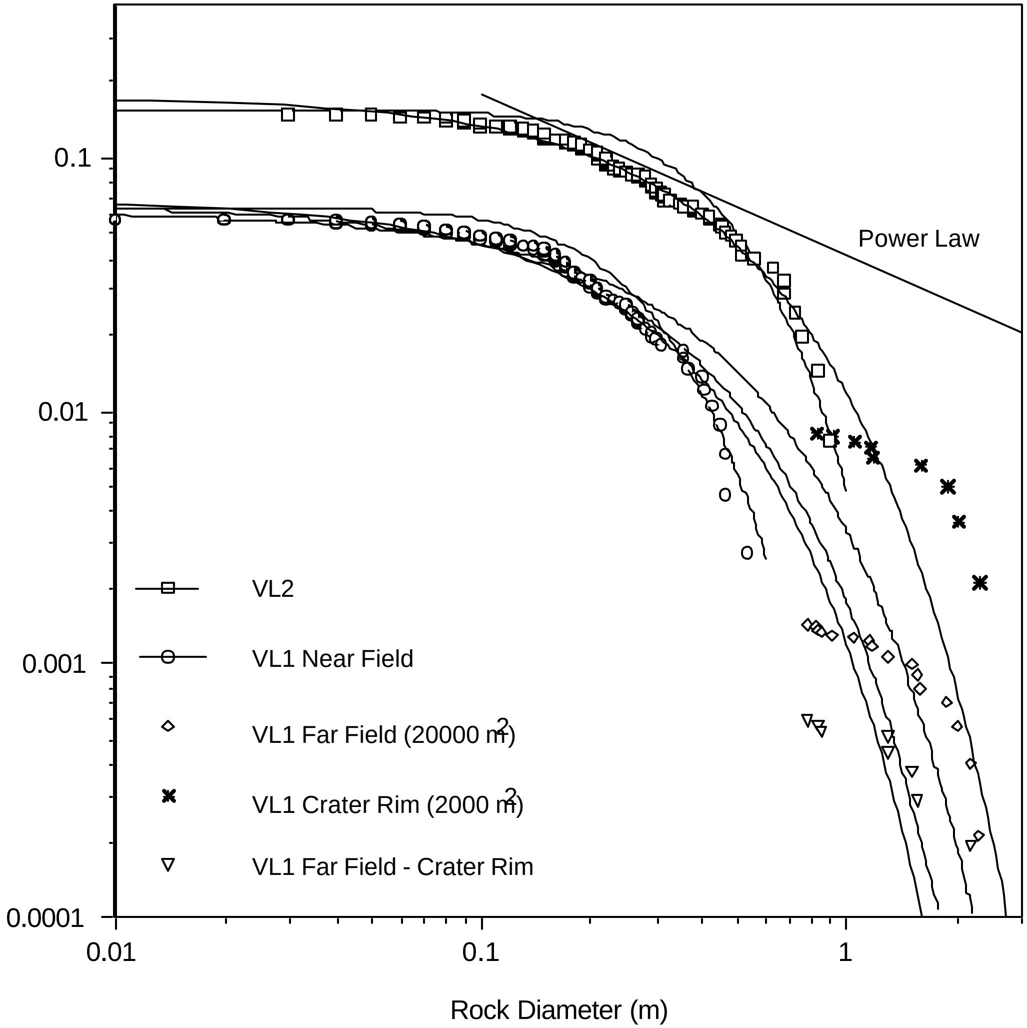
Probability of Impacting Potentially Hazardous Rocks

- Use Model Size-Frequency Rock Distributions and Thermal Differencing Rock Abundance Estimates to Determine Frequency of Potentially Hazardous Rocks
- Not for the Faint of Heart; Lots of Uncertainties
  - Assumes IR Rock Abundance is Accurate (~20-25%) from Scale of IR Pixel to Landed Surface
  - Assumes Rock Abundance is Made up of Individual Rocks
  - Outcrops and Non-Uniform Distributions
  - Assumes Model Rock Distributions are Representative and Apply
- But [Best Can Do with What Have]
  - IRTM Rock Abundances are 3 for 3, within 20% of Landed Count
  - Rock Distribution Models Appear Representative of Many Natural Surfaces - On Earth and Mars: Fracture & Fragmentation Theory
  - Model Accurately Predicted Distribution of Rocks at MPF Site

Viking Lander Rock Distributions

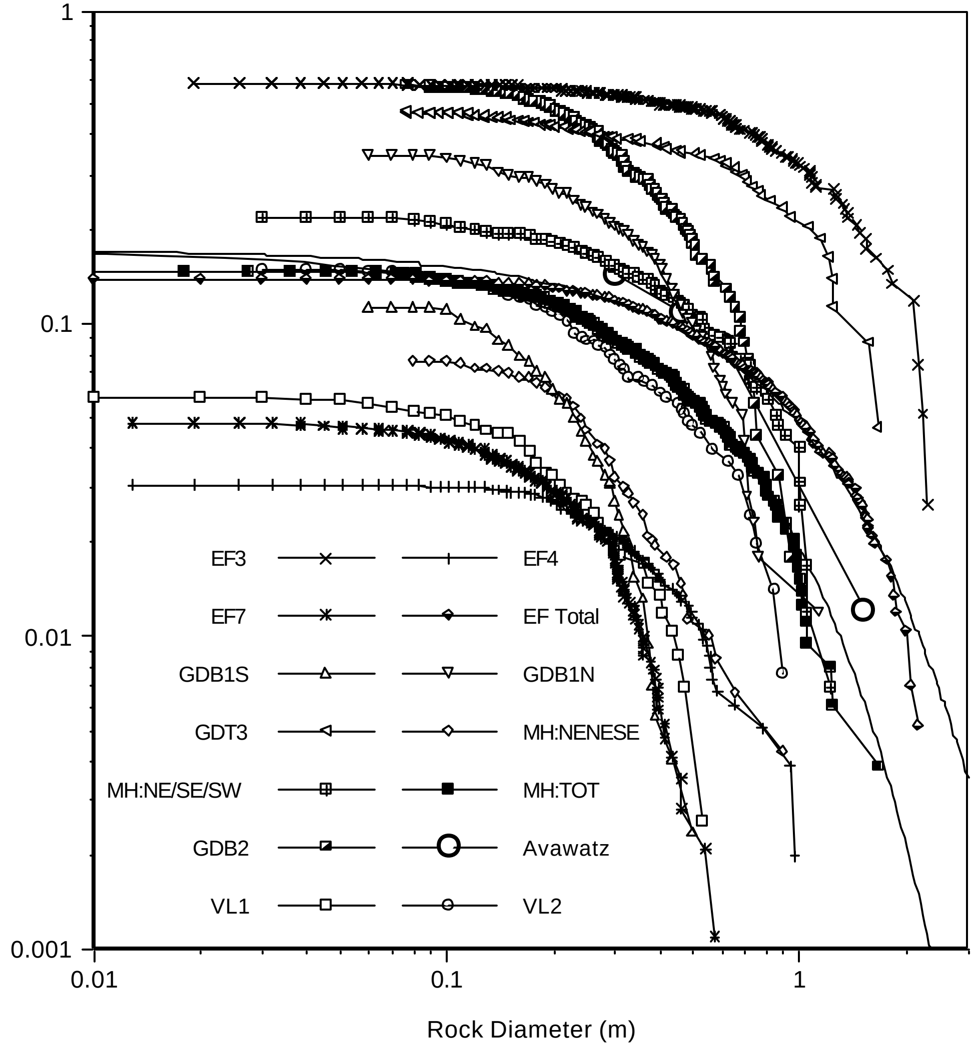


Cumulative Area versus Diameter - Exponential Decay

Cumulative Area is Rock Abundance

VL1 w/o Outcrops

Rock Distributions on Earth

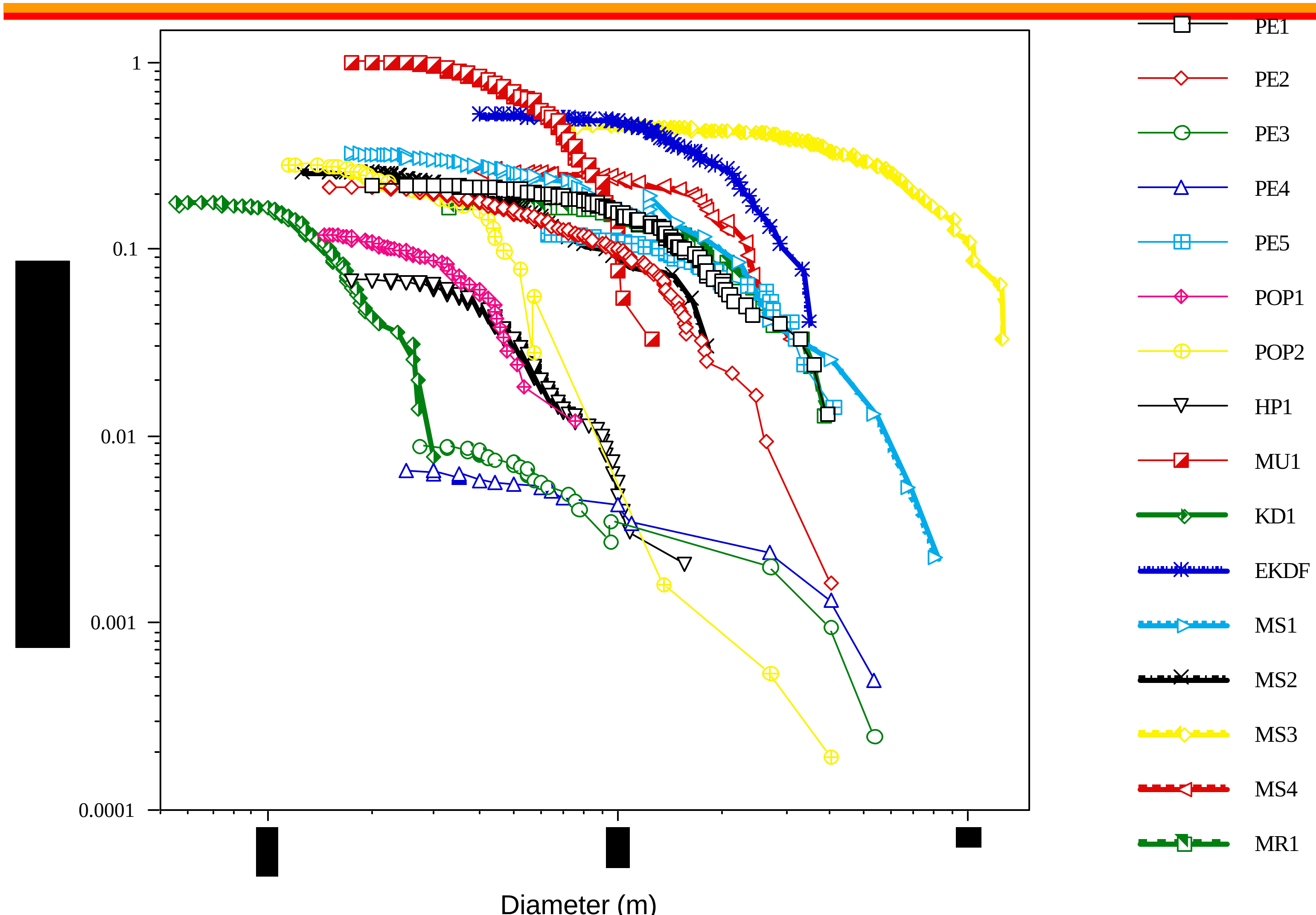


Cumulative Area versus Diameter -
Same Exponential

Wide Variety Surfaces
Weathered Volcanic
Ephrata Fan
Alluvial Fan

Fracture & Fragmentation Theory - Failure By Propagation of Ubiquitous Flaws

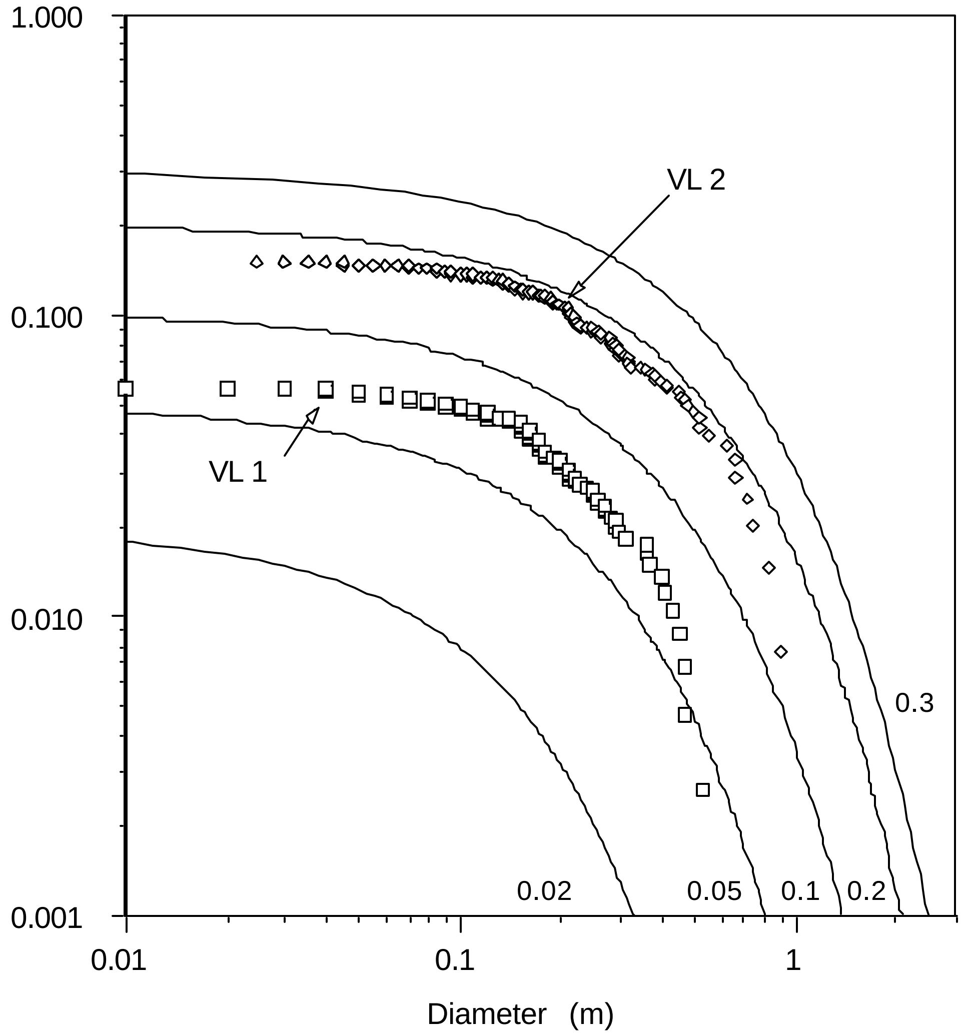
Rock Distributions in Hawaii



Same Exponential Shape

Wide Variety of Surfaces: Fresh & Weathered Lava Flow Surfaces, Chemically Weathered, Frost Shattering, Phreatic Eruptions, etc.

Model Rock Size-Frequency Distributions



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

$F_k(D)$ Cum. Frac. Area

k is Total Rock Abundance

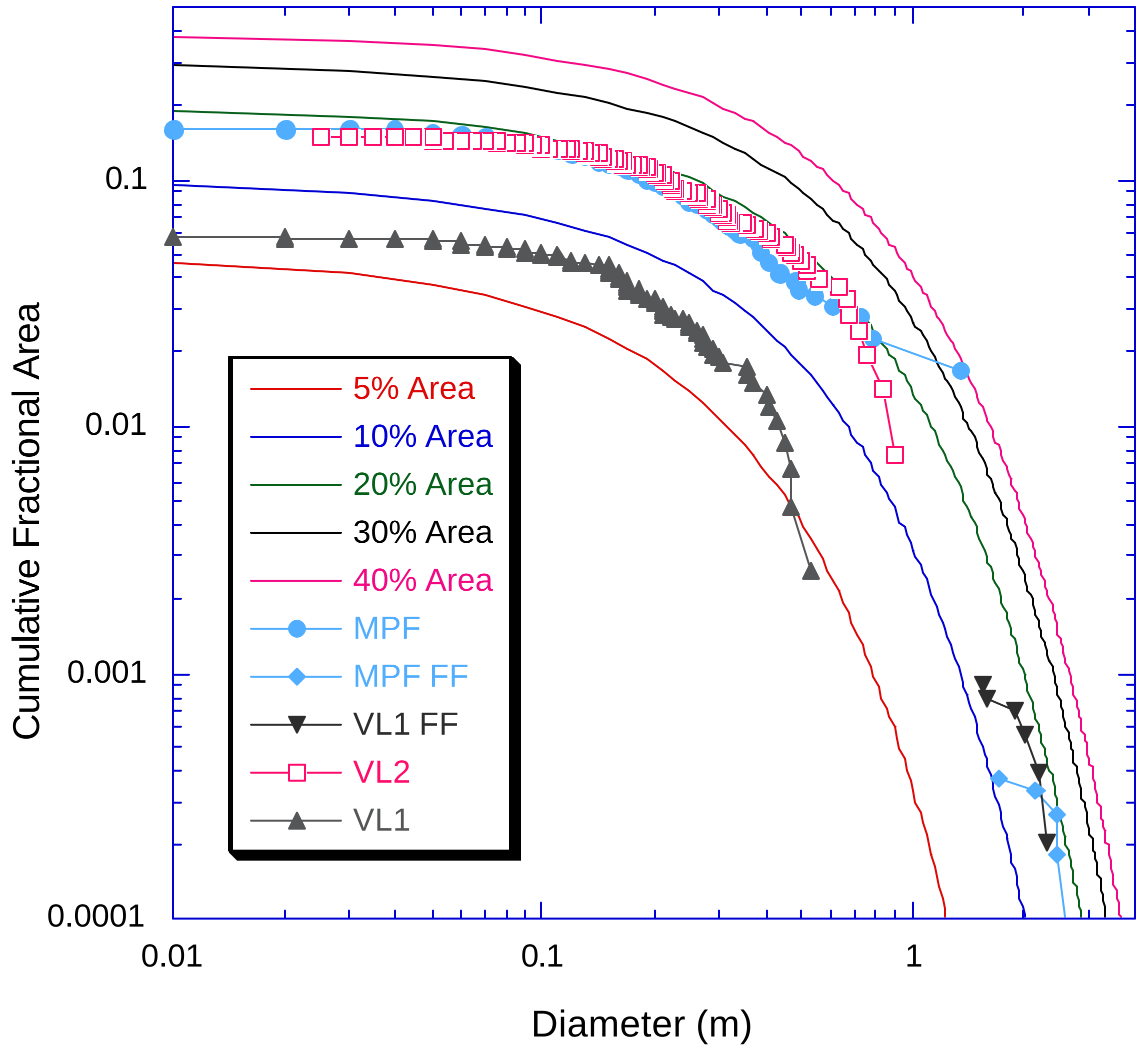
q(k) Governs Drop with D

$q(k) = 1.79 + 0.152/k$

Predicted 0.01 Area at MPF

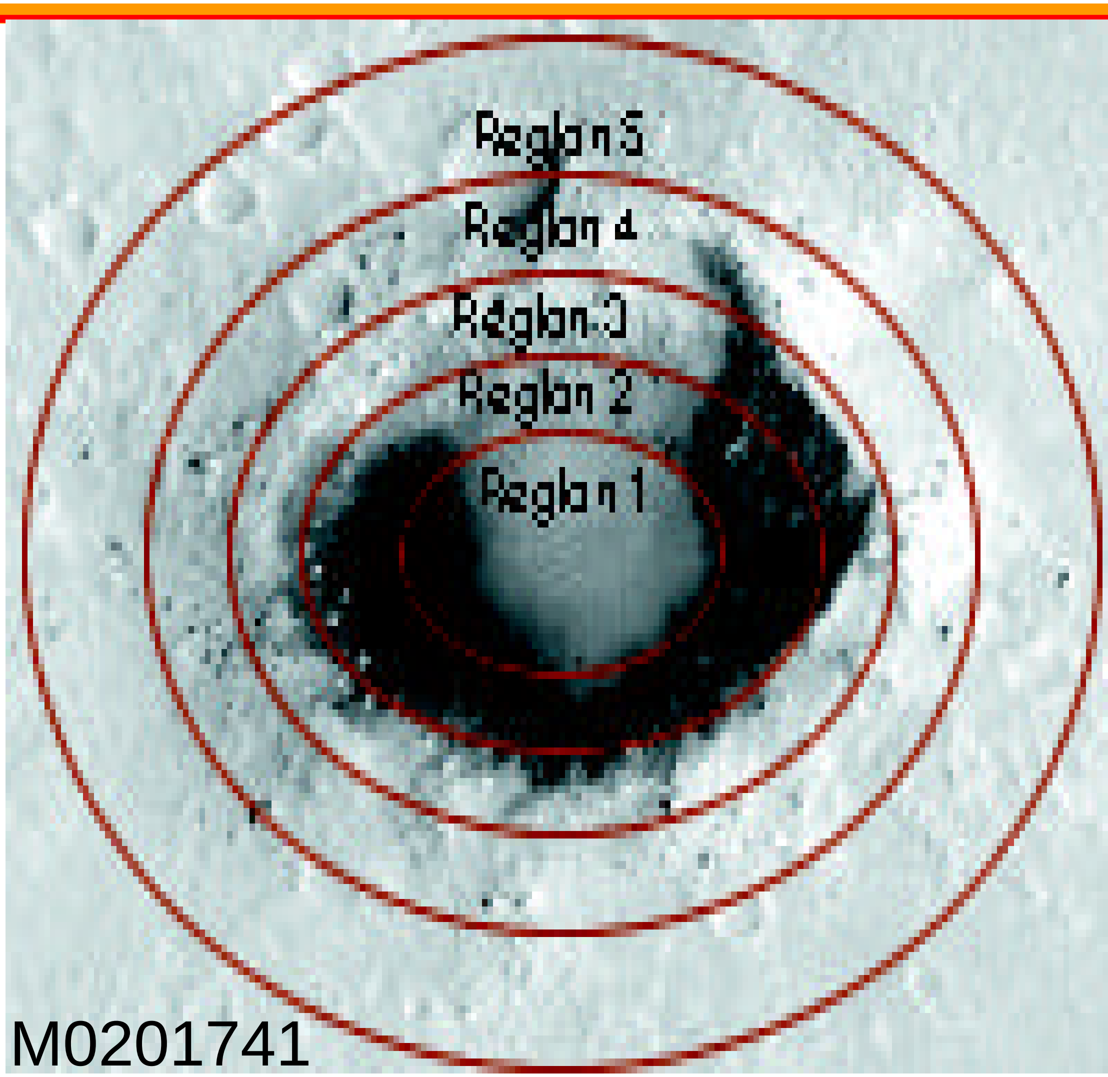
Covered by Rocks D>1 m

Prediction Successful!



Measured Rocks in Near and Far Field Match Model for MPF IRTM Rock Abundance

Boulders in MOC Images



Counted Boulders in MOC Images as Check on Large Dia. Rock Distribution

Boulders Show Up as Light/Dark Pixel Pairs in Low Sun Images

480 m Dia. Crater;
Largest Boulder 14 m
250 Boulders Counted
1 pixel Rock=1.5 m Dia

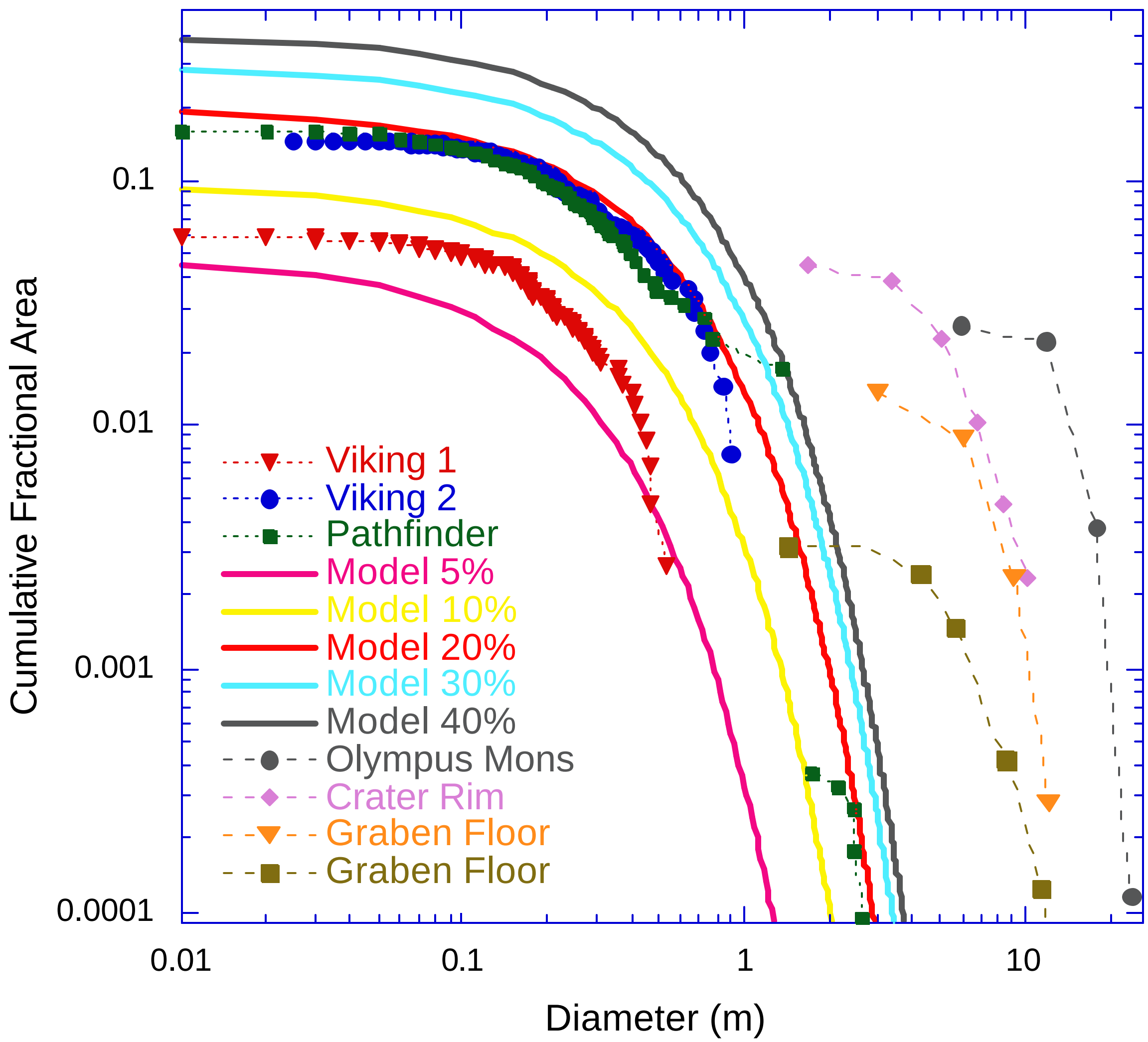
Boulder Fields in MOC Images

MOC Image (M0402248)
Olympus Mons Caldera
Scarp Boulder Field,
45° Sun Angle,   6 m/pixel
5182 Boulders, Max 24 m

M0202582 Graben Floor
39° Sun Angle, 3 m/pixel
4143 Boulders,
Max Rock 12 m Diameter

Rockiest Locations on Mars

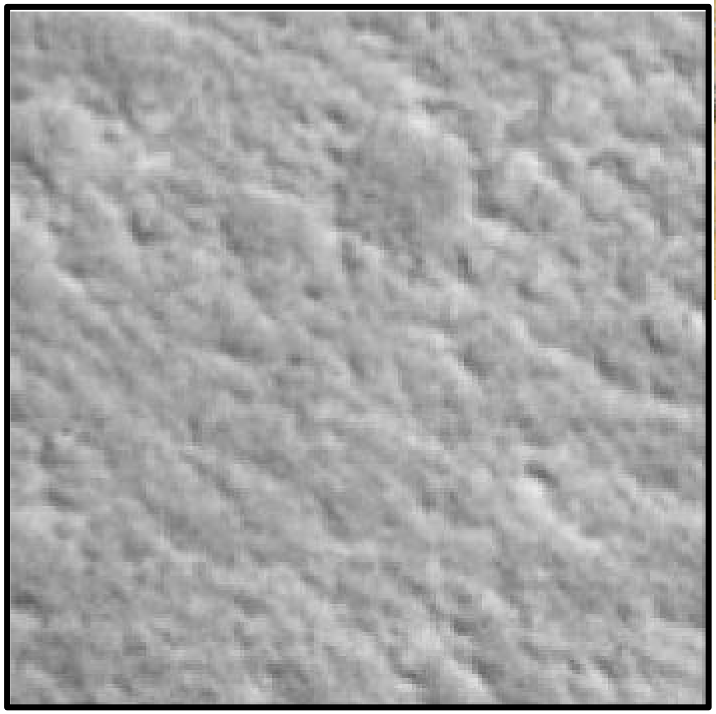
Boulder Size-Frequency Distributions



- Boulder Fields Rare
  - ~0.1% of MOC Image
  - Low Sun >38°
- Plotted Max Subareas
  - Ave, Min 2-10 x Lower
- Extreme Distributions
  - Steep Slope, Exponential Decay
  - Similar to Model Dist.
- ~1% Surface Covered by 3-10 m Diameter Boulders
- Can't See Boulders at 3 Landing Sites, 20%
  - If Can't See, <20% Rock Abundance

Boulders at Mars Pathfinder Site

Largest Rocks Visible from Lander Difficult to See in Highest Resolution MOC Images

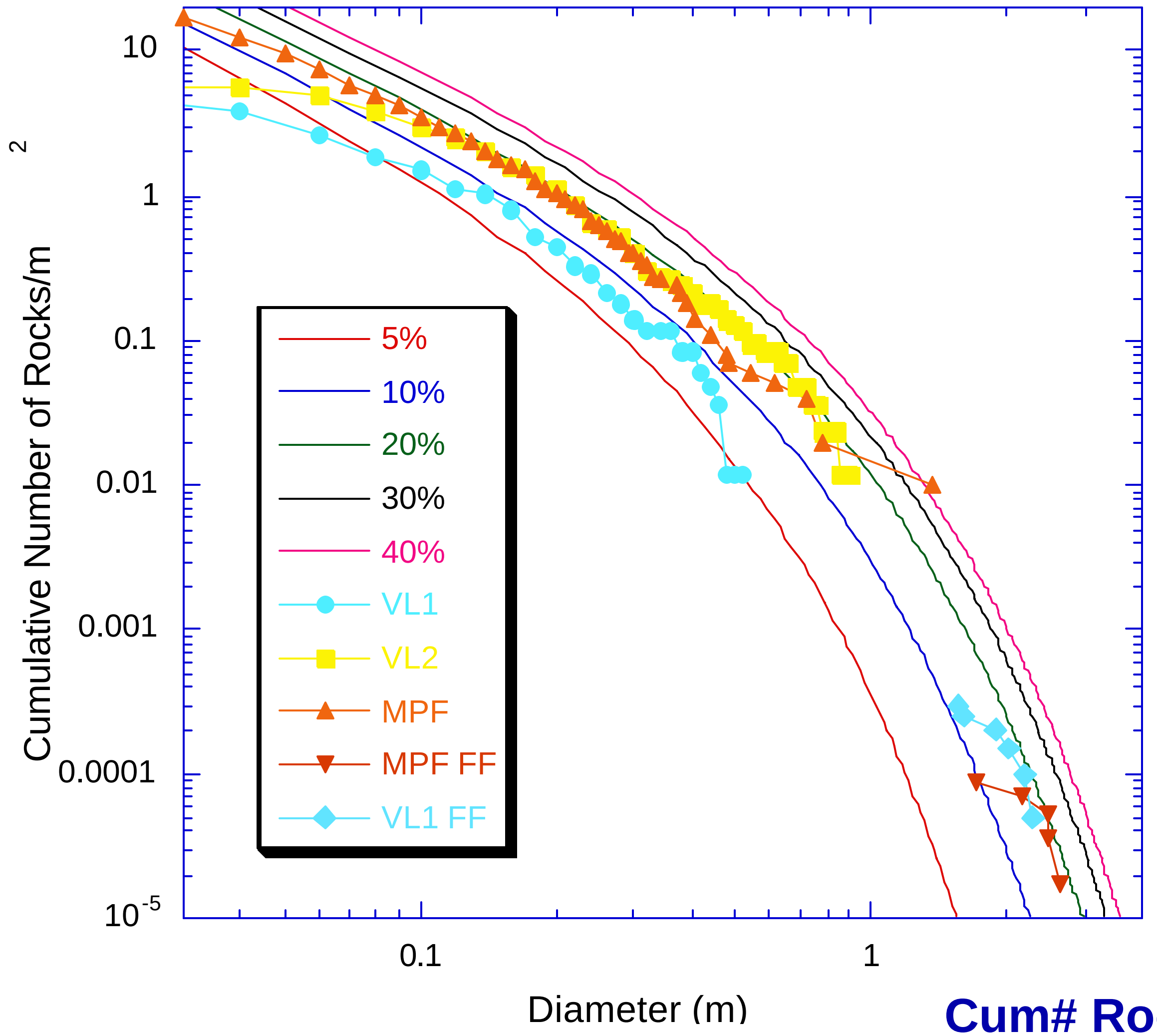


Highest Resolution (1.5 m/pixel) MOC Image of MPF Landing Site

Boulders Difficult to Identify, Even though MPF Among Rockiest Locations on Mars, ~20%

If Can't See Rocks in MOC Images then No Rockier than MPF, ~20% Rock Abundance

Cumulative Number Inversion



Numerically Integrate Cumulative Area Curves

Predict Cumulative Number of Rocks/m^2 of Diameter D or Greater for Any Rock Abundance

In General, H=D/2
So 1 m Dia Rocks are 0.5 m High

MPF ~0.01 Rocks/m^2 D>1 m
MPF Bounced 15-20 Times
Each Bounce ~15 m^2
MPF 200-300% Chance Hit D>1 m or 100% Chance Hit 2-3 D>1 m Rocks without Damage

Cum# Rocks in MPF Far Field Consistent with the Lack of Boulders >3 m Dia in MOC Images

Probability (%) of Impacting Rock of Dia. > 1 m

Landing Site	IRTM Rock Abundance	Cum. # Rocks>1m	2 Bounces	4 Bounces	10 Bounces	60 Bounces
Hematite	5 (average)	0.0004	1.2	2.4	6	36
	7	0.001	3	6	15	90
Melas	11 (average)	0.003	9	18	45	270
	13	0.005	15	30	75	450
Gusev	7	0.001	3	6	15	90
	8	0.002	6	12	30	180
Isidis	13	0.005	15	30	75	450
	15	0.006	18	36	90	540
Athabasca	11 (average)	0.003	9	18	45	270
	6	0.0005	1.5	3	7.5	45
	16	0.06	18	36	90	540
Eos	17	0.01	30	60	150	900
	22	0.015	45	90	225	1350

Assumes Each Bounce 15 m^2

Airbag Drop Test Platform

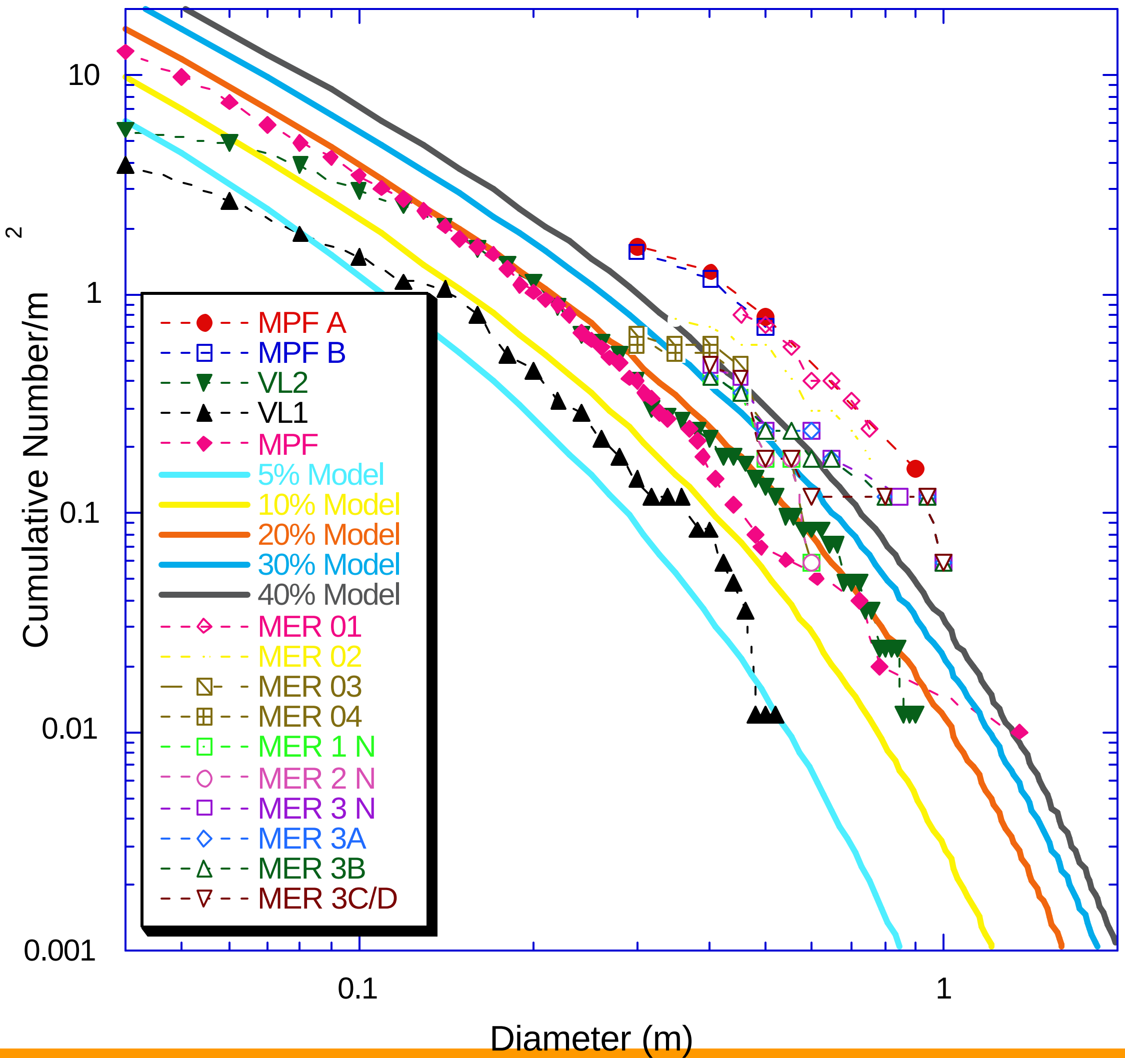
60° Dipping Platform at Plum Brook Largest Vacuum Chamber in World

- Fully Inflated Airbags Around Full Scale Lander
- Bungee Chord Pulls Lander to Impact Velocities
- Airbags Impact First at Edge Between Tetrahedrons & Then Rotates to Face

MER Airbag Drop Tests

Mostly Sharp Andesites, All Rocks Chalked, Placed at Key Locations to Test Lobe Edges and Bladder

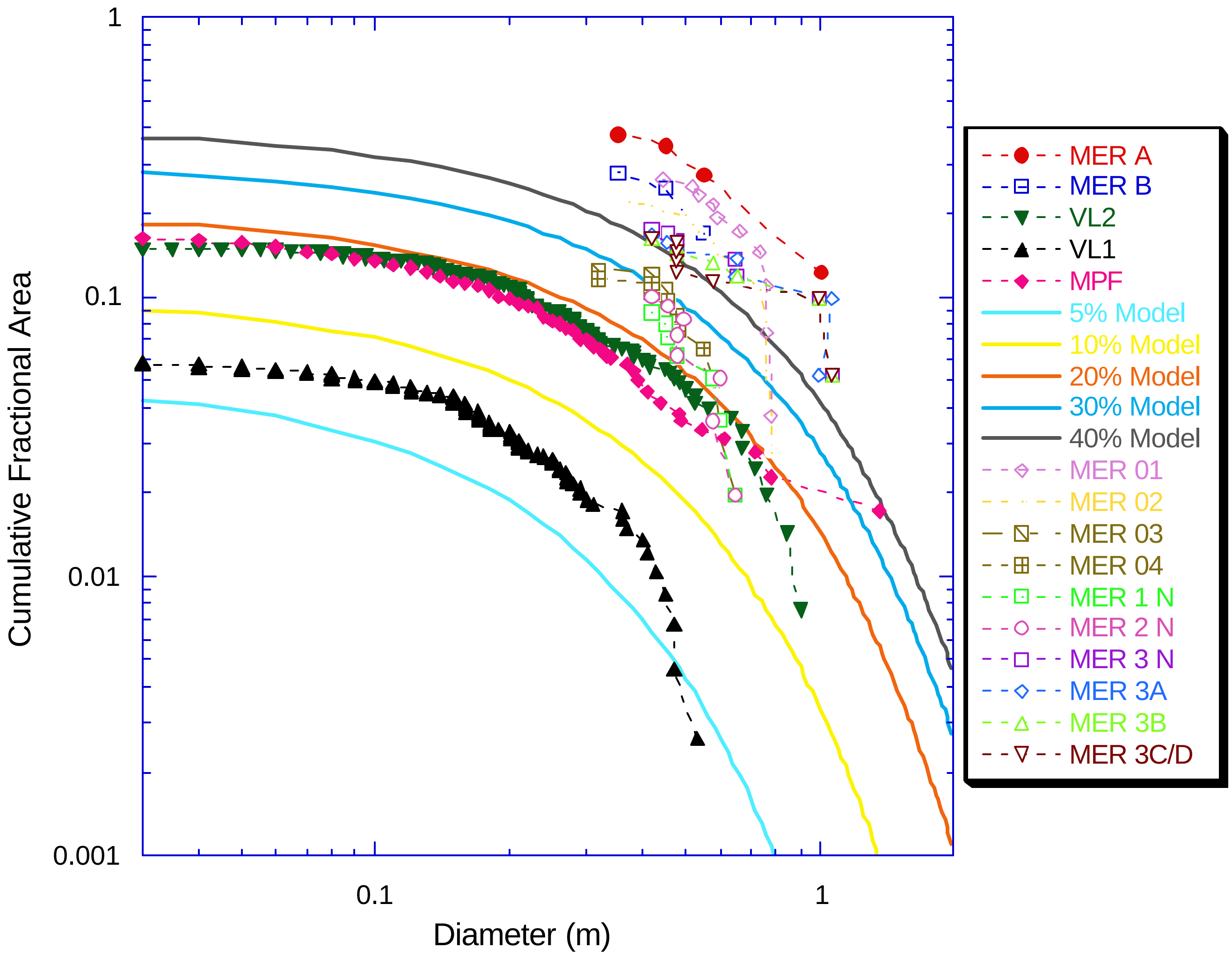
Airbag Drop Tests



Airbags Have Been Tested to Extreme Cumulative Number versus Diameter Distributions: 20 to >40%

Tests 5-10 Times Greater Number of 1 m Diameter Boulders than at MPF or VL2

Airbag Drop Tests



Airbags Have Been Tested To Extreme Cum. Area versus Dia. Distributions: 20->40% Model

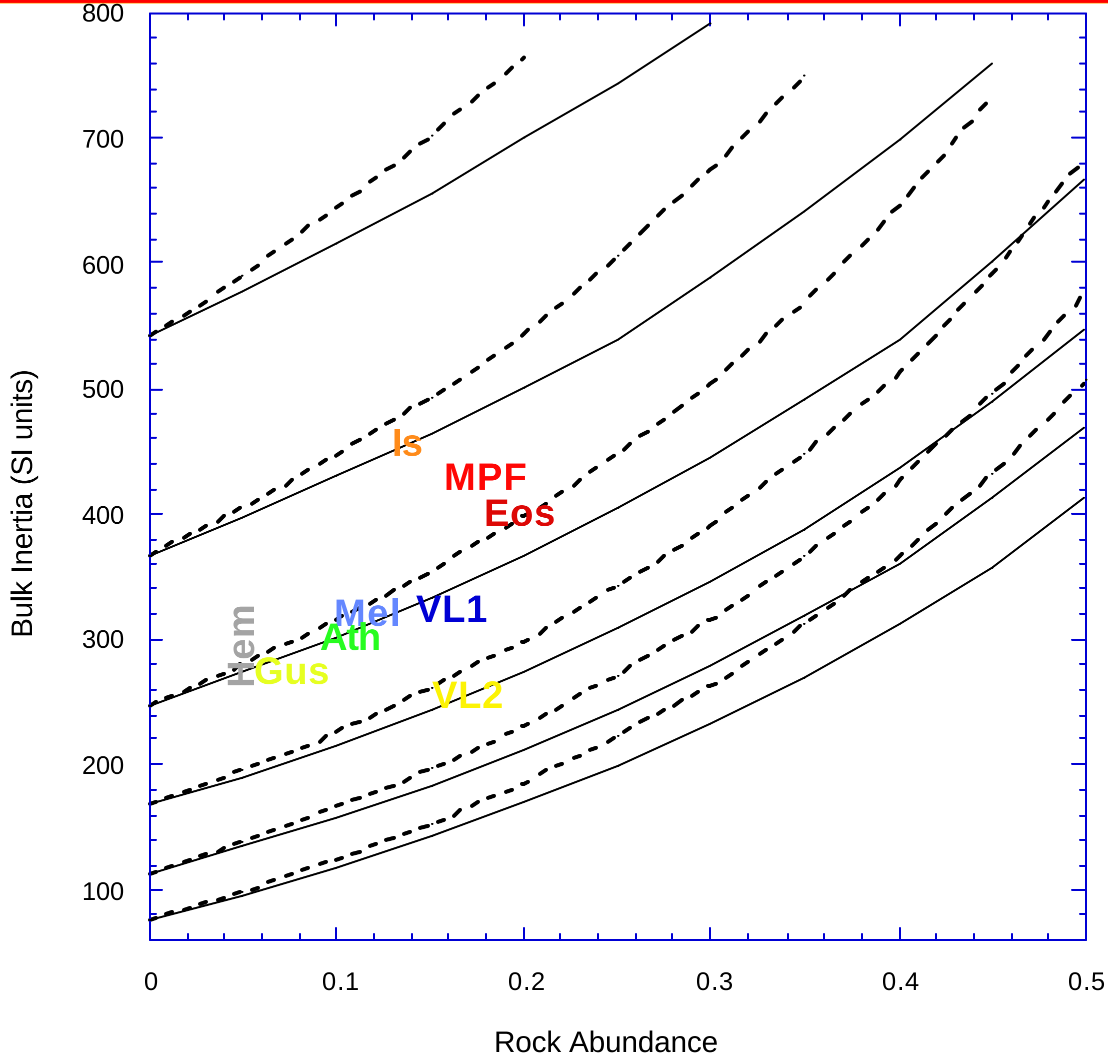
10% Surface Covered by 1 m Diameter Rocks

30% Surface Covered by>0.4 m Diameter Rocks

Risk From >1 m Diameter Rocks

- Airbags Have Been Tested Successfully Against 1 m Diameter Rocks
- Rapid Drop Off in Model with Increasing Diameter
- 10 Times Fewer 1.5 m Diameter Rocks (vs 1 m)
  - In 4 Bounces: <1% Gusev, ~1% Gusev, 2-3% Melas 3-4% Isidis, 1-4% Athabasca, 6-9% Eos
- 100 Times Fewer 2 m Diamter Rocks (vs 1 m)
  - In 4 Bounces: <0.1% Gusev, ~0.1% Gusev, <0.3% Melas, <0.4% Isidis, <0.4% Athabasca, <1% Eos
- Numbers are 1/2 These for First 2 Bounces

Bulk I Versus Rock Abundance



For Lines of Constant Fine Component I for Effective I Rock of 2100 (dashed lines) & 1300 (solid lines) - 20% Possible Rock Abundance Change

High I Landing Sites Not that Different from MPF So Probably OK