ROCK SIZE-FREQUENCY DISTRIBUTIONS AT THE MARS EXPLORATION ROVER LANDING SITES: IMPACT HAZARD AND ACCESSIBILITY.

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Introduction: The Viking and Mars Pathfinder landing sites and a wide variety of rocky locations on the Earth show size-frequency distributions that follow an exponential when expressed in cumulative fractional area covered by rocks of a given diameter or larger versus diameter plots. Mars lander rock distributions have been fit by an equation of the form: $F_k(D) = k \exp [-q(k) D]$, where $F_k(D)$ is the cumulative fractional area covered by rocks of diameter D or larger, k is the total area covered by all rocks, and an exponential $q(k) = 1.79 + 0.152/k$, which governs how abruptly the area covered by rocks decreases with increasing diameter [1]. These distributions form a family of non-crossing curves that flatten out at small rock diameter at a total rock abundance of 5-40%.

Probability of Impacting Rocks: The probability of the airbag-encased lander impacting rocks of any size is computed assuming that the number of rocks per unit area can be modeled as a Poisson distribution appropriate for the natural processes that produced these distributions. The probability, p, of a single rock in any given area, c, is proportional to c, as $p = 1/(c\ L)$, where L is the number of rocks per unit area (assumed to be uniform). The probability of exactly n rocks in any area (c L) is then expressed as, $P(n, c\ L) = (c\ L)^n \exp(-c\ L)/n!$. The probability that at least one rock of a specified size is within the area c is then $1 - P(0, c\ L) = 1- \exp(-c\ L)$.

Rock abundance estimated from thermal differencing techniques [2] is used to pin the cumulative fractional area covered by rocks >0.1 m in diameter, which is close to k above. The cumulative number of rocks/m^2 of any given diameter is derived by numerically integrating the cumulative fractional area model curves. The calculation assumes that the rock abundance estimate is accurate and made up of individual rocks defined by the model that are uniformly distributed; results should be considered best guess statistics.

The airbags were tested on rocks up to 0.5 m high (~1 m diameter). Rocks larger than this are considered potentially hazardous as the stroke of the airbags may be insufficient to keep the lander from impacting the rock. The rock abundance [2] of pixels that cover a significant portion of the ellipse [3] is: TM20B2, Meridiani average 5% (pixels 1, 6, 6, 7%), EP55A2, Gusev average 7.5% (pixels 7, 8% plus a small bit of 3%), EP78B2, Elysium average 5% (7 pixels are 1, 6, 6, 6, 8, 6% plus a small bit of 11%), IP84A2, Isidis average 14% (pixels 13, 15%). Probabilities are calculated for 2, 4, and 10 bounces (bounces after the first 10 are unlikely hazardous to the airbags). Each airbag bounce is assumed to cover either 16.98 m^2 or 8.95 m^2, which represent the area the airbags cover when landing with or without significant horizontal velocity.

The probability of impacting a >1 m diameter rock for a minimum rock abundance (evaluated at 2% rock coverage, close to the 1% minimum) at Meridiani and Elysium is 0.02-0.03% in 2 bounces, 0.04-0.07% in 4 bounces, and 0.09-0.17% in 10 bounces. The probability of impacting a >1 m diameter rock for the average 5% rock abundance at Meridinai and Elysium is ~1%, ~2% and ~5% in 2, 4 and 10 bounces, respectively. The probability of impacting a >1 m diameter rock at the average for Gusev and the maximum at Elysium (8% rock abundance) is 3.5-6.6%, 6.9-12.7% and 16.4-28.8% in 2, 4 and 10 bounces, respectively. These probabilities rise dramatically with increasing rock abundance, increasing to ~14%, ~26% and ~50% in 2, 4 and 10 bounces, respectively, for ~15% rock abundance applicable to Isidis.

Engineering analysis indicates that the likelihood of failure does not increase significantly until the rock height exceeds 0.7 m. Because of the rapid decrease in the model rock distribution curves, there are 10 times fewer rocks >1.5 m diameter and 100 times fewer rocks >2 m diameter. As a result the probability of impacting a >1.5 m diameter rock is <0.14% in 2 bounces, <0.27% in 4 bounces, and <0.68% in 10 bounces at Gusev and Elysium (for the maximum rock abundance of 8%). For Isidis these probabilities rise to roughly <2%, <4%, and <10% in the first 2, 4, and 10 bounces, respectively. For rocks higher than 0.7 m, the hazardous nature of the rock increases slowly with increasing height. The probability of impacting a rock >2 m diameter (1 m high) is 100 times lower than for 1 m diameter rocks and is <0.03%, <0.07% and <0.17% in 2, 4, and 10 bounces, respectively, at maximum rock abundance (8%) areas of Meridiani, Gusev and Elysium. These results suggest that the probability of impacting a hazardous >1 m diameter rock during the initial airbag bounces is relatively low at Meridiani, Gusev and Elysium.

MER airbag drop tests have shown that the internal bladder, which maintains the airbag gas under pressure, is susceptible to tensile failure when impacting triangular shaped rocks greater than 0.2 m high.

Deeply buried rocks that do not move during impact are also more likely to cause both abrasion of the outer layers and tensile stressing of the interior bladder. Roughly one third of the rocks >0.2 m high at the three landing sites are triangular and 7% of the rocks are triangular and deeply buried [4].

The probability of impacting a >0.4 m diameter rock (>0.2 m high) is 40-100 times greater than for 1 m diameter rocks. For an average rock abundance of 5% at Meridiani, Gusev and Elysium, the probability of impacting a >0.4 m diameter rock in 2 bounces is 41-64%. For the maximum rock abundance at these sites, the probability of impacting a >0.4 m diameter rock rises to 92-99%. If the fraction of triangular rocks (considered potentially hazardous) at the low rock abundance (5%) prospective landing sites is similar to that observed at the 3 landing sites (1/3), then there is 16-29% chance of impacting a triangular rock >0.2 m high in the first 2 bounces. These numbers rise to 57-80% chance of impacting a triangular rock >0.2 m high in the first 2 bounces for the maximum rock abundance at Gusev and Elysium. If the percentage of triangular rocks that are deeply buried (considered potentially more hazardous) at the low rock abundance sites is similar to that observed at the 3 landing sites (7%), then the chance of impacting a buried triangular rock >0.2 m high in the first 2 bounces is 1-2%, 4-7%, and 16-28% for surfaces covered by 2%, 5% and 8% rocks, respectively. In contrast, the high rock abundance landing sites have a 38-78% chance of impacting a buried triangular rock during the first 2 bounces. These results suggest the probability of impacting potentially hazardous triangular rocks that are buried is reasonably low at the Meridiani, Gusev and Elysium landing sites. The actual probabilities of impacting a rock >0.4 m diameter certain to be hazardous to the lander is less than these numbers as bladder failure against triangular rocks occurred in only certain drop tests and this failure mode has been largely ameliorated by the addition of a second interior airbag bladder.

Proximity of Rocks to MER: The model rock size-frequency distributions can also be used to calculate the number of rocks, or probability of encountering a rock large enough for analysis with MER instruments within a particular area. A rock large enough to place the instruments on the Instrument Deployment Device (IDD) up against is probably about 0.1 m in diameter. A rock with enough mass to remain stationary during abrasion by the Rock Abrasion Tool (RAT) has been estimated to be 0.3 m diameter. The cumulative number of rocks/m^2 larger than 0.1 m and 0.3 m in diameter is taken from the model distribution for different total rock abundance values at the landing sites and evaluated over 2 different areas.

The first area is an annulus 0.9 m beyond the obscuration zone of roughly 2.5 m radius created by the rover solar area when imaged from above by the Navcam and Pancam cameras (0.8 m above the rover deck) and is an area that can be reached by an easy rover drive of less than 3 rover lengths (rover wheel base is ~1.4 m). This annulus has an area of ~18.5 m^2 and is used in the calculation of the probability of a target rock for study near the rover. The second area (3.14 m^2) is within 2 m from the front of the vehicle near the instrument deployment device (IDD).

All of the sites have a 94-100% chance of having at least one rock greater than 0.1 m diameter within the area in front of the IDD and a 100% chance of having such a rock within the larger annulus. These results suggest that rocks large enough to be analyzed by instruments on the IDD should be ubiquitous at any of the landing sites; rocks of this size should be close enough to be targeted by the IDD just about anywhere, given the assumptions.

For rocks large enough (>0.3 m diameter) to remain stationary during abrasion by the RAT, fewer rocks will likely be present than those >0.1 m diameter. For the average rock abundance of 5% at the Meridiani and Elysium sites, there is a 23% chance that a single rock >0.3 m in diameter will be present within the area in front of the IDD. However for these rock abundance sites, there is a high probability (79%) that a single rock this size will be present within a single easy Sol's drive (3 rover lengths). For sites with 8% rock abundance (Gusev average, maximum at Elysium), about 2.8 rocks >0.3 m diameter will be present within ~3 rover lengths, or about 96% chance that a single rock will be present within any such area. For higher rock abundance sites (15% rock coverage), there is about a 67% chance that a single rock >0.3 m in diameter will be present within the IDD single command area. For these sites, about 6 rocks will likely be present within an annulus of an easy rover drive in a single Sol and there is a 99.9% chance that a single rock will be present within such an annulus. These results suggest that at all of the landing sites, rocks large enough to RAT should be available within an easy single Sol drive by the rover.

Conclusions: Model rock size-frequency distributions indicate a low probability of impacting hazardous rocks during MER landing. Rocks large enough to analyze and abrade by the rover should be plentiful within an easy Sol's drive.

References: [1] Golombek M. & Rapp D. (1997) *JGR, 102,* 4117-4129. [2] Christensen P.R. (1986) *Icarus, 68*, 217-238. [3] Golombek M. et al. (2002) *LPS XXXIII,* Abstract #1245, (2003) *LPS XXXIIII* Abstract. #1754. [4] [DiMaggio E.N. et al. (2003) *LPS XXXIIII* Abstract #1589.