ROCKS AND ROCK SIZE-FREQUENCY DISTRIBUTIONS AT THE MARS SCIENCE LABORATORY LANDING SITES. M. Golombek¹, A. Huertas¹, and D. Kipp¹, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109.

Introduction: Rocks and rock size-frequency distributions were accurately measured in the northern plains using software that segmented shadows cast in High Resolution Imaging Science Experimant (HiRISE) images. Measurement of rocks in HiRISE images of the Phoenix landing site using this technique correctly predicted the distributions measured by the lander. This abstract, describes the method and results for the Phoenix landing site selection, describes several improvements to the automated rock counting algorithm, and presents the rock distributions measured at the four Mars Science Laboratory (MSL) landing sites.

Phoenix Rock Distributions: To aid in the selection of the Phoenix landing site, an automated rock detector algorithm that fits ellipses to shadows and cylinders to the rocks, accurately measured rock diameter and height (within 1-2 pixels by comparison to spacecraft of known size) of ~10 million rocks over >1500 km² of the northern plains [1]. Results show that the size-frequency distributions of rocks >1.5 m diameter are fully resolvable in HiRISE images of the northern plains and follow exponential models developed from lander measurements of smaller rocks [2] and are continuous with rock distributions measured at the landing sites. Above ~1.5 m diameter, HiRISE resolves the same population of rocks seen in lander images and thus size-frequency distributions can be extrapolated along model curves to estimate the number of rocks at smaller diameters [1]. Extrapolating sparse rock distributions in the Phoenix landing ellipse indicates <1% chance of encountering a potentially hazardous rock during landing or that could impede the opening of the solar arrays [1, 3]. Extrapolations further suggest rocks large enough to depress the ground ice table [4] and small enough to be picked up or pushed by the robotic arm should be present within reach for study after landing. These predictions were correct as determined by rock counts around the Phoenix lander [5]. The location where Phoenix landed had the lowest rock abundance measured within the ellipse (~5%), which agreed with the lack of large rocks at the landing site and the low rock abundance measured at the surface (~5%). Small rocks were plentiful at the surface and were moved by the robotic arm [6] and were observed to affect the ice table depth [7].

Improved Rock Mapping Techniques: Enhancements to the rock mapping techniques were motivated primarily by the considerable increase in the complexity and diversity of the terrain in the proposed MSL landing sites.

A subset of the HiRISE images having very high signal to noise were selected and straightforward blind deconvolution was applied to sharpen the images [e.g., 8]. The deconvolution process is applied uniformly in four iterations to the images by initializing the point-spread function (PSF) to a 7x7 Gaussian kernel (σ = 1.0) that approximates the PSF of the HiRISE camera [9]. Our deconvolution experiments agreed with previous work on iterative deconvolution approaches that suggest a leveling-off of the mean square error after four iterations [10].

The rock detector incorporates adaptations that tune its analysis to image contrast, blur and noise. The variability of the topography and surface albedo that can be present suggest processing each image in sections to allow finer tuning of the parameters that drive these adaptations. Each image was partitioned into eight equal sections, which resulted in improved detection results at sites with increased local or broader albedo variation (e.g., Mawrth and Gale).

Processing of HiRISE images for the Phoenix landing site selection [1] indicate that shadow segmentation was able to reliably and robustly detect and analyze shadow regions with >5 pixels (~0.4 m²) in their umbra. With the images sharpened by deconvolution we were able to improve that limit to just 3 pixels (~0.24 m²). This results in more smaller rocks being detected. Tests using twelve sub-images of previous Mars landing sites that included the landers themselves and the surface rock measurements indicates that the resolution roll off (the diameter at which all rocks are not detected) decreases from about 1.5 m to 1.2 m diameter rocks (Fig. 1).

The automated process has a limited ability to differentiate non-rock features that cast shadows, such as

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Fig. 1. Cumulative number of rocks/m² versus diameter (blue) from original images detecting 5 pixel shadows (left) and sharpened images detecting 3 pixel shadows (right) for the area around the Mars Pathfinder lander. The surface rock count is in black from [2].
portions of escarpments from actual rocks. Because most of these non-rocks are large, they have an large effect on the cumulative size-frequency curves, making correlation with model distributions [2] difficult. To address this, user-assisted tools were developed that allow operators to exclude non-rocks from the maps. This was tested in a pilot study that evaluated 4 zones (each a square with 1.05 km sides) selected for diversity in each landing site. For each 150 m sided tile within the zones, an operator excluded non-rocks allowing comparison of the size-frequency distributions before and after editing. Results showed that most non-rocks are greater than 2.25 m diameter and that after editing, the size-frequency distributions followed the model distributions. Because interactive editing of all tiles in the landing sites would take a prohibitive amount of time, an automated approach was developed. The total number of rocks smaller than 2.25 m (smaller than most non-rocks) and larger than 1.5 m (roughly the resolution roll off) was determined over 450 m sided square areas (9 tiles). The total number of rocks 2.25-1.5 m diameter was matched to the closest model distribution (each model has a unique number of rocks in this size range). Tests of this method for the pilot study zones shows that the model distribution selected for each area matched the operator edited rock size-frequency distribution (Fig. 2).

Maps and Data:
Maps and data provided to the MSL project for incorporation into landing simulations include: diameter, height and location of every rock detected in 150 m by 150 m tiles; summary size frequency distributions in 450 m by 450 m areas, and the cumulative number of rocks/m² >1.5 m diameter and the best fit model distributions from the number of rocks/m² 1.5-2.25 m diameter; and maps of the total number of rocks per tile and best fit cumulative fractional area model rock abundance. Maps of the cumulative number of rocks in 150 m tiles vary from 0 to >130, with most of the surfaces covered by <4 rocks. Small areas at Gale and Eberswalde exceed 30 rocks per tile and very small areas exceed 60 rocks per tile.

Results: The total area covered by measured rocks at the landing sites is small and measures 0.014%, 0.015%, 0.047% and 0.054% at Holden crater, Mawrth Vallis, Gale crater and Eberswalde crater, respectively. Because of the resolution roll off in the measured rock diameters, this area is approximately equal to the percent area covered by rocks greater than 1.5 m diameter. These rock abundance areas were extrapolated along the model size frequency distributions [2] to derive the area covered by rocks >0.1 m diameter, which corresponds to the rock abundance estimated from thermal differing [11, 12] for comparison to previous landing sites [13]. Results suggest that Gale and Eberswalde sites have bulk rock abundances of around 6% and Holden and Mawrth have bulk rock abundances of <5%, making these sites qualitatively similar to different parts of the Gusev cratered plains [13]. These results contrast with rock abundance estimates from thermal differing of 10-15% for coarse resolution data [11] and 13-39% for higher resolution data [12], a difference attributable to the preponderance of layered outcrop at the sites, which would appear as rock thermally, but not as individual rock hazards, for which the size-frequency model distributions were developed. Bulk rock abundances of <6% indicate the probability of encountering 1 rock higher than the 0.6 m (corresponding to a 1.2 m diameter rock) under the area of the rover during touchdown is <1% (using the method in [2]) and thus meet the engineering criterion for safe landing.