ESTIMATES OF THE NUMBER AND SIZE OF ROCKS WITHIN REACH OF THE ROBOTIC ARM DURING PHOENIX SURFACE OPERATIONS ON MARS. M. Golombek[1], H. G. Sizemore[2], A. Huertas[1], L. Tamppari[1], and M. T. Mellon[2], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, [2]Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, CO 80309.

Introduction: The size-frequency distributions of rocks >1.5 m diameter, fully resolvable in High Resolution Science Experiment (HiRISE) images of the northern plains, follow exponential models developed from lander measurements of smaller rocks [1, 2] and are continuous with rock distributions measured at the landing sites [3]. As a result, measurements of rock distributions in HiRISE images can be extrapolated to smaller diameter to estimate the number of rocks in the Phoenix robotic arm workspace that could be beneficial to the mission. For example, an important science objective of the Phoenix lander is to analyze the composition and chemistry of the soil overlying the ground ice and as a result the thickness of this overlying soil was a factor in site selection [4]. However, there is concern that the descent engines could possibly blow away overlying soil during landing, which is estimated to be only several centimeters thick at the selected landing site [4]. Detailed thermal modeling by Sizemore and Mellon [5] shows that rocks 0.05 to 1 m in diameter that protrude from the surface would maintain an ice free zone comparable to the dimension of the rock. As a result, rocks of this size range would have ice free soil around them that would be less likely to be dispersed by the thrusters during landing.

Rocks in the 2-7 cm diameter size range are small enough to fit within the scoop at the end of the robotic arm and can be picked up. Picking up small rocks offers the prospect of examining rock texture, fabric, morphology and color to help identify mineralogy and rock type more closely at higher resolution with the cameras. Rocks of this size and up to 10 cm in diameter can also be pushed on the surface, allowing the inspection of the rock underside to look for variations in surface weathering and to investigate the soil beneath the rock. All rocks with diameters from 2 cm to 1 m will be an asset to direct investigation of soils, because the ice table is expected to be deeper than average in the region of a rock's thermal influence. Larger rocks, tens of cm to 1 m, will not be movable by the scoop, but should be associated with laterally extended regions of relatively deep ice-free soil, which would provide soil at greater depths for examining possible gradients in soil texture or chemistry and possible gradients in thermal environment that could affect soil moisture and the presence of potential habitats and/or the deposition and accumulation of salts. Moving small rocks and measuring the thickness of the ice free soil around larger rocks will allow for direct comparison to simulations of the thermal response of ground ice to soil heterogeneities [5]. This type of detailed comparison can be used to better understand ground ice stability in the current climate and the dynamical response to climate change.

Method: To estimate the number of small diameter rocks at the Phoenix landing site, representative size-frequency distributions measured in HiRISE images of the landing ellipse are extrapolated along exponential model curves. In general, areas within the landing ellipse have very low rock abundance with rock counts in HiRISE images that correspond to model distributions around 1-5% cumulative fractional area coverage [3]. Other surfaces in the vicinity of the landing ellipse have small areas with rock counts in HiRISE images that correspond to model distributions of around 10%, 20% and >20% cumulative fractional area coverage [3]. As a result, first the model cumulative number of rocks greater than diameter 2, 5, 7, 10, 25, 50 and 100 cm per m^2 was calculated by numerically integrating the exponential cumulative fractional area distributions [2]. Next, to determine the number of rocks per m^2 within any given diameter interval, the cumulative number of rocks greater than the maximum diameter per m^2 is subtracted from the cumulative number of rocks greater than the minimum diameter per m^2. This number is multiplied by the robotic arm workspace area, estimated to be a 1.95 radian sector annulus from 0.6 m to 2.07 m distance that measures ~3.8 m^2. The number of rocks of 5-100 cm, 7-100 cm, 10-100 cm, 2-7 cm, 5-7 cm and 5-10 cm diameter intervals expected within reach of the arm are shown in Table 1 for 1%, 5%, 10%, 20% and 40% cumulative fractional area rock coverage.

The first 3 intervals correspond to rocks that could produce depressions in the ice layer thickness that would be helpful for sampling dry layer material [5]. Because rocks larger than 5 to 10 cm are estimated to produce a layer of dry soil around them, the number of rocks greater than 5, 7, and 10 cm but smaller than 1 m are estimated. The next 2 intervals are the number of rocks small enough to be picked up by the scoop. Because of uncertainties in the number of small pebbles in the 2 to 5 cm diameter range, estimates are provided for the number of pebbles larger than each, but smaller than 7 cm. Rock counts from existing landing sites with more dust have fewer small pebbles compared to the model than less dusty landing sites (dust can easily mask small pebbles) [6]. Counts of pebbles on the lower albedo cratered plains of Gusev show distributions that match the model distributions down to 2 cm [7]. The albedo (a proxy for dustiness of the surface [6]) of the Phoenix landing site is moderate and comparable to portions of the Gusev cratered plains and the Mars Pathfinder landing site, both of which have a large population of pebbles comparable to the model distributions so to first order there is no reason to expect that the Phoenix landing site would not have plenty of pebbles in the 2-5 cm size range. The final interval of rocks (0.05-0.1 m) are those that should be able to be pushed by the arm, providing the opportunity to explore dry material under rocks.

It should be noted that this method assumes that the model distributions apply and those measured in HiRISE images can be extended to small diameter as argued by the comparison with ground truth at the landing sites [3]. The distribution of rocks on the surface is also assumed to be homogeneous for any given total rock coverage. Processes that could sort or process rocks such as periglacial processes suggested by the ubiquitous polygons would obviously alter the spatial distribution of rocks. Thermal contraction polygons are known to process rocks on the surface, creating rubble piles or concentrating rocks along polygon edges, both of which are observed in HiRISE images of the northern plains. Nevertheless, the exponential model distribution is based on basic fracture and fragmentation theory that has been applied successfully to a broad variety of surfaces on the Earth and terrestrial planets [1, 2], which suggests that the basic population of rocks is likely similar due to the similar production process, but that periglacial processes have simply spatially sorted the populations in the northern plains. In any case, this is a hypothesis that can be tested using the model distribution extrapolations and results provide a quantitative estimate of what to expect and that can be used for planning operations.

Results: Results are encouraging that there will be rocks within the robotic arm workspace even for fairly rock free areas being targeted for landing Phoenix. For areas with only 1% rock coverage, at least 1 rock 0.07-1 m diameter should be in the area that can be reached by the arm (Table 1). Areas with higher rock coverage (5-10%) should have more rocks (7-12, respectively). High rock abundance areas (>20%) that are generally being avoided for landing Phoenix, but for which some small areas cannot be avoided in the ellipse, should have even more rocks 0.07-1 m in diameter (22-40 rocks for 20-40% rock coverage). These calculations suggest that even for very low rock abundance areas within the ellipse, rocks large enough to create a surrounding ice free soil layer large enough to be sampled by the robotic arm should be present [8], thereby partially ameliorating concerns of the descent engines blowing away all surface soil.

Table 1: Model number of rocks in the indicated rock diameter interval expected within the 3.8 m^2 area that the Phoenix arm can reach for different cumulative fractional area (CFA) rock coverage.

Rock Diameter Interval (m)	Number Rocks, 1% CFA	Number Rocks, 5% CFA	Number Rocks, 10% CFA	Number Rocks, 20% CFA	Number Rocks, 40% CFA
0.05-1.0	3.4	13.2	21.2	35.5	63.2
0.07-1.0	1.4	7.7	12.9	22.2	40.0
0.1-1.0	0.5	4.1	7.4	13.1	24.0
0.02-0.07	20.4	42.1	60.5	95.4	164.4
0.05-0.07	2.0	5.5	8.3	13.3	23.1
0.05-0.1	2.9	9.1	13.9	22.4	39.1

Extrapolations to rock diameters small enough to be picked up by the robotic arm (2-7 cm diameter) suggest that multiple rocks should be present for investigation even in very low rock abundance areas. Assuming 2-7 cm pebble distributions are similar to the model, results suggest that 20-60 rocks of this size range are expected to be present in areas of 1-10% rock coverage (Table 1). Areas with total rock coverage of 20-40% are expected to have 95-164 rocks of 2-7 cm diameter available for manipulation with the robotic arm and scoop. If areas where Phoenix lands have fewer pebbles in the 2-5 cm diameter range than suggested by the extrapolations but similar to dustier landing sites, there still should be 2-8 rocks of 5-7 cm diameter available in the robotic arm workspace for investigation.

Rocks large enough to create an ice free soil zone surrounding them, but small enough to be pushed by the robotic arm are also expected to be present. For areas with total rock coverage of 1-10%, 3-14 rocks 5-10 cm in diameter are expected to be present within reach of the robotic arm (Table 1). For areas with total rock coverage of 20-40%, 22-39 rocks 5-10 cm in diameter are expected to be present. These results suggest that the Phoenix mission will have the opportunity to investigate ice free soils beneath rocks at levels below the expected average ice table depth [8].

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