DETERMINING THE BEARING CAPACITY OF PERMANENTLY SHADOWED REGIONS OF THE MOON USING BOULDER TRACKS. H. M. Sargeant[1], V. T. Bickel[2,3], C. I. Honniball[4], S. N. Martinez[5], A. Rogaski[6], S. K. Bell[7], E. C. Czaplinski[8], B. E. Farrant[7], E. M. Harrington[9], G. D. Tolometti[9], and D. A. Kring[10]. [1]The Open University, United Kingdom (Email: hannah.sargeant@open.ac.uk), [2]Max Planck Institute for Solar System Research, Germany,[3]Swiss Federal Institute of Technology, Switzerland, [4]University of Hawai'i, United States, [5]Tulane University, United States, [6]South Dakota School of Mines & Technology, United States, [7]University of Manchester, United Kingdom, [8]University of Arkansas, United States, [9]University of Western Ontario, Canada, [10]Lunar and Planetary Institute, Universities Space Research Association, United States,[11]NASA Solar System Exploration Research Virtual Institute, United States.

Introduction: Permanently Shadowed Regions (PSRs) are areas that do not experience direct sunlight and are commonly found in the polar regions of the Moon. PSRs can reach temperatures as low as 30 K and are of interest because there is direct and indirect evidence to suggest the presence of water (H_2O/OH-) inside most PSRs [1,2].

Several missions to explore PSRs have been proposed, but little is known about the strength of regolith near potential landing sites. Hints about regolith porosity have been extracted: The LCROSS impactor into a lunar PSR resulted in ejecta angles and flashes expected in highly porous material of ~70 % to equivalent depths of 2-3 m [3]; LRO DIVINER low thermal inertia values suggest the upper few centimeters of high-latitude regions of the Moon are highly porous [4]; and laboratory studies suggest material experiencing low thermal cycling, such as that in PSRs, will be more porous [5]. If such high porosity soils truly exist, they may not be able to sustain loads as well as that in areas already explored on the Moon, requiring significant changes to landing pad and rover wheel designs. To test those findings, we analyze boulder tracks to determine the bearing capacity of lunar soils in lunar south polar PSRs. Those results are then used to evaluate the trafficability of these regions.

Lunar boulder tracks: Rockfalls and their associated boulder tracks are abundant on the Moon [6,7]. The dimensions of tracks with respect to associated boulders can be used to infer soil strength using bearing capacity theory. This work uses a variation of Hansen's formula [8]:

$$q_f=cN_cs_cd_ci_cb_cg_c+q_oN_qs_qd_qi_qb_qg_q+0.5\gamma B_H N_\gamma s_\gamma d_\gamma i_\gamma b_\gamma g_\gamma \quad (1)$$

where c is the cohesion of the soil, q_0 is the vertical stress within the soil, γ is the unit weight of the soil, B is the width of footing, $N_{(c,q,\gamma)}$ are the bearing capacity factors, $d_{(c,q,\gamma)}$ are the depth factors, $s_{(c,q,\gamma)}$ are the shape factors, $g_{(c,q,\gamma)}$ are the local slope inclination factors, and $i_{(c,q,\gamma)}$ and $b_{(c,q,g)}$ are the load and foundation inclination factors, respectively. Hansen's formula considers slope angles and rectangular shaped boulders. This was deemed suitable for application to the generally non-spherical boulders found on the Moon and their boulder tracks which are generally formed on crater walls and slopes [8].

Methods: Representative PSRs were selected from a recent map of PSRs [9]. Narrow Angle Camera (NAC) images of those areas were stretched by enhancing contrast and brightness to identify boulder tracks in shadowed areas. Only areas with secondary sunlight, diffusely reflected from crater walls into PSRs, were used in this initial study as a minimum amount of illumination was required to identify boulders.

Images were processed with two customized spatial filters to remove excess noise that was amplified during NAC contrast and brightness adaptation (Fig. 1). Boulder and track dimensions, and the associated shadows produced, were recorded for each of 13 boulder tracks identified in 5 PSRs. The illumination angle of the secondary light was estimated by determining the midpoint of the illuminated slope and its height above the boulder and its track. The illumination angle could then be used with track measurements to estimate the track depth.

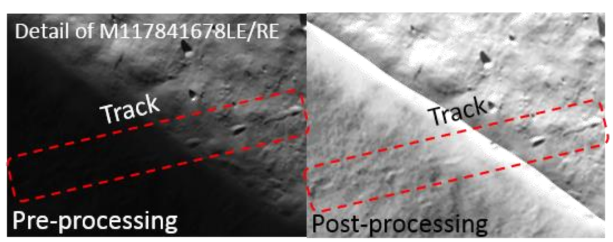

Fig. 1 Pre- and post- image stretching and filtering. A boulder track can be seen entering a shadowed region.

All measurements and soil properties from the literature were then input into Hansen's formula (1) to estimate the bearing capacity. All results were compared with values obtained in previous work from this team [8] for highland, mare, and pyroclastic regions on the Moon.

Results: The analysis indicates boulder tracks formed in PSRs have qualitatively similar morphologies to those formed in highland, mare, and pyroclastic regions (Fig. 2).

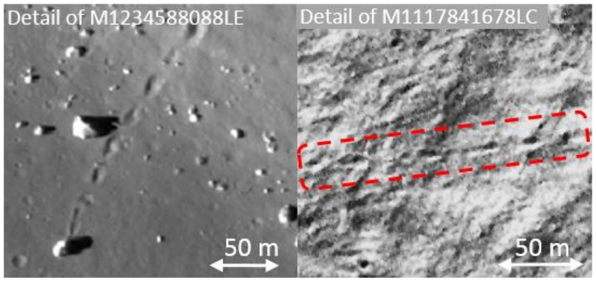

Fig. 2 Left – boulder track in Aristarchus (highland slope). Right - boulder track near Schrödinger (PSR slope).

Calculated bearing capacities increase with depth for all terrains, although PSR and pyroclastic regolith is generally stronger than highland and mare regolith at equivalent depths (Fig. 3).

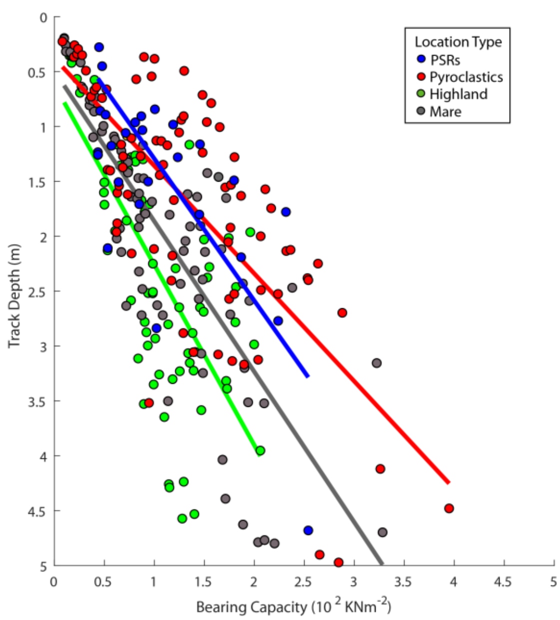

Fig. 3 Bearing capacity as a function of depth for all location types on all slopes.

Calculated bearing capacities and interpolation of PSR data also indicate steeper slopes cannot support boulders as well as flatter slopes (Fig. 4), a result of the reduced soil volume bearing the boulder [10]. PSRs are significantly stronger than mare regions in the upper 0.28 to 1 m of regolith and at slopes of 0°, with estimated bearing capacities of 123±18 kNm^{-2} and 93±23 kNm^{-2}, respectively. PSRs are statistically similar to pyroclastic deposits which have calculated bearing capacities of 131±21 kNm^{-2} [8]. There was insufficient data in the upper 1 m of highland regolith for a statistical comparison.

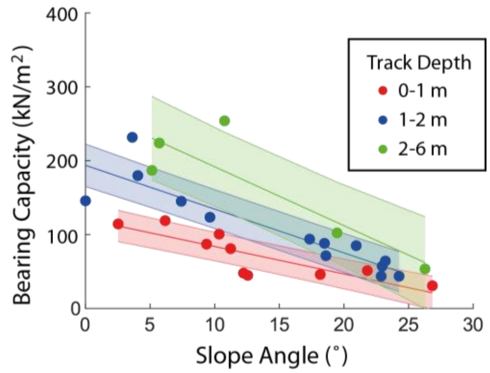

Fig. 4 Bearing capacity as a function of slope for a range of boulder track depths for PSRs.

It should be noted that this technique is limited by the minimum depth of measured boulder tracks (≳28 cm in PSRs). The minimum track depth measured is constrained by the minimum track shadow length measured, which in turn is constrained by the resolution of the available NAC imagery (~0.5 m/pixel).

Discussion and Conclusions: This boulder track study suggests that regolith in PSRs is significantly stronger than mare regolith at depths ≳28 cm, potentially contradicting reports of very high porosity in PSRs [3,4,5] or restricting those proposed high porosity conditions to the uppermost 28 cm. In either case, trafficability of PSRs may be possible with wheel diameters ≳56 cm. *In situ* analyses are still required to verify these results and to establish the strength of the uppermost 28 cm of regolith.

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