DO BARE ROCKS EXIST ON THE MOON ?

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Introduction: Astronaut surface observations and close-up images at the Apollo [1] and Chang'e 1 landing sites confirm that at least some lunar rocks have no discernable dust cover. However, ALSEP measurements as well as astronaut and LADEE orbital observations and laboratory experiments [2] possibly suggest that a fine fraction of dust is levitated and moves across and above the lunar surface. Over millions of years such dust might be expected to coat all exposed rock surfaces. This study uses thermal modeling, combined with Diviner orbital lunar eclipse temperature data, to further document the existence of bare rocks on the lunar surface.

Eclipse: Lunar eclipses, with large thermal excursions on a timescale of hours, provide unique information on the upper few mm of the Moon's surface [3]. Data for this study were obtained during the total eclipse of April 4-5, 2015. Eclipse duration was 5 hours and 44 minutes of Earth time. The eclipse shadow crossed the study area during the lunar morning, at approximately 0900 local time.

Study Area – Aristarchus Plateau: A pyroclastic deposit many meters thick covers most of the Aristarchus plateau [4; Fig. 1]. The deposit displays a range of basaltic pyroclastic glass concentrations and spectral signatures. *Weitz et al.* [5] determined that one of the least contaminated areas of the deposit is near Herodotus χ, close to the edge of the present study area. Western Schroter's Valley, a large sinuous rille, is included in the southern portion of the study area.

Thermal Model: A model was developed, based on work by Bandfield and colleagues [6, 7, 8], to predict the thermal behavior of mare soil, bare rocks, and rocks covered with various thicknesses of soil. This model was run for the Aristarchus plateau and the insolation conditions before and during the April 2015 eclipse. The modeled temperatures of the upper few mm of soil closely followed the changing solar insolation. Bare rocks have considerably higher thermal inertia than lunar soil, thus rock surface temperatures change more slowly than those of the soil. Rocks were predicted to be significantly cooler than soil during the lunar morning but significantly warmer than soil during an eclipse.

The model also predicts that a very thin coating of lunar soil is sufficient to mask rock temperatures. The model was run for rocks with soil coatings of 1.9 to 9.6 mm thickness, and in all cases the predicted temperature of a coated rock was within a few degrees of the soil-only temperature.

The model used the thermal characteristics of mare soil, while a thick deposit of pyroclastic material covers the Aristarchus plateau. Basaltic pyroclastic material from the Taurus Littrow deposit, sampled by the Apollo 17 astronauts, has approximately the mean grain size of mare soil – around 100 µm – but a significantly lower albedo. The average temperature of the Aristarchus pyroclastic deposit is roughly 10 K warmer than that of the nearby mare, likely due to albedo effects [9]. However, the thermal characteristics of pyroclastic material and mare soil are considered similar enough to use the thermal model in this study.

Diviner Observations: Diviner is a mapping radiometer on the LRO spacecraft [10]. The spacecraft altitude during the eclipse resulted in a Diviner detector "pixel" around 600 m (in track) by 300 m (cross track).

The current study uses measurements from Diviner's band 7 (wavelength range 25-41 µm), which provide high signal/noise ratios over the full range of equatorial surface temperatures [7]. T7 temperatures are precise and accurate to approximately +/- 1 K.

This study includes data from LRO orbits 26083 and 26085, taken prior to and during the eclipse. Diviner targeted the western Aristarchus plateau from 24.8 N to 27.1 N and 306.6 E to 308.7 E.

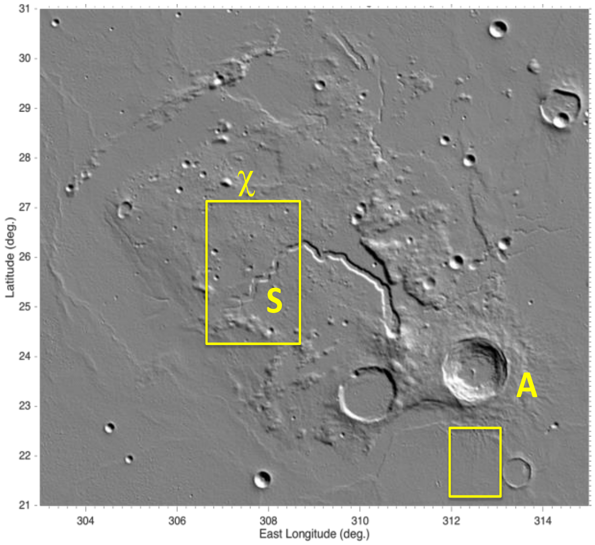

Fig. 1. Aristarchus plateau; shaded relief with the study area shown in yellow; χ = Herodotus χ, S = Schroter's Valley, A = Aristarchus crater

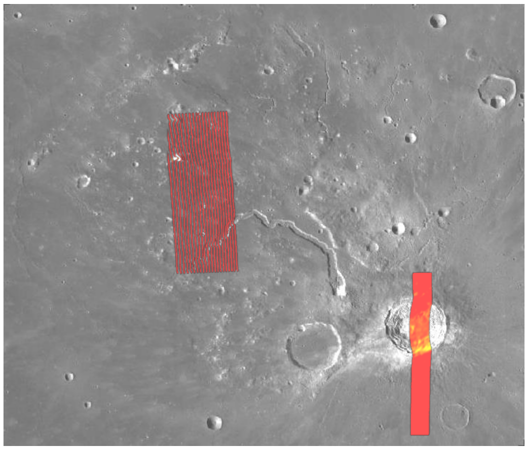

Fig. 2. Pre-eclipse Diviner T7 temperature measurements; orbit 26083; color stretch in Figs. 2 and 3 range from 375 K (red) to 100 K (blue)

Pre-Eclipse (orbit 26083; Fig. 2): Thermal modeling predicts that, during the lunar morning, the near-surface temperature of the pyroclastic deposit should be approximately 50 K warmer than the temperature of bare rocks. This is due to the more rapid heating of the finely-divided pyroclastic material relative to the rocks. Diviner measurements indicate that the mean temperature of the least contaminated pyroclastic material was 359 K (σ = 1 K). The lowest temperature in the study area, within Schroter's Valley, was 339 K.

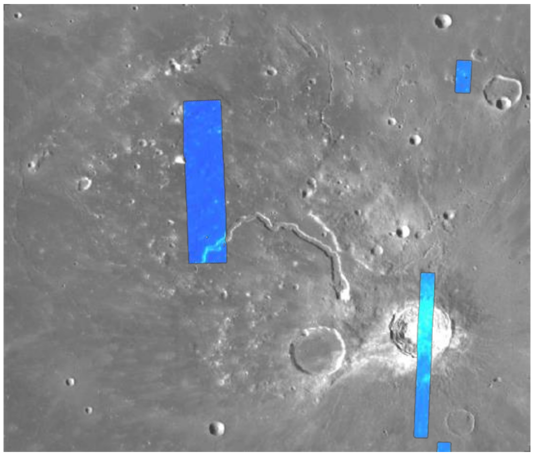

Fig. 3. Total eclipse Diviner T7 temperature measurements; orbit 26085

Total Eclipse (orbit 26085; Fig. 3): Thermal modeling predicts that, during eclipse totality, the pyroclastic material should rapidly cool by approximately 175 K from its pre-eclipse value. Bare rock, however, should cool by only around 15 K and thus the pyroclastic material should be significantly colder than any bare rocks. Diviner measurements taken during totality show a mean temperature for the least contaminated portion of the pyroclastic deposit of 155 K (σ = 5 K). The highest temperature in the study area, within Schroter's Valley, was 208 K.

Discussion: Diviner observations of the Aristarchus plateau show temperature differences between the pyroclastic deposit and areas within Schroter's Valley that are consistent with the presence of both rocks and pyroclastic material in the valley. During the lunar morning prior to the eclipse, measured temperatures on the pyroclastic deposit were as much as much as 20 K warmer than temperatures in the valley. During the eclipse, measured temperatures on the pyroclastic deposit were as much as 53 K colder than temperatures in the valley. In both cases, within Schroter's Valley the temperature in each Diviner "pixel" was derived from the combined fluxes of rocks and surrounding pyroclastic material.

High resolution LROC images clearly show meter-scale and larger rocks on the walls and floor of Schroter's Valley. The areal density of these rocks exceeds 10% in the sections of the valley where Diviner measured the largest temperature differences prior to and during the eclipse. Exposed rocks are rare in other areas of the pyroclastic deposit.

The thermal model also predicts that soil coatings as thin as 1.9 mm should almost completely mask the temperatures of underlying rocks. The fact that Diviner observations unambiguously show thermal signatures of rocks demonstrates that the thicknesses of soil coatings on a significant proportion of the rocks in Schroter's Valley are millimeter-scale or less.

Conclusions: Diviner temperature measurements before and during a lunar eclipse are consistent with a significant population of exposed rocks within Schroter's Valley. Any soil coatings on these rocks are millimeter-scale or thinner. Bare rocks – and possibly rocks with extremely thin dust coatings – do exist on the Moon. This conclusion presents a strong constraint on models of dust transport and deposition on the lunar surface.

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References: [1] Schmitt H.H., Science 182, 682, 1973 [2] Wang X. et al, GRL 43, 6103, 2016 [3] Hayne P.O. et al, AGU abs. P13D-1712, 2011 [4] Gaddis L.R. et al, Icarus 161, 262, 2003 [5] Weitz C.A. et al, JGR, 103, 22725, 1998 [6] Bandfield J.L. et al, Icarus, 231, 221, 2014 [7] Vasavda A.R. et al, JGR DOI: 10.1029/2011JE003987, 2012 [8] Hayne P.O. et al, LPSC abs. 3003, 2013 [9] Allen C.C. et al. LPC abs. 1309, 2015 [10] Paige D.A. et al, Space Sci. Rev. DOI 10.1007/s11214-009-9529-2, 2009