ADRESSING LUNAR SCIENCE QUESTIONS AT THE LUNAR SOUTH POLE. C.R. Neal, Dept. Civil & Env. Eng. & Earth Sciences, University of Notre Dame, Notre Dame, IN 46556, USA [neal.1@nd.edu].

Introduction: It is an exciting time for lunar science (and exploration) given that the current plan for the US human space exploration program is to return humans to the lunar surface by 2024, and establish a field station on the lunar surface by 2028. The location chosen for this return is the lunar south polar region (Fig. 1) ostensibly to make use of the water ice deposits present in some permanently shadowed craters in this region [1-3]. If this region is to become a center of human activity in the 21st century, there are a remarkable amount of scientific opportunities that could be implemented as part of our permanent return to the Moon.

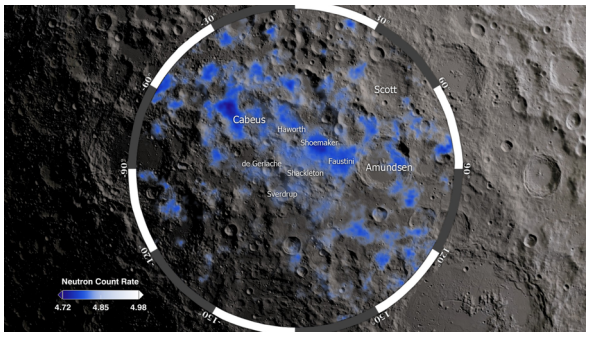

Figure 1: The South Pole of the Moon with neutron counts from LRO-LEND showing potential ice deposits

Investigation of Permanently Shadowed Regions (PSRs). These extreme environments have been hypothesized to contain volatile deposits since before Apollo [4]. The Clementine and Lunar Prospector missions in the 1990s gave credence to the presence of such deposits [5,6]. The Lunar Reconnaissance Orbiter mission has quantified the environment of these regions as some of the coldest in the Solar System using the Diviner radiometer [7]. The LOLA instrument also showed the presence of surface ice/frost from brighter than expected reflections [1]. Maybe the best indication of significant water ice at the surface of these PSRs came in 2018 [3] with several datasets being integrated to demonstrate the presence of surface water ice. Integrating these with neutron data shows these deposits extend into the upper meter or two of the regolith in these PSRs (S. Li and R. Elphic, Pers. Comm). The use of such deposits has been championed by the NASA Administrator for sustaining humans on the lunar surface and potentially providing the raw material for rocket fuel [8]. Investigating these regions will require technological innovation to survive the extreme cold (~40 K), but the scale of some of these PSRs (Fig. 2) is often overlooked. However, groundtruthing these deposits is

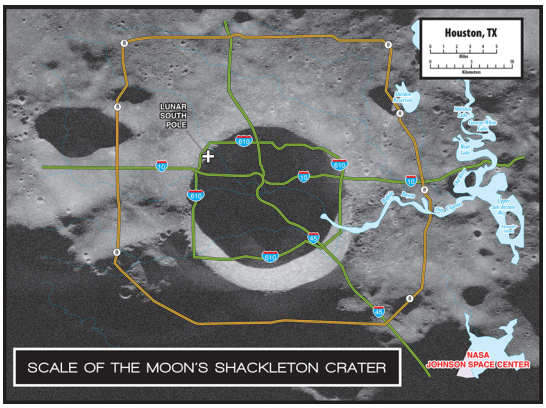

Figure 2: Shackleton Crater at the lunar south pole with the Houston metro area overlain for comparison. Image from the Lunar & Planetary Institute [8].

essential to understand their scientific and resource potential. Exploring the interiors of PSRs will address questions such as: Can these deposits be mined and refined in situ? Do they contain ancient prebiotic materials that may have produced life on Earth? Are they a renewable resource? What is their origin?

Understanding the Lunar Polar Environment. The polar regions of the Moon are unexplored and apart from containing some of the coldest places in the Solar System, the environment at these locations may be somewhat different from that experienced at the equatorial Apollo sites. The low sun angle and different diurnal cycles define a different environment [9]. Also, the idea of volatile migration to and from the poles can be tested [10-12]. Exospheric monitoring stations (mass spectrometers, dust detectors, etc.) around PSRs will allow the polar space environment to be quantified and understand volatile migration into and out of the PSRs.

Lunar Seismic Hazards. The Apollo Lunar Surface Experiment Packages (ALSEP) contained passive seismometers at Apollo 11, 12, 14, 15, and 16. While the Apollo 11 instrument malfunctioned soon after deployment, the remainder demonstrated the Moon was seismically active, with four types of activity being detected: deep moonquakes (DMQs) [13], shallow moonquakes (SMQs) [14], thermal moonquakes [15], and meteoroid impacts [16]. The SMQs (AKA high-frequency teleseismic events) are the largest lunar seismic events, with 7 recorded from 1970-1977 with a body wave magnitude of 5 or more, but their origin is still unknown. Apollo data demonstrated that significant SMQ activity occurred in the south polar region [14] (Fig. 3), although the location was very approximate. Results

from LRO have shown that thrust faults are in the region of the south pole, and SMQs are thought to be a result of movement along these still active faults [17]. A new seismic network will also inform us of the density of meteoroid impacts around the Moon along with the real frequency. These are important issues in understanding the space environment around the Moon and also for allow humans to survive and thrive on its surface. Therefore, fundamental questions remain regarding lunar seismicity due to the narrow aperture of the Apollo seismic network. Do DMQs occur on the farside of the Moon? What is(are) the origin(s) of the SMQs ? Do they

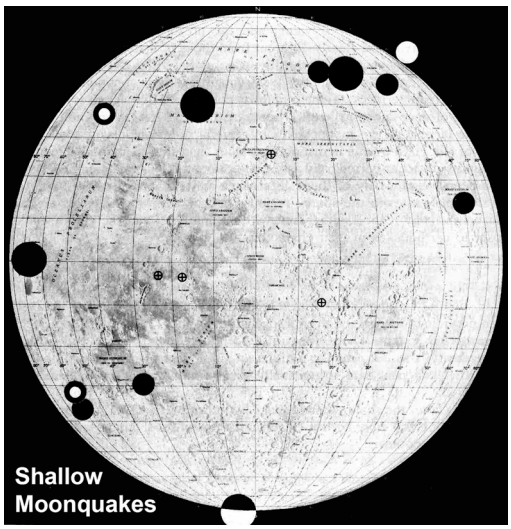

Figure 3: Approximate shallow moonquake epicenters [17]

pose a hazard to human presence and infrastructure? Including a geophysics station at the south pole to be part of the Lunar Geophysical Network mission [18] would be an important part of the early infrastructure to support permanent human presence on the lunar surface, and return important science data. This could be established by the first human lunar mission in the 21st century.

Examining the Geology in the South Polar Region. The lunar south pole is situated in the Feldspathic Highlands Terrain (FHT) and encompasses the outer portion of the South Polar-Aitken (SPA) basin [19]. Samples from the SPA basin and the FHT will be present in the regolith to examine is the farside highlands are more Mg-rich than the highlands samples returned by Apollo, as proposed by [20].

Given the heavily cratered nature of the farside FHT it is likely that the regolith at the south pole will also contain materials from within the SPA basin (farside volcanics, SPA basin impact melt, etc.). Therefore, sampling and returning kilogram quantities of the regolith from the lunar south pole will allow our first real exploration of lunar farside material and test the suggestion that that at least some of the recognized lunar meteorites are actually sourced from the farside [21].

Other Science. The types of research presented above are focused on lunar science. There are many more examples that can be given of this than those highlighted here. However, the Moon at the south pole can be used for Earth observations, heliophysics and astrophysics research. These are highlighted in the LEAG Lunar Exploration Roadmap [22]. Also, the Moon can be used as a research base for partial gravity studies (physics, biomedical, etc.) and these types of activities are also highlighted in [22].

Concluding Remarks. The refocus of US space policy on the Moon represents an opportunity to conduct scientific research in a new area and a new way. The target of the south polar region allows a new and unique area of the Moon to be studied. This will advance our understanding Moon in ways heretofore not possible. In addition to lunar science, the knowledge gained can also be used to support human exploration through safety (seismic/impact hazards) and resource utilization (e.g., water ice). The Moon is also a research platform to conduct Earth observations, study of the Sun, and also exploring the universe through astrophysical observations (detailed in [22]). Therefore, the Moon is our gateway to explore the Earth-Moon system, the Solar System, and the universe.

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