Investigations Regarding Subsurface Temperature Profiles at Polar Regions on the Moon

Submitted to Science Definition Team for Artemis

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Introduction and Background

During Apollo 15 and 17, experiments were conducted to determine the heat loss from the lunar interior by temperature and thermal property measurements at the surface and in the subsurface to estimate the global lunar heat flow [1-3]. These Heat Flow Experiments (HFE) were part of the Apollo Lunar Surface Experiment Package (ALSEP), and also helped to investigate the thermal properties of the landing site, specifically how deep insulation-induced thermal waves penetrated the regolith, as well as providing information about the thermal conductivity of the regolith.

By experiment design, two astronauts drilled 2 holes, roughly 10-meter apart, and installed a heat probe in each hole. The holes were 1- and 1.4-m deep at the Apollo 15 site and 2.4-m deep at the Apollo 17 site. The probes monitored surface and subsurface temperature at different depths for multiple years (Apollo 15 from July 1971 to January 1977, Apollo 17 from December 1972 to September 1977). These observations showed that the annual, insolation-induced, thermal waves reached ~1.5-m depth. The endogenic heat flow was then determined to be 21 and 16 mW/m2 at the site of Apollo 15 and 17, respectively [4]. This was a striking discovery, demonstrating the variability in heat flow across the Moon, which was attributed to different abundances of radioactive elements at both landing sites contributed by the Procellarum-KREEP Terrain (PKT) [5]. However, it also made the global lunar heat flow estimate difficult. Additional experiments at different site are necessary for a more representative estimate.

The experimental design had one flaw that emerged from the multi-year data collection. The data showed a gradual warming of the subsurface at depths below 1 meter (depth unaffected by insolation). In essence, the insertion of two highly conductive rods into the ground distorts the natural temperature profile, as well as the disturbance of surface albedo (i.e., darkening) due to EVA activities causing greater solar heat intake that resulted in a heat propagation into the subsurface [6].

Objectives and Relevance to Artemis III

The heat flow varied by the Apollo mission landing site in mid-latitude regions of lunar near-side. Consequently, we must assume that this is also true for polar regions because (a) unlike the Apollo 15 and 17 landing sites, the Artemis III landing site is far away from the PKT and also not at the edge of a thorium-rich geochemical province, and (b) the insolation conditions (i.e., inclination) near the poles is much different and therefore insolation-induced thermal waves may be different (i.e., “thermal skin-depth”). Heat flow experiments conducted during the Artemis III mission provide an opportunity to test these hypotheses while simultaneously contributing to the fundamental understanding of the Moon. Such measurements, and in discussion to the ones employed during Apollo 15 and 17, enables fundamental scientific investigations to understand the geology of the Moon near the south pole (e.g., bulk composition and abundances of radioactive elements), because the heat flow is directly linked to the types of crustal rocks (e.g., basaltic vs anorthositic) and its thickness.

In addition to the scientific investigations, understanding the thermal gradient and temperature distributions in the subsurface directly links to in situ resource utilization (ISRU) for a sustainable human presence on the lunar surface. For example, understanding the subsurface thermal condition on the Moon is helpful in designing surface operations. It also helps to understand the possible distributions of (temperature-dependent) volatiles in the lunar regolith, the most important of which of course is water. However, volatile trace elements like Cd, Hg, C, and N have been considered [7-11], although probably more important are H and ^{3}He [12,13] and its retention.

Recommendations

In conclusion, we recommend that the Artemis III mission includes subsurface heat flow experiments to address outstanding scientific questions that also relate to ISRU in support of a sustainable human presence on the Moon. In retrospect to Apollo generation HFE's, an experimental design less intrusive to the environment and artificially altering the data that are being collected should be preferred, especially if long-term, multi-year data collection is desired.

Natural thermoluminescence measurements enable many of these issues to be addressed and flows naturally from the work being done as part of the ANGSA program by our group and the Ames thermoluminescence laboratory [14,15].

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