Regolith coring and long-term heat flow observation through the subsurface zone of ice stability

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Presence of volatiles on the surface of the permanently shadowed regions (PSRs) in the lunar south polar region has been detected by remote-sensing means [e.g., 1-2]. A recent examination of the Diviner data [3] suggests that, inside the 85° S circle, many non-PSR areas may also meet the condition in which water ice is stable in shallow subsurface (~1-m depth) (Fig. 1).

We suggest that Artemis III lands in one of such areas just outside a PSR where volatile presence has been detected. We propose that the astronauts take drill cores of the regolith down to 2.5-m depth and subsequently install an instrument in the left-over hole to monitor heat flow through the regolith for one year or longer. Our overall objective is to characterize the surface and shallow subsurface thermal environment and the regolith properties to better understand stability and transport of volatiles in this region (Concept 4 of [4]). The core samples will have many analytical uses both in-situ and on Earth. Here, we focus on the heat flow observation.

We have four specific objectives for the heat flow observations. First, we validate the subsurface temperature estimates based on the Diviner data [3,5] using in-situ subsurface measurements. Second, we characterize the heat flux through the regolith, as it fluctuates with the complex interaction between sunlight and the local terrain. Third, we attempt to detect indirectly possible presence of ice mixed in the regolith surrounding the hole by carrying out in-situ thermal conductivity measurement. Fourth, we constrain the flow of heat originating from the deeper interior of the Moon.

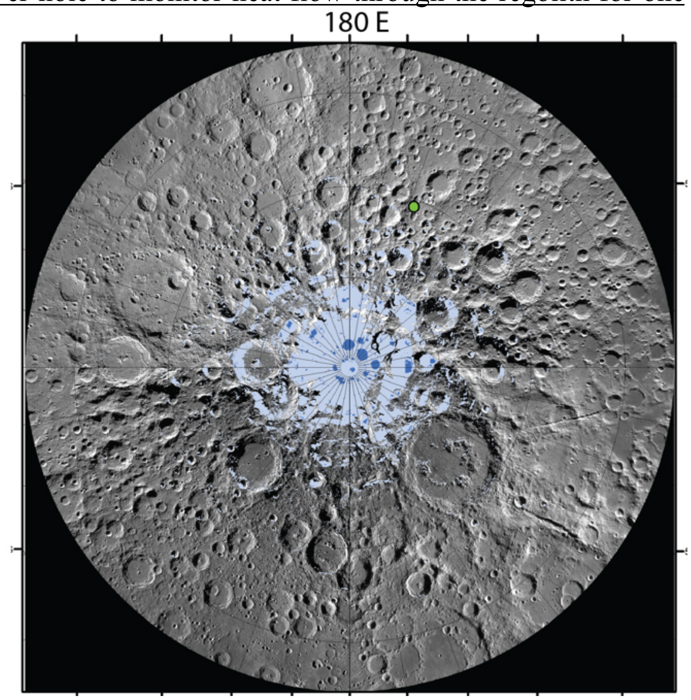

Figure 1. A Map showing the areas of surface (dark blue) and subsurface (light blue) ice stability [3].

The methodology for the heat flow observation proposed here will be similar to that for the Apollo Heat Flow Experiments [6-7], and it will be based on measurements of temperature and thermal conductivity at multiple depths. The instrument currently under development by our group [8] can be deployed directly into the open hole left behind the coring operation [9].

Objective 1: Validation of the Diviner-derived subsurface temperature estimates. Subsurface temperature estimates from the Diviner data lose fidelity with depth and, to some degree, depend on the regolith thermal property model used for the estimation [10]. In-situ subsurface temperature measurements by the heat flow instrument will validate the Diviner-derived estimates. Such validation will improve the Diviner-based assessment of the subsurface ice stability elsewhere in the south polar region.

Objective 2: Detailed characterization of heat flux through the regolith and local thermal setting. At middle through low latitudes of the Moon, temperature of shallow subsurface (< ~1-m depth) fluctuates sinusoidally with the diurnal and annual insolation cycles with some phase shift. In the polar regions, because of the low sun angle, insolation is heavily influenced by the local topography. Diurnal and seasonal fluctuation patterns can vary drastically between areas of short distances [5]. In addition, the effect of the 18.6-year nodal precession may be most pronounced at the poles. A year-long observation at the Artemis III landing site will provide a case study for the complex heat exchange through the shallow subsurface. Knowledge from this study would be applied to other areas to add more details to their ice stability models.

Objective 3: Possible detection of presence of ice in regolith. Thermal conductivity of lunar regolith (0.01 – 0.02 W/mK) is typically almost 2 orders of magnitude less than that of soils on Earth (0.5 – 1 W/mK), mainly due to lack of atmosphere. Heat transport through the lunar regolith is limited to the grain-to-grain contact points, while soils on Earth can transport heat also through the air that fills the pore spaces. If the pore spaces of the regolith around the coring hole are partially filled with ice, its bulk thermal conductivity may be significantly higher than that of dry regolith, for which we already have some data from the Apollo experiments [6,11].

Objective 4: Determination of the endogenic heat flow. The two Apollo heat flow stations [6], and the new measurement planned on the Commercial Lunar Payload Services flight to Mare Crisium in 2023 are all located in the mid- to low latitudes. A new measurement at the south pole would provide an important anchor point to the lunar global thermal structure model [e.g., 12]. The hole depth of 2.5 m should be sufficient for capturing the flow from the deeper interior, as proven by the Apollo 17 experiment [6]. Apollo 17 also showed that a ~3-m-deep open hole can remain intact for a later downhole instrument deployment [13].

Coring and deployment of one heat flow instrument can be carried out well within the EVA time allotted for the two Artemis III astronauts. For comparison, on Apollo 17, Gene Cernan and Jack Schmitt deployed two heat flow probes, including drilling holes for them, in less than 2 hours.

Finally, we envision the proposed heat flow observation as part of a multi-instrument, long-term monitoring station like the Apollo Lunar Surface Experiments Package (ALSEP). It is possible to power the instruments continuously using the combination of the long lunar day and night-time battery power.

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