Temperatures At The Taurus-Littrow Valley: Legacy Of The Apollo 17 Heat Flow Experiment And Lro Diviner

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Introduction: The Apollo Heat Flow Experiment (HFE) Data from the Taurus-Littrow Valley (Figure 1) represents our best geothermal measurement of another solar system body. With the upcoming InSight mission to Mars (with its Heatflow and Physical Properties Probe; HP^3) and a hopeful near-future lunar geophysical network mission, this seems a pertinent time to reflect on the experience from Apollo 17 and the legacy of the heat flow measurements.

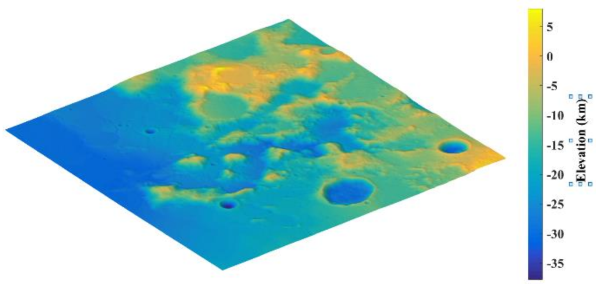

Figure 1: 3D view of the Taurus-Littrow Valley using LRO LROC WAC 100m resolution DEM.

Apollo Heat Flow Experiment Data: Learning from the Apollo 15 and (the unfortunate) Apollo 16 HFE deployments, the Apollo 17 borehole drillstem was redesigned [1]. This, and careful work by Astronauts Cernan and Schmitt, allowed the Apollo 17 heat flow drills to reach nearly a meter deeper than their predicessors. This allowed the experiment to measure the thermal gradient well below the reaches of diurnal temperature variations that dominated Apollo 15 data (see Figure 2) [2]. As the 2018 Mars InSight mission plans to drill to ~5m depth on Mars without the assistance of an astronaut, it is critical to re-examine the successes and enduring mysteries of these Apollo measurements.

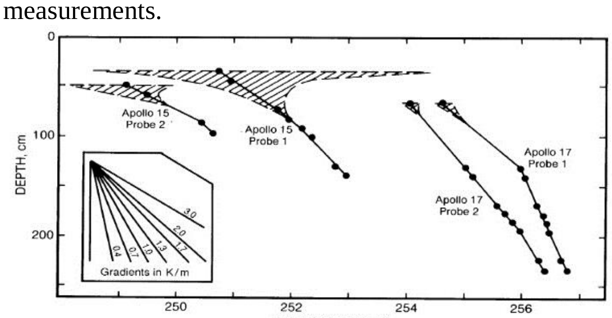

Figure 2: Subsurface temperatures recorded by the Apollo HFE, from [2].

Apollo 17 and its representation of the Moon: One of the most important facts we have learned from the Apollo HFE is the importance of context in applying results to a global understanding of heat production. The Apollo 17 site was situated at the edge of the Procellarum KREEP Terrain, the most radiogenic rich (as identified by Lunar Prospector Thorium [3], Figure 3) region of the lunar crust. This, fact alone makes it difficult to understand exactly how much of the geothermal contribution measured is from the mantle vs the crust of the Moon. If the thorium measured at the surface is equally distributed through the crust, then the mantle radioactivity could be quite small; if it is highest at the surface, mantle contributions could be quite large [4]. Such highly radiogenic regions will help constrain crustal contributions to heat flux relative to other regions, but make it difficult to see mantle heat flux contributions. This should be accounted for in future heat flux measurements on the Moon and elsewhere and demonstraits the importants of global element mapping prior to the dedication of a landed geothermal mission.

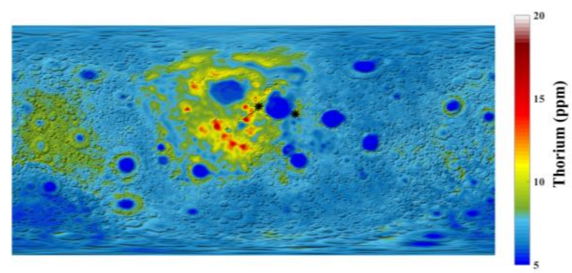

Figure 3: Lunar Crustal Thorium from Lunar Prospector Neutron Spectrometer GRS instrument.

Additionally, the Taurus-Littrow valley lies at the edge of a large change in crustal thickness and density, which has now been well-characterized by the GRAIL mission [5]. Lateral shunting of heat between the relatively thin-curst, high thermal conductivity of Mare Serenitatis and neighboring highlands also effects the total heat flux observed by Apollo 17. This may prove important to the 2018 InSight mission which is landing near a similar change in crustal thickness on Mars. Local topography (the fact that Taurs-Littrow is a mare-filled valley) will also effect the net geothermal heat reaching the surface. Heat can transfer laterally if equator facing valley walls have higher average temperatures and topography and density can focus heat flow.

This Analysis: Here we attempt to fully recreate the surface and subsurface thermal environment of the Apollo 17 landing site to the full extent possible. The Apollo HFE measurements provide a unique tool for extending surface temperature measurements from LRO Diviner [6] into the subsurface. Once a model has been produced that is fully consistent with the Apollo 17 data, it will greatly increase confidence in global models of subsurface temperature derived from Diviner. These models will serve as a basis for selecting future landed geothermal measurements, providing landing sites that can best constrain crustal vs. mantle heat production [7]. Orbital and Earth-based microwave measurements may also allow for detailed constraint of subsurface thermal gradients and heat flux variations globally [8].

We are currently using a ray tracing model designed for analyzing LRO Diviner infrared data to recreate the thermal environment at Taurus-Littrow during the Apollo 17 HFE duration. We can recreate surface illumination for any given topography and sun position. Combined with modeled near-surface thermal and radiative properties, this model can calculate the incident visible and infrared flux on a given location. Detailed LRO LROC Apollo 17 site topography [9] (Fig. 1) allow us to examine both at large scale illumination effects (such as hills blocking illumination) and small scale illumination effects (such as surface roughness) on the Diviner measurements.

The thermal model will be constrained to this Diviner data, we will create a fully accuarate representation of Apollo 17 surface temperature conditions. Figure 4 shows some example Diviner termperature coverage at the Apollo 17 site at multiple times of day in 15 minute windows. With 8 years of data acquired by Diviner, the density of data is beginning to provide adequate local time coverage at a high enough spatial resolution to constrain our model. This multi-scale model can also be used as a general reference to predict likely temperatures as a function of depth over the entire measured lunar surface. Implimenting these properties into the full ray tracing tools developed for Diviner [6], rock abundance, near subsurface thermal property or dramatic heat flow differences from this regolith model are hoped to be be visible in the Diviner data set. This will allow for a global predictive model of lunar geothermal heat which has potential to be constrained by exisiting (e.g. Chang'E microwave radiometer) and future (e.g. LGN or future orbital instruments) data [7].

References: [1] Keihm S. and Langseth (1975) Icarus 24, 211-230 [2] Keihm, S. J., & Langseth, M. G. (1977) LPSC (Vol. 8, pp. 499-514).[3] Lawrence et al.(2003) Science [4] Siegler and Smrekar (2014) JGR Planets, [5] Wieczorek et al. (2015) Science [6] Paige et al. (2010) Science [7] Siegler et al. (2017) AGU[8] Siegler et al. (2017) LPSC [9] Robinson et al. (2012) Remote Sensing and Spatial Information Sciences, Volume XXXIX-B4.

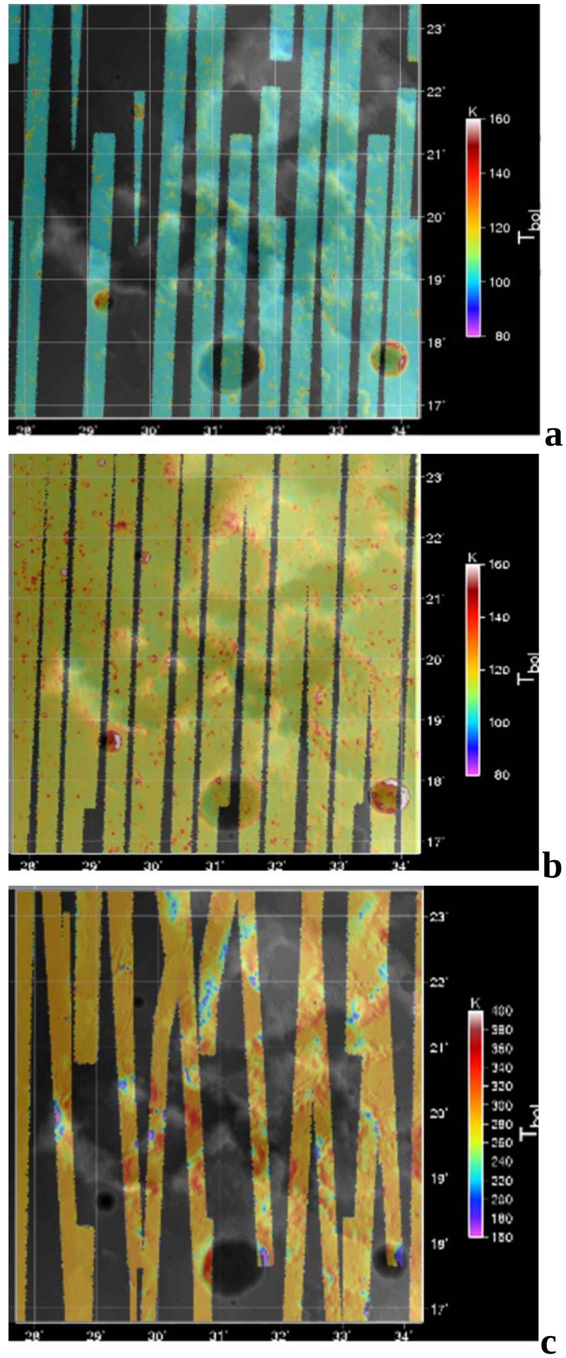

Figure 4: Example 300m resolution LRO Diviner temperature mosaics for the Taurus-Littrow Valley at ~ (b) 7:30am, (c) 6pm, and (d) 10pm local time draped over LROC WAC shaded relief.