THERMOPHYSICAL PROPERTIES OF LUNAR VOLCANIC DEPOSITS.
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Introduction: The formation mechanism, age, and composition of volcanic features on the Moon offer clues about the bulk composition and thermochemical evolution of the Moon. Additionally, some volcanic deposits, in particular lunar pyroclastic deposits, have been suggested as good sites for future in situ resource extraction [e.g. 1].

Thermal inertia is a key indicator of material properties that vary among geologic units, such as porosity and particle size. For example, pyroclastic deposits may have a lower thermal inertia than their surroundings because juvenile pyroclastic material may contain fewer small rock fragments than typical lunar regolith. Large pyroclastic deposits are thought to be composed primarily of crystalline black beads and/or glass beads that formed through continuous fire-fountain eruptions [2], whereas small pyroclastic deposits more likely formed through shorter duration Vulcanian-style eruptions forming deposits that incorporate a relatively higher fraction of country rock and basaltic cap rock [3]. If individual pyroclasts were warm when they were deposited, they would have welded together raising the bulk thermal inertia of the deposit [4]. Deposits composed exclusively of fine-grained juvenile material are expected to have a lower thermal inertia than deposits that incorporate a significant fraction of rock or deposits composed of welded clasts. However, their thermal inertia could also be affected by exposure of subjacent material in thin deposits, and/or post emplacement modification by impacts.

Previous work has shown that several of the very large pyroclastic deposits have anomalously low minimum temperatures and low anisothermality which suggests a low thermal inertia [5]. [6] investigated 35 localized deposits (<2500 km^2) and found that while some have a lower thermal inertia than their surroundings many do not and of those that do, the difference was often 'barely noticeable.' Recently [7] argued that the low thermal inertia of the largest smooth mound in Ina (an irregular mare patch) could be explained by pyroclastic deposits. Here we map the thermal inertia of the 75 pyroclastic deposits considered in [2] and the four silicic regions identified by [8] and ask: Do silicic volcanic features have a thermal inertia that differs from regolith? Do most pyroclastic deposits have a thermal inertia lower than regolith? And do smaller Vulcanian-style deposits have a higher thermal inertia than large fire-fountain deposits?

Methods: Lunar surface temperatures measured by Diviner [9] can be used to derive regolith properties [10], including the so-called "H-parameter": the characteristic length scale over which regolith density increases with depth. Thus, higher H-parameter values correspond to lower thermal inertia (lower density) of the uppermost regolith. Although we derived the H-parameter from temperatures where the largest (> 1 m) rocks were empirically removed [11], any remaining small rocks will lower the measured H-parameter values suggesting a higher thermal inertia for the unit.

Results and Discussion: Most of the 75 pyroclastic deposits investigated by [2] do not have an H-parameter significantly higher than their surroundings, which suggests that their thermal inertia is similar to typical lunar regolith. This is consistent with the results of [6]. However, the difference in H-parameter between pyroclastic deposits and typical lunar regolith may be smaller than the variation in H-parameter caused by other factors such as small (<1 m) rocks and cold spots. Future work to remove the contribution of small rocks (~1 cm – 1 m) to the H-parameter [12] may enable a more direct comparison between regolith and pyroclastic deposits.

We find that the very large pyroclastic deposits containing high-titanium, crystallized black beads do have a higher H-parameter than their surroundings (figure 1). [13] found low circular polarization ratios at these deposits which is also consistent with rock poor material. However, we find that Sulpicius Gallus has a lower thermal inertia than Vaporum whereas [13] found Vaporum has a lower circular polarization ratio than Sulpicius Gallus. This may indicate that the surface of Vaporum is covered by more small rocks than Sulpicius Gallus, but that Vaporum contains fewer subsurface rocks. We find high H-parameters at some other large pyroclastic deposits (e.g. Aristarchus) but not all (e.g. Nectaris). The Tacquet Formation and Rima Hyginus, identified as possible pyroclastic deposits by [13, 14, 15], also have H-parameters slightly higher than their surroundings which is consistent with a pyroclastic origin.

All four silicic regions identified by [8] are associated with a high H-parameter (e.g. figure 2). Previous work has shown that no clear relationship exists between thermal inertia and composition; rather density and crystallinity control thermal inertia [16]. However, evidence for pyroclastic activity has not previously been identified at all of the silicic regions. The low thermal inertia may be related to the low bulk density observed by GRAIL at two of the silicic regions [18].

Implications: Many pyroclastic deposits (in particular small deposits) do not have a lower thermal inertia than lunar regolith. This could be due to age, deposit

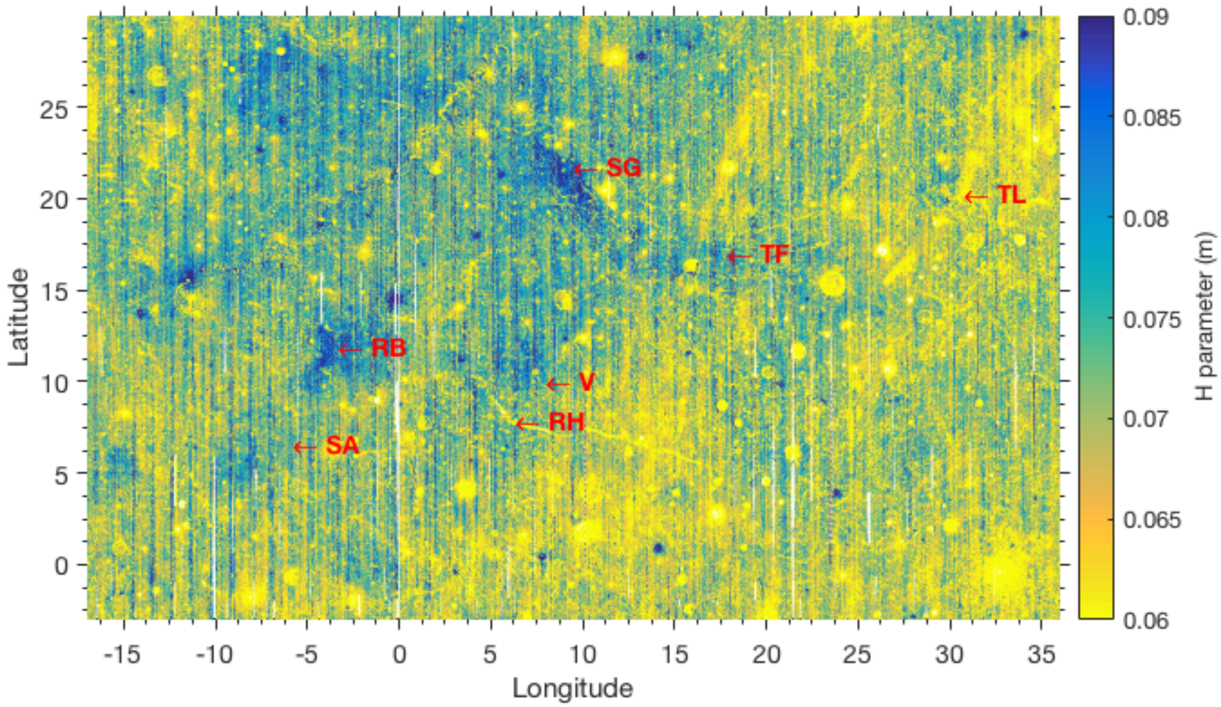

Figure 1: H-parameter map with Sinus Aestuum (SA), Rima Bode (RB), Sulpicius Gallus (SG), Vaporum (V), Taurus-Littrow (TL), the Tacquet Formation (TF), and Rima Hyginus (RH) labeled in red.

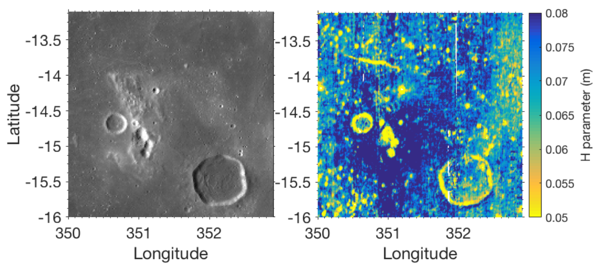

Figure 2: The LROC WAC mosaic (left) and H-parameter map (right) of the Lassell Massif region (which may have experienced some pyroclastic activity [17]).

thickness, or formation mechanism. Small deposits are thought to have formed through Vulcanian-style eruptions incorporating country rock and basaltic cap rock [3] which could obscure the low thermal inertia signal of the fine grained juvenile material. Even the deposits that began as a layer predominantly composed of fine-grained material with a low thermal inertia, could now have a thermal inertia similar to their surroundings, because over time, nearby impacts will throw rocks on top of the deposit and some larger impacts will puncture through the deposit exposing the rockier material below. This degradation will happen faster for thin deposits, which can be penetrated by smaller impacts. Thus, an initially high H-parameter should be expected to decrease with time.

Although multiple factors could cause a pyroclastic deposit to have a thermal inertia similar to its surroundings, a number of pyroclastic deposits do have an anomalously low thermal inertia consistent with fine-grained material. Thus, H-parameter or thermal inertia could potentially be used to find previously unidentified pyroclastic deposits such as those seen at Ina.

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