INFERRED THERMO-PHYSICAL PROPERTIES OF LAVA FLOWS – IMPLICATIONS FOR REMOTE SENSING OF PLANETARY TERRAINS.

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Introduction: Lava terrains on other planets and moons are abundant, with morphologies similar to those found on Earth, such as flat and smooth pāhoehoe, which can transition to rough, jagged \`a\`ā terrains. The morphology of lava flows is governed by eruptive conditions such as effusion rate, underlying slope, and the fundamental thermo-physical properties of the lava, including temperature (T), composition (X), viscosity (η), the volume fractions of entrained crystals (ϕ_c) and vesicles (ϕ_b). As the lava cools, the temperature decrease leads to an increase in crystallinity, which increases the viscosity of the lava [1].

The textural and rheological changes were previously studied and quantified for a Hawaiian lava [2] that started as channelized pāhoehoe and transitioned into a rough \`a\`ā flow, demonstrating a systematic trend of T, X, η, ϕ_c and ϕ_b. The transition into \`a\`ā morphologies coincided with an abrupt change in slope causing greater strain rates. This drastic affect of underlying topography on lava flow morphology was demonstrated for alkali basalts erupted at the flanks of Pacaya volcano, Guatemala [3].

In this study, we present field work done at a ~3.0 km long Holocene lava flow belonging to the Blue Dragon (BD) lavas erupted at the Craters of the Moon (COM) National Monument and Preserve, Idaho (Figure 1). Lava erupted from a chain of spatter cones and then coalesced into channelized flows.

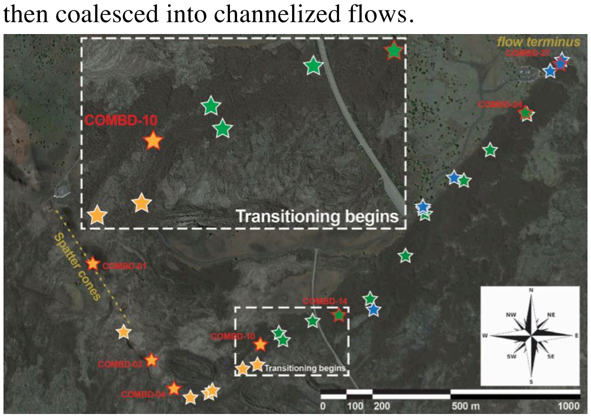

Figure 1: Blue Dragon flow studied at the Craters of the Moon. Star symbols represent surface sample locations, including channel levees. Orange sympbols represent samples classified as pāhoehoe. The onset of transition (green) starts at around 1.2 km from our first sample location, and turns to an \`a\`ā dominated area near the terminus. Levees exibit \`a\`ā earlier on, while the channel interior remains transitional. Satellite imagery from Google Earth.

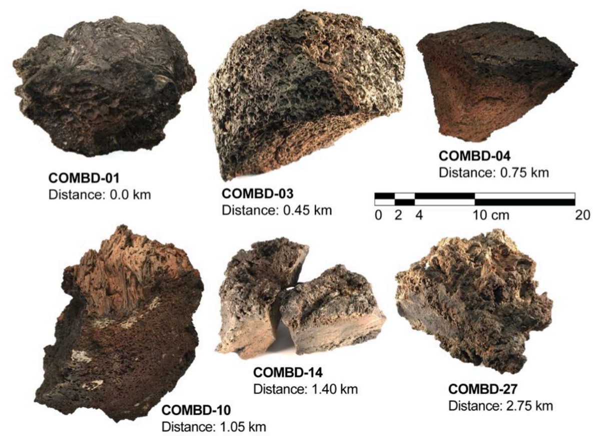

Figure 2: Representative sample photographs with distance from the vent. Samples are oriented with the surface being on the top. Samples are highly porous and smooth to shiny at the vent, becoming more dense towards the flow terminus, with thin, spiney and frothy rinds.

Our aim is to tie the physical properties of the lava to its surface morphology. Once these morphologies are mapped and high resolution DEMs are available, applying mathematical descriptions of these morphologies [4] should allow us to extract these properties (including temperature) for volcanic surfaces of known composition on other planets and moons. This is crucial to evaluate volcanic terrains for future robotic or human science and exploration missions.

Results: *Fieldwork.* We mapped and sampled the studied lava flow every 200 m from vent to toe, including levees. The flow begins smooth pāhoehoe section with lobes and ropes, then breaks up into rubbly and slabby pāhoehoe at about ~1.1 km from our first sample location. Further downflow, the morphology changes over the length of ~1.6 km to \`a\`ā surfaces (Figure 2), identical to surfaces observed in Hawai'i [2]. All these changes are due to cooling, as an abrupt break in slope is absent.

Density and Porosity. We measured the bulk density (ρ) of seven samples from vent to toe, and find that sample density increases from ~750 to 2500 kg m^{-3} within the first ~1.2 km and remains constant thereafter. We also measured the porosity of these samples, which is dominated by interconnected pores, and closes further downflow at ~1.4 km distance from the vent

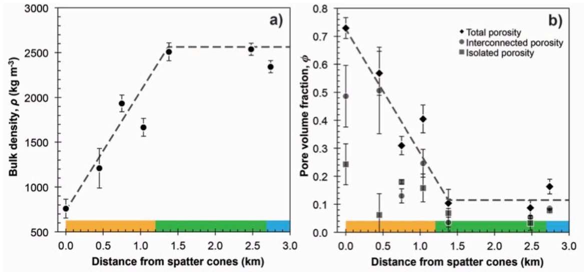

Figure 3: (a) Bulk sample density and (b). porosity determinations. Color bars at the bottom represent classification of pāhoehoe, transitional, and `a`ā according to Figure 1.

(Figure 3). Measurements of the remaining 21 samples are currently underway and will be presented.

Petrology. Preliminary micro probe analyses of sample COMBD-10, just before the pāhoehoe break-up, indicate ~17 vol% An_{64} microcrystals, ~5 vol% Fo_{52}, and ~2 vol% FeTi-spinel. The total crystal fraction (ϕ_c) 0.27 is characteristic for samples that exhibit transitional surface textures [1,2]. We will determine the modal abundances and chemistry of crystalline phases in our full sample suite.

Lava viscosity and rheology. In order to correlate viscosity and temperature to the morphology, we measured the rheology from 1600 ºC down to 1163 ºC by concentric cylinder viscometry. We find that the melt is about ~3.5 times more viscous than Kilauea basalt at the same temperatures. The viscosity rapidly increases (several orders of magnitude) with the presence of crystals. We observed the appearance of FeTi-spinel at 1310±10 ºC, increasing to a total crystal fraction of 0.15 at our lowest measured temperature of 1163 ºC, at which An_{72} microcrystals at 5 vol% start to appear among acicular apatite. By analogy with the rheologic conditions of the pāhoehoe to `a`ā transition for Hawaiian basalts, the Blue Dragon 1163 ºC isokom corresponds to transitional samples (Figure 4), and lava should shortly turn to `a`ā with further cooling.

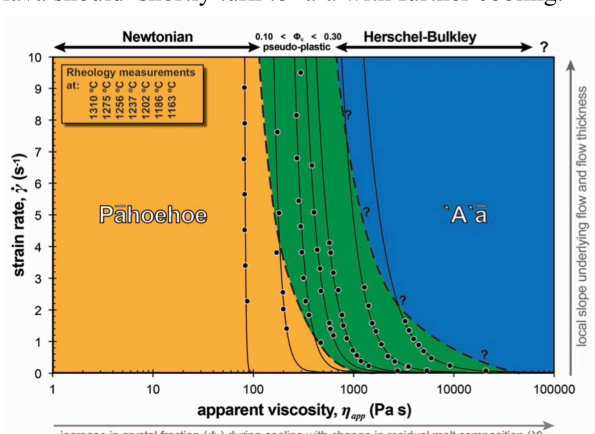

Figure 4: Temperature isokoms of seven rheology experiements from 1310 to 1163 ºC show the T-η-morphology relationship for COM lavas over a wide range of strain rates.

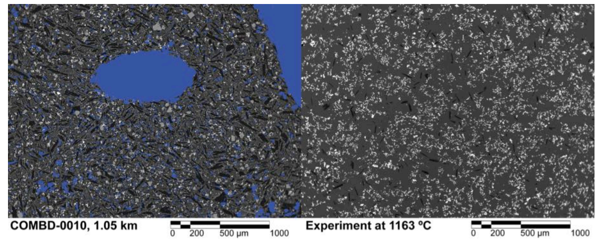

Figure 5: Back scattered electron images for transitional sample (left, vesicles in blue), and sample texture of experimental sample equilibrated at 1163 ºC (right).

Discussion: Comparing these experimental results to sample location COMBD-10 (Figure 5), the lower crystal fraction of plagioclase at 1163 ºC indicates that emplacement temperatures of the lava must have been lower to generate greater plagioclase contents (which is consistent with observed An_{64} microcrystals in the sample), probably at a T of ~1130 ºC applying thermodynamic modeling of phase equilibria [5]. As shown in Figure 5, the field sample contains bubbles, and is less oxidized compared the experimental samples, likely to cause minor deviations in rheological behavior between the two.

Conclusions: Our preliminary results confirm similar trends for ρ, ϕ_b, ϕ_c whereby $\phi_c > 0.25$ marks the transition from pāhoehoe to `a`ā, as documented by field sample surface textures and mapped morphologies. Rheology measurements, albeit not quite reaching temperatures low enough to reproduce the assemblages of sample COMBD-10 and further downflow, are consistent with previous results and enable us to correlate temperatures to morphology. We acquired high resolution aerial stereo imagery of our study area, allowing us to generate DEMs to which we can apply mathematical models [4] and correlate these values to these physical properties. This correlation will be tested for other flows in the area.

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