SEEING PĀHOEHOE FROM ORBIT (WITHOUT SQUINTING). E. I. Schaefer[1], C. W. Hamilton[1], C. D. Neish[2], M. M. Sori[1], A. M. Bramson[1], S. P. Beard[1], S. I. Peters[3], T. A. Miller[4], and E. L. Rader[5], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721 USA (schaefer@lpl.arizona.edu), [2]Department of Earth Sciences, Western University, London, ON N6A 5B7 Canada, [3]Mars Space Flight Facility, School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85281, USA, [4]Warner College of Natural Resources, Colorado State University, Fort Collins, CO, 80523 USA, [5]NASA Ames Research Center, Moffett Field, CA 94035 USA

Introduction: In field volcanology, morphologic lava flow type (e.g., ‘a’ā) is one of the most basic and useful observations one can make because it can provide insight into the dynamics, rheology, and effusion rate of the flow at the time of emplacement [1–3].

However, flow type is largely defined by submeter textures [3] that are difficult to resolve from orbit. Planetary volcanology would therefore benefit from alternative methods for inferring flow type from coarser scales.

One promising method leverages “fractality”, which describes patterns that appear similar across a wide range of scales. Early work [4,5] showed that basaltic flow margins are fractals, and Bruno et al. [6] found systematic differences in the flow margin fractality for ‘a‘ā versus smooth pāhoehoe, the two end-members of basaltic lava flows. Using field observations in Hawaii, they showed that these differences extended from decimeter to kilometer scales. However, they focused on “simple cases”, where the substrate was level and flat, and post-emplacement modification was not significant.

Do these promising results generalize to lava flows outside Hawaii, and to lava types other than ‘a’ā and smooth pāhoehoe? If we lack ground truth to determine whether a case is simple, is the technique still reliable? Can fractality be measured from orbit with sufficient precision? In this study, we examine these questions.

Methods: In the field, we mapped 19 flow margins in Hawaii, Iceland, and Idaho using differential GNSS at an effective precision of ~30 cm, after accounting for measurement precision and ~15 cm point spacing. Margin lengths vary from ~100 m to ~2 km, plus a 24.5-km margin collected as a case study of the 2014 Holuhraun flow in Iceland. To complement Bruno et al. [6], we include mantled, confined, and other non-simple cases.

We then used the “divider method” to calculate how the apparent length of the margin changes when measured with virtual rods of different lengths [7,8]. Each such measurement results in an approximation of the original line with inter-vertex segments equal to the rod length. These measurements are then plotted as in **Fig. 1** [6]. If the measurements have a linear trend in log-log space, the flow margin is fractal with a fractal dimension $D = 1 - m$, where m is the slope of the best-fit line.

Results: Results are presented in **Fig. 2**. Note that all margins exhibited high fractality ($R^2 > 0.996$).

Discussion: Across 8 simple ‘a’ā and smooth pāhoehoe margins, we consistently reproduce the main

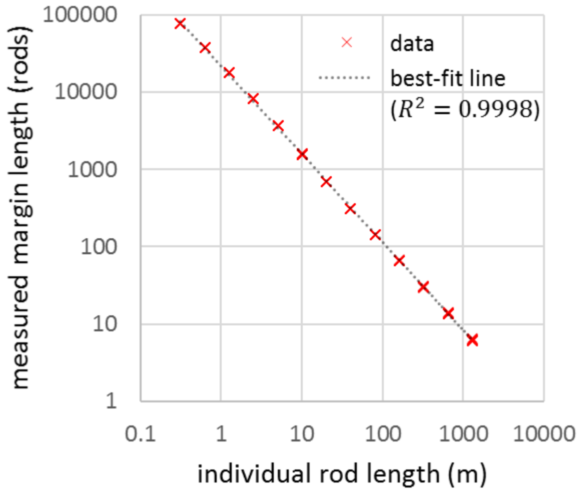

Figure 1: Fractal analysis results from a case study of the 2014 Holuhraun flow in Iceland indicate that the margin is strongly fractal from 31 cm to 1.3 km.

conclusion of Bruno et al. [6]: ‘a’ā flows have $D < 1.09$, and smooth pāhoehoe flows have $D > 1.15$. Hereinafter, these are referred to as the “nominal” ranges, between which lies the ambiguous range $1.09 < D < 1.15$. Bruno et al. also observed some extreme values outside these ranges, which we refer to as “observed” ranges hereinafter. Although we discuss several complications of this simple picture in the following discussion, note that none affects $D > 1.16$.

Other flow types. Both a blocky lava margin ($D = 1.07$) and the apparent margin (disruption edge) of a primary lobe of toothpaste lava [9] ($D = 1.08$) plot within the nominal ‘a’ā range. A rubbly pāhoehoe margin ($D = 1.12$) plots as ambiguous, but a margin that transitions from rubbly to slabby pāhoehoe along its length ($D = 1.16$) plots within the nominal smooth pāhoehoe range. A margin that transitions from slabby pāhoehoe to ‘a’ā along its length ($D = 1.10$) plots as ambiguous but within the observed ‘a’ā range.

Topography. Topography can significantly affect D. The 24.5-km-long spiny pāhoehoe margin that we measured from Holuhraun ($D = 1.14$) plots within the observed smooth pāhoehoe range, just below the nominal range. However, a second spiny pāhoehoe margin from Holuhraun that was confined by an existing river channel ($D = 1.08$) plots within the nominal ‘a’ā range. We also mapped two sides of the same smooth pāhoehoe lobe on the Hōlei Pali (sea cliff). The 14°

slope margin plots as ambiguous but within the observed ‘a’ā range, and the 19° slope margin has $D = 1.04$, the lowest value measured by Bruno et al. or us.

Mantling. Sediment mantling seems to have little effect on D. We measured two intervals along the same flow in the Ka’ū desert, one dominated by slabby pāhoehoe and the other by rubbly pāhoehoe. Sandy pyroclastic deposits consistently cover ~70% of the flow top, and the mapped “margin” is in fact the interface between exposed flow and sand drifts that partly bury the flow. Nonetheless, $D = 1.15$ for both intervals, which is very similar to the $D = 1.16$ that we measured for an unmantled slabby-rubbly pāhoehoe flow.

Finest required scale? By subsampling our data to a coarser interval, we can approximate the effects of mapping the same margin from orbital imagery with a resolution equal to that interval. For the 24.5-km-long segment of the Holuhraun margin, we find that losing successively coarser scales up to 80 m has no biasing effect on D, and that including scales finer than 80 m was not necessary to approximate D to within ~0.015. For sufficiently long margins, these results suggest that orbital imagery ≤80 m/pixel is sufficient to measure D with useful precision, but additional tests are ongoing.

Conclusions:

- If a basaltic flow margin has fractal dimension $D > 1.16$, it is likely smooth pāhoehoe.
- If $D > 1.14$ for a basaltic margin, it is likely some form of pāhoehoe (e.g., smooth, rubbly, slabby).
- A margin $D < 1.14$ is not uniquely indicative of any particular flow type or context (e.g., steep slopes), though smooth pāhoehoe is unlikely if the substrate is level and flat.
- Margin D is robust to mantling but sensitive to substrate slope and topographic confinement.
- Margin D may be measurable from orbital imagery with resolution as coarse as 80 m or possibly coarser, raising the potential that some of the highest resolution Io, Mercury, and Venus data may be suitable, in addition to global data from Mars and the Moon.

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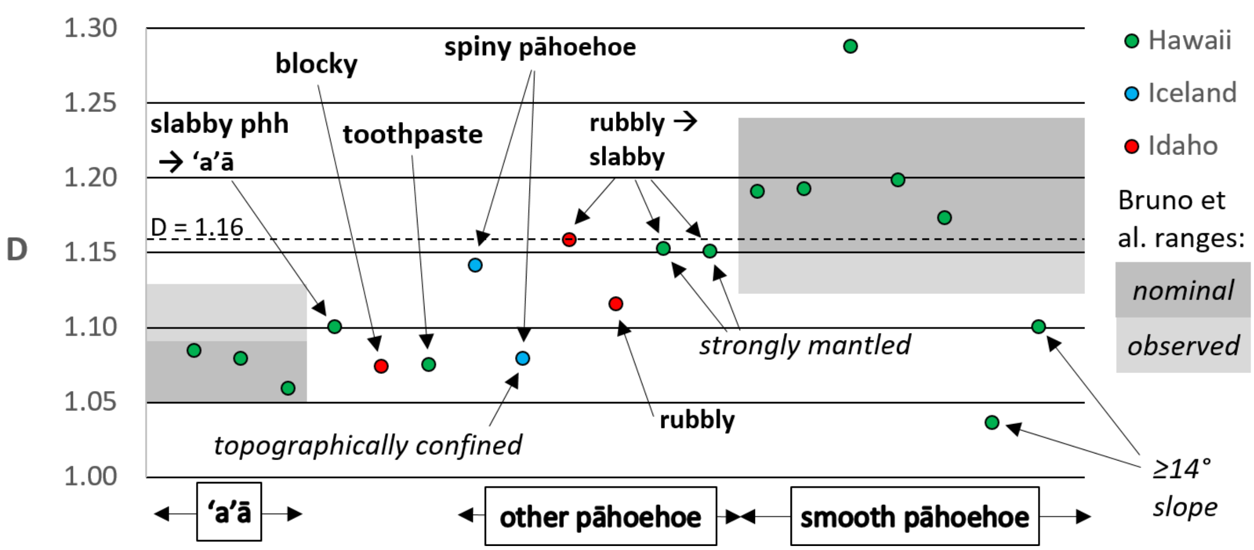

Figure 2: Fractal analysis results. All margins in this study have $R^2 > 0.996$, indicating strong fractality. Note both the agreement with the ‘a’ā and smooth pāhoehoe ranges of [4] (gray boxes) and the complications introduced by other lava types (e.g., blocky, toothpaste), topographic confinement (center), and steep slopes (bottom right).