Mandelbrot's inferno:
Exploring the fractality of lava flow margins in Iceland and Hawaii

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20 Second Summary

- Lava flow margins are fractal across dm- to km-scales.
- Fractal analysis can reveal flow type from imagery at orbital resolutions.
- Flow margin fractality may reflect flow roughness → enabling estimation of mantling from orbit, identification of ultramafic flows on Io?

Introduction

Studying lava flows on other planetary bodies is essential to characterizing eruption styles and constraining the bodies' thermal evolution. For example, flow type is a critical observation that provides dynamical and rheological insight, and can constrain effusion rate [1,2]. However, flow type and other small-scale characteristics are not resolvable in orbital imagery.

Can we measure these characteristics *indirectly*? We hypothesize that

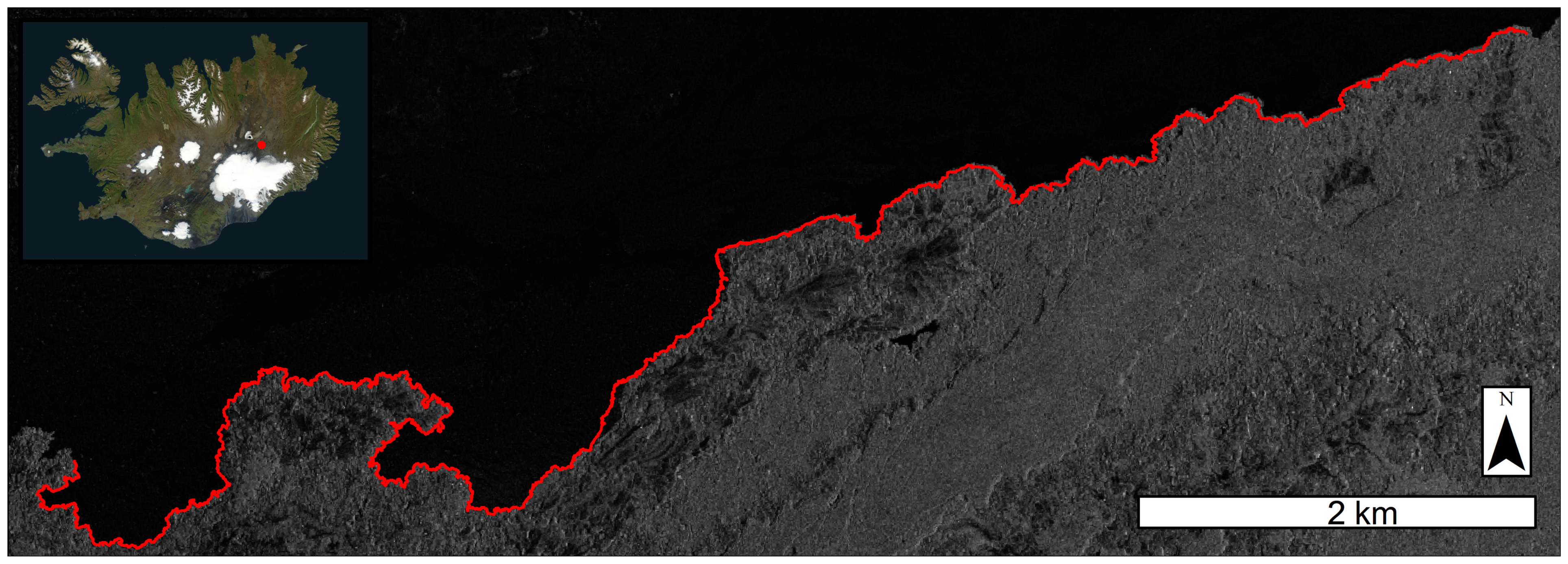
- Basaltic flow margins are sufficiently fractal that their fractal dimension *D* can be measured with precision at orbital resolutions.
- *D* correlates with the scale-dependence *H* of margin surface roughness, providing insight into flow type.
- Sediments embayed by flows alter margins' lacunarity ("gappiness") [3], allowing the degree of sediment mantling to be estimated from orbit, thereby further constraining flow type.

[4,5] demonstrated the approximate fractality of basaltic flow margins, and [4] found a correlation between non-mantled margins' *D* and flow type, consistent with our hypotheses. A *D-H* correlation is also plausible based on geometric arguments [3,6], and could permit identification of low-viscosity (ultramafic?) flows on Io [7,8], if low-viscosity impact melt flows are suitable analogs [9].

Methods

We acquired margin traces at decimeter spacing with differential GPS from flows in Iceland and Hawaii. In future fieldwork at Craters of the Moon (Idaho) and Hawaii, we will additionally collect similar data across near-margin surfaces and measurements of sediment thickness and area fraction. *D* and lacunarity are measured from margin traces using the "divider method" [10] and the technique of [11], respectively. *H* is measured from surface profiles after [6].

Results



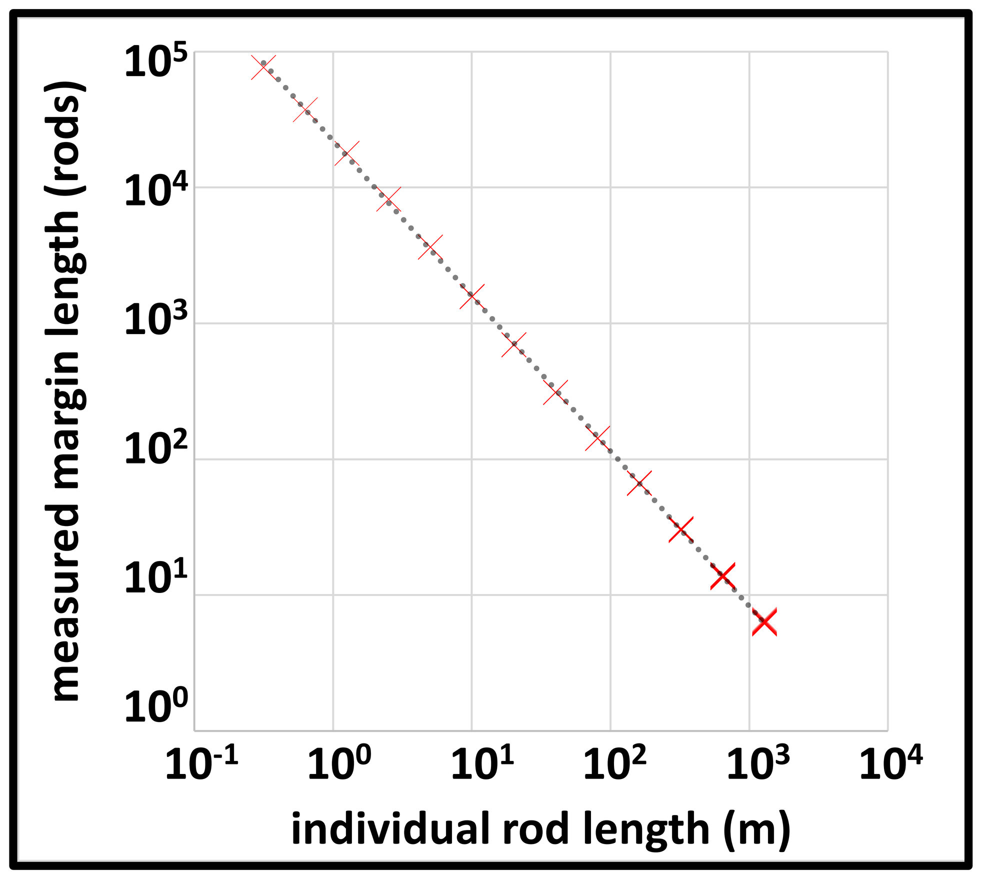


Figure 1 (above): Map of differential GPS margin trace (—) of 2014 Holuhraun flow, Iceland. Trace length is 24.7 km with ~15 cm spacing. Base map is UAVSAR L-Band total radar backscatter.

Figure 2 (left): Fractal analysis results (x) from a case study of the 2014 Holuhraun flow in Iceland (Figure 1) indicate that the margin is nearly perfectly fractal from at least 31 cm to 1.3 km. (Power law fit (•••) has $R^2 = 0.9998$.) Such near-perfect fractality suggests that sub-meter characterization from orbit is possible.

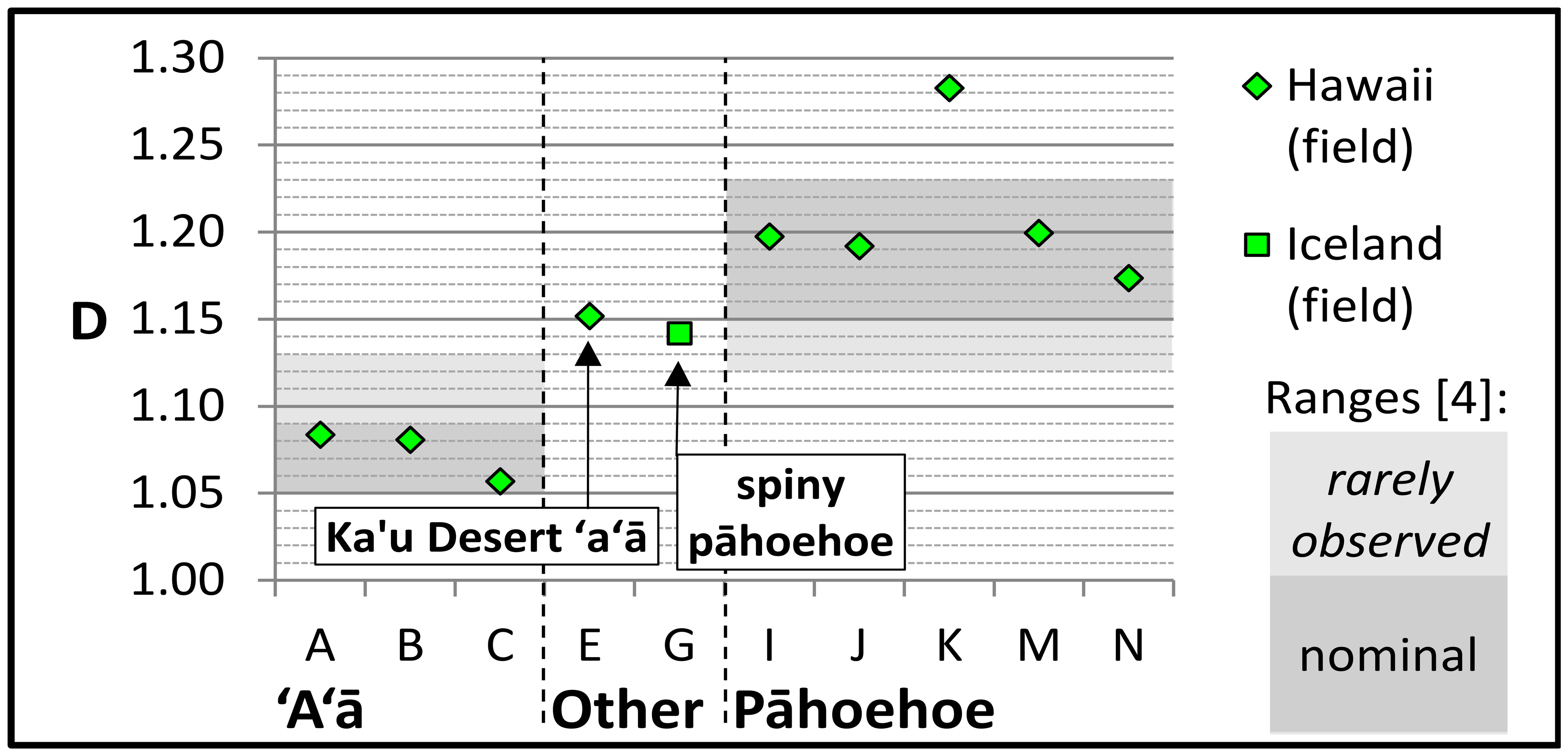


Figure 3: Results from a pilot study in Hawaii [12] and a case study at Holuhraun (Iceland). Note that all fractal dimension (*D*) values for simple 'a'ā and pāhoehoe margins lie in the respective nominal ranges of [4] for each flow type (dark gray shading) or are more extreme (only K). Conversely, a significantly mantled 'a'ā flow in the Ka'u Desert (E) has a pāhoehoe-like *D*, and the spiny pāhoehoe Holuhraun flow (G) has an unusually low *D* relative to classic pāhoehoe. These exceptions are qualitatively consistent with the hypothesized margin-roughness (*D-H*) correlation, as the Ka'u Desert flow is smoothed by mantling (increasing *D*) and spiny pāhoehoe is rougher than classic pāhoehoe (decreasing *D*). All margins exhibit strong fractality (power law fits have $R^2 > 0.996$).

Conclusions

- Based on the case study at Holuhraun (**Figs. 1-2**), basaltic flow margins exhibit extremely consistent fractality from dm- to km-scales.
- All results (**Fig. 3**) from Hawaii [12] and Holuhraun are qualitatively consistent with a correlation between surface roughness (*H*) and flow margin fractal dimension (*D*), and two results are especially suggestive.
- Together, these conclusions suggest that sub-meter flow roughness, and hence type, can be inferred from orbital imagery.

Future studies in Idaho and Hawaii will quantitatively test for correlations between *D* and *H* and between lacunarity ("gappiness") and degree of mantling. If confirmed, these correlations could shed light on whether low-viscosity and possibly ultramafic flows exist on Io and enable estimation of SO_2 frost depths on that moon's flows.

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Acknowledgements

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Further Information

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