FRACTAL VARIATION WITH CHANGING LINE LENGTH: A POTENTIAL PROBLEM FOR PLANETARY LAVA FLOW IDENTIFICATION, *Richard K. Hudson[1], Steven W. Anderson[1], Shawn McColley[2], Jonathan H. Fink[3],* [1]Black Hills State University, Spearfish South Dakota 57799-9102, [2]Department of Planetary Geosciences, Brown University, Providence, Rhode Island 02912, [3]Department of Geological Sciences, Arizona State University, Tempe, Arizona 85287

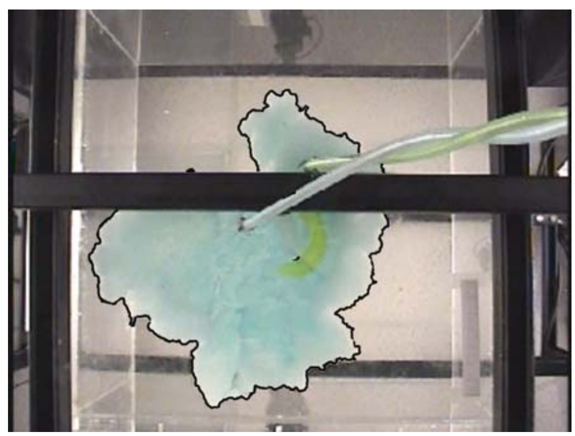
Introduction: Fractals are objects that are generally self similar at all scales. Coastlines, mountains, river systems, planetary orbits and some mathematical objects are all examples of fractals. Bruno et al. [1,2] used the structured walk model of Richardson [3] to establish that lava flows are fractals and that lava flow morphology could be determined by looking at the fractal dimension of flow margins. They determined that Hawaiian a'a flows have fractal dimensions that range from 1.05 to 1.09 and that the pahoehoe lava flows have a fractal dimension from 1.13 to 1.23. We have analyzed a number of natural and simulated lava flow margins and find that the fractal dimension varies according to the number and length of rod lengths used in the structured walk method. The potential variation we find in our analyses is sufficiently large so that unambiguous determination of lava flow morphology is problematic for some flows. We suggest that the structured walk method can provide meaningful fractal dimensions if rod lengths employed in the analysis provide a best-fit residual of greater than 0.98, as opposed to the 0.95 cutoff used in previous studies. We also find that the use of more than 4 rod lengths per analysis also reduces ambiguity in the results.

Fractal Calculations: Several previous studies of planetary lava flows [1,2,4] have employed the use of the structured walk method to calculate fractal dimensions, although another method (box counting) has also been used [5]. The structured walk model involves measuring the length of a margin by "walking" rods of various length around the perimeter. The "length" of the margin will change slightly according to the number of rod lengths required to traverse the margin, At least 4 rod lengths are used to determine the slope (S) of a best fit line for a "Richardson plot" of the log of the rod length versus the log of the margin length. A best fit line is fitted to the points and a residual is calculated. If the residual is greater than .95 then the flow is determined to be fractal [1,2]. The fractal dimension (D) is calculated as $D = 1-S$ where S is the slope of the best fit line.

These previous studies all point out the potential ambiguity in using fractal dimensions for the determination of lava flow morphology. Bruno et al. [1,2] showed that both pahoehoe and a'a lavas could have fractal dimensions in the range of 1.09-1.13. Norman [5] showed that a range of box sizes (analogous to rod lengths in the structured walk method) must be used to provide meaningful results, and suggested that fractal dimension values may only be useful as relative measurements rather than absolute values. Lipkaman and Gregg [4] used the structured walk method with 5 line lengths and found poor fit for many terrestrial and planetary flows. Because of these acknowledged difficulties with using fractals for lava flow morphology determination, we here investigate the source of variation of fractal dimension of exterior flow margins using the structured walk method.

Fractal Dimensions of Exterior Flow Margins - Methods: Previous studies have focused on the fractal behavior of lava flow margins. Here we examine the fractal dimension variation of a flow margin from an inflated pahoehoe flow from the 1970-72 eruption of Mauna Ulu, Hawaii. The flow margin was mapped using real-time differential GPS logging once per second with horizontal and vertical accuracies of <1m.

We also determined the fractal variation of simulated lava flow margins using an analog fluid [6,7]. Various colors of polyethylene glycol (PEG) were sequentially extruded from a point source into a tank containing a cold sucrose solution. The setup was videotaped from the top, side and bottom to provide time-lapse views of the developing flow. The top- and side-mounted cameras showed the development of the surface morphology, and the bottom-mounted camera captured the interaction of the different PEG colors in the flows interior. We conducted 20 experimental runs with different emplacement conditions.



Video of the flow margin development taken from the bottom of the tank was imported into the computer and still images of equally spaced time were taken and then opened in Adobe Photoshop 6.0. In Photoshop, the flow margin was outlined using the magic wand tool and the option stroke. The magic wand tool has the ability to decipher different shades of colors by adjusting the tolerance. The image was then opened in Canvas 8.0 and varying line lengths are plotted around the perimeter using a tool called the smart mouse. The smart mouse has the ability to maintain a constant line length as you "walk" the line along the margin. The number of lines required and the line length measured is then used to produce the log-log Richardson plot and the resulting fractal dimension.

The Mauna Ulu pahoehoe flow and all 20 of our simulated flows were determined to be fractal by using the structured walk method with at least 5 line lengths. Here we picked a subset of 6 runs that showed exceptionally high or low best fit residual values. Fractal dimensions were calculated for each of the flow margins using several different combinations of line lengths.

Results: The fractal dimension of the Mauna Ulu pahoehoe flow calculated using various combinations of 4 different rod length varied from 1.10 (in the pahoehoe-a'a overlap range of Bruno et al [1,2]) to 1.16 (pahoehoe range). Of interest is that all fractals with residuals over 0.98 yielded unambiguous results, whereas 2 of the 3 fractals calculated with lower residuals yielded results that could be interpreted as pahoehoe or a'a. We also calculated a fractal dimension of 1.13 and residual of 0.9803 (pahoehoe) using all 11 line lengths.

Residual	Fractal Dimension
0.9978	1.16
0.9949	1.16
0.9932	1.15
0.9971	1.15
0.9994	1.14
0.9928	1.13
0.9922	1.13
0.9654	1.13
0.9744	1.12
0.9767	1.11
0.954	1.10

The fractal dimension of the 6 simulated flow margins varied in excess of 0.08. The flows with the most diverse flow morphology had the greatest deviation. All of the flows did have variations in fractal dimension due to the variations of rod lengths used in the analysis.

Image 101 at 150 seconds shows one of the most drastic changes in fractal dimension. The fractal dimension for this image varies .08 which is enough variation in a natural flow to classify it as either an a'a flow or a pahoehoe flow. Image 116 at 120 seconds has very little deviation in fractal dimension due to its highly circular margin. Little deviation should be expected because the flow margin is less complex and that very little of the flow margin would be missed by changing line length.

Image	Seconds	Residual	Fractal Dimension
101	150s	0.9336	1.1666
101	150s	0.9708	1.1087
101	150s	0.9539	1.1172
101	150s	0.9757	1.0859
101	150s	0.9269	1.1383
101	150s	0.9885	1.1080

Planetary Considerations: The use of fractals for identification of planetary flow morphology is a potentially powerful tool for evaluating the geologic history of volcanic regions on other planetary bodies. To provide unambiguous results, our analysis suggests that the most consistent and unambiguous results are obtained for fractal dimensions with residuals of >0.98 are used. Our analysis of the Mauna Ulu margin also suggests that meaningful results may be obtained if more than 4 or 5 rod lengths are used in the determination of the fractal dimension. In conclusion, lava flows are fractal indeed but the fractal variation with changing line length is cause for concern when trying to correlate lava flow morphology and fractal dimension. From the data presented above fractals are most reliable with a higher (0.98) residual and larger numbers of rod lengths.

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Acknowledgements: This work was supported by a NASA South Dakota Space Consortium Workforce Development Grant to R.H., a Black Hills State University Faculty Research grant to S.A., and NASA grant NAG5-11655 to J.F.