VISCOSITY OF VENUSIAN LAVA FLOWS: CONSTRAINTS FROM FRACTAL DIMENSION AND CHEMICAL COMPOSITION.

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Overview: This study attempts to develop a relationship between the fractal dimension of lava flow margins and lava viscosity. At four Vega and Venera landing sites we find a relationship between a flow's fractal dimension and its viscosity as calculated from major element chemistry. Less viscous lava produces a more sinuous flow margin with a higher fractal dimension. We find that it is thus possible to extend this relationship to a global sample of flow margins; fractal dimension can be used to infer viscosity of the original melts and possible compositions.

Introduction: Fractal analysis can be used to quantify the morphology of lava flow margins. Prior research [1,2] has demonstrated that terrestrial and venusian flows of basaltic composition are fractal and that fractal dimension can be used to categorize flows as a'a, pahoehoe, or transitional. One determinant of flow type and rheology, which are reflected in the flow margin, is lava viscosity [1]. Viscosity is dependent upon chemical composition, which at several sites on Venus has been measured by Venera and Vega landers. This study attempts to associate the fractal geometry of venusian lava flows with chemical data derived from lander measurements and terrestrial analogs. We hypothesize that a low-viscosity lava will produce a more sinuous flow margin, thus having a greater fractal dimension than a viscous lava. We endeavor to develop fractal analysis as a tool for use in the determination of lava viscosity and composition where lander data are unavailable.

Methods: Our sample contains 72 flow margins on Magellan F-MIDR and C1-MIDR radar images. The flows exhibit slopes of less than one degree and are free of cratering and tectonic or volcanic deformation. Thirteen flow margins are located within the 300 km landing ellipses of Vega 2, Venera 8, Venera 13, and Venera 14.

We prepared three independent traces of each flow margin in the sample, and each trace was imported into Fractal Dimension Calculator 1.0 [3] for analysis. This software program uses a box-counting algorithm to estimate the fractal nature of the flow margins. The relationship $L=N(s)*s$ approximates the length L of the flow margin trace, where $N(s)$ is the number of boxes of side length s needed to cover the trace. As s decreases, $N(s)$ increases according to a power law and L becomes an increasingly more accurate approximation of the length of the curve. The power that reflects the nonlinear growth in $N(s)$ is the fractal dimension D. Venusian lava flows have been shown to have D from 1.04 to 1.24 [2].

We specified ten box sizes s covering three orders of magnitude (roughly 75 m to 11 km at F-MIDR resolution). The slope of a modified Richardson plot, showing $\log [N(s)]$ versus $\log [1/s]$, is our approximation of D. The mean D of the three traces of each flow margin is adopted as each flow's fractal dimension.

To estimate the original viscosity of the landing site rock we used a previously established procedure [4]. This technique employs rock chemistry, water weight percent, and the temperature of the original melt. Rock chemistry is given by the weight percent major element data provided by Vega 2, Venera 13, and Venera 14. As no major element data exist for the Venera 8 site, we inferred a high-K basaltic chemistry from Th-U-K data [5]. From these data we established four terrestrial analogs as possible Venera 8 materials: leucitite, nepheline syenite, shoshonite and subalkaline basalt. The major element chemistry of these analogs is used in place of lander data. Water weight percent of the lava is estimated from the K_20 weight percent determined by the landers [6]. The last component of the procedure is temperature; as venusian lavas are thought to be generally basaltic [2], we defined the possible viscosity range at each site by using the liquidus and solidus of basalt as end-member temperatures [4].

Results and Discussion: The fractal dimension of flow margins in our sample ranges from 1.04 to 1.19. Using established categories of flow type and associated D [2], we find that 35 of the 72 flows are a'a, having $D \leq 1.09$, while 17 have $D \geq 1.13$ and are pahoehoe. Twenty flows fall in the transitional area between these categories.

The correlation coefficients between D and altitude as well as D and latitude or longitude are not significant. There is thus no meaningful relationship between D and either flow margin altitude or geographic location.

Because the exact flow on which a lander performed a chemical analysis is not known, we must assume that all lava within each landing ellipse is of the composition measured by the lander. We thus take the mean *D* of all flow margins examined within the ellipse as the characteristic *D* of that landing site. We find the range of landing site fractal dimensions to be dichotomous. The mean fractal dimension of flow margins within the Venera 14 landing ellipse is 1.06, and is 1.07 within the Vega 2 ellipse. Within the Venera 8 landing ellipse the mean *D* is 1.12, although there is a large range (*D*=1.04 to *D*=1.18). The mean is 1.16 within the Venera 13 ellipse. The Venera 14 and Vega 2 fractal dimensions suggest a'a lavas, while the higher *D* values for Venera 13 suggest pahoehoe or transitional lavas.

We also find two distinct viscosity ranges. At 25% partial melt, the viscosity of the Venera 14 sample is calculated to be 615 poise, the Vega 2 sample to be 422 poise, and the Venera 13 sample to be 10 poise. The analogs of the Venera 8 sample have a range of viscosities: leucitite is 12 poise, nepheline syenite is 73 poise, shoshonite is 220 poise, and subalkaline basalt is 703 poise.

Figure 1 shows the inverse relationship between *D* and viscosity at three landing sites (V2=Vega 2, V14=Venera 14, V13=Venera 13), and the range of D and viscosity values for Venera 8 (V8). Viscosity is shown on a natural log scale for ease of comparison. The Vega 2 and Venera 14 lavas are similarly viscous, as their viscosities are an order of magnitude larger than are those in the Venera 13 ellipse.

Flow margins within the Venera 8 landing ellipse have a range of *D* values, and the four possible analogs have a range of viscosities. Because of uncertainty in the location of Venera 8, we are unable to determine which flow and associated *D* value corresponds to the chemical data or which analog is most accurate. The Venera 8 data are unsuitable for use in developing a correlation between fractal dimension and viscosity.

Our study thus indicates that the Venera 13 sites are characterized by pahoehoe lavas with high *D* and low calculated viscosity, while the Vega 2 and Venera 14 sites have a'a lavas with low *D* and high calculated viscosity. The hypothesis that high fractal dimension indicates a low viscosity is supported by these data. Furthermore, high K_2O and associated water content is reflected in high fractal dimension. Less viscous lava thus produces a more sinuous flow margin, resulting in a high fractal dimension.

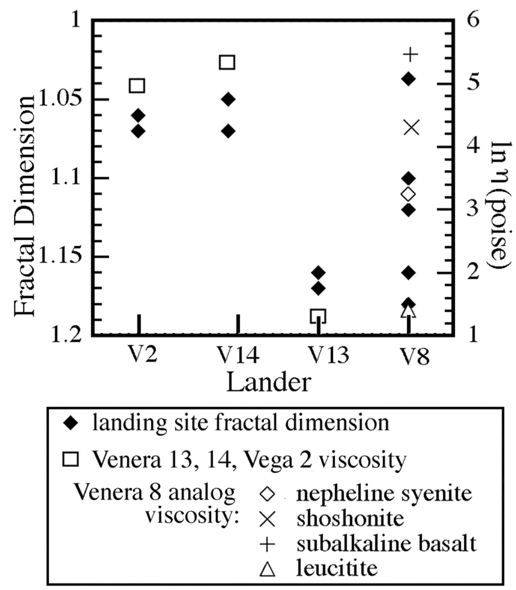

Fig. 1: D and viscosity at landing sites

Our results for the 13 flow margins within a landing ellipse indicate an inverse relationship between fractal dimension and viscosity. We may thus theorize about the composition of the 59 flows in the sample located in areas where chemical data are unavailable. Half of these flow margins have *D*≤1.09, implying high-viscosity melt. One-quarter of these margins have *D*≥1.13 and thus a melt with a low viscosity.

References: [1] Bruno B.C., et al. (1994) *Bull. Volc., 56*, 193. [2] Bruno B.C. and Taylor G.J. (1995) *GRL*, *22*, 1897. [3] Bourke P. (1997), www.mhri.edu.au/~pdb/software, 24 July 1997. [4] Shaw H.R. (1972) *Amer. J. Science*, *272*, 870. [5] Basilevsky A.T. (1997) *JGR*, *102*, 9257. [6] Johnson M. et al. (1994) in *Volatiles in Magmas*, ed. Caroll M.R. and Holloway J.R., 281.

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