A possible third festoon flow in Atalanta Planitia, Venus

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INTRODUCTION

The majority of volcanic features on Venus are thought to be of basaltic composition [*Head et al.*, 1992]. One exception to the uniformity of this composition may be the unusual festoon-type flow. Festoons, as defined by *Head et al.* [1992], are "radar-bright flows that show organized patterns of internal streamlines (looped or curved components) analogous to the ridge and flow bands typical of viscous terrestrial lava flows known as coulees." Two festoon flows have been identified and studied in detail [*Moore et al.*, 1992; *Schenk and Moore*, 1992; *Permenter and Nusbaum*, 1994; *Head and Hess*, 1996], one in a lowland plains and one in a highland area. However, a third possible flow, located in the plains region Atalanta Planitia, in the northern hemisphere (latitude 69.8° to 70.8°N, longitude 200.9° to 203.1°E) has not yet been studied in detail [*Head et al.*, 1992]. In Brown University's tabulated catalog of volcanic features on Venus this festoon is cited with a question mark. This indicates that authors are unsure about whether or not it qualifies as a festoon [*Crumpler et al.*, 1997]. Through comparison with the other two festoon flows and terrestrial analogs, we will evaluate whether or not this third flow should in fact be formally classified as a festoon. See Figure 1.

METHODS

Using Magellan data and several computer programs which allow us to interpret the data, we acquired measurements of altitude, reflectivity, emissivity and root-mean-square (RMS) slope and determine the flow area of the third possible festoon. The data measurements were used in the interpretations section to compare the flows and determine whether or not the third flow is a festoon. We also used terrestrial analogs to support these types of conclusions.

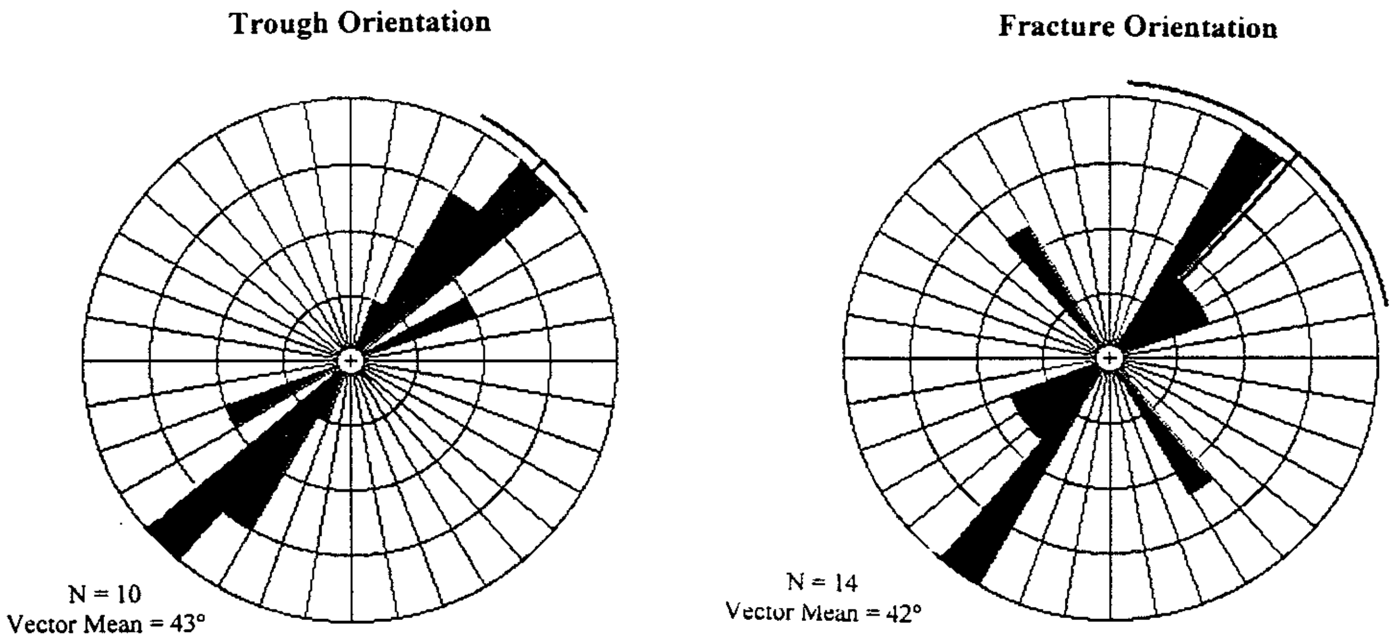
In order to identify the characteristic features of festoon flows, we tabulated specific quantitative attributes of the first two festoons. Then, to facilitate comparison, we took the same measurements for the Atalanta flow. The tabulated characteristics of the festoons include data acquired during the Magellan mission, such as emissivity, reflectivity and RMS slope. We used Magellan altimetry data to determine the altitude, topography, and thickness of the flow. We also calculated north-south and east-west dimensions, the area, and the ridge spacing of the ogive-looking features (the alternating light and dark bands on a glacier concave in the direction of flow). Using the thickness and the area values we calculated the volume of the flow. Finally we determined bulk density, yield strength and viscosity using a combination of previous measurements. See Table.

Root-Mean-Square Slope. The RMS slope is a measure of the roughness of the surface due to undulations larger than the wavelength of the radar (12.6 cm) [*Ford et al.*, 1992].

Density. Measurements of reflectivity can be used as indicators of surface density [*Tyler et al.*, 1976]. To make the correlation between density and reflectivity, first we used the Fresnel coefficient formula which relates the reflectivity to the dielectric constant of a material [*Ford et al*, 1993]. The equation is:

$$p=\left(\frac{1-\sqrt{e}}{1+\sqrt{e}}\right)^2 \qquad [1]$$

where p is the Fresnel reflection coefficient (reflectivity) of the flow and e is the dielectric constant. Fresnel reflectivity measures how well a material can reflect electromagnetic radiation. Therefore, the dielectric constant, which is an indicator of a material's electromagnetic properties, can be related to reflectivity. However, the assumption must be made that the material does not contain any conducting particles [*Pettengill* et al., 1991]. In addition, the equation assumes that the surface is free of sharp discontinuities and is homogeneous [*Tyler et al.*, 1976]. Using Maple software we solved equation 1 for dielectric constant using both the high and low bounds of reflectivity measurements for the Atalanta flow. We then solved for the bulk density of the flow material using a relationship determined by *Olhoeft and Strangway* [1975] for lunar rocks and soils using the equation:



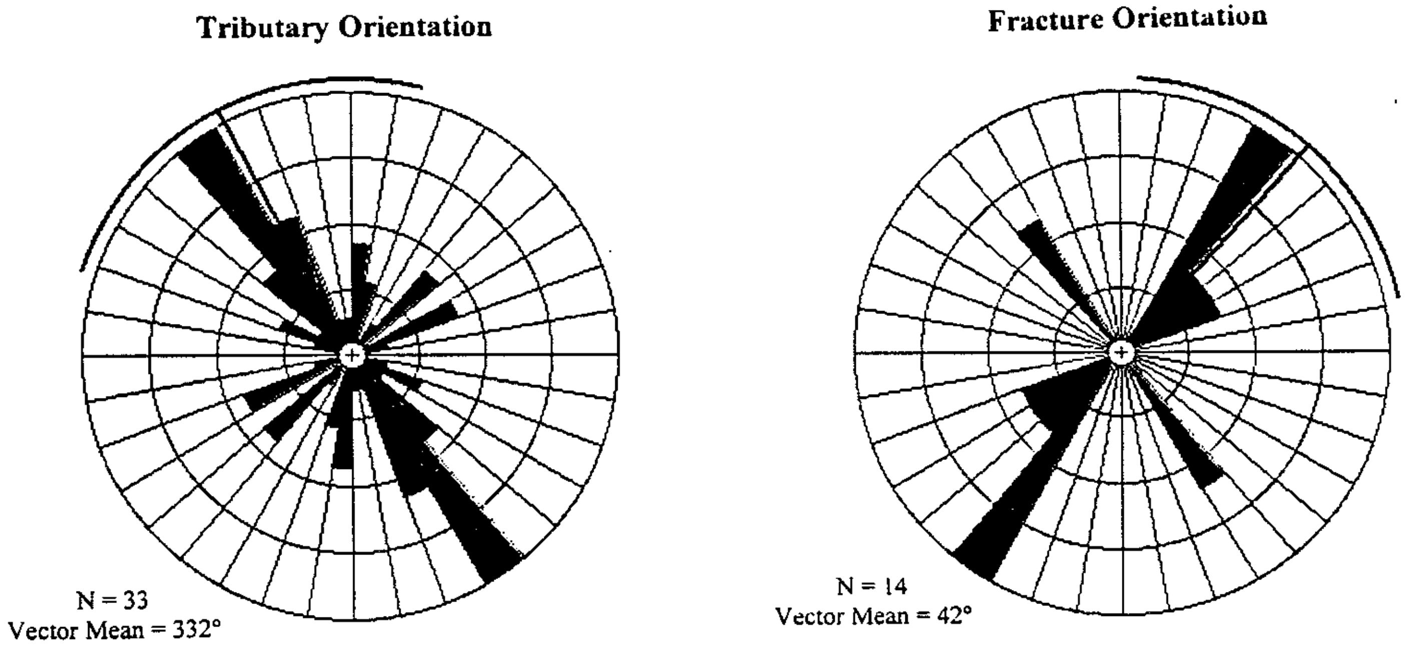
Trough Orientation

N = 10
Vector Mean = 43°

Fracture Orientation

N = 14
Vector Mean = 42°

Figure 2 – The trough (left) has a dominant orientation of 30°-50°. The regional fractures have 2 main orientations. The dominant orientation of the fractures (right) is very similar to the orientation of the trough, 30°-40°. The fractures have a secondary orientation of 320°-330°.



Tributary Orientation

N = 33
Vector Mean = 332°

Fracture Orientation

N = 14
Vector Mean = 42°

Figure 3 – The tributaries along the side of the trough (left) have a similar orientation to the secondary set of regional fractures. The tributaries are oriented primarily at 320°-330°. For comparison, the orientation of the fractures is shown on the right.

$$e = (1.93 \pm .17)^{\rho} \qquad [2]$$

where e is the dielectric constant and ρ is the density of the flow. Once again, several assumptions must be made. While this equation is valid for both soils and solids on the moon, moisture has a large effect on the relationship. Most other absorbed gases do not have an effect though, so this equation should apply to a dry planetary surface *[Olhoeft and Strangway*, 1975]. At the high temperature on the surface of Venus, the surface should be dry. This same method was used to determine the bulk density for the Artemis-Imdr festoon [*Moore et al*, 1992] and the Ovda festoon [*Permenter and Nusbaum*, 1994]. The determined range of densities is listed in Table 1.

Yield Strength. The next measurement, yield strength, was determined using the following relationship:

$$\tau_1 = \frac{\rho g H^2}{W} \qquad [3]$$

where τ_l is the yield strength, ρ is the density, g is the acceleration of gravity on Venus (8.87 m/s^2), H is the thickness of the lobe and W is the width of the lobe [*Orowan*, 1949]. This equation for yield strength was chosen because it does not require knowledge of the underlying slope angle. However, when comparing the method used for the festoon flows (equation 3), with the following method (equation 4), using terrestrial flows, values range enough that compositional inferences should not be made with too firm a conclusion [*Moore et al.*, 1992]. The method that incorporates topographic gradient is:

$$\tau_2 = \rho g H \sin \Theta \qquad [4]$$

where τ_2 is the yield strength, ρ is the density, g is the acceleration of gravity on Venus, H is the thickness of the lobe and θ is the slope angle. For example, for a'a and blocky basalt, equation 4 provides a value of 5.3×10^3 Pa and equation 3 provides 2.4×10^3 Pa. For our purposes, equation 3 provides the best comparison between the festoon flows and the Atalanta flow, because the yield strengths of the other two festoons have been determined in the same way [*Moore et al.*, 1992, *Schenk and Moore*, 1992]. The width of several different lobes was determined using the following criteria. Each lobe is characterized by an unconstrained (not shaped by local topography or environment) flow and is bounded by a geologic unit boundary, which we determined when mapping the flow. Measurements were taken across the greatest width of the determined lobe. These widths were then correlated with respective lobe thicknesses from altimetry data.

Viscosity. The viscosity measurements were derived from yield strength. The relationship provides an order of magnitude estimate of viscosity using the equation:

$$\eta_B = 6 \times 10^{-4} \tau_y^{\,2.4} \qquad [5]$$

where η_B is the Bingham viscosity and τ_y is the yield strength. The relationship was derived using topographic data and a cooling model [*Moore and Ackerman*, 1989]. The complexity of the Atalanta flow (See Figure) makes it difficult to make viscosity estimates as easily as for less complicated volcanic domes for which the relationship was developed. Once again, this same method was used for the other two festoons*[Moore et al.*, 1992, *Schenk and Moore*, 1992, *Permenter and Nusbaum*, 1994]. A wide variety of viscosity measurements were obtained.

Morphology. The Atalanta flow has a more complex morphology than the two documented festoons, indicating a difference in the nature of flow emplacement between the flow and the festoons. The Atalanta flow was emplaced over a large (≈100 km wide) north trending ridge system and these ridges may contribute to the more complex flow morphology. The combination of plains and this large ridge area creates incongruities in the substrate of this flow. This may be one of the reasons why the Atalanta flow does not have a lobe-like flow edge along some of its boundaries, whereas the two documented festoons, which are lobed along all boundaries, lie on uniform plains or uniform highly ridged tessera terrain.

DISCUSSION

The Atalanta flow shows characteristics both similar to and different from the Artemis-Imdr and Ovda festoons.

Similarities are:

- all three flows exhibit similar radar brightness;
- ogive pressure ridges are present on all three flows and ridge spacing measurements are similar;
- thickness measurements for the Atalanta flow and Ovda festoon are most similar, but all three are fairly thick flows;
- density measurements of the Atalanta flow are near the lower bounds of the other two festoons;
- yield strength and viscosity measurements of the Atalanta flow fall within the range of the measurements of the other two festoons.

Differences are:

- smaller area and volume of the Atalanta flow by an order of magnitude;

- morphological differences in roughness of the Atalanta flow.

However, these differences do not describe properties intrinsic to a festoon. The quantitative and qualitative characteristics that strongly correlate with the other two festoons overwhelm the differences and indicate a more viscous evolved magma.

CONCLUSION

We conclude that this flow fits the definition of a festoon. The radar brightness, ogive ridges, thickness, density, yield strength and viscosity characteristics support this conclusion. Size differences indicate that the magmatic source of the Atalanta flow was smaller, which suggests that the process that forms festoons is variable. Morphologic differences indicate that the flow was emplaced over a large ridge system as opposed to a more uniform surface such as plains or tessera; this is a reflection of environment of formation and not a property specific to the lava. The presence of a third example of this unusual volcanic feature could have great implications for volcanism and magmatic evolution and differentiation on Venus.

REFERENCES CITED

Crumpler, L.S., J.C. Aubele and J.W. Head, 10 July 1997, "The Tabulated Magellan Venus Volcanic Feature Catalog" Online. **Brown University's Planetary Geosciences Group of the Department of Geological Sciences**, World Wide Web. Available: *http://www.planetary.brown.edu/planetary/databases/venus.cat.html*

Ford, J.P., J.J. Plaut, C.M. Weitz, T.G. Farr, D.A. Senske, E.R. Stofan, G. Michaels, T.J. Parker, 1993, Guide to Magellan Image Interpretation: NASA, Jet Propulsion Laboratory.

Head, J.W., L.S. Crumpler and J.C. Aubele, 1992, Venus Volcanism: Classification of Volcanic Features and Structures, Association and Global Distribution from Magellan Data, *J. Geophys. Res.*, v. 97, p. 13153-13197.

Head, J.W. and P.C. Hess, 1996, Formation of Tertiary Crust on Venus by Remelting of Tessera Crustal Roots: The Ovda Regio Festoon, *Lunar Planet. Sci. Conf.*, v. XXVII, p. 513-514.

Moore, H.J. and J.A. Ackerman, 1989, Martian and terrestrial lava flows (abstract), *Reports on Planetary Geology Geophysics Program - 1988, NASA Tech. Memo.*, v. TM-4130, p. 387-389, in Moore, H.J., J.J. Plaut, P.M. Schenk and J.W. Head, 1992, An Unusual Volcano on Venus, *J. Geophys. Res.*, v. 97, p. 13479-13493.

Moore, H.J., J.J. Plaut, P.M. Schenk and J.W. Head, 1992, An Unusual Volcano on Venus, *J. Geophys. Res.*, v. 97, p. 13479- 13493.

Olhoeft, G.R., and D.W. Strangway, 1975, Dielectric Properties of the First 100 Meters of the Moon, *Earth and Planetary Science Letters*, v. 24, p. 394-404.

Orowan, E., 1949, Remark from the joint meeting of British Glaciology Society British Rheologists' Club, and Institute of Metals, *J. Glaciol.*, v. 1, p. 231, in Moore, H.J., J.J. Plaut, P.M. Schenk and J.W. Head, 1992, An Unusual Volcano on Venus, *J. Geophys. Res.*, v. 97, p. 13479-13493.

Permenter, J.L. and R.L. Nusbaum, 1994, The Thick Festoon Flow and Adjacent Dark Flow, Ovda Regio, Venus, *Lunar Planet. Sci. Conf.*, v. XXV, p. 1067-1068.

Pettengill, G.H., P.G. Ford, W.T.K. Johnson, R.K. Raney, and L.A. Soderblom, 1991, Magellan: Radar performance and data products, *Science*, v. 252, p. 265-270.

Schenk, P.M. and H.J. Moore, 1992, An Unusual Thick Lava Flow in Ovda Regio, Venus, *Lunar Planet. Sci. Conf.*, v. XXIII, p. 1217-1218.

Tyler, G.L., D.B. Campbell, G.S. Downs, R.R. Green and H.J. Moore, 1976, Radar Characteristics of Viking 1 Landing Sites, *Science*, v. 193, p. 812-815.

	Artemis-Imdr Festoon (3)	Ovda Festoon	Atalanta Flow
Latitude	35.9-38.7S	6.0-6.5S	69.8-70.8N
Longitude	163.5-166.7E	95.5E	200.9-203.1E
Geologic Area	Dark lowland plains	Highland tessera	Northern trending ridge system in lowland plains
Region	Aino Planitia	Ovda Regio	Atalanta Planitia
Emissivity Values	.848-.898	.5-.86 (2); .42-.78 (4); .26-.84 (1)	.87-.89; Mean=.88
Reflectivity	.065-.150	.16-.46 (4)	.07-.13
RMS slope range (Degrees)	Average range1.03-4.16; total range 0.5-9.0	1.7-9.0	2.2-6.7
Altitude (km)	6051.14	6054.5-6056.6(1)	6050.5-6051.75
Thickness (estimated, m)	500	50-150 (1); 180-280 (5); 52-144 (4)	32-388; mean=65
Ridge Spacing (m)	Mean=686m.	640 (4); 625-770 (5); 500-750 (3)	487-575
Dimensions (km)	180 x 250	250 x 300 (1); 280 x 320 (5)	70 x 85
Area (km^2)	47,700	45,000	3500
Volume (km^3)	7,520-11,400	5,500 (1); 4,545 (4)	215-430
Yield Strength (Pa)	2-30x10^4	2-6 x 10^5 (4)	2.3 x 10^3-3.4 x 10^5 (see table 2)
Viscosity (inferred) (Pa-s)	1.0 x 10^7-8.0 x 10^9	2.0 x 10^7-2.6 x 10^9 (4); 10^{16} & 10^6 (5)	7.21 x 10^4-1.14 x 10^{10} (see table 2)
Bulk Density kg/m^3	2,110-2,360	3,010 and 2,550 (4)	1,649-2,297

1) *Head J.W. and Hess P.C.,* 1996
2) *Izenberg N.R. and Arvidson R.E.,* 1994
3) *Moore et al.,* 1992
4) *Permenter J.L. and Nusbaum R.L.,* 1994
5) *Schenk p. and Moore H.J.,* 1992

Table 1

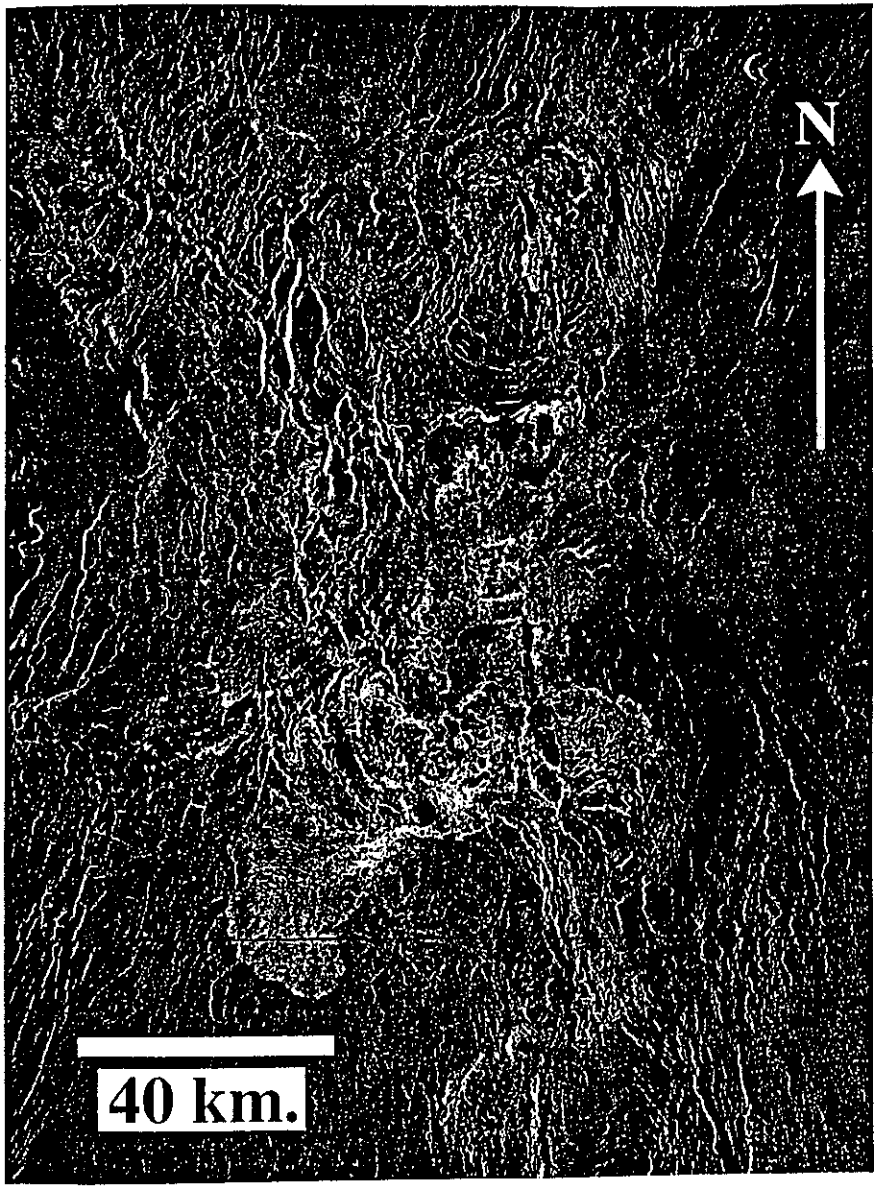


Figure 1

THE OREGON KECK PROJECT:

The Geology of the Klamath River Canyon Astride the California-Oregon Border

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