VOLCANIC ERUPTIONS FROM LINEAR VENTS ON EARTH, VENUS AND MARS: COMPARISONS WITH CENTRAL VENT ERUPTIONS. L. S. Glaze[1], S. B. Baloga[2] and J. Wimert[3], [1]NASA's Goddard Space Flight Center (Code 698, Greenbelt, MD 20771, Lori.S.Glaze@nasa.gov), [2]Proxemy Research (20528 Farcroft Lane, Gaithersburg, MD 20882, Steve@proxemy.com), [3]University of Maryland (jwimert@umd.edu).

Introduction: The conditions required to support buoyant convective plumes from centralized and linear vents on Earth, Venus and Mars are investigated. It is shown that the vent geometry (linear versus central) plays a significant role in the ability of an explosive eruption to sustain a buoyant, convective plume. The long vents on Venus and Mars favor column collapse and the formation of pyroclastic flows because the range of conditions required to establish and sustain buoyancy is relatively narrow. When buoyancy can be sustained, however, maximum plume heights are essentially independent of the nature of the vent geometry. These results have implications for the injection and dispersal of particulates into the planetary atmosphere and the ability to interpret the geologic record of planetary volcanism.

Convective Plume Model: The approach to modeling linear volcanic vents described here builds on the original work by Stothers [1], but takes advantage of substantial improvements that have been made in volcanic plume modeling over the last 20 years. In general, the complete system of equations describing buoyant plume rise requires at least a half dozen differential equations and another half dozen equations describing parameters and constraints within the plume and ambient atmosphere. For the cylindrically axisymmetric system of differential equations given in [2], the control volume is defined as $V = \pi r^2 dz$. The area through which ambient atmosphere is entrained is $A_e = 2\pi r\, dz$, where r is the plume radius and z is vertical distance. The analogous linear vent system has a corresponding control volume, $V = 2bLdz$ and entrainment area, $A_e \approx 2Ldz$, where L is the length of the linear plume, $2b$ is the width of the linear plume, and it is assumed that $L >> b$. The results described below assume L remains relatively constant as a function of z. Thus the resulting linear plume height estimates are not dependent on L.

Results: Figure 1 illustrates a basic comparison of predicted plume heights on Earth for a range of vent sizes. On the most basic level, a simple comparison can be made of plume height as a function of either b_o (for linear vents) or r_o (for circular vents). For the results shown in Figure 1, all of the boundary values at the vent are kept the same, except for the size of the vent opening. The vent conditions used for both geometries are velocity, $u_o = 300$ m s^{-1}, temperature, $\theta_o = 1000$ K, and the mass fraction of water vapor, $n_o = 0.03$. For this example, the plumes are assumed to rise from sea level into the US Standard atmosphere (e.g., [3]).

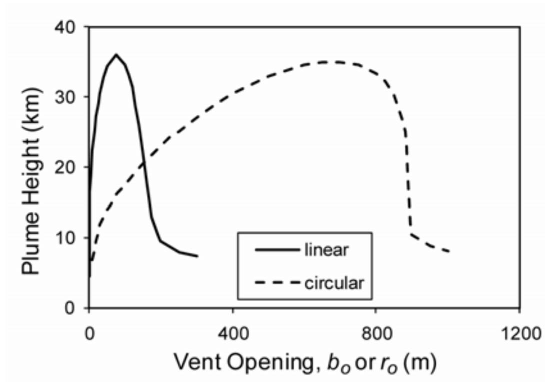

Figure 1. Maximum predicted plume heights as a function of vent radius (for circular vents), r_o, or half width (for linear vents), b_o. Models assume terrestrial ambient atmospheric conditions.

For this set of boundary conditions both the linear and circular vent models produce a maximum plume height of around 35 km. Figure 1 shows maximum plume heights for circular and linear vents, plotted for a broad range of vent sizes. From this plot, it can be seen that buoyant, convecting plumes originating from circular vents can be maintained with substantial maximum heights over a wide range of vent sizes. For the boundary conditions used in this analysis, plumes from circular vents collapse, or are otherwise unable to maintain a steady column, for vent sizes greater than about 900 m. However, the linear vent plumes are much more sensitive to the vent size, and can maintain a convective plume only over a much more narrow range of half widths. For the same boundary conditions (temperature, velocity, gas mass fraction), plumes from linear vents only reach significant heights for values of b_o of a few meters to ~200 meters. For this set of boundary conditions, the peak plume height from a linear vent occurs when $b_o \approx 75$ m.

Because one of the main drivers of plume height is the mass flux at the vent, a better comparison between linear and circular vents can be made by examining predicted plume heights for equivalent mass fluxes. The mass flux at the vent is defined as the density of the erupted material multiplied by the cross sectional area of the vent and the exit velocity ($= \rho_{Bo} u_o A_o$). Keeping the bulk plume density and exit velocities the same for both linear and circular vents, the key parameter for comparison becomes the cross sectional vent area, where $A_o = \pi r_o^2$ for the circular vent, and $A_o = 2b_oL$ for the linear vent.

Figure 2 illustrates the plume heights corresponding to a range of vent areas. Noting that the original definition of a linear vent included the assumption that $L >> b$, the figure only considers values for b_o that are less than an order of magnitude smaller than L. From Figure 2, it can be seen that as L increases, linear plumes become more capable of establishing a convective regime over a broad range of b_o, similar to the circular vents. This is primarily because as L increases, the entrainment area of the linear plumes increases, relative to the control volume. The ability of a plume to become buoyant is driven by whether or not sufficient air can be entrained (and warmed) to reduce the bulk plume density before upward momentum is exhausted. From mass conservation, the mass of dry air entrained by the linear plume is roughly the same as the cylindrical case when $uL \approx \pi ur$. Thus, the linear plumes surpass circular vents in entrainment efficiency approximately when $L_o \geq 3r_o$.

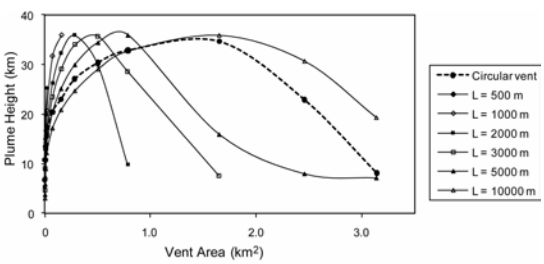

Figure 2. Maximum predicted plume heights on Earth as a function of vent area. Model boundary conditions are the same as those in Figure 1. The linear vent results are shown for multiple choices of active fissure length.

Figure 3 illustrates results for current atmospheric conditions on Venus. The plume heights reached for circular and linear vents for a range of radii and half widths are shown. Several significant points emerge-from this figure. First, consistent with work by others [4,5], the range of conditions over which plumes can be maintained on Venus is very narrow (note the range on the x-axis is only 300 m, compared to > 800 m on Earth). Also, the shape of the curve for circular vents is substantially different from the terrestrial case, with an almost linear relationship between vent radius and maximum plume height. The primary explanation for this difference in shape is the much higher pressure of the ambient atmosphere.

The maximum plume height achievable from a circular vent for the given boundary conditions on Venus is ~52 km, corresponding to a vent radius of 247 m. For linear vents, the range of conditions that can maintain a convective plume is very narrow, with the maximum plume height of ~69 km occurring when b_o = 16 m. Unlike the terrestrial case, linear vents on Venus appear capable of driving a plume to somewhat higher maximum altitudes, for all other things remaining equal, albeit under very limited conditions.

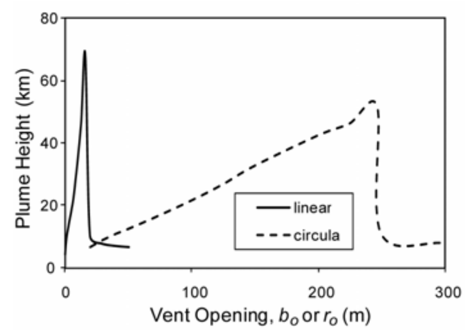

Figure 3. Maximum predicted plume heights on Venus as a function of either vent radius or half width. Models assume northern Venus latitude ambient atmospheric conditions, u_o = 270 m s^{-1}, θ_o = 1400 K, and n_o = 0.05.

Similar analyses were conducted for current atmospheric conditions on Mars. Results indicate a preference for the formation of pyroclastic flows on Mars from both circular and linear vents, as opposed to widely dispersed airfall deposits.

Conclusions: When buoyancy is sustained, linear vents appear to be equally capable of injecting volcanic ash and volatiles into the atmosphere. For analogous mass flux rates at the vent, the maximum heights to which linear and cylindrical plumes can rise are essentially equivalent. In cases where the length of active linear vent is less than approximately $3r$, the entrainment area of linear plumes is significantly less than the cylindrical equivalent. Thus the range of vent widths that can sustain a buoyant plume is narrow and these plumes are more likely to collapse.

Only the Earth, with its thick wet atmosphere, favors explosive eruptions that can maintain convective plumes reaching 10s of km in altitude over a broad range of eruptive conditions. Conversely, the range of plausible conditions that can produce a buoyant convective plume on Venus is very restricted. On Mars, results favor interpretations of pyroclastic flows (instead of airfall deposits) at major volcanic centers.

References: [1] Stothers, R.B. (1989) *J Atmos Sci, 46*, 2662-2670. [2] Glaze. L.S., Balgoa, S.B., and Wilson, L. (1997) *JGR, 102,* 6099-6108. [3] Wallace, J.M. and Hobbs, P.V. (1977) *Atmospheric Science*. [4] Glaze, L.S. (1999) *JGR, 104*, 18,899-18,906. [5] Thornhill, G.D. (1993) *JGR, 98,* 9107-9111.