TABLE 3. Minimum Volatile Contents and Magma Source Depths Required to Ensure Explosive Activity in Venusian Magmas

Magma-Volatile Combination	4 MPa Surface Pressure		10 MPa Surface Pressure	
	Volatile Content, wt %	Source Depth, km	Volatile Content, wt %	Source Depth, km
Water in basalt	1.1	1.0	2.5	3.2
Water in rhyolite	1.6	0.5	3.3	2.2
CO_2 in any melt	2.0	35	4.7	83

projected out into the atmosphere. These mixtures are generally denser than the surrounding atmosphere. Specifically, mixtures of silicate fragments and magmatic water vapor at magmatic temperatures on Earth will only be less dense than the atmosphere if the water vapor mass fraction exceeds 15%, a situation only likely to occur in explosions which concentrate the volatile into the upper part of the available magma: this can happen in Strombolian [Blackburn et al., 1976] and Vulcanian explosions [Self et al., 1979]. On Venus the corresponding limit is 45-50% (depending on the local atmospheric pressure) if CO_2 is the volatile phase and 18-20% if the volatile is H_2O.

Immediately after leaving the vent, the explosion products interact with the planetary atmosphere in two ways. Sufficiently coarse clasts decouple rapidly from the gas flow and follow approximately ballistic paths back to the ground. Sufficiently fine clasts remain locked to the gas flow regime and become involved in the next phase of the explosion, which is the entrainment and heating of atmospheric gases. In this way, thermal energy is converted to buoyancy (and hence kinetic energy), the bulk density of the mixture decreases, and a convecting cloud may form over the vent. A completely stable cloud can only form if atmospheric gas is mixed as far as the center of the cloud before the upward velocity of the material there decreases to zero as a result of the action of gravity [Sparks and Wilson, 1976]. If a stable condition is not reached, part or all of the ejected material will rise to a large fraction of the ballistic height which would have been reached in the absence of an atmosphere and then collapse back to the ground. Depending on the initial temperature and on the grain size and flight time, and hence amount of cooling, of the clasts, this material may form an unwelded air fall ash/scoria deposit, a welded deposit of similar type, or a pyroclastic flow or may coalesce to form a lava flow.

Establishment of a stable convecting plume will be encouraged if the ejection velocity from the vent is large and the radius of the vent is small (since these conditions minimize the lateral distance to which the atmosphere must mix to reach the cloud center and maximize the time available for this to happen) and if the jet of material emerging from the vent is well-collimated. Calculations given by Sparks et al. [1978] can be used to show that the minimum eruption speed V_m through a vent of radius R_v needed to ensure stable convection is

$$V_m = \frac{80\, R_v\, (\beta_m - \beta_a)}{\beta_m} \qquad (28)$$

where β_m and β_a are the bulk density of the erupting gas-clast mixture and the density of the surrounding atmosphere, respectively. This relationship was developed for eruptions on Earth, but there is experimental evidence to suggest that the entrainment process is geometrically similar over a wide range of density contrasts between the inside of the cloud and the surrounding atmosphere [see Turner, 1979; Sparks and Wilson, 1982]. We shall use equation (28) in later sections to assess the stability of convecting eruption clouds on Venus and the likelihood of pyroclastic flow formation.

4.4. Heights of Eruption Clouds

Once stable convection is assured, the height to which a cloud can rise is determined by the structure of the surrounding atmosphere and the thermal input to the cloud. Theoretical studies of idealized plumes [Morton et al., 1956], numerical calculations for volcanic clouds, and field observations [Wilson et al., 1978; Settle, 1978] show that for clouds forming above a vent which is releasing material at a constant rate, the maximum height reached is proportional to the fourth root of the heat release rate (which is in turn proportional to the mass eruption rate of clasts small enough to be entrained into the cloud). For clouds forming above sudden, discrete explosions, the height is proportional to the fourth root of the amount of heat released rather than the release rate [Morton et al., 1956]. However, if discrete explosions occur sufficiently close together in time, the result may be a relatively steady convecting cloud with a height determined by the time-averaged heat release rate. This is likely to happen if the time needed for the decay of the velocity field induced in the atmosphere by one explosion is less than the time interval between successive explosions. The decay time will certainly be less than the time which would be required for fragments projected upward at the same speed as the gas stream to come to rest under the action of gravity alone (since entrainment of the surrounding atmosphere will exert an additional retarding force on the ejecta). The ballistic rise time is equal to the initial velocity divided by the acceleration due to gravity and since the gravities on Venus and Earth are similar, we find that for both planets, a steadily convecting cloud will form over a vent producing discrete explosions if the time interval between explosions is less than the following values: for an ejection velocity of 10 m/s, 1 s; for a velocity of 30 m/s, 3 s; for 100 m/s, 10 s; and for 300 m/s, 30 s.

Early estimates of the rise heights of steady