TABLE 1. Variation of Implied Values of Fissure Width W, Magma Rise Velocity u, Fissure Length L, and Reynolds Number Re as a Function of Z, the Assumed Value of L/W

Z	W, m	u, m/s	L, m	Re
1	18.3	32	18.3	1.6×10^4
10	10.3	10	103	288
10^2	5.8	3.2	580	52
10^3	3.3	1.0	3300	9
10^4	1.8	0.3	18000	1.5

density differences exist in eruptions where magma is accelerated by an excess pressure in the magma chamber [*Wilson and Head,* 1981*b*]. A useful value to choose for μ is 10^3 Pa s. For viscosities of this order or larger, it can be shown [*Wilson and Head,* 1981*b*] that the rise speeds of the largest bubbles which can form in the magma as it approaches the surface (bubble diameters of a few millimeters [*Sparks,* 1978]) are less than 0.1% of the minimum rise speed of the magma (of the order of 10 mm/s, the value being set by the requirement that the magma must not cool too much during its ascent) and bubble coalescence is of negligible importance under all conditions. Also, since u is inversely proportional to $\mu^{0.5}$ (equation (7)), lower values of μ than 10^3 Pa s will certainly lead to higher rise velocities than those calculated with this value. Thus if the velocities found using $\mu = 10^3$ Pa s are greater than the critical velocity of 0.5 to 1 m/s, then it can be guaranteed that bubble coalescence could not have been important in the Hecates Tholus eruption.

Table 1 shows the results of the calculations of W, u, and L for Z = 1, 10, 100, 1000, and 10,000. The Reynolds number, $Re = W\rho u/\mu$, is also included in each case to confirm the assertion that magma motion is laminar ($Re \lesssim 500$) in all cases except $Z = 1$. Clearly, u is greater than the critical value of 0.5 to 1 m/s as long as Z is less than 1000, which is exactly the result we are seeking. The implied active fissure (and, hence, surface vent) length could lie anywhere in the range from a few tens of meters to about 3 km, again consistent with the range of sizes of topographic structures visible in and around the caldera. Even if Z were as large as 10,000, the eruption would only be slightly unsteady with u = 0.3 m/s; however, if $Z = 10^4$, then L = 18 km and a linear vent structure of this dimension would easily be visible in the Viking images, since the vent would exceed the 10-km diameter of the summit caldera complex (see Figure 2). Thus we conclude that, at a discharge rate of 3×10^7 kg/s, the Hecates eruption would have been of a steady plinian type whatever the magma composition.

A final factor in the eruption deserves attention: the source of the volatile component in the erupting magma. We have demonstrated earlier that a stable convecting eruption cloud could only have existed if the erupting magma contained at least 1 wt % H_2O or 2 wt % CO_2 and have so far assumed that the volatile phase was present in the magma at depth in the crust. There are two possible mechanisms of introducing volatiles into the magma during the eruption: (1) incorporation of volatile-bearing country rock into the erupting magma by attrition and assimilation of conduit walls and (2) entrainment by the magma of liquid water from an aquifer intersecting the conduit system.

In order to introduce 1 wt % water into the total erupted deposit volume of 23 km³ (dense rock equivalent) we could reasonably postulate that the erupting magma incorporated 10% by weight, i.e., 2.3 km³, of country rock which contained 10% by weight H_2O as ice. This proportion of country rock is quite common in plinian deposits. The latent heat required to melt and evaporate the ice could be taken from the magma with negligible effect on the temperature at this low volatile concentration. Permafrost may exist on Mars down to depths of several kilometers [*Carr and Schaber,* 1977] and if we assume a depth of 5 km, the required volume of country rock could be supplied by the excavation of a region having the shape of an inverted circular cone if the cone had a diameter of 1.3 km at the surface. This diameter happens to be close to (and, as is necessary, less than) the 1.6-km-diameter surface vent size calculated above as being needed to allow the emerging mixture of clasts and gas to decompress to the local atmospheric pressure. It is likely that a vent structure with the steep-sided geometry implied by this calculation would be unstable after the eruption ceased. The collapse of the deeper parts of the vacated region would enlarge the surface expression of the vent. If the collapse continued until the slopes were everywhere at a typical angle of rest of 30°, the resulting structure would be a depression just over 3 km in diameter and 900 m deep. Since the greatest depth of the caldera currently appears to be no more than 450 m, the diameter of the depression should in fact be at least 4.4 km, a value somewhat larger than the size of the largest of the four discrete craters visible within the caldera complex. It would clearly be necessary to postulate that at least two of these craters formed as a direct consequence of the country rock excavation process. The above calculation would not be changed significantly if CO_2 ice were used as the volatile; given the current uncertainties in estimates of the permafrost content of the Martian near-surface layers, it seems that we should not exclude the possibility that a significant contribution to the magma volatiles was made by such near-surface layers.

The main problem associated with supplying water to the magma from an aquifer is the need to maintain the temperature of a large enough volume of subsurface layers within the appropriate range (0°C to a few hundred degrees Centigrade, the exact upper limit depending on the pressure and, hence, depth of the base of the aquifer). Given the availability of water, there seems no reason to think that the magma cannot assimilate it [*Stewart and Hulston,* 1976]. A constraint on the required geometry can be set by considering an aquifer intersecting the fissure feeding the vent. Let the horizontal flow speed of water through the contact area be v and let the contact area be of vertical extent h along both sides of the fissure of length L. The mass rate at which water must be supplied to the magma is $0.01M$, since we require 1 wt % of water to be mixed with the magma erupting at mass rate $M = 3 \times 10^7$ kg/s. Hence we have

$$0.01M = 0.3(2L)\rho_w vh \tag{9}$$

where ρ_w is the water density and the factor 0.3 is a deliberately generous estimate of the pore space fraction in the aquifer. For any chosen value of L (see Table 1) we can find pairs of values of v and h which satisfy the equation. If we choose L = 3300 m, the largest allowed value for Z less than 1000, we shall obtain the most conservative values for v and h. Information on likely values of v comes from data on hydraulic conductivities of terrestrial aquifers [*De Weist,* 1965]: in coarse gravels, v may be as large as 0.1 m/s; more typical values for sandstones cover the range 10^{-3} to 10^{-6} m/s. Table 2 shows the values of h implied by assuming values