where λ is a dimensionless scale factor given by

$$\frac{Q\,\pi^{\frac{1}{2}}}{c_L\,(T_s - T_0)} = \frac{\exp\,(-\lambda^2)}{\lambda\ \mathrm{erf}\,(\lambda)} \tag{10}$$

Q and c_L are the latent heat of fusion and the specific heat of the magma (taken as 4×10^5 J kg^{-1} and 1500 J kg^{-1} K^{-1}, respectively), and erf (λ) is given by

$$\mathrm{erf}\,(\lambda) = \frac{2}{\pi^{1/2}} \int_0^\lambda \exp\,(-z^2)\ dz \tag{11}$$

convenient values of which are tabulated by Carslaw and Jaeger [1959]. The vertical temperature gradient in the flow between the surface and the base of the solid crust is [Turcotte and Schubert, 1982]

$$\frac{\partial T}{\partial y} = \frac{(T_s - T_0)}{(\pi\,\kappa\,t)^{1/2}}\ \frac{\exp\,(-y^2/4\kappa t)}{\mathrm{erf}\,(\lambda)} \tag{12}$$

The heat flow through the surface at y = 0 is equal to the temperature gradient at the surface multiplied by the thermal conductivity of the lava, k_L, taken as 3 W m^{-1} K^{-1}, and must be equal to the total surface heat flux given in Table 1 for the appropriate surface temperature T_0:

$$F_T = \frac{k_L\,(T_s - T_0)}{(\pi\kappa t)\ \mathrm{erf}\,(\lambda)} \tag{13}$$

The method of solution is to select a value of T_0 from Table 1 and evaluate the left-hand side of equation (10). Turcotte and Schubert [1982] give a graphical solution of (10) from which λ can be determined. This value of λ is inserted, together with T_0, into equation (13) to solve for t, the time from the commencement of cooling on leaving the vent at which these values of T_0 and λ are reached. Finally, λ and t are inserted into equation (9) to find the corresponding value of C, the thickness of the solid crust. Figure 5 gives the values of T_0 and C as a function of time evaluated in this way for flows on Venus and Earth and shows that during most of the first hour after leaving the vent, surface temperatures on terrestrial flows will be greater than on Venusian flows: convective heat loss is very efficient in the dense Venusian atmosphere. At times significantly longer than 1 hour, however, temperatures will be higher on Venusian flows as the flow surface temperature asymptotes to the higher ambient temperature. The thickness of the rigid crust on a flow is greater on Venus than on Earth immediately after the flow leaves the vent; however, after about 30 min, by which time the crust thickness exceeds 60 mm, the crust is thicker on a terrestrial flow. These results are confirmed by an analysis given by Frenkel and Zabaluyeva [1983] and lead to the following comparisons between the expected features of lava flows on the two planets.

3.2 Lengths of Lava Flows

Flow units which come to rest after traveling for less than about 1 hour will be systematically longer, if we consider only the consequences of cooling, on Earth than on Venus, whereas flows traveling for much more than 1 hour will be longer on Venus. This relationship follows from the nature of the cooling process in the interior of a flow. The thickness of cooled crust on a flow is an indicator of the penetration of a wave of cooling into the flow; and since the rheological properties of a lava are dominated by its temperature, the wave of cooling may be thought of as a wave of modification of rheology. A flow will cease to move on a given slope under a given stress regime when its interior rheology has been sufficiently modified [Kilburn, 1983]. It is found empirically for terrestrial basaltic flows that motion will cease when the value of the dimensionless Graetz number Gz has fallen from an initially high value to about 300 [Hulme and Fielder, 1977; Pinkerton and Sparks, 1978]. Gz is defined as

$$Gz = \frac{u\,D^2}{\kappa x} = \frac{D^2}{\kappa t} \tag{14}$$

where D is the flow thickness, κ is the lava thermal diffusivity, x is the distance flowed by the lava at mean speed u, and t is the time since leaving the vent. Gz is simply the reciprocal of the parameter $\kappa t/D^2$ which is commonly used to characterize cooling problems, and Gz = 300 corresponds approximately to a situation in which the central one half of the vertical thickness of a flow is unaffected by cooling (see section 3.4 of Carslaw and Jaeger [1959]). If we use the relative thicknesses of crusts as a function of time on Venusian and terrestrial lava flows given in Figure 5b as an index of the relative penetration of thermal waves, we find that for flows moving for periods much less than 1 hour, the time available for motion will be about 1.3 times longer on Earth than Venus; for flows moving for significantly longer than 1 hour (by far the commonest circumstance on Earth), the time available will be about 1.1 times longer on Venus than Earth. This ratio is significantly smaller than that found in an earlier analysis which neglected the buffering effect of latent heat release [Head and Wilson, 1982] and implies that the maximum length of lava flows can be written

$$X = \frac{D^2 u}{\Lambda\kappa} \tag{15}$$

where Λ, the critical Graetz number, is taken as 300 for Earth and 270 for Venus.

The treatment of lava flow lengths given above is somewhat idealized relative to the behavior of real basaltic flows. It has been tacitly assumed here that the liquid lava motion is laminar beneath a rigid crust. In most lava flows the deformation is relatively laminar, but shearing is commonly observed to take place in the surface layers, especially near the vent, in such a way as to expose fresh, hot lava to the atmosphere. This process inevitably increases the rate of heat loss from a given part of the flow surface and ultimately leads to a greater rate of thickening of the crust with time than calculated. Also, the above treatment is intended to apply to lava moving in open channels rather than in the closed