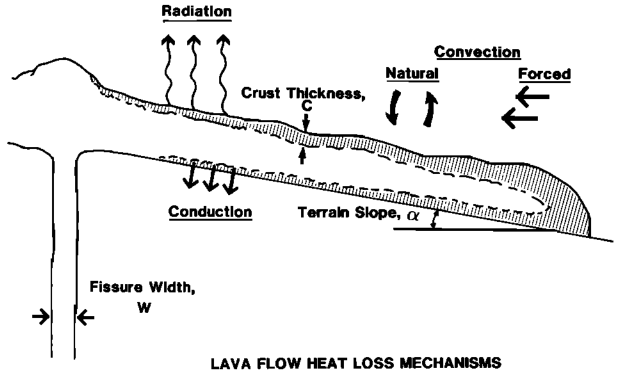

Fig. 4. Heat loss mechanisms from simple lava flow on any planet having an atmosphere. Either natural or forced convection will eventually dominate the radiation and conduction processes. Solid crust thickness will increase with time and hence distance from the vent. The motion of a flow lobe will cease when cooling fronts have penetrated to a sufficient fraction of its thickness.

1983]. As a consequence, fire fountains on Venus (Figure 3) will be denser (in terms of the number of pyroclasts per unit volume) and will have a greater optical thickness than fountains from terrestrial eruptions with the same mass flux. This will lead to less heat loss for most of the clasts (see, for example, Wilson et al. [1982]) and thus both welding of near-vent deposits and, more importantly, coalescence of pyroclasts on landing to form lava flows will be more likely. Thus a number of factors collaborate to ensure that explosive basaltic eruptions are much less likely to occur on Venus than on Earth and that if magmas do erupt explosively on Venus, the clasts falling near the vent are likely to be subject to less cooling on Venus than on Earth by the process of emerging through the vent.

A further aspect of the reduction of volatile release on Venus concerns the rheological properties of the lava flows which move away from the vent. Magma rheology is strongly controlled by its volatile content, especially the H_2O content, as we have seen above. Sparks and Pinkerton [1978] have pointed out that volatile release by terrestrial magmas can commonly lead to a significant increase in viscosity and yield strength. The solidus and liquidus temperatures rise as the volatiles are lost, and even if the temperature of the lava itself does not change at all during its passage through the vent, its temperature relative to the liquidus decreases, with a consequent increase in the rate of phenocryst formation.

In summary, both the temperature and the rheological properties of the near-vent lava flows are likely to be much closer to the properties of the magma at depth on Venus than on Earth. Next, we consider the subsequent motion of such flows.

3. Effusive Eruptions

3.1. Cooling of Lava Flows

The morphological evolution, surface texture, and maximum length of a lava flow are all controlled ultimately by its thermal state, which changes with distance from the vent as a result of cooling processes. Heat loss takes place by conductive heat transfer into the ground over which the flow moves, by radiation from all exposed lava surfaces, and if a planetary atmosphere is present, by either natural or forced convection (Figure 4). All of these processes occur for lava flows on both Venus and Earth; there are, however, significant differences in their relative and absolute importance [Frenkel and Zabaluyeva, 1983]. The following analysis uses standard treatments of the various heat loss mechanisms taken from McAdams [1954].

Radiative loss from the surface of a flow is controlled by the surface temperature T_0 and emissivity ε; the heat energy loss per unit time per unit surface area is F_R, where

$$F_R = \varepsilon\sigma\,(T_0^4 - T_e^4) \tag{2}$$

σ is the Stefan constant (5.6703×10^{-8} W m^{-2} K^{-4}) and T_e is the effective temperature of the environment into which the heat is lost. For both Earth and Venus, T_e is taken as the temperature of the near-surface atmosphere: the values used in the subsequent illustrative calculations are 300 K for Earth, 650 K for the Venusian highlands and 750 K for the Venusian lowland areas. Given the measured reflectivities of rock-forming minerals [Washburn et al., 1926], the emissivities of all basaltic rocks can conveniently be taken as 0.75, and so the main cause of differences in radiative cooling rates of lavas between Venus and Earth is the high Venusian surface temperature. Table 1 shows some typical values of F_R as a function of T_0 for the two planets.

If a finite atmospheric wind is present over a lava surface, heat loss also occurs by forced convection. The forced heat loss rate per unit surface area of the flow F_F is obtained from

$$\mathrm{Nu} = \mathrm{Pr}^{\frac{1}{3}}\,(0.036\ \mathrm{Re}^{0.8} - 836) \tag{3}$$

where the dimensionless Nusselt number (Nu), Prandtl number (Pr), and Reynolds number (Re) are defined by

$$\mathrm{Nu} = \frac{F_F\ L}{k\ (T_0 - T_e)} \tag{4}$$

$$\mathrm{Pr} = \frac{\mu\ c}{k} \tag{5}$$

$$\mathrm{Re} = \frac{W\ L\ \beta}{\mu} \tag{6}$$

In these equations, L is the typical horizontal length scale of the lava flow (generally taken as the arithmetic mean of the length and width of the flow, though, as we shall see, the exact value is not important), W is the mean speed of the wind, and K, c, μ, and β are the thermal conductivity, specific heat at constant pressure, viscosity, and density of the atmospheric gas, respectively (air in the case of Earth, essentially pure CO_2 in the case of Venus). The values of the latter four parameters are to be evaluated at the mean temperature of the lava-atmosphere interface, $1/2\ (T_0 + T_e)$ and can be obtained from Washburn et al. [1926]. Table 1 shows examples of values of F_F