make a preliminary assessment of the nature and spectrum of Venusian volcanic activity. We conclude with a discussion of surface observations required during future exploration of Venus in order to assess the full range of volcanic activity and to understand the role of volcanism in the evolution of the planet.

2. Production and Ascent of Magmas on Venus

2.1. Conditions in the Lithosphere

To produce quantitative assessments of the nature of possible eruptions on Venus, we first need to assume values for those physical properties of the magmas which control the eruption process, the most important of which are the rheological parameters defining the ways in which the magmas respond to shearing stresses. We also need values for the bulk densities of the magmas and for the pressure gradients or density contrasts driving them to the surface from high-level magma reservoirs.

Although the rheological properties of magmas, especially at subliquidus temperatures, are in general complex [e.g., Shaw, 1969], they can be modeled adequately, for the purposes of describing many aspects of their eruptive behavior, as Bingham plastics [Hulme, 1974]. The response of the magma to shearing stresses is then defined by a yield strength Y, which the applied stress must exceed before deformation occurs, and a plastic viscosity η, which is the (constant) ratio of applied stress in excess of the yield strength to strain rate. Both of these rheological parameters are functions of magma composition and temperature.

Modeling studies of the interior of Venus suggest that although there must be broad similarities to Earth, there may also be important differences in the chemistry [Wood et al., 1981]. It is by no means a trivial observation, therefore, that the major element compositions measured at two sites on the Venus surface by the Venera landers [Surkov et al., 1983] were very similar to those of two types of terrestrial basalt: an alkali basalt at the Venera 13 site and a tholeiite at Venera 14. We will use the properties of terrestrial magmas of these types as starting points for estimating the properties of candidate Venusian magmas. No direct evidence was obtained from the Soviet probes about the minor element and volatile compositions of the rocks at the landing sites; however, the low water content and high halogen content of the carbon-dioxide-dominated atmosphere [Hoffman et al., 1980] suggest that magmas erupted on Venus (at least in geologically recent periods) may be water depleted (and possibly carbon dioxide or halogen enriched) relative to otherwise similar terrestrial counterparts [Ringwood and Anderson, 1977]. Both of these factors tend to increase the solidus and liquidus temperature of basalts and would imply that if the crustal temperature gradients on the two planets were equal, magma source regions and crustal reservoirs would not be found as close to the surface on Venus as on Earth. That the temperature gradients on the two planets are not the same, however, is one of the consequences of the very different atmospheres.

On Venus the large atmospheric mass is responsible for both a high surface pressure (4-10 MPa) and a high surface temperature (650-750 K) and so leads to smaller values for both the pressure and temperature gradients in the upper part of the crust relative to those of Earth. The pressure gradients are significantly different only within about 1 km of the surface, whereas the temperatures in the two planets at a given depth differ over a much greater range of depths. The fact that the temperature is higher at a given depth on Venus than on Earth will, therefore, tend to counteract the effects of possible water depletion of Venusian magmas on their depths of origin.

A further consequence of the lower Venusian temperature gradient is that there will be less cooling of magma in the final stages of its approach to the surface. This means that the minimum fissure width needed to allow magma to reach the surface before significant chilling occurs will be smaller on Venus than on Earth and that the magma energing through a fissure of a given width will be hotter on Venus. However, the differences between the two cases will not be very great: the temperature difference between the magma and the surface rocks will be about (1500-750 =) 750 K on Venus and about (1500-300 =) 1200 K on Earth, so that the ratio of the heat loss rates is less than a factor of 2 even at the surface where the contrast is greatest. On Earth the eruption temperatures of basalts appear to range up to, but not appreciably above, the liquidus and down to a value about 100 K below it. This range of temperature is clearly related to the range of rise speeds and dike widths that characterizes the ascent of such magmas through the crust [Fedotov, 1978; Wilson and Head, 1981; Delaney and Pollard, 1982]. Delaney and Pollard [1982] treat the thermal behavior of erupting basaltic magmas in terms of a dimensionless temperature parameter θ_s given by $(T_s - T_e)/(T_0 - T_e)$, where T_e is the temperature of the environment (in this case, of near-surface rocks), T_0 is the eruption temperature of the magma, and T_s is its solidus temperature. Substituting typical values for these parameters on Earth and Venus shows that while θ_s is close to 0.96 for terrestrial eruptions, the value will be closer to 0.94 for basalts on Venus. However, the numerical results of Delaney and Pollard [1982] demonstrate that except for eruptions in which the magma rise is very close to being suppressed as a result of cooling effects, differences in θ_s of the above order will have very little effect on the amount of heat loss from an ascending magma. We will assume, therefore, that the temperatures of magmas moving through the Venusian crust lie between the liquidus and a value about 100 K lower.

Figure 2 shows some of the few data currently available on the variation with temperature of plastic viscosity and yield strength for tholeiitic and alkali-basaltic magmas [Murase, 1962; Shaw, 1969] and an andesite sample [McBirney and Murase, 1984]. Comparison of the data for an anhydrous tholeiite (curve A in Figure 2a) with measurements on a similar hydrated melt (curve B) shows that anhydrous Venusian melts may have viscosities about one order of magnitude larger at a given temperature, and liquidi some 50 K higher, than terrestrial equivalents. However, as we have argued above, the Venusian magmas should erupt at similar temperatures relative to their liquidi. The two sets of dashed lines in Figure 2a link