magmas with sufficiently low viscosities were erupted on Venus.

## 4. Explosive Eruptions

### 4.1. Volatile Sources

Explosive volcanic activity always involves the release and expansion of a vaporized volatile phase. This is true whether the activity accompanies relatively steady release of magma from a vent or consists of a series of abrupt and intermittent episodes of discharge of magma or vent-blocking debris. The vapor may be generated by volatile exsolution from the magma or may be derived from the decomposition and/or evaporation of substances existing on the surface in the vicinity of the vent or present as a component of crustal rocks through which the magma rises. On Earth the magmatic volatiles are generally dominated by $H_2O$ or $CO_2$, though sulfur compounds and halogens may be important in some magmas [Anderson, 1975; Luhr et al., 1984; Varekamp et al., 1984]. The main volatile derived from surface layers is $H_2O$ in the form of liquid water or ice; water is also the main subsurface volatile, though decomposition of carbonate sediments cut by feeder conduits may release small amounts of $CO_2$ into some erupting magmas [Lirer et al., 1973]. On Venus the predominance of $CO_2$ in the atmosphere may suggest that $CO_2$ is currently the major magma volatile; however, while some models of the formation of Venus call for extreme initial $H_2O$ depletion, there is as yet no direct evidence that Venusian magmas do not contain appreciable amounts of $H_2O$. Additionally, as on Earth, other volatile species such as halogens or sulfur compounds may be present in significant amounts. However, data on the solubility of volatiles in magmas which are adequate for modeling the detailed eruption dynamics exist only for $CO_2$ and $H_2O$, and we will use these species as being representative of the effects of low- and high-solubility volatiles, respectively. In considering nonjuvenile volatiles, we note that the surface temperature and geothermal gradient on Venus are such as to ensure that liquid water, water ice, and solid $CO_2$ cannot exist in the lithosphere (in contrast, liquid sulfur, if present, would be stable everywhere on the Venus surface under present conditions). We will examine the possibility that thermal decomposition of carbonates may release $CO_2$ to interact with some magmas.

### 4.2 Explosion Mechanisms

A fundamental feature of all explosive eruptions is the generation of gas (by exsolution from the magma or evaporation of accidental volatiles) at some pressure which is greater than that of the planetary atmosphere. It is the expansion of the gas down to atmospheric pressure which provides the energy to drive explosions. The amount of energy released is roughly proportional to the natural logarithm of the ratio of the initial and final gas pressures [L. Wilson, 1980]. In the case of a magma progressively exsolving volatiles as it approaches the surface, there is no single pressure at which gas expansion begins; however, the final velocity of the ejected gas and pyroclasts in the vent can be quite closely predicted if it is assumed that gas expansion effectively begins at the pressure, and hence depth below the surface, at which the magma is disrupted from a continuous liquid into a mixture of gas and fluid fragments [L. Wilson, 1980]. In the case of transient explosions involving the release of the pressure built up under a chilled retaining cap by either evaporation of accidental volatiles or exsolution of magmatic volatiles, the starting pressure differential for the gas expansion is essentially equal to the strength of the cap [Self et al., 1979]. Both of these initial pressure conditions are very close to being independent of the planetary environment, and so it is mainly the final pressure reached by the expanding gas, i.e., the atmospheric pressure, which controls the nature of the explosion. It is inevitable, therefore, that the high atmospheric pressure will lead to less gas expansion and hence smaller ejection velocities in explosive eruptions on Venus [Wood, 1979; Garvin et al., 1982; Head and Wilson, 1982]. We examine the consequences of this phenomenon in detail in later sections.

When magma does rise steadily to the surface, exsolving gas into growing bubbles, disruption of the magma probably takes place when the volume fraction of the bubbles reaches about 0.75% [Sparks, 1978]. This requirement sets a limit on the minimum amount of gas needed to cause magma disruption. Because the solubility of all magmatic volatiles increases with pressure, the fact that Venus has a higher atmospheric pressure than Earth means that greater initial magma volatile contents are needed there to ensure that an eruption is explosive. We have used the method outlined by Wilson et al. [1980] and the solubility functions given by Wilson and Head [1981] for $CO_2$ and $H_2O$ in common magmas to find the minimum volatile contents needed to produce explosions (see Table 3) for two sets of Venusian environmental conditions: atmospheric pressure = 100 MPa, ambient temperature = 750 K, corresponding to the lowland areas, and pressure = 4 MPa, temperature = 650 K, values more relevant to the upper highlands or the summits of proposed volcanic constructs [Campbell et al., 1984]. It is found that if the volatile phase is $H_2O$, the minimum amounts needed lie within, but near the upper end of, the range of water contents inferred to be common in terrestrial magmas. If the volatile phase is $CO_2$, however, the amounts needed are very large compared with what is regarded as common on Earth; indeed, the gas solubility data show that a magma would need to rise from a source region at a depth between 35 and 83 km (for highland and lowland vents, respectively) to permit it to contain the required amount of the volatile. This result implies that if volatiles more soluble than $CO_2$ are not available to Venusian magmas, explosive activity may be rare on the planet. However, since there is no specific evidence precluding the presence of either of these volatiles in magmas on Venus, we will explore the nature of explosive eruptions involving both of them and draw some general conclusions relevant to events which may involve these or other volatiles.

### 4.3 Eruption Cloud Formation

All volcanic explosions produce some kind of mixture of gas and fragmental material which is