ARE PLINIAN TYPE ERUPTIONS POSSIBLE ON VENUS?

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Calculations of dynamics of eruption plumes in the Venusian atmosphere reveal the following results: I) Conditions for a convective eruption column are very limited on Venus with required magma temperatures higher than $1100^\circ$K. Otherwise pyroclastic flows form. II) Once a convective eruption column is established, it may extend as high as about the tropopause (~60km). III) Critical eruption velocities for a convective eruption column as a function of temperature and gas content of magma may provide a useful tool for estimating interior condition of Venus, including its volatile inventory.

**Introduction:** Volcanism is a major process to transport volatile from mantle of a planet to its surface (degassing) as well as heat and mass, all of which affect planetary evolution. For example, after completion of planetary accretion, volcanism is the dominant continuous degassing process for all the terrestrial planets. Explosive volcanism is a very important process for mantle degassing due to its high magma gas content. Consequently, eruption styles and the controlling physical processes need to be understood.

Recent satellite and terrestrial ground-based observations suggest existence of explosive volcanism on Venus \cite{1, 2, 3, 4} even though explosive volcanism is very difficult to occur on Venus due to its high atmospheric pressure \cite{5, 6}. The purpose of this study is to investigate dynamics of explosive eruption on Venus and the relation between eruption conditions such as gas content and temperature of magma and eruption velocity, and eruption styles such as Plinian type and pyroclastic flow type.

**Model of Eruption Plume:** A one-dimensional, steady state, single phase, fluid dynamical model of the eruption column takes into account the vertical structure of the Venusian atmosphere and changes in specific heat of gas as a function of temperature change with altitude. It is assumed that eruption smoke is an ideal gas, and that pressure and temperature are locally in equilibrium. Under these assumptions, equations for mass conservation, momentum conservation, and energy conservation, and equation of state for an ideal gas are combined and solved. Prandtl's jet theory \cite{7} is used to describe turbulent entrainment of ambient air into the eruption column. The temperature profile of Venus atmosphere is given by a first order Simpson function modified from \cite{8}.

**Numerical Results:** We carried out numerous calculations using a fourth-order Runge-Kutta scheme. Figure 1 shows distinct contrasts in column height between pyroclastic flow cases (small column height) and stable convective eruption column cases (large column height). The bulk density in the eruption column is much higher than the ambient air at the vent. But the density decreases rapidly due to air entrainment by turbulence. If the density becomes less than the ambient air before vertical velocity in the eruption cloud becomes zero, the cloud rises buoyantly until its thermal energy is exhausted. This represents a stable eruption column \cite{9}. Otherwise, a pyroclastic flow is formed, whose height is controlled by its initial momentum.

Height of a stable convective column is higher than on the Earth \cite{9}. There are two reasons for this: I) The thermal gradient of Venusian troposphere (~60km) is almost adiabatic for CO\textsubscript{2}, which is the dominant component in the Venusian atmosphere \cite{10}. On Earth, the thermal lapse rate in the atmosphere is considerably smaller than the dry adiabat of air because of the condensation of H\textsubscript{2}O. II) The height of the tropopause is much larger on Venus than on Earth.

Conditions for a stable convective eruption column depend on initial temperature $T_0$, initial gas mass fraction $n_0$, initial eruption velocity $U_0$, and vent diameter $D$. Figure 1 shows the dependence of column height on these parameters. The abrupt change in column height indicates the transition from a pyroclastic flow to a stable convective eruption column. Higher temperatures, higher gas ratios, higher eruption velocities, and smaller vent diameters favor a stable convective eruption column. A smaller vent prevents an eruption column from collapsing because it entrains air more efficiently. Higher gas ratio and smaller vent diameters decrease the heights of stable convective eruption columns because of smaller mass discharge rates, which have a positive correlation with column height \cite{11}.

The transition from a pyroclastic flow to a stable convective eruption column is so abrupt that a critical velocity for each set of $T_0$, $n_0$, and $D$ can be defined. The definition of the critical velocity $U_{cr}(T_0, n_0, D)$ is that an eruption column collapse occurs with an initial velocity smaller than $U_{cr}$ under the condition that initial temperature, initial gas ratio, and vent diameter are $T_0$, $n_0$, and $D$, respectively. Critical velocity $U_{cr}$ becomes smaller with higher initial temperature, initial gas content, and smaller vent diameter (Figure 2). The absolute value of the critical velocity is much larger than on the Earth \cite{9} because the temperature of ambient air on Venus...
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is much higher, thereby reducing thermal buoyancy of the eruption cloud. A stable convective eruption column is barely formed with an initial temperature less than 1100°K.

Implication; Eruption velocity $U_e$ can be determined theoretically if temperature and composition of magma and geometry of conduit and magma chamber are known [12], although the real nature of an eruption is very complicated. For a given vent diameter $D$, the eruption velocity $U_e$ should be larger for larger temperature $T_0$ and gas mass fraction $n_0$ of magma [12], while $U_{cr}$ is smaller for larger $T_0$ and $n_0$. Therefore, the surface of $U_e$ in $U-T-n$ space and that of $U_{cr}$ must intersect. This line depends on $D$, which can be determined from observations. Thus, if the vent radius of a volcano and eruptive styles can be established (i.e., pyroclastic flow or Plinian style), temperature and gas content of the magma beneath the volcano can be constrained.

Since the atmosphere of Venus is presently extremely hot, it is impossible for the familiar volatiles such as H2O and CO2 to condense. Therefore, it is highly probable that volcanic gas of Venus is juvenile [5]. Plinian type eruption on Venus could be evidence for a very volatile rich Venusian interior, since the explosive volcanism on the Earth is mainly induced by recycled water from the hydrosphere.


Fig. 1 Maximum height of eruption column as a function of initial temperature and gas mass fraction of magma. Initial velocity and vent diameter is 300m/s and 50m, respectively.

Fig. 2 Critical velocity necessary to form a stable convective eruption column as a function of initial temperature and gas mass fraction. Vent diameter is 50m. Note that direction of axis of temperature is reverse from Fig. 1.