Turbulent mixing inside and around the volcanic eruption clouds

Yujiro Suzuki[1]; Takehiro Koyaguchi[2]

[1] Frontier Sciences, Univ Tokyo; [2] ERI, Univ Tokyo

http://www.gaea.k.u-tokyo.ac.jp/~yujiro/

Plinian eruptions involve continuous discharge of a mixture of hot gas and solid fragments from volcanic vents. As the mixture rises, surrounding air is entrained; the air expands due to heating from the hot pyroclasts, which can cause the mixture in the column to become buoyant. Therefore, mixing of eruption clouds and air is one of the most important processes for eruption cloud dynamics. In order to investigate the effects of turbulent mixing on eruption cloud dynamics, we construct a numerical model of eruption clouds. Previous numerical models of eruption cloud [Woods, 1988; Dobran and Neri, 1993] employed empirical parameters in order to reproduce the turbulent mixing. On the other hand, our numerical model can reproduce the global features of turbulent mixing using three-dimensional coordinates and third-order accuracy scheme without empirical parameters.

The results indicate that turbulent mixing has a close relation to two physical processes; (1) the entrainment of surrounding air, and (2) the homogenization of clouds. The entrainment of ambient air is caused by turbulent motion of eddies at the boundary between eruption cloud and air. This process determines the mixing ratio of eruption cloud and air in the cloud. The homogenization of eruption cloud is caused by turbulent motion of eddies inside the cloud. In general, the material ejected from the vent mixes ambient air from the edge of jet. The inner boundary of mixing shear layer moves inwards and erodes a core of ejected material, which is known as the 'potential core'. If the inner boundary of the annular shear layer meets the axis of the jet, the potential core disappears. As a result, the eruption column becomes a fully developed turbulent plume.

The above two physical processes account for the diversity of the dynamics of eruption clouds. The mass of entrained air determines whether the cloud becomes a column, a partially collapsed column, or a pyroclastic flow, because it determines the average density of eruption cloud. The behavior of the eruption cloud is also dependent on the degree of homogenization of mixture. If the potential core remains even when the initial momentum is exhausted, the dense cloud is characterized by the radially suspended flow at that height. Such a structure is called 'fountain'. On the other hand, if the potential core disappears before the initial momentum is exhausted, the eruption column becomes a homogeneous flow.

We analytically examine the physical meanings of the conditions for the generation of fountain and pyroclastic flow, and express those conditions by simple combinations of exit conditions, such as magmatic temperature, volatile content, and mass of entrained air. The generation of fountain is determined by the competition of the length of potential core (L) and the highest point of parabolic orbit (H). When H is larger than L, fountains cannot be generated because the potential core disappears before the initial momentum is exhausted. When H is smaller than L, on the other hand, the potential core remains, and then fountain develops. Parameter studies indicate that the generation of fountains can be predicted by H/L=0.8, and it is independent of the magmatic temperature and volatile content. Whether or not the cloud becomes buoyant critically depends on the average density of eruption cloud. If the density of mixture is smaller than the ambient air, an eruption column develops. If the density is larger than the air, a pyroclastic flow is generated. As the mass of entrained air, temperature, and/or volatile content increase, the density of mixture decreases. Therefore, the critical condition for the generation of pyroclastic flow critically depends on the mass fraction of magmatic component, temperature, and volatile content.