An analysis of sedimentation processes in pyroclastic density currents based on a two-layer depth-averaged model

*Hiroyuki A. Shimizu[1], Takehiro Koyaguchi[2], Yujiro J. Suzuki[2]

1. National Research Institute for Earth Science and Disaster Resilience, 2. Earthquake Research Institute, The University of Tokyo

During volcanic eruptions, a mixture of volcanic particles and gas is ejected from the volcanic vent and can flow along the ground surface as a pyroclastic density current (PDC). PDCs are characterized by a vertical stratification of particle concentrations in the currents; they are composed of a voluminous dilute turbulent suspension part with low particle volume fractions (<~10^{-3}) and a thin basal part with high particle volume fractions (~10^{-2}-10^{-1}). The basal part plays a major role in the sedimentation processes in PDCs. The characteristics of the basal part strongly depend on geological factors such as the particle concentration at the source; the basal part flows as a dense fluidized granular flow with very high particle volume fractions (~0.4; referred to as the “dense underflow”), or as a flow of saltating/rolling particles with relatively small particle volume fractions (~10^{-2}; referred to as the “bedload”). To understand the sedimentation processes in PDCs, it is important to elucidate the mechanisms that lead to the diversity of the basal part.

Previously the sedimentation processes of the basal part are investigated mainly from the viewpoint of the vertical particle transport. When the particle supply rate from the upper dilute part is larger than the deposition rate at the bottom of the basal part, the mass of the basal part increases and vice versa. The vertical particle transport is affected by various physical processes such as the particle cluster, the basal air lubrication, and the basal saltating/rolling particles. These processes explain some of the diverse sedimentary structures observed in PDC deposits. However, to understand the lateral variations of PDC deposits (e.g., the distributions of various sedimentary facies), additional considerations of horizontal particle transport are necessary.

This study aims to understand the flow and sedimentation processes of the basal part using a two-layer depth-averaged model of stratified PDCs (Shimizu et al., 2019, J. Volcanol. Geotherm. Res., 381, 168-184). This model allows us to discuss the diverse characteristics of the basal part (i.e., the dense underflow and the bedload) by considering both the vertical and horizontal particle transports. In this model, the stratification in PDCs is modeled as dilute and basal currents; the two currents are coupled through mass and momentum exchanges as suspended particles in the dilute current settle into the basal current. The two-layer model can generate various types of basal current from dense underflow to bedload depending on the source conditions. The simulation results quantitatively reproduce the fluid dynamical features and sedimentation processes observed in laboratory experiments (e.g., Shimizu et al., 2020, JpGU-AGU Joint Meeting, SVC42-P05).

To evaluate the effect of the horizontal particle transport, we derive an analytical solution of the steady-state horizontal mass flux of solid particles in the basal current as a function of horizontal distance (x) by integrating the mass conservation equations; we assume that a two-layer PDC is generated by a steady supply at the source point (x=0) and it flows into a one-dimensional run-out section (x>0). The analytical solution clearly expresses how the evolution of the basal current depends on (1) the horizontal supply of the basal current at the source (x=0), (2) the deposition at the bottom of the basal current at x >0, and (3) the vertical particle supply from the upper dilute current at x>0. The results of a parametric

study based on the analytical solution suggest that the characteristics of the basal current generated at the source (x=0) govern the flow and sedimentation processes of the basal current at x>0. The run-out distance of the basal current depends also on the balance between the vertical particle supply and the basal deposition at x>0. The variation in the run-out distance explains the lateral variations of PDC deposits.

Keywords: Pyroclastic density current, Two-layer model, Sedimentation process, Deposit distribution, Dense underflow, Bedload

