Dynamics of pyroclastic density currents

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"The only real knowledge is experience." *E.*

Rare painting of a pyroclastic flow that likely occurred during the 1810 Vesuvius eruption.
Alfano and Friedlander, Die Geschichte des Vesuv, plate 35.

Abstract

Pyroclastic density currents (PDCs) are the most dangerous mass flows on Earth. Yet they remain poorly understood because internal measurements and observations are hitherto non-existent. In this thesis, the first measurements and views into experimental large-scale PDCs synthesized by "column collapse" provide insights into the internal structure, transport and emplacement dynamics of dense PDCs or pyroclastic flows.

While from an outside point of view, PDCs resemble dilute gravity currents, the internal flow structure shows longitudinal and vertical complexities that greatly influence the PDCs' propagation and emplacement dynamics. Internal velocity and concentration profiles from direct observations provide the evidence of an unforeseen intermediate zone that plays an important role into the transfer of mass from the ash-cloud to the underflow. The intermediate zone is a "dense suspension" where particle cluster in bands to form mesoscale structures. These reduce particle drag and yield an extreme sedimentation rate of particles onto the newly-formed underflow. These findings call into question the existing paradigm of a continuous vertical concentration profile to explain the formation of massive layers and an underflow from ash-clouds. Instead, a sharp concentration jump occurs between the intermediate zone, with concentrations of the order of few volume percent, and the underflow, with concentrations of c.45%.

PDCs were found to be composed of 4 main zones identified as the underflow, and the ash-cloud head, body and wake. Following the evolution of the PDC structure over time allows the formation of a complex ignimbrite deposit sequence to be uncovered, reproducing experimentally the "standard ignimbrite sequence" reported from field studies. Experiments revealed that each flow zone deposited the particulate load under contrasting emplacement timescales (spanning up to 5 orders of magnitude), which are primarily controlled by the concentration of the zone.

The ash-cloud head is the most dynamic zone of the PDC, where proximally mass is intensively transferred downward and feeds the underflow front, while at all times, the finest particles are entrained upward and feed the wake through detachment of large Kelvin-Helmholtz instabilities. Subsequently, kinematic coupling between the moving underflow and overriding ash-cloud leads to a forced-supercriticality, preferentially affecting the head. The wide range of particle sizes and densities yield a spectrum of gas-transport behaviours ranging from a poorly coupled and rapid-sedimenting mesoscale regime up to a homogeneously coupled long-lived suspending regime.

Internal velocity and concentration profiles illuminate the role of boundary velocity, which yields forced-acceleration of the ash-cloud. Kinematic coupling of the ash-cloud with the underflow induces a velocity at the lower flow boundary, while shear stress at the ash-cloud/underflow wanes and results in the shrinking of the maximum velocity and concentration heights. Therefore, the ash-cloud can reach high velocities and multiply its destruction potential.

The experimental work presented in this thesis provides the first datasets of the internal physical properties of PDCs, which can be used to test the validity of current numerical models and highlight their limitations.

This thesis also presents the study of a small hydrothermal blast that occurred at Mt. Tongariro, New Zealand, on the 6th of August 2012. The study of the blast is subdivided into two phases: the PDC phase and the ballistic phase. The detailed study of the PDC along the main propagation axis highlighted the role of the longitudinal zoning of the current, which was reflected in the complex tripartite deposit architecture.

The study of the blast-derived ballistic crater field revealed a zone of high crater density that was related to the focus of ballistic trajectories around the main explosion direction. Simple inverse ballistic modelling provided evidence for a shallow blast (c. 5° above horizontal) from Te Maari. Furthermore, a comparison of ballistic block lithologies confirmed the origin of the elongated succession of craters or fissures formed by successive blasting during the eruption.

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