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Pyroclastic Density Currents Over Ice: An Experimental Investigation of Microphysical Heat Transfer Processes

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Pyroclastic density current (PDC) interactions with ice are common at high altitude and latitude stratovolcanoes. When PDCs propagate over ice, melt and steam are generated. The incorporation of melt and steam into PDCs can alter the flow dynamics by reducing friction at the particle-ice interface and between individual particles. Melt incorporation can also transform a PDC into an ice-melt lahar. The hazardous and temporally unpredictable nature of these flows limits field observations. Conceptual models of PDC-ice interactions for hazard assessment and modelling exist, but quantifications of the microscale physical processes that underpin these interactions are limited. We use experiments to characterise the melting and friction reduction that occur when PDCs are emplaced onto ice.

In experiment set one, a heated particle layer was rapidly emplaced onto a horizontal ice layer contained within an insulated beaker 7.3 cm in diameter. The particle types used were glass ballotini, crushed pumice, and Ruapehu PDC samples, covering a diverse range of grain characteristics. The particle layer was varied in thickness up to 45 mm and across temperatures up to 700 °C. In each experiment, the mass of melt and steam were quantified, and the time evolution of temperature through the particle layer was measured.

Across all particle types, increasing particle layer mass (therefore layer thickness) and temperature increased melt and steam production. However, Ruapehu and pumice melt masses showed greater sensitivity than ballotini to particle temperature for any given layer thickness. Conversely, steam production was greater for the ballotini for any given layer thickness and was more sensitive to ballotini particle temperature.

Localised steam escape, fluidisation, capillary action, and particle sinking, were observed to varying extents in the experiments. These phenomena caused melt to be incorporated into the particle layer. The rate of increase in melt generation decreases with increasing particle layer thickness. This is due to increasing steam production, the increasing temperature of incorporated meltwater, energy losses to the atmosphere, and alterations to the bulk particle diffusivity.

Experiment set two characterised the mobility of particles over frozen and non-frozen substrates. Pumice and Ruapehu particles of varying temperature and layer thickness were poured into a 4.5 cm diameter alumina tube, which was rapidly lifted, allowing the particles to radially spread over the substrate. This configuration has been widely studied in experiments on granular flow mobility. The initial and final aspect ratios of the particle layer were measured, and conform to a power-law form previously interpreted as showing that frictional interactions are only important in the final stages of flow emplacement. Enhanced particle layer mobility over ice was only observed for Ruapehu particles above 400 °C, which we interpret to be due to fluidisation of the particles by rising steam. This is consistent with experiment set one, where Ruapehu particles produced more steam than pumice, and were often fluidised above 400 °C.

Experimental data will be used to calibrate surface flow hazard models for PDC runout and lahar generation, enabling prediction of PDC-ice interaction hazards. These models will be tested at Mt. Ruapehu, New Zealand.