Inverting pyroclastic flow deposits from the characteristics of substrate-derived clasts: an experimental investigation

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Pyroclastic flows commonly propagate on granular substrates formed by earlier geological events and whose properties may influence the emplacement dynamics. We addressed this issue through scaled laboratory experiments on granular flows propagating on a granular substrate. The flows were generated from the release of columns of fine (80 microns) glass beads into a 3 m-long horizontal channel whose base consisted of an unconsolidated granular layer. The initial column was either non-fluidized or gas-fluidized in order to investigate flows having a range of properties. Pore pressure measurements revealed an upward pressure gradient at the flow-substrate interface because a dynamic underpressure (relative to that of atmosphere) proportional to the square of the front velocity was generated there while (atmospheric) pressure within the substrate was unchanged. A smooth substrate of fine (80 microns) particles was sheared by the sliding head of the flow, leading to the formation of small-height (1 mm) bedforms. These structures stretched horizontally as the flow propagated so that there was almost no evidence of entrainment in the deposit. In contrast, in the case of a rough substrate of coarse (1.6 mm) beads, most of the uppermost particles were first dragged horizontally individually. Then, many of these particles were uplifted to a height that increased up to 6-8 mm at flow velocities up to 2.5-3 m s-1. They were entrained over significant distances of several tens of cm, and then fell down so that the basal layer of the resulting deposit consisted of a mixture of fine and coarse particles. Assuming particle uplift was caused by the upward pressure gradient evidenced by our measurements, we did a theoretical analysis to determine the critical pressure gradient and the corresponding flow velocity at which uplift can occur, and found that this depended basically on the mass of individual particles entrained and on the flow bulk density. These contrasting modes of substrate entrainment are counterintuitive but nonetheless consistent with field observations. As shown by the Peach Springs tuff, an unconsolidated substrate of relatively fine (typically less than 1-2 mm) particles can be preserved at the base of a pyroclastic flow deposit whereas a substrate made of large particles (pebbles, boulders) is commonly reworked. The latter phenomenon is also observed at Mt St-Helens, where the 1980 pyroclastic flows emplaced on a debris avalanche deposit and entrained dense lava boulders of size up to several tens of cm on subhorizontal slopes. Using our model in order to invert the deposits, assuming a bulk flow density of 875-1400 kg m-3, we obtain flow velocities of 9-13 m s-1 in agreement with field observations.