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# Dune bedforms formed by dilute pyroclastic density currents

Guilhem Amin Douillet (1), Daniel Alejandro Pacheco (2), Ulrich Kueppers (1), Jorge Bustillos (2), and Donald Bruce Dingwell (1)

(1) Ludwig-Maximilians-Universität, Department of earth and environmental sciences, Munich, Germany, (2) Instituto Geofísico, Escuela Politécnica Nacional, Quito, Ecuador

Pyroclastic density currents (PDC) are gravity flows emitted during explosive volcanic eruptions. They are composed of a hot mixture of volcanic rock fragments and gas, travelling along the ground at high velocities (10s of m/s) to distances of up to tens of kilometres from the volcano. PDCs show a wide range of origins and behaviours but two end members can be defined: dense pyroclastic flows (PF) that behave as avalanches, and dilute PDCs with a much lower particle concentration and density that are accordingly less affected by topography (similar to turbidites). This latter end member produces stratified deposits that sometimes contain dune bedforms. They differ from aeolian and water dunes because:
1) their stoss face is usually much steeper,
2) they show frequent stoss face aggradation in cross section, and
3) they have a much more polydisperse grain size distribution.

We present data from the deposits of the 2006 eruption of Tungurahua volcano (Ecuador). We study the dilute and finer grained facies deposited as sedimentary wedges, the surface of which being covered by thousands of dune bedforms. The height, width, length, orientation, and sharpness of 350 dunes has been measured. We found heights from 0.1 to 2 meters, lengths between 1 and 20 meters, widths between 1 and 42 meters, and stoss and lee side with angles up to 35º with horizontal. Internally, the dunes are well stratified and grain size varies from fine gravel to fine silt with occasional lenses containing blocks with decimetric radius. The inner structure of the dunes shows two principal patterns:
-Sharp climbing dunes with deposition on both lee and stoss sides with a slight upstream migration of the crest alternating with phases of erosion on the stoss face.
-Thick (10cm) lenses or lensoidal layers accumulated on the stoss side of bed disturbances with a very strong grain size variation.
Combining shapes and internal structures, four different dune types have been defined. These types are found grouped together in successive zones showing a decrease in flow energy.
1) Smoothly rounded, low amplitude antidunes in very high energy deposition zones (DZ).
2) Sharply crested, large, transverse climbing dunes in high energy DZs and high sedimentation rate.
3) Sharply crested, small, lunate climbing dunes in intermediate energy DZs and high sedimentation rate.
4) Broad (width) and short (length) 2 dimensional dunes in DZs of low energy.
Based on their shape characteristics, they can easily be distinguished.

The conditions producing PDC dunes are very special (very hot gas as transporting fluid and ambient medium, highly polydisperse grain size and varying density of the transported particles). The genesis of pyroclastic dunes is only scarcely studied. We compare dunes from Tungurahua with PDC dune outcrops at Ubehebe crater (USA) and Laachersee (Germany). We discuss whether we only deal with antidunes (produced under supercritical flow conditions), if PDC dunes are megaripples (dune size but ripple genesis) and try to understand the reasons for steepness and stoss side aggradation. We also address the question of to what extent we can compare PDC dunes to aeolian or water structures.