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Insights into the origins of drumbeat earthquakes, periodic low frequency seismicity, and plug degradation from multi-instrument monitoring at Tungurahua volcano, Ecuador, April 2015

Andrew Bell (1), Stephen Hernandez (2), Elizabeth Gaunt (2), Patricia Mothes (2), Silvana Hidalgo (2), and Mario Ruiz (2)

(1) University of Edinburgh, School of GeoSciences, Edinburgh, United Kingdom (a.bell@ed.ac.uk), (2) Instituto Geofisico, Escuela Politecnica Nacional, Quito, Ecuador

Highly-periodic repeating 'drumbeat' earthquakes have been reported from several andesitic and dacitic volcanoes. Physical models for the origin of drumbeat earthquakes incorporate, to different extents, the incremental upward movement of viscous magma. However, the roles played by stick-slip friction, brittle failure, and fluid flow, and the relations between drumbeat earthquakes and other low-frequency seismic signals, remain controversial. Here we report the results of analysis of three weeks of geophysical data recorded during an unrest episode at Tungurahua, an andesitic stratovolcano in Ecuador, during April 2015, by the monitoring network of the Instituto Geofisico of Ecuador. Combined seismic, geodetic, infrasound, and gas monitoring has provided new insights into the origins of periodic low-frequency seismic signals, conduit processes, and the nature of current unrest.

Over the three-week period, the relative seismic amplitude (RSAM) correlated closely with short-term deformation rates and gas fluxes. However, the characteristics of the seismic signals, as recorded at a short-period station closest to the summit crater, changed considerably with time. Initially high RSAM and gas fluxes, with modest ash emissions, were associated with continuous and 'pulsed' tremor signals (amplitude modulated, with 30-100 second periods). As activity levels decreased over several days, tremor episodes became increasingly intermittent, and short-lived bursts of low-frequency earthquakes with quasiperiodic inter-event times were observed. Following one day of quiescence, the onset of pronounced low frequency drumbeat earthquakes signalled the resumption of elevated unrest, initially with mean inter-event times of 32 seconds, and later increasing to 74 seconds and longer, with periodicity progressively breaking down over several days. A reduction in RSAM was then followed by one week of persistent, quasiperiodic, longer-duration emergent low-frequency pulses, including 'double events'. The unrest finished with a series of minor explosions and ash emissions, and a reduction in RSAM. None of the seismic events were associated with significant infrasound or ground-coupled acoustic waves.

The persistent and steadily evolving periodicity of seismic signals, and contemporaneous inflation-deflation tilt cycle, suggest that incremental upward movement of a viscous magma plug determines the system periodicity, likely controlled by the balance between magma ascent rate, magma compressibility beneath the plug, and resisting forces at the plug margin. However, relations between a range of observations, including waveform similarity, periodicity, and amplitudes of contemporaneous discrete and continuous signals, suggest that the detected seismic signals are predominantly generated by gas flow that is largely decoupled from the magma ascent rate. Signals are generated by both continuous flow through longer-lived pathways, and by gas pulses passing through transient pathways generated by slip at the plug margins. The nature and amplitude of signals is therefore a product of the rate of gas flux and the evolving state of the degassing pathway, controlled in part by degradation and healing of the plug margins.