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Forecasting volcanic eruptions: the narrow margin between eruption and intrusion

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Volcano-tectonic (VT) seismicity is one of the primary geophysical signals for monitoring volcanic unrest. It measures the brittle response of the crust to changes in stress and provides a natural proxy for gauging the stability of a pressurizing body of magma. Here we apply a new model of crustal extension to observations from the 2015 unrest of Cotopaxi, in Ecuador. The model agrees well with field data and is consistent with accelerating unrest during the pressurization and rupture of a vertically-extended magma source within the volcanic edifice.

At andesitic-dacitic stratovolcanoes in subduction zones, unrest after long repose is often characterised by increases in VT event rate that change from an exponential to hyperbolic trend with time. This sequence was observed when renewed unrest was detected in April 2015 at Cotopaxi, following at least 73 years of repose. After about 80 days of elevated seismicity at an approximately steady rate, the numbers of VT events increased exponentially with time for c. 80 days, before increasing for c. 15 days along a faster, hyperbolic trend. Both trends were characterised by the same value of 2 for the ratio of maximum applied stress S_F to tensile strength of the crust σ_T, consistent with the pressurization of an approximately vertical, cylindrical magma body. The hyperbolic trend indicated a potential rupture on 25 September. Rupture appears to have occurred on 21-22 September, when the VT rate rapidly decreased. However, no major eruption accompanied the change, suggesting that a near-surface intrusion occurred instead.

Although the quantitative VT trends were consistent with the rupture of a magmatic body, they could not on their own distinguish between an eruptive or intrusive outcome. An outstanding goal remains to identify additional precursory characteristics for quantifying the probability that magma will reach the surface after escaping from a ruptured parent body. Data for this analysis were kindly made available by the Instituto Geofísico in Quito, Ecuador (www.igepn.edu.ec).