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Volcano-earthquake interactions associated with system criticality at Sierra Negra volcano, Galapagos Islands

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The onset of eruption at a closed-system volcano requires the failure of a pressurized magma reservoir. In perhaps the simplest scenario, ascending magma inflates a shallow reservoir, and failure occurs when magma overpressure exceeds the strength of the surrounding rock. Under these conditions, understanding how the volcanic edifice responds to increasing magma pressure is key for interpreting geophysical monitoring data, and providing reliable forecasts of the nature, location, and timing of eruption. Here we describe the edificial response to inflation, and volcano-earthquake interactions, associated with the approach to eruption at Sierra Negra, a large basaltic shield volcano in the Galapagos Islands, Ecuador. Over 5 m of surface uplift and 100,000s of volcano-tectonic (VT) earthquakes were recorded between the end of the 2005 eruption and the start of the subsequent eruption in June 2018, associated with progressive inflation of a shallow magma reservoir. Through most of the unrest, increasing stress within the edifice resulted in accelerating seismicity rates as a function of surface uplift. Locally high stress levels made the system susceptible to small stress perturbations, evidenced by repeated episodes of dynamic triggering of local VT seismicity by large teleseismic earthquakes. Triggering resulted from high amplitude surface- and, more rarely, body-wave arrivals, and triggered earthquakes originated from some of the same long-lived source locations as non-triggered seismicity. By late 2017, stress levels were sufficiently high to activate a system-scale ‘trapdoor’ fault network, generating a series of shallow >M4 inflationary earthquakes. 3-4 days of seismic quiescence followed each earthquake, indicating a transient reduction in stress before recovery to previous levels, and likely prolonging inflation and unrest, whilst the longer-term seismicity rate as a function of uplift remained constant. The ultimate approach to eruption lasted only 3 hours and followed a final M5.2 inflationary earthquake, suggesting that once in this critical regime, warning times for eruptions may be inherently short.