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Eruption precursors: Manifestations and strategies for detection

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The past several decades have seen a rapid increase in volcano monitoring and modeling capabilities. Diverse arrays of instrument networks can detect a variety of pre-, co-, and post-eruptive phenomena, and remote sensing observations are available across a range of spatial, temporal, and spectral resolutions. A growing class of models, based on the physics of magmatic systems, are making use of these expanding datastreams, providing probabilistic assessments of such parameters as magma supply, volatile content, and eruption duration. To what extent, however, do these developments heighten our ability to identify eruption precursors? The advent of better data and new models provides an opportunity to reexamine our understanding of pre-eruption unrest, as well as our ability to detect and recognize it as such.

An idealized model of the buildup to a volcanic eruption might include magma ascent from a deep source region and accumulation in the mid- to upper crust in the preceding months to years. The process might be manifested by surface inflation and deep long-period earthquakes, and accompanied by an increase in CO_2 emissions. As magma continues to accumulate, distal volcano-tectonic earthquakes may result as stress builds on nearby faults, H2S emissions may increase as sulfur in a shallow reservoir is hydrolyzed by groundwater, and fumarole and spring temperatures may increase and show changes in chemistry. In the days to hours before an eruption, sudden changes in the rate and style of earthquakes (including repeating earthquakes and tremor) and deformation may occur as the magma reservoir ruptures and magma moves laterally or vertically. Phreatic eruptions might result as ascending magma comes into contact with groundwater, and SO_2 emissions might increase as the path between the magma and surface dries out.

How often does such a sequence actually occur? Relatively few volcanoes are comprehensively monitored prior to obvious expressions of unrest, so this is not an easy question to answer. From the limited record, it appears that at least a few volcanoes follow the model. For example, deep inflation, long-period earthquakes, and CO_2 emissions were detected months before the 2009 eruption of Redoubt (Alaska). In the weeks to days before the eruption onset, fumarole temperatures and SO_2 emissions increased, tremor was noted, and phreatic explosions presaged the extrusion of magma at the surface. Other volcanoes buck this idealized trend. Calbuco (Chile), for instance, showed no indication of inflation or seismicity in the days to years prior to the sudden onset of a magmatic eruption in 2015, despite InSAR and seismic monitoring that should have detected such unrest. Most volcanoes seem to fall between these two extremes, providing some indication of their eruptive potential via gas, thermal, seismic, or geodetic anomalies over timescales ranging from hours to years. Given limited resources and the challenges in terrestrial monitoring of all potential long- and intermediate-term eruption precursors, strategies for exploiting the wealth of remote sensing data and integrating derived insights into models of volcanic unrest are an important investment. Short-term eruption precursors, however, are best detected by ground-based monitoring—especially seismic and geodetic instruments.