Chapter 18

Volcanic unrest and short-term forecasting capacity

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18.1 Background

Most volcanic eruptions are preceded by a period of volcanic unrest that perhaps is best defined as the deviation from the background or baseline behaviour of a volcano towards a behaviour which is a cause for concern in the short-term because it might prelude an eruption (Phillipson et al., 2013).

Although it is important that early on in a developing unrest crisis scientists are able to decipher the nature, timescale and likely outcome of volcano reawakening following long periods of quiescence there are still major challenges when assessing whether unrest will lead to an eruption in the short-term or wane with time.

18.2 Analysis of volcanic unrest

An analysis of 228 cases of reported volcanic unrest between 2000 and 2011 (Phillipson et al. (2013); Figure 18.1) recognises five primary observational (predominantly geophysical and geochemical) indicators of volcanic unrest:

Ground deformation: Restless volcanoes often undergo periods of ground uplift or subsidence driven for example by pressure changes in their magma reservoir or overlying geothermal reservoir. In some cases pressure increase may break the ground surface. Ground deformation is generally recorded by ground or space-borne techniques [see also Chapter 17].

Degassing: Plumes of gas may be released from craters or other vents (fumaroles) on a volcanic edifice craters. Alternatively the amount of gas released may increase or the chemical composition of gases may change over time. Ground and space-borne techniques are usually applied to monitor degassing behaviour [see also Chapter 17].

Changes at a crater lake: These changes include variations in lake temperature, lake levels, level of water chemistry, lake colour and gas release and are generally recorded using ground-based or air-borne techniques.

Thermal anomaly: Anomalous temperature changes of the ground or of fumarolic gases can be recorded by ground-based, air or space-borne sensors [see also Chapter 17].

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Seismicity: The movement of magma, fluids and gas can cause seismic signals at restless volcanoes as does the breaking of rock from stress increases at depth. Particular seismic wave forms are generated from such processes which may provide clues as to what is driving unrest at a particular volcano. Seismic observations are generally made on the ground.

The same study also recognises five idealised classes of volcanic unrest based on the temporal behaviour of these five most-commonly reported unrest indicators which can be depicted in unrest timelines and whether or not eruptive behaviour resulted from the unrest. These classes of unrest include reawakening, prolonged, pulsatory, sporadic and intra-eruptive unrest. An example of pulsatory unrest is shown in Figure for the case of Cotopaxi volcano in Ecuador. This volcano underwent a non-eruptive period of unrest during 2001 and 2003. Pulsatory unrest consists of episodes of unrest activity (lasting for days) separated by intervals of days to weeks without activity. In contrast, prolonged unrest is often expressed by long-term (years to decades) ground deformation, which may only be identifiable at volcanoes with a long-term geodetic monitoring network or satellite remote sensing.

Phillipson et al. (2013) also showed that unrest episodes at different types of volcanoes have different median unrest durations before the start of an eruption. At stratovolcanoes they last for a few weeks while at calderas their median length is two months. Shield volcanoes have the longest median unrest duration at 5 months. However, volcanoes with long periods of quiescence between eruptions do not necessarily undergo long periods of unrest before their next eruption.

To improve the knowledge-base on volcanic unrest, a globally validated protocol for the reporting of volcanic unrest (Newhall and Dzurisin, 1988) and archiving of unrest data is needed (Venezky and Newhall, 2007). Such data are important for the short-term forecasting of volcanic activity amid technological and scientific uncertainty and the inherent complexity of volcanic systems.

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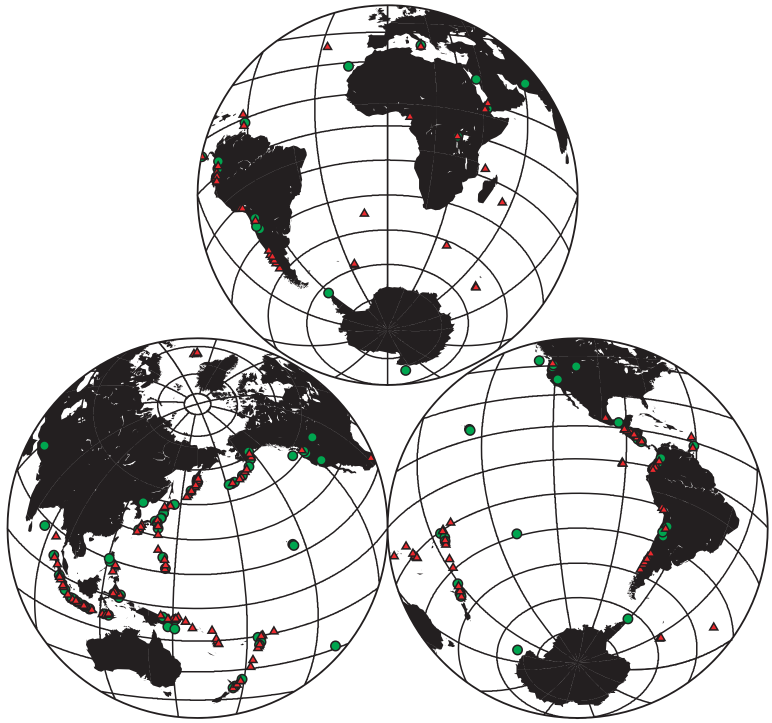

Figure 18.1 Location maps of 228 volcanoes with reported unrest between January 2000 and July 2011. Green circles show volcanoes with unrest not followed by eruption within reporting period, while red triangles show those with eruption .

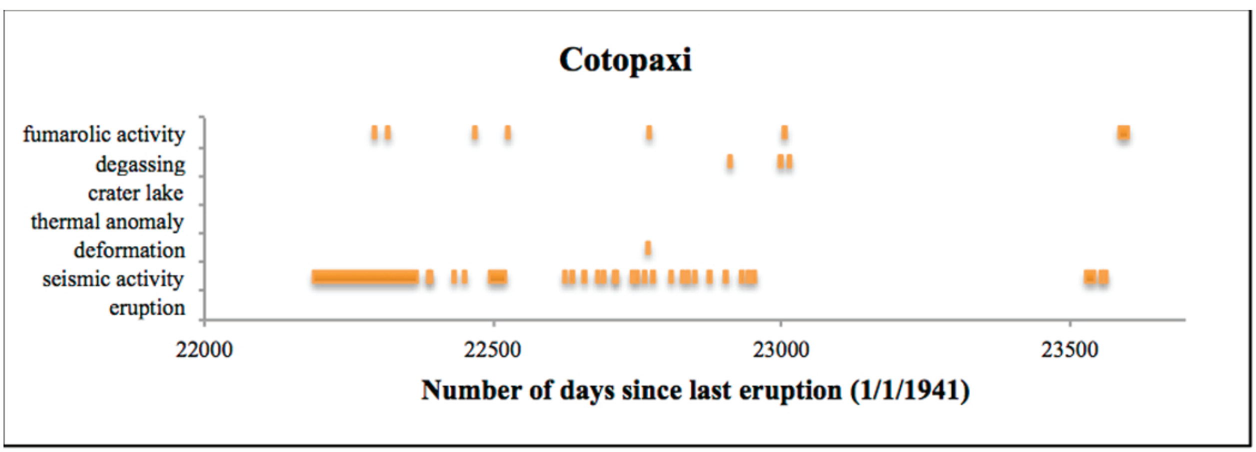

Figure 18.2 An example of a pulsatory unrest timeline using five key unrest indicators from Cotopaxi volcano in Ecuador from 27/3/2001 to 21/11/2005 (modified from Phillipson et al. (2013)). This episode of intense unrest did not culminate in an eruption.

18.3 Short-term forecasting capacity

Forecasting the outcomes of volcanic unrest requires the use of quantitative probabilistic models (Marzocchi et al., 2008, Marzocchi and Bebbington, 2012, Sobradelo et al., 2014) to address adequately intrinsic (epistemic) uncertainty as to how a unrest process may evolve as well as aleatory uncertainty regarding the limited knowledge about the process. Probabilistic forecast models applied in modern volcanology follow event tree structures which allow

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conditional probabilities to be attributed to different possible future eruptive or non-eruptive scenarios in an evolving unrest crisis.

An example of individual notes of an event tree structure of the HASSET (Sobradelo et al., 2014) probabilistic forecasting tool is shown in Figure . This event tree includes unrest scenarios that culminate in an eruption but also those that do not. For the probabilistic assessment of outcomes of volcanic unrest it is particularly important to assess a number of scenarios regarding the causes of unrest such as magma movement, geothermal excitation, tectonic activity or other processes. It is crucial to discriminate between unrest caused by internal triggers (magma movement) or by external triggers (regional tectonics), which ultimately condition the outcome and further development of unrest.

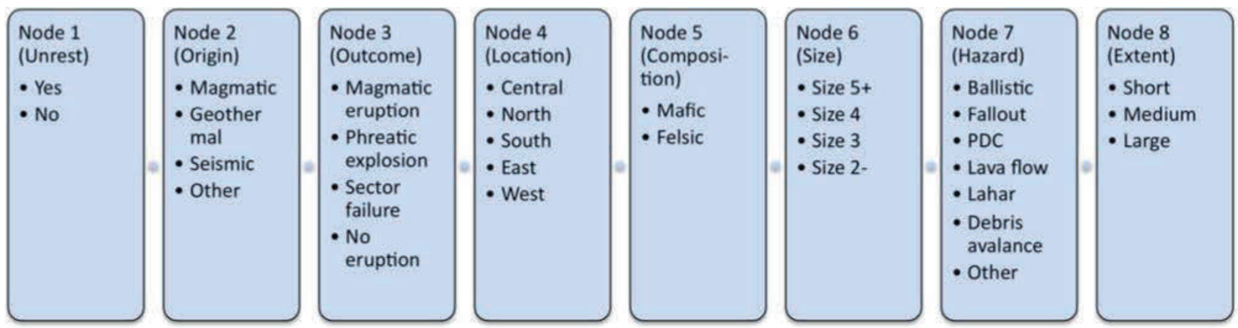

Figure 18.3 Event tree structure of the HASSET probabilistic forecasting tool (from Sobradelo et al. (2014)) formed by eight individual nodes and corresponding mutually exclusive and exhaustive branches. By the condition of independence of the nodes, the probability of a particular volcanic scenario, as a combination of branches across nodes, is the product of the individual probabilities of occurrence of each branch in that scenario.

Probabilistic forecasts may influence selection of appropriate mitigation actions based on informed societal or political decision-making. Properly addressing uncertainties is particularly critical for managing the evolution of a volcanic unrest episode in high-risk volcanoes, where mitigation actions require advance warning and incur considerable costs (Marzocchi and Woo, 2007). A major evacuation over a period of 4 months in excess of 70,000 individuals on Guadeloupe in the French West Indies in 1976 [see also Chapter 8] was initiated as a result of abnormal levels of volcanic background activity, which culminated in a series of eruptions of hot gas, mud and rock, before waning. Fortunately, no life was claimed by the activity, however, the estimated cost of the unrest was about US$ 1bn in current currency. Ninety percent of these costs were incurred by the evacuation, rehabilitation and salvage of the French economy. This in turn suggests that had the outcome of the unrest on Guadeloupe been predicted correctly the cost of the unrest would have been almost negligible. At the same time it is now acknowledged that the "proportion of evacuees who would have owed their lives to the evacuation, had there been a major eruption, was substantial" (Woo, 2008).

An improvement of the knowledge base on causes and consequences of volcanic unrest is shared the geohazards community. A number of multi-national projects are dedicated to working towards a better understanding of volcanic unrest including:

- The VUELCO project (www.vuelco.net), a European Commission-funded project on volcanic unrest in Europe and Latin America.

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- The European Commission-funded MEDSUV (http://med-suv.eu) and FUTUREVOLC (http://futurevolc.hi.is) projects as part of the Geohazard Supersites and Natural Laboratories initiative (supersites.earthobservations.org/).
- The WOVOdat database, which enables the comparison of volcanic unrest data using time-series and geo-referenced data from volcano observatories worldwide in common and easily accessible formats (www.wovodat.org).

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